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Mineral Reconnaissance Programme

Mineral Exploration in the Pitlochry to Glen Clova Area, Tayside Region, Scotland

Department of Trade and Industry

MRP Report 126
Technical Report WF/93/1

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J S Coats, M H Shaw, K E Rollin, S Robertson and S D Redwood

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BRITISH GEOLOGICAL SURVEY

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CONTENTS

TABLES

FIGURES

SUMMARY

Reconnaissance drainage sampling of the area between Pitlochry and Glen Clova in the Highlands of Scotland was undertaken in 1987 and 1988. 309 stream sediment and 347 panned concentrate samples were collected and analysed for a variety of major and trace elements.

Four areas were identified with potential for economic gold mineralisation, Glen Clova, Glen Uig, east of Dunkeld and Bridge of Cally. Detailed sampling and follow-up investigations in Glen Clova identified a gold-bearing fault zone in the Burn of Fleurs. Levels up to 7 ppm Au were detected in clay fault gouge and the fault can be traced by geophysical methods for 1.6 km. Features with a similar trend, such as the orientation of stream courses, can be identified extending for a further 10 km to the southeast. Recommendations for further work to investigate this and other prospective areas are presented.

The potential of the area for base metal deposits is probably low and the few suphide-bearing veins are of little economic significance when compared to the stratabound deposits in the Middle Dalradian. The economic potential of the Highland Boundary fault zone was, however, unexplored.

INTRODUCTION

Over the past decade exploration for gold mineralisation in the Dalradian of Scotland has been concentrated in the southwest and central Highlands, culminating in the discovery of the Cononish and Calliachar Burn prospects by Ennex International and Colby Resources (Parker et al., 1991; Mason et al., 1991). The Calliachar Burn deposit near Aberfeldy occurs in an area of historically recorded gold occurrences (Figure 1), which appears to be bounded to the northeast by the northwest - southeast line of Strath Tay. This lineament may be coincident with the Aberfeldy lineament described by Fettes et al. (1986). The area to the northeast has seen little mineral exploration. On this basis in 1987 it was decided to focus the Mineral Reconnaissance Programme (MRP), which is funded by the Department of Trade and Industry with the aim of encouraging mineral exploration in new areas, on a reconnaissance drainage survey of the area extending east of Strath Tay. The survey area was limited to the Southern Highland Group Dalradian which is apparently the favoured host of many of the gold occurrences in the Central Highlands of Scotland. The Southern Highland Group is bounded to the north by the Loch Tay Limestone, which marks the boundary with the stratigraphically underlying Argyll Group of the Dalradian. The southern margin of the area was taken just to the south of the Highland Boundary Fault and the survey extended as far east as the catchment of the River South Esk in Glen Clova.

The area of the reconnaissance drainage study (Figure 2) covers about 700 square kilometres. The maximum elevation rises to 947 m at the head of Glen Clova but most of the hilltops are in the 400 - 500 m range. The main rivers run in a general southeasterly or southerly direction and the sampling was mainly restricted to the first and second order tributaries. The flatter, lower valleys are under arable cultivation but the valley sides are extensively planted with conifers. Upland areas are used as sheep pasture or as deer and grouse moor. The population is very scattered with only the small towns of Dunkeld, Blairgowrie, Alyth and Kirriemuir forming centres

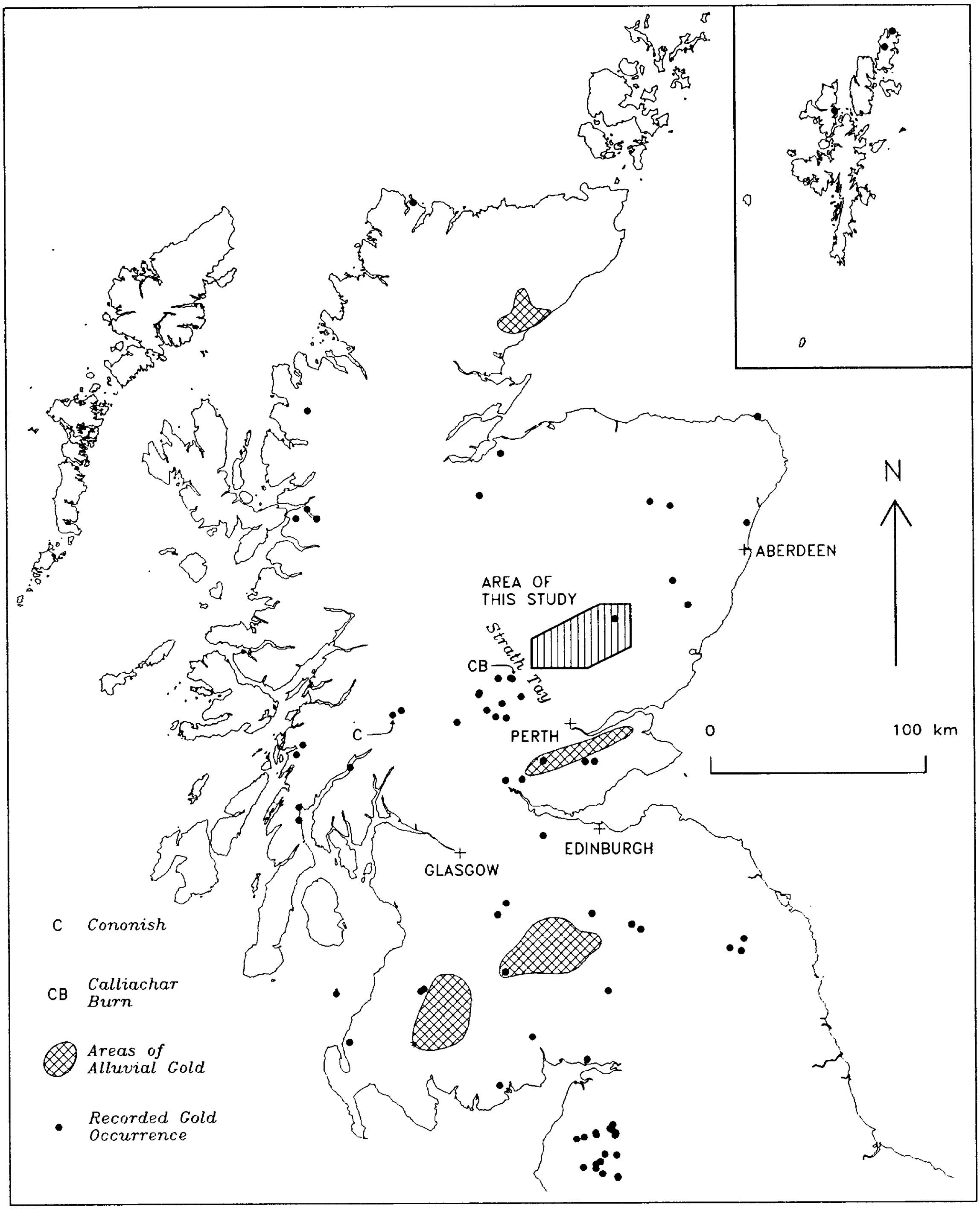

Figure 1 Location of study area and recorded gold occurrences in Scotland

of population where the main rivers emerge on to the flatter land at the Highland Border. Pitlochry is the other major settlement in the west of the area and is situated on the A9, the main trunk road north through the Highlands. All locality names used in this report are given on the relevant 1:25 000 topographic sheets and are normally present in the Ordnance Survey gazetteer.

An historical record of gold from the area is mentioned by Atkinson (1619) as "Some report, that at Clovo, at the head of South Esk, some eight miles from Killiemuir, there is found gold and silver". Apart from this rather obscure record, there are few authenticated indications of gold mineralisation in the area (Adamson, 1979). Adamson also quotes a record of gold in Glen Mark but this is thought to be an inaccurate reference to the lead (and silver) mine in the Glen.

Minor base metal occurrences in the form of galena are found in Glen Mark to the east of the survey area and Glamis to the south (Wilson and Flett, 1921). To the north-west a minor base metal and fluorite occurrence is found in veins associated with the intersection of the Loch Tay fault and the diorite intrusion in Glen Tilt (Gallagher et al., 1971; Coats, unpublished work, 1977). Stratiform baryte with associated adularia and minor base metal sulphides is found replacing the Loch Tay limestone formation at Nether Craig (N J Fortey, personal communication, 1987); the streams in this area were resampled during this survey. A baryte vein with minor base metals associated with a Caledonian felsite intrusion is found near Meall Odhar in Glenshee (Coats et al., 1987; D G Cameron, personal communication, 1985) but is outside the area covered by this survey. Lead mineralisation is also recorded in the Dunkeld area by Gallagher et al. (1971). The MRP has published several reports on the stratabound mineralisation in the Middle Dalradian (Smith et al., 1977; Pease et al., 1986; Coats et al., 1987; Gallagher et al., 1989) but these cover areas which lie to the north-west of this study.

REGIONAL GEOLOGY

Southern Highland Group Dalradian

The Southern Highland Group of the Dalradian of the Southern Highlands, here defined as the succession stratigraphically above the Loch Tay Limestone, consists predominantly of rocks of turbiditic greywacke facies, together with units of volcaniclastic and metabasic rocks. The sequence has been subjected to several phases of deformation and metamorphism. Intrusive igneous rocks are not abundant in the Strath Tay - Glen Clova area.

The basal part of the Southern Highland Group succession is dominantly semipelitic and termed the Pitlochry Schist in Perthshire and the Longshank Gneiss (Robertson, 1991) and Glen Effock Schist (Harte, 1979) in Glens Clova and Esk respectively. Garnetiferous mica schists together with minor quartzose gritty metagreywackes are the characteristic lithology in Perthshire whereas in Angus the dominant lithologies are migmatitic micaceous psammites and semipelitic gneisses. The Longshank Gneiss in Glen Clova contains abundant magnetite (Robertson, 1991). Magnetite-bearing rocks are also present locally in the Pitlochry Schist in Perthshire (Watkins, 1984). The semipelitic succession passes both laterally and stratigraphically upwards into a sequence dominated by gritty greywackes together with interbedded semipelitic lithologies. This sequence of more proximal turbidites is referred to as the Ben Ledi Grits in Perthshire (Mendum and Fettes, 1985), the Rottal Formation in Glen Clova (Robertson, 1991) and the Glen Lethnot Grits in Glen

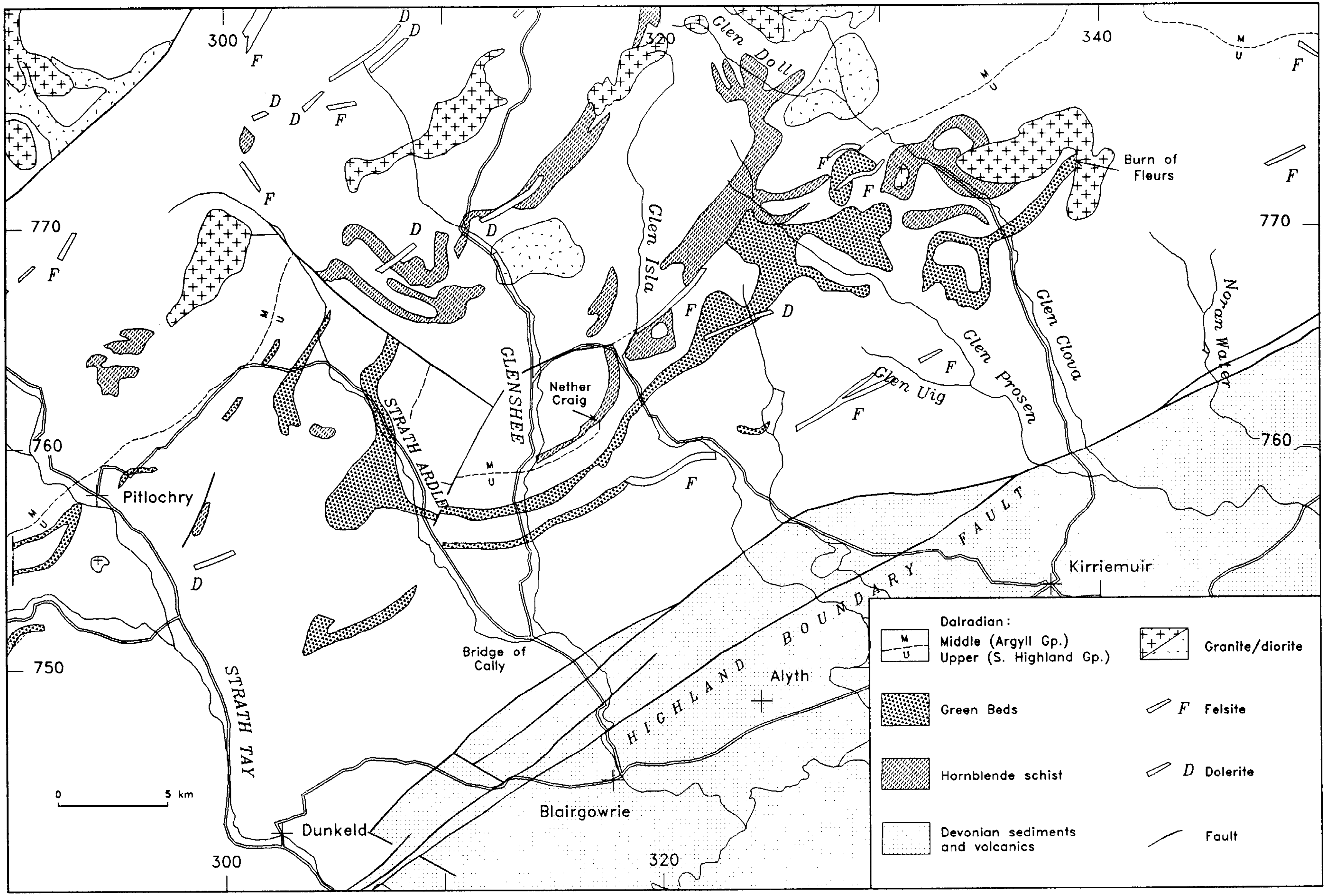

Figure 2 Sketch map of geology of the area taken from the Tayforth 1:250 000 Sheet 56N 04W

Esk (Harte, 1979). Locally the basal semipelite is not well developed such that the grit succession directly overlies the Loch Tay Limestone.

Green Beds, composed of a variety of chloritic and hornblendic lithologies, interpreted as volcaniclastic in origin, are widespread in the lower part of the Southern Highland Group Dalradian. Amphibolites are associated with the Green Beds in places. In the Glen Isla area, green beds interbedded with gritty psammites and semipelites occur near the base of the Southern Highland Group Dalradian succession. In Glen Clova, however, Green Beds are absent from the Longshank Gneiss and first occur in the basal part of the stratigraphically overlying grit succession. Green Beds are not recognised northeast of the watershed between Glen Clova and Glen Lethnot.

Four main phases of deformation (D_1-D_4) are recognised in the Southern Highland Group Dalradian. D_1/D_2 produced large-scale recumbent fold structures related to the formation and modification of the Tay Nappe although D_2 structures are not present in the structurally higher level rocks close to the Highland Border (Harte et al., 1984). Isotopic ages constrain the age of D_1/D_2 deformation to the period between 595 Ma and 590 Ma (Halliday et al., 1989; Rogers et al., 1989). Much of the Southern Highlands lies within the overall gently inclined, lower, inverted limb of the Tay Nappe ('flat belt'). In general, the Southern Highland Group sequence dips towards the northwest whereas progressively younger rocks are found towards the southeast. Small-scale D_3 structures are recognised throughout the Southern Highlands (Harte et al., 1984; Mendum and Fettes, 1985) whereas larger, kilometre-scale reclined to recumbent D_3 structures occur in the Glen Clova area (Robertson, 1991). Isotopic ages constrain the age of D_3 deformation to the period between 490 Ma and 470 Ma (Pankhurst, 1970; Kneller and Aftalion, 1987). D_4 deformation and differential uplift produced a zone of steeply dipping rocks along the Highland Border to the south of a monoclinal fold known as the Highland Border Downbend (Harte et al., 1984). Other 'steep belts' such as the Tummel Steep Belt, which lies to the north of the 'flat belt', have also been attributed to D_4 deformation and uplift (Dempster and Harte, 1986).

Metamorphism of the Dalradian succession is thought to have culminated in peak pressures and temperatures approximately coeval with D_3 deformation. A Barrovian sequence of metamorphic zones developed, ranging from a chlorite zone close to the Highland Boundary Fault to staurolite- or kyanite-bearing zones over much of the area. Kyanite and fibrolitic sillimanite zones are developed in Glen Clova. Migmatisation of the semipelitic Longshank Gneiss occurred at this time.

Intrusive igneous rocks are not abundant but were emplaced at several intervals punctuating the structural history of the area. In the Glen Clova region, the Rough Craig granite was emplaced prior to D_2 whereas the Cairn Trench granite post-dates D_3 and is thought to be Ordovician in age (Robertson, 1991). The Dunfallandy Hill granite sheet in Strath Tay has been dated at 481 ± 15 Ma (Pankhurst and Pidgeon, 1976). The only significant Late Silurian intrusion in the Southern Highland Group Dalradian of the Strath Tay-Glen Clova area is the Glen Doll diorite in Upper Glen Clova. This is in contrast to the abundant Late Silurian granites elsewhere in the Grampian Highlands. Felsites and other minor intrusions are widespread.

Northeast - southwest transcurrent faults occur in the Southern Highlands; examples include the Glen Doll Fault and the Highland Boundary Fault. These structures were active in Late Silurian to Early Devonian times and probably have experienced a prolonged history of activity from the Ordovician onwards. Northwest-southeast trending faults are also a feature of this area.

Highland Border Complex

The Highland Boundary Fault generally separates the Southern Highland Group Dalradian from the Devonian of the Midland Valley. A succession of rocks termed the Highland Border Complex (Henderson and Robertson, 1982; Harte et al., 1984) crop out sporadically along the Highland Boundary Fault zone. The complex consists of lenses and fault-bounded blocks of a wide variety of lithologies of mostly Ordovician age varying from gritty psammites and limestones to basalts and serpentinites (Henderson and Robertson, 1982; Curry et al., 1984). Highland Border Complex and Dalradian rocks are considered to have been juxtaposed by transcurrent motion along a boundary transform fault in conjunction with late-Caledonian uplift of the Dalradian block (Harte et al., 1984). To the east of Dunkeld, Devonian rocks occur to the north of the Highland Boundary Fault where they rest unconformably on both the Highland Border Complex and the Dalradian.

REGIONAL DRAINAGE GEOCHEMISTRY

Introduction and sampling methods

A programme of regional geochemical sampling was conducted in May 1987 and June 1988 and involved the collection of 309 stream sediment and 347 panned concentrate samples. The stream sediment samples were collected using the standard BGS technique of wet sieving in the field through a 150 micron aperture nylon mesh, allowing to settle and decanting excess water. The panned concentrates were prepared by panning approximately 4 litres of -2 mm sediment down to a 50 ml concentrate. The panned concentrates were examined visually in the field and the heavy minerals noted on field cards. Observations of visible gold were recorded and normally confirmed by binocular microscope in the field office. Care was taken in avoiding winnowed, surficial sediment depleted in gold and to dig below the open framework gravels. Sieved sediment was washed by careful agitation under water to reduce the risk of fine gold loss due to surface tension effects.

The stream sediments were analysed for Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Mo, Ag, Sn, Sb, Ba, Ce, Pb, Bi, Th and U by X-ray fluorescence spectrometry (XRF) in the BGS laboratories after drying and fine grinding. The panned concentrates were ground in a tema mill with a tungsten carbide barrel and a 50 g split taken for gold analysis by Caleb Brett International Limited using atomic absorption spectrometry after concentration in MIBK following an aqua regia attack. A second 12 gm split was analysed by XRF for Ca, Ti, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Mo, Ag, Sn, Sb, Ba, Ce, Pb, Bi and Th. The results of the analyses are available from the MRP database in Keyworth.

Log-probability plots were constructed for each of the elements but are not presented in this report. Breaks in the populations were identified from changes of slopes on these plots and used as thresholds for the interpretation. These plots, summary statistics and Spearman correlation coefficients were calculated using the SAS statistical package on the VAX minicomputer at Keyworth. The results are plotted on an outline geological base map (Figure 2) using Autolisp programs written by the chief author. Each sample is represented by an expanding, filled circle whose radius is related linearly to the element content. Any truncation is indicated in the key and large filled circles are hatched so that adjacent sample points remain visible. For some elements (e.g. barium in panned concentrates) the results from several MRP investigations are combined with those from the present survey, but only where the same analytical method has been employed. These plots therefore show a larger number of sample points. The text, however, describes in detail only the results from this study.

Stream sediment samples

The summary statistics of the 309 stream sediment samples are given in Table 1. Comparison of the median values with those from similar upland areas of the Scottish Highlands (Coats et al., 1981 and 1982) indicates that the area has higher median levels of V, Cr, Mn, Fe, Ni, Cu, and Zn. Levels of Ba, Pb and U are comparable with the other areas. However, the data must be treated with caution since different methods of analysis were employed. Plant et al. (1984) have noted the higher contents of basic elements in samples collected from streams draining the Southern Highland Group Dalradian elsewhere in the Highlands compared to the Argyll Group Dalradian which forms the bulk of the other two areas.

Table 1 Summary statistics on stream sediment samples from the Pitlochry - Glen Clova Area

	N	Mean	Median	Lower Quartile	Upper Quartile	Minimum	Maximum
Ca	309	15328	14200	9300	20600	1700	57800
Ti	309	7632	7480	6615	8390	4060	17350
V	309	139	133	110	159	57	369
Cr	309	119	99	85	118	35	746
Mn	277	4291	3030	1800	5190	0	22560
Fe	309	71659	66300	57400	81800	33200	178000
Co	309	44	39	30	53	15	163
Ni	309	47	42	35	50	17	219
Cu	309	33	29	20	40	6	174
Zn	309	234	203	157	268	50	1287
As	309	34	15	8	26	1	859
Mo	309	1.2	1	0	2	0	8
Ag	309	1.4	1	0	2	0	8
Sn	309	1.3	0	0	2	0	15
Sb	309	0.5	0	0	0	0	22
Ba	309	617	521	414	687	190	10258
Ce	309	76	66	49	92	10	277
Pb	309	50	42	30	58	6	204
Bi	307	0.8	0	0	1	0	81
Th	309	10	9	7	12	4	32
U	309	4	4	2	6	0	34

1. All elements in ppm.
2. Method of analysis X-ray fluorescence spectrometry.

Table 2 Spearman rank correlation coefficients (>99% significance level) for stream sediment samples

Ca	V+0.66	Ba-0.60	Cu+0.57	Th-0.50	Ti+0.39	Cr+0.37	As-0.33
	Fe+0.31	Ce-0.30	Ni+0.28	Pb-0.23	Co+0.21	Ag+0.19	
Ti	Ba-0.50	V+0.50	As-0.44	Ca+0.39	Cr+0.24	Zn-0.22	Cu+0.20
V	Cu+0.77	Cr+0.72	Ca+0.66	Fe+0.57	Ti+0.49	Ni+0.49	As-0.33
	Ba-0.29	Co+0.29	Ag+0.22	Th-0.22	Ce-0.20	Sn-0.19	Zn+0.15
	Pb-0.14						
Cr	V +0.72	Ni+0.62	Cu+0.60	Fe+0.37	Ca+0.37	As-0.30	Ti+0.23
	Co+0.17	Pb-0.17	Ba-0.16	Ce-0.16			
Mn	Co+0.67	Zn+0.60	Fe+0.36	Pb+0.34	Ni+0.29	As+0.29	Ce+0.16
Fe	Co+0.72	V +0.57	Zn+0.51	Ni+0.49	Cu+0.46	Cr+0.38	Mn+0.36
	Ca+0.31	Ag+0.30	Ce+0.25	Pb+0.25	U+0.21	Mo+0.15	
Co	Fe+0.72	Zn+0.67	Mn+0.67	Ni+0.58	Pb+0.33	Cu+0.30	V +0.29
	Ag+0.28	As+0.23	Ca+0.20	Cr+0.17	Ce+0.16	Sb+0.15	
Ni	Cr+0.62	Cu+0.58	Co+0.58	Zn+0.57	V +0.49	Fe+0.49	Mn+0.29
	Ca+0.27	Ag+0.24	Ba+0.19	Th-0.18			
Cu	V +0.77	Cr+0.60	Ni+0.58	Ca+0.56	Fe+0.46	Co+0.30	As-0.23
	Ag+0.22	Zn+0.22	Ba-0.20	Ti+0.19			
Zn	Co+0.67	Mn+0.60	Ni+0.57	Fe+0.51	Pb+0.41	As+0.40	Ba+0.33
	Ti-0.22	Cu+0.22	Ce+0.21	Ag+0.20	U +0.19	V +0.15	
Mo	U -0.18	Th+0.18	Fe+0.15				
Ag	Fe+0.30	Co+0.28	Ni+0.24	Cu+0.22	V +0.22	Zn+0.20	Ca+0.19
	Th-0.17						
Sn	Sb+0.30	U +0.25	Ce+0.22	Pb+0.20	V -0.19	Th+0.16	
Sb	Sn+0.30	Ce+0.16	Co+0.15				
Ba	Ca-0.60	As+0.50	Ti-0.50	Zn+0.33	V -0.29	Cu-0.20	Ni+0.19
	Cr-0.16						
Ce	Th+0.69	U +0.47	Pb+0.42	Ca-0.29	Fe+0.24	Sn+0.22	Zn+0.21
	As+0.21	V -0.20	Co+0.16	Sb+0.16	Cr-0.16	Mn+0.15	
As	Ba+0.50	Ti-0.43	Zn+0.40	V -0.33	Ca-0.32	Cr-0.30	Mn+0.28
	Pb+0.25	Cu-0.23	Co+0.23	Ce+0.21			
Pb	Ce+0.42	U +0.42	Zn+0.41	Mn+0.34	Co+0.33	Th+0.31	As+0.25
	Fe+0.24	Ca-0.22	Sn+0.20	Cr-0.17	V -0.14		
Bi	-						
Th	Ce+0.69	Ca-0.49	Pb+0.31	V -0.22	U +0.21	Mo+0.18	Ni-0.18
	Ag-0.17	Sn+0.16					
U	Ce+0.47	Pb+0.42	Sn+0.25	Th+0.21	Fe+0.21	Zn+0.19	Mo-0.18

Calcium

Calcium is found in the stream sediments from this area (Table 1) at levels (median 1.42% Ca) which are similar to the rest of the United Kingdom (median 1.68% Ca). Examination of the log-probability plot shows that there are population breaks at 1% and 2.4% Ca. The population below 1% Ca reflects streams draining areas of acid upland soils developed on calcium-poor bedrock. The population with >2.4% Ca comprises 36 samples and these samples are from sites draining the Glen Doll diorite intrusion, the Green Beds in Glen Prosen and the Loch Tay Limestone at Nether Craig in Glen Isla (Figure 3). In the streams draining the diorite and the meta-tuffs the calcium is probably found in mafic minerals such as hornblende or in calcic plagioclase. Positive correlations with V, Cu, Ti, Fe, and Ni confirm this association (Table 2).

Titanium

Titanium levels in the area are relatively high with median content of 0.76% Ti (Table 1) against a median for the UK of 0.60% Ti. The area may contain a higher percentage of metabasic rocks than normal and which accounts for some of the increase. Additionally, stream sediments in upland areas are enriched in resistate elements such as titanium by the removal of more easily weathered rock-forming minerals such as feldspars. The log-probability plot shows a fairly clear threshold at 1% Ti and five percent of the samples exceed this level. These titanium-enriched samples were collected from Glen Clova and Glen Prosen and the predominant rock type described from these samples was hornblende schist. The metabasic intrusives and tuffs are enriched in titanium compared to both the normal Dalradian metasediments and the Glen Doll diorite.

Vanadium

Vanadium has similar geochemical properties to Ti and Fe. In this area vanadium has a strong positive correlation with titanium (Table 2) and the log-probability distribution is similar, with 5% of the samples being anomalous. Two samples, KLC 122 with 331 ppm V and KLC 127 with 369 ppm V, are strongly anomalous (>300 ppm V). These two samples were collected from Rough Burn and Cald Burn which are very steep streams draining the Glen Doll diorite. The high energy flow in these streams has preferentially upgraded the heavy Fe-Ti oxides in the stream sediment and enhanced the vanadium.

Chromium

Chromium shows a very marked population break in the log-probability plot at the 95th percentile (165 ppm Cr) and 14 samples exceed this level. These samples, with two exceptions, were collected from streams draining the Glen Doll diorite and specially the Burn of Kilbo, which is a northward flowing stream that drains the ultramafic portion of the intrusion. Chromium levels reach 746 ppm and the element is probably contained in spinels enriched in the ultramafic parts of the body. The two samples outside of Glen Doll are KLC 168 (166 ppm Cr) and KLC 2519 (178 ppm Cr), which were collected from Glen Prosen and Noran Water respectively. The first sample was collected from a stream draining hornblende schist but the second does not come from an area with any known mafic rock in the catchment and the reasons for its high chromium are unknown.

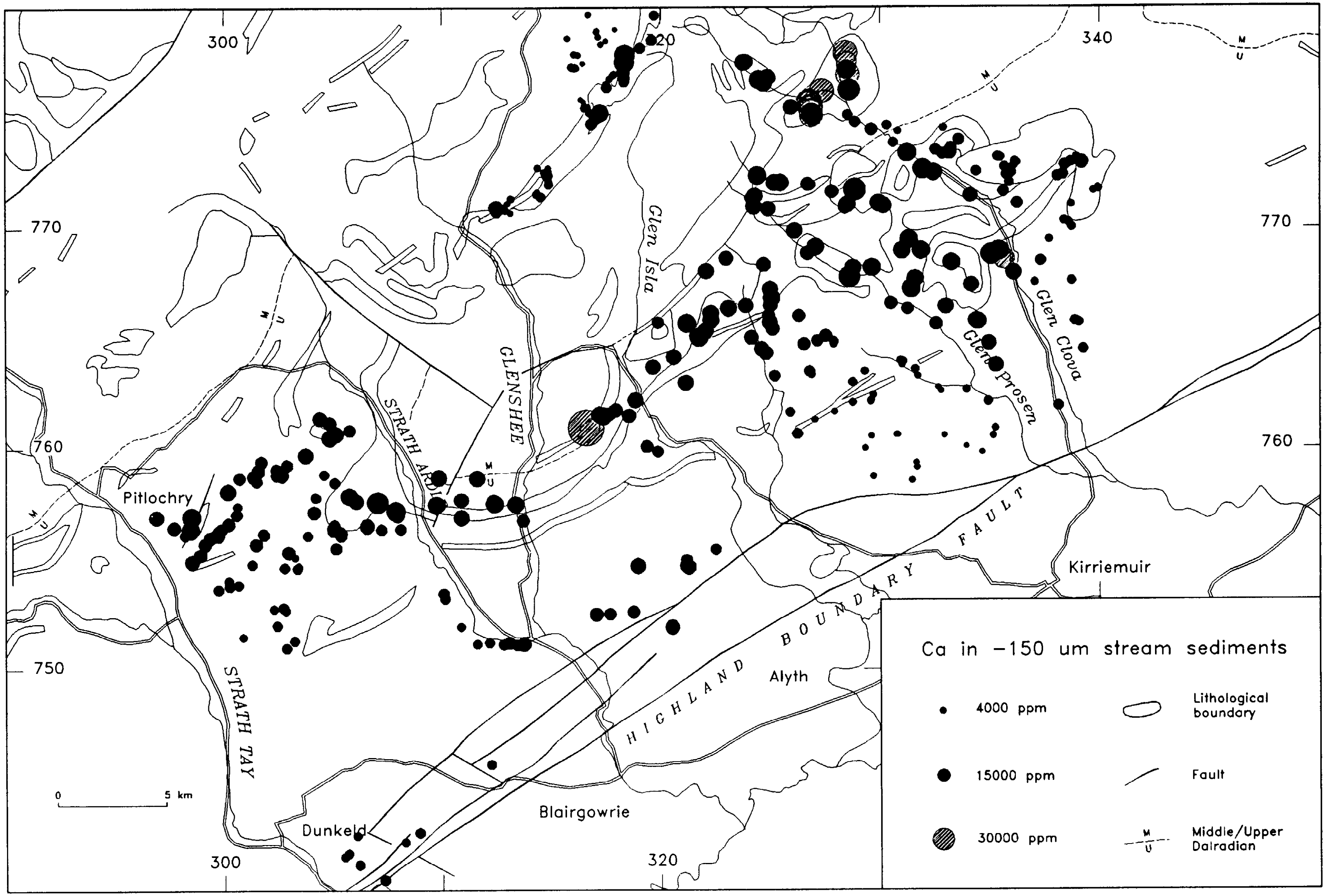

Figure 3 Distribution of calcium in stream sediments

Manganese

Manganese in stream sediments is strongly controlled by redox reactions in the surface levels of the stream sediment profile and high levels of manganese reflect secondary precipitation of Mn-oxides rather than dispersion from Mn-rich sources. The median level in this area (0.30% Mn) is similar to normal levels in stream sediments elsewhere in Scotland. There is a break in the log-probability plot at the 95 percentile level (1.28% Mn) but, unfortunately, this is near the upper limit of detection reported by the BGS XRF laboratory in early 1989 and a further 30 samples have indeterminate, very high manganese concentrations. Many of these samples come from the area east of Pitlochry and in particular the streams flowing into or from Loch Broom, Lochan Oisinneach Mor, Loch Ordie and Pitcarmick Loch. The artificially impeded drainage in these gently rolling peaty upland areas is the most likely cause for the high manganese in the stream sediments. Contrastingly, in the streams with a steeper gradient, such as those in Glen Clova, there is much more rapid bed turnover and the secondary manganese does not precipitate to such an extent.

Iron

The log-probability plot shows a relatively uniform distribution from 5.7 to 8.1% Fe, the interquartile range, but there is a marked population break at the 95th percentile at 11.1% Fe. As with Mn, many of the samples above this threshold come from the area east of Pitlochry and were described in the field as being heavily iron-stained. However, there are some Fe-rich samples from Glen Doll where steep gradients increase the stream flow rate and naturally upgrade the heavy mafic minerals derived from the diorite intrusion.

Cobalt

The log-probability plot shows the presence of two lognormal populations at 25 - 50 ppm and 74 - 100 ppm with a mixed intermediate group. Five samples exceed the top threshold and all these samples are from the area east of Pitlochry that has high manganese in the stream sediments. Cobalt is strongly scavenged by manganese oxide precipitation and this is the most important factor in the element distribution. The Co - Mn correlation of +0.67 (Table 2) would have been higher if the detection limit for Mn had been increased above 1% (Table 2).

Nickel

The median content of 47 ppm Ni is slightly higher than other areas of the Dalradian. The log-probability plot shows a single lognormal population from 17 to 85 ppm above which there is a sharp break. Fifteen samples exceed this level and all except three were collected from the Burn of Kilbo and Moulzie Burn which drain the ultramafic portion of the Glen Doll diorite. The other three samples are scattered over the survey area. KLC 24 was collected from a stream flowing into Loch Broom and was recorded as being heavily iron-stained. This sample contains 17.49% Fe and nickel is probably upgraded by secondary iron precipitation. KLC 72 was collected from a tributary flowing into Loch Eisg (spelt Loch Esk on the 1:50 000 topographic map). This sample contains 8.24% Fe and greater than 1% Mn, so secondary precipitation again cannot be ruled out. However, because this sample also contains 867 ppm Zn and 1955 ppm Ba mineralisation is probably present in the catchment. One small grain of gold was observed in the pan and may be linked to this mineralisation.

Copper

Levels of copper in this area are not exceptionally high compared to other parts of the Dalradian such as central Argyll (Coats et al., 1982) and there is little evidence for a strongly mineralised separate population. A threshold was therefore taken at the 90th percentile level of 55 ppm which has been used elsewhere in the Dalradian (Coats et al., op cit). Copper in stream sediments can be related to many factors such as contamination, scavenging by secondary iron oxides and mineralisation. All three factors are present in this area. Three samples KLC 26 (56 ppm Cu), KLC 60 (60 ppm) and KLC 66 (73 ppm) collected from Loch Broom Burn and Allt na Coille east of Pitlochry also have anomalously high levels of iron which has enhanced the copper by secondary oxide scavenging. These samples also have elevated levels of arsenic, another element similarly enhanced in stream sediments. Most of the other anomalous samples are probably related to mineralisation. They are grouped (Figure 4) in Glen Isla eastwards to Glen Prosen, in Glen Doll draining the diorite and in the Burn of Fleurs, Glen Clova. The 'mineralised group' can be distinguished from the high-Fe group on the plot of Cu - Fe plot (Figure 5) showing a vertical trend at average iron contents. The positive correlations with V, Cr, Ni, Ca and Fe indicate that copper is mainly concentrated in the metabasic rocks and this is confirmed by the distribution with the grouping in Glen Isla to Glen Prosen being coincident with the outcrop of the Green Beds (Figure 4). The Green Beds are known to be enriched in copper in the Aberfeldy area (unpublished MRP data) and in central Argyll (Coats et al., 1982). The presence of grains of pyrite in the corresponding pan samples also indicates that the Green Beds are enriched in sulphides.

Zinc

The normal threshold for this element in the Dalradian is taken at 300 ppm (Smith et al., 1984) but a large number of samples exceed this level in this area and a more realistic threshold is taken at the upper population break of 500 ppm Zn. High correlations (Table 2) with Co and Mn indicate that secondary manganese oxide precipitation is a strong factor in the element distribution. All the thirteen anomalous Zn-rich samples have manganese levels above the detection limit which supports this conclusion. The majority of these samples come from the area east of Pitlochry (Figure 6) which has been noted previously. Mineralisation may be present in this area as the levels of Ba are enriched in the stream sediments but, again, this element is also affected by manganese oxide precipitation. The four samples collected outside this part of the area have high Ba and Pb levels (Table 3) and probably represent dispersion from mineralised sources. Pyrite was recorded in all the pans collected from these sites and sulphide mineralisation is probably present in all these catchments.

Table 3 Locations of stream sediment samples with anomalous zinc indicating mineralisation

Number	Grid Reference	Locality	Zn ppm	Ba ppm	Pb ppm
KLC 146	[324300 771470]	Snow Burn, Glen Prosen	1287	1065	170
KLC 148	[324210 771370]	Doups Burn, Glen Prosen	731	1083	113
KLC 497	[326860 774950]	Burn of Kilbo, Glen Clova	693	737	108
KLC 1536	[338720 770030]	Corwiry Burn, Glen Clova	582	1368	63

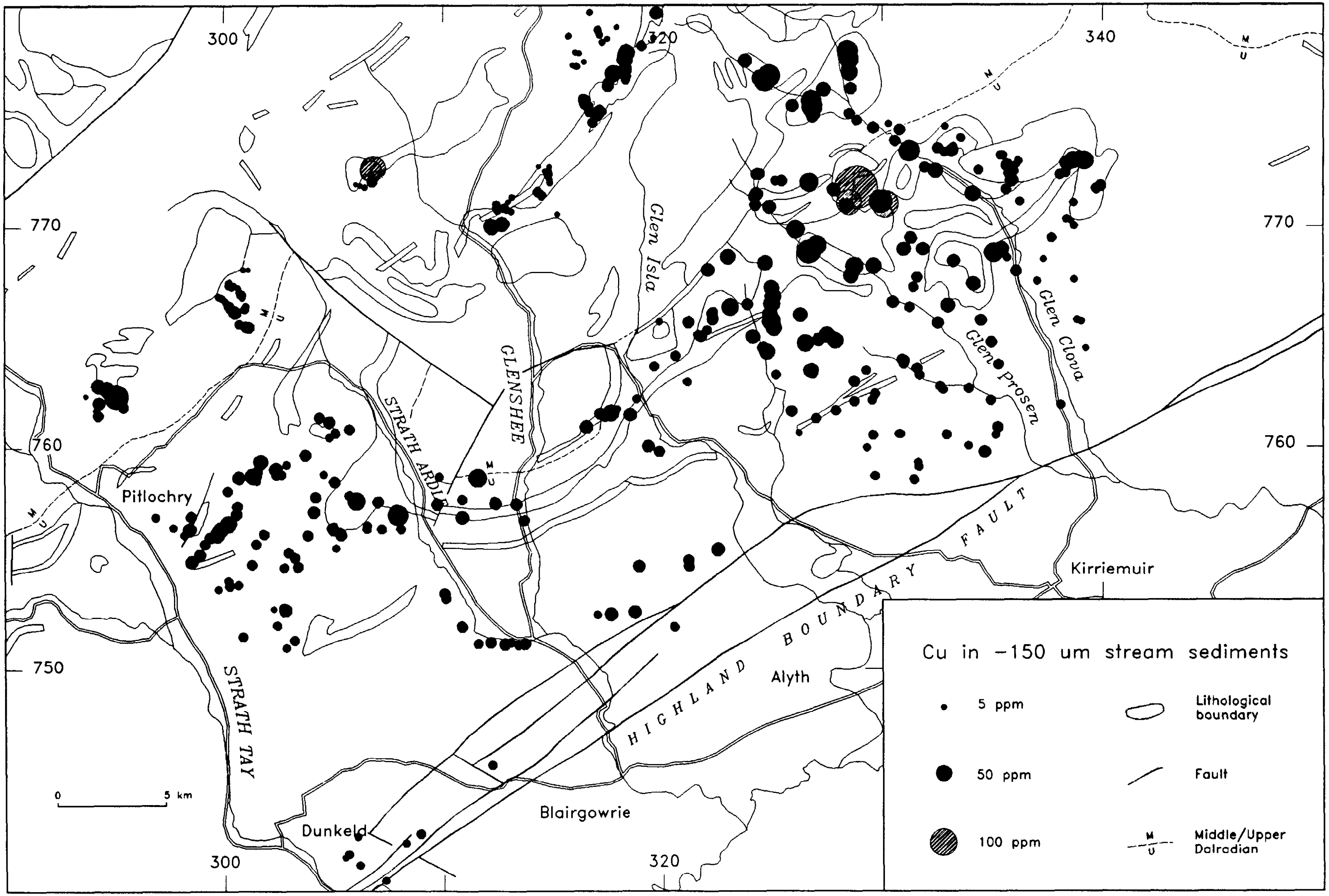

Figure 4 Distribution of copper in stream sediments

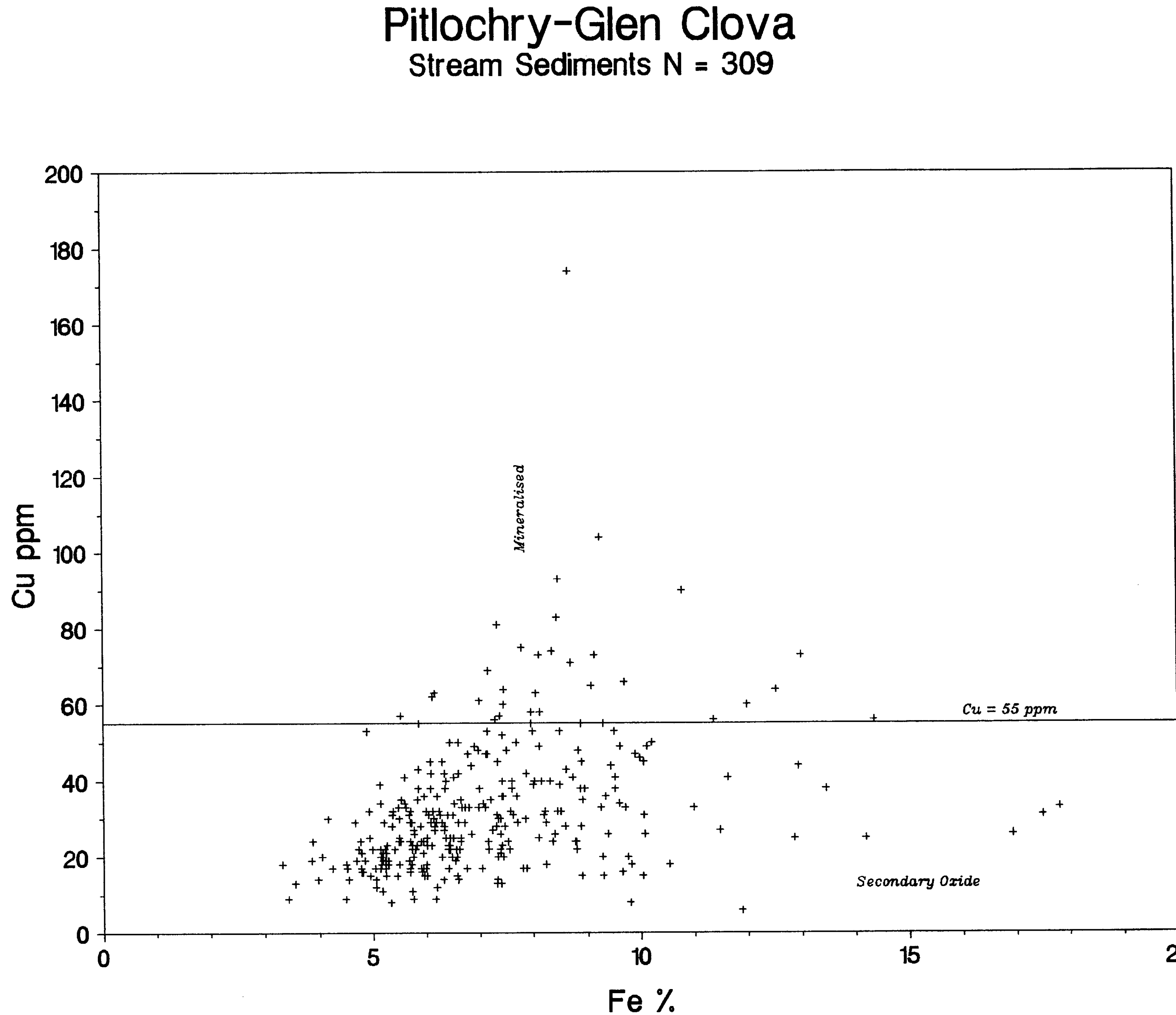

Figure 5 Plot of copper vs iron in stream sediments

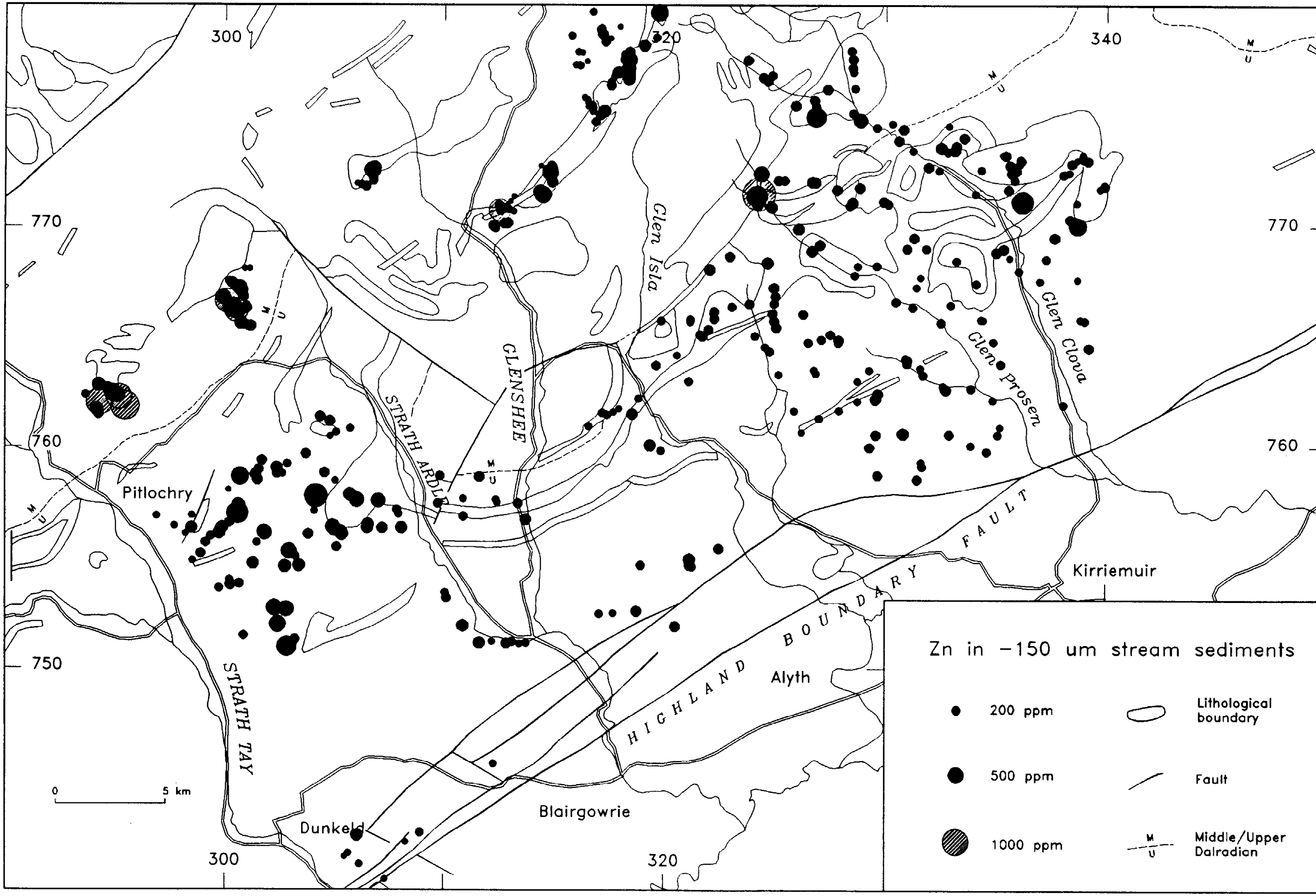

Figure 6 Distribution of zinc in stream sediments

Arsenic

Arsenic has a large range of values in stream sediments from this area (Table 1) but the median value of 15 ppm is relatively low. The log-probability plot shows a single population from 5 - 30 ppm, which probably represents normal background levels in stream sediments, an intermediate population from 30 - 70 ppm and an upper group extending up to the maximum of 859 ppm. Nearly all the anomalous samples (>100 ppm As) are found to the east of Pitlochry in the Loch Broom, Lochan Oisinneach Mor, Loch Pitcarmick and Allt Cul na Coille catchments (Figure 7). This area shows up as being one of the highest arsenic areas in the Geochemical Survey Programme Atlas (BGS, 1992). Many of these samples have high iron (6 out of 20 samples) and high manganese (11 out of 20 samples). This is illustrated in Figure 8 where there is a good correlation between high arsenic and high iron. The iron-rich sample (17.8% Fe) with low arsenic is KLC 498 which was collected from Burn of Loch Wharral, Glen Clova. This sample is probably enriched in primary iron oxides and arsenic is not available in this catchment to be upgraded. In the Pitlochry area the major factor in the extremely high levels of arsenic is the scavenging effect of secondary oxide precipitation but primary sources have not been found. Various bedrock sources can be postulated, such as minor sulphide veins with arsenopyrite or stratabound disseminations of sulphides in the Green Beds or metasedimentary rocks. The stratigraphical and structural level of this part of the area is similar to that of the Calliachar Burn gold deposit (Aberfeldy) but there is little or no indication of gold mineralisation. However, the Pitlochry area is poorly exposed and fine-grained gold may be present, which would not necessarily be picked up by the sampling methods used in this survey.

Molybdenum

Molybdenum only occurs at low levels in this area and 4 ppm forms a fairly low threshold value. Five samples exceed this level and these were collected from the following locations.

Table 4 Locations of stream sediment samples with anomalous molybdenum

Number	Grid Reference	Locality	Mo ppm
KLC 66	[307940 756960]	Allt Cul na Coille, Strath Ardle	8
KLC 78	[304820 761160]	Tullochcurran Burn, Strath Ardle	7
KLC 148	[324210 771370]	Doups Burn, Glen Prosen	5
KLC 444	[316550 760940]	Drumore Loch, Glenshee	5
KLC1501	[335980 772500]	Burn of Eskielawn, Glen Clova	5
KLC1568	[330820 760620]	Addabing, near Cat Law	5

The first sample may reflect mineralisation because it also contains anomalous copper and arsenic but the molybdenum value may be enhanced by elevated iron (13% Fe). No mineralisation is recorded in the second stream and this area is poorly exposed. Doups Burn, which runs into Snow Burn in Glen Prosen, probably contains minor sulphide mineralisation with barium, zinc and lead also being anomalous. The stream draining into Drumore Loch has the Nether Craig baryte locality in its catchment and small amounts of base metal sulphides are present. Molybdenite may also be present at this locality. The sample from the Burn of Eskielawn does not drain any known mineralisation but a rock sample (KLR 1152) collected in the adjacent stream to the southeast

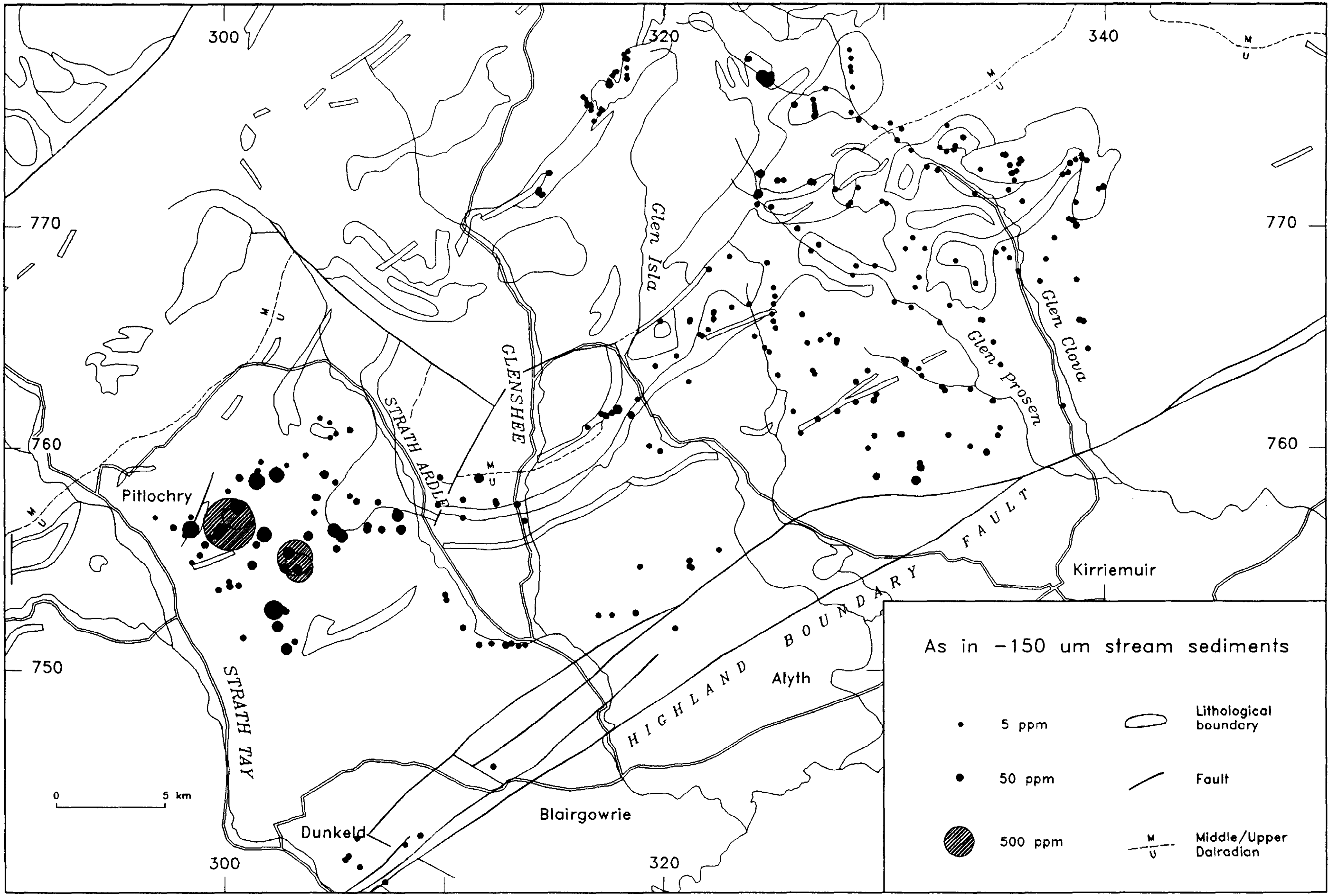

Figure 7 Distribution of arsenic in stream sediments

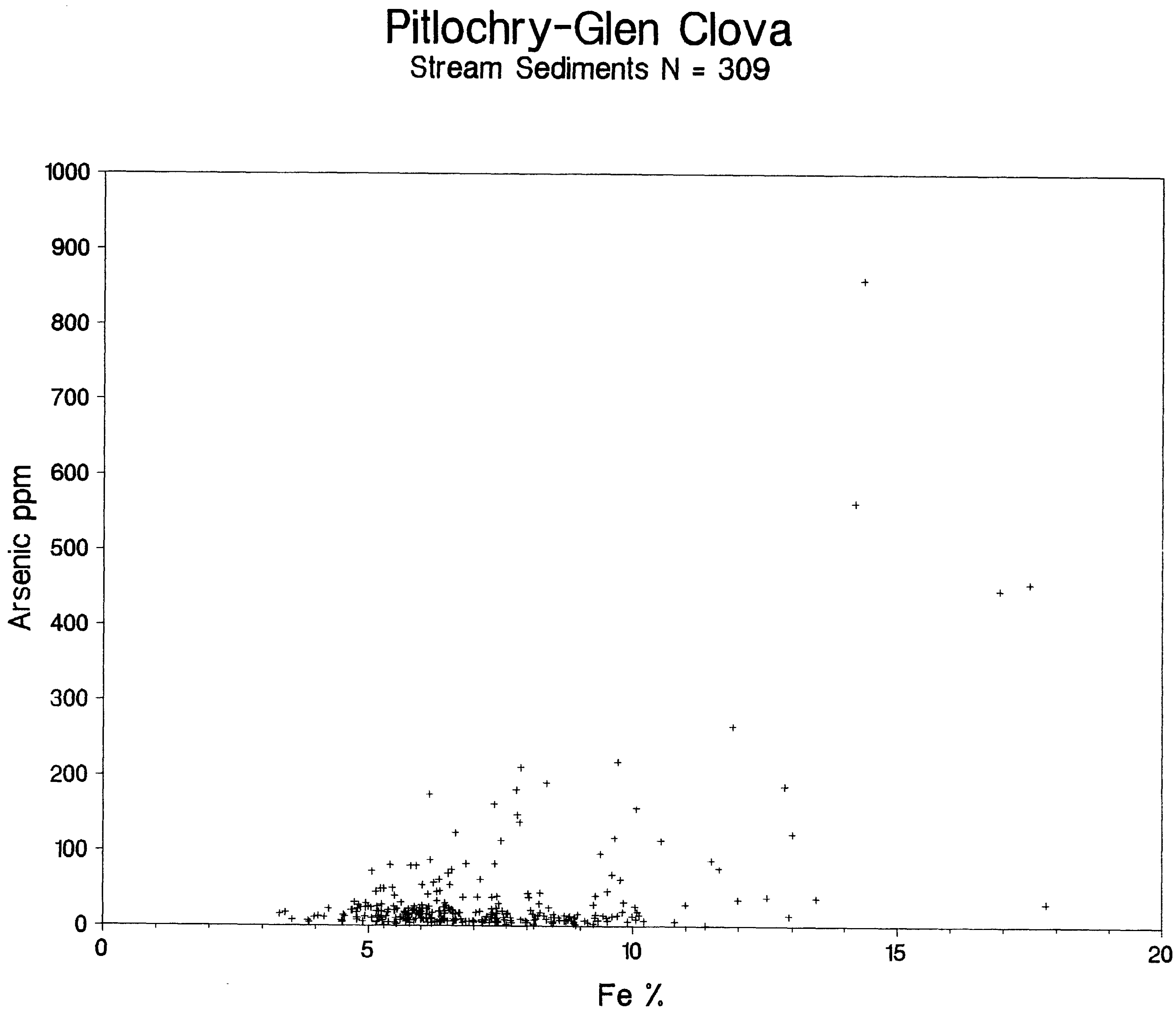

Figure 8 Plot of arsenic vs iron in stream sediments

contains molybdenite and pyrite in an irregular granite sheet. Similar mineralisation is probably present in the catchment of the Burn of Eskielawn. No mineralisation is known at the Addabing locality but a similar source is proposed.

Silver

The median level is below the limit of detection of the XRF method of analysis so that most of the silver analyses reflect instrumental error rather than real geological variation. Silver has significant correlation coefficients with the mafic elements Fe, Co, Ni, Cu, V and Zn (Table 2) so that an association with the metabasic rocks may be present. Alternatively, this may represent an interference effect in the analysis. The lack of correlation between silver in stream sediments and panned concentrates also indicates that the analytical method is not sufficiently accurate.

Four samples exceed 5 ppm which is probably a realistic threshold value that reflects the large analytical error. These samples are scattered from the Allt Ruigh an Lagain (near Pitlochry), Fee Burn in Glen Doll, Tarabuckle Burn in Glen Clova to the Burn of Drimmie, north of Blairgowrie. The sample from the first named stream has high levels of manganese, arsenic and moderately elevated levels of zinc and barium. The silver content is probably elevated by secondary manganese scavenging from a minor mineralised source.

Tin

This element is most strongly correlated with antimony and this association is typical of human contamination, the two elements together with lead being distinctive components of tin cans, solder and Pb shot. There are, however, also correlations with U, Ce and Th and several samples from Glen Clova have tin levels of 6 - 7 ppm which are probably present in heavy minerals associated with the Glen Clova intrusions or with glacially transported material from the more differentiated granites further north.

Antimony

Contamination is the major factor in the distribution of antimony in stream sediments with those samples having approximately equal, anomalous levels of tin and antimony being visibly contaminated. KLC 26 collected from the Loch Broom catchment [NGR 300210 756580] contains 22 ppm Sb and 857 ppm As and this stream is probably the only one draining Sb-As mineralisation. Samples KLC 18 and 24 were collected nearby and their anomalies (6 ppm and 24 ppm Sb) may have a similar origin but contamination cannot be ruled out.

Barium

Barium shows a single lognormal population on the log-probability plot up to a threshold of 1300 ppm, where there is a steep rise up to the maximum of 1%. Seven samples exceed this threshold level and all would normally be taken as indicating baryte mineralisation. However, the low values in panned concentrates of six of these samples (Figure 9) indicate that baryte is not present in these panned concentrates or stream sediments. These six samples have manganese greater than the 1 % detection limit and scavenging by manganese oxide precipitation is the cause of the barium upgrading in the stream sediment. Only site KL 439 [317180 761540] has high barium in both the stream sediment and the pannned concentrate and is downstream of the baryte mineralisation at Nether Craig.

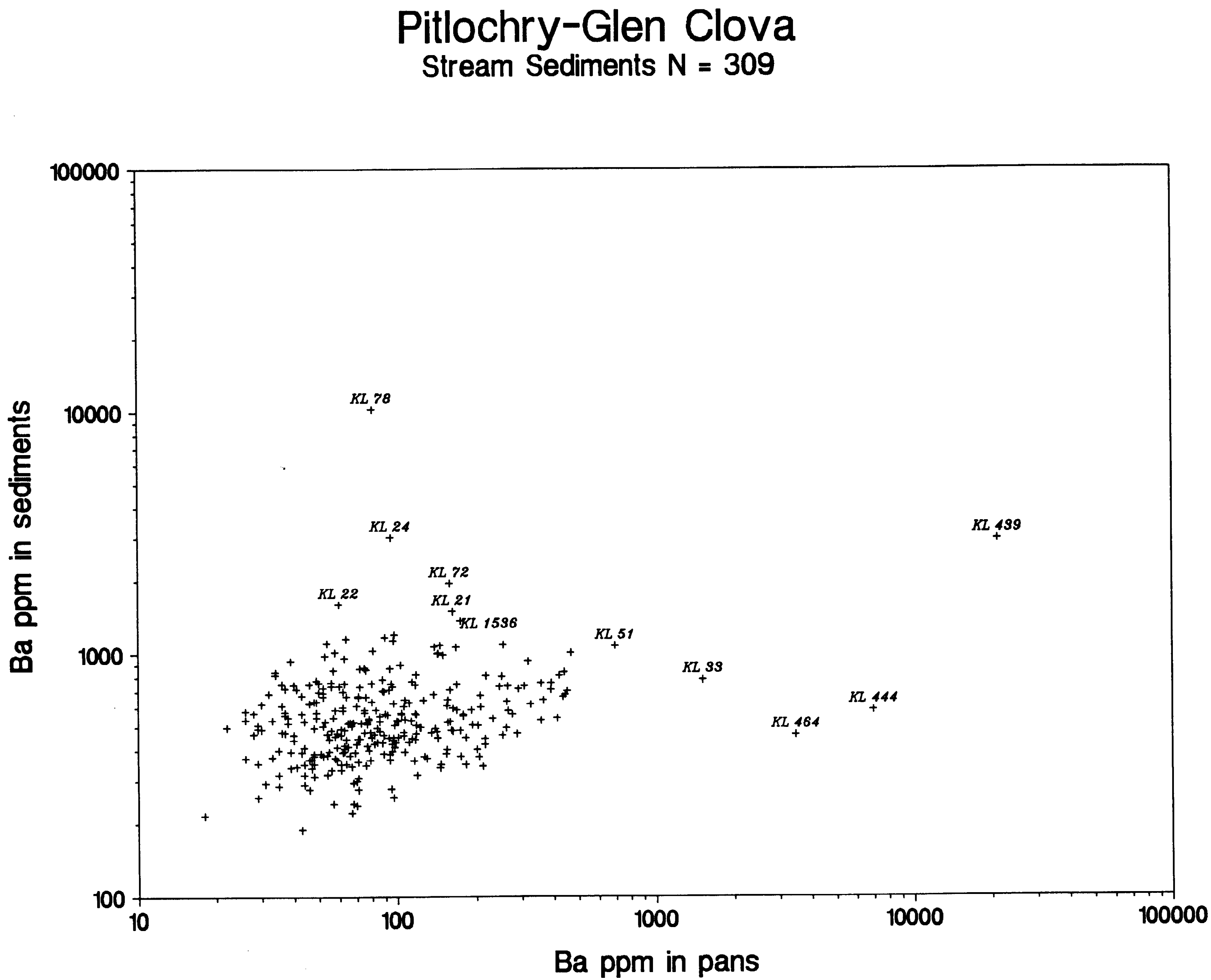

Figure 9 Plot of barium in stream sediments vs barium in panned concentrates

Cerium

The cerium values from the sampled area are comparable to the average for cerium in the MRP database. The log-probability plot shows that the distribution is lognormal up to the 95th percentile (160 ppm) and there is a further break at the 99th percentile (220 ppm). With only one exception all the samples with >160 ppm Ce were collected from the streams draining the northeast side of Glen Clova, such as Burn of Eskielawn, Loch Wharral, Loch Brandy, Bonhard Burn and Corrie Burn. There are good correlations with Th and U (Table 2) indicating a heavy mineral association in monazite or possibly allanite. The high levels are probably related to degrees of fluvial upgrading of the mineral in these catchments as much as the possible presence of higher levels of cerium in the Older Granites in Glen Clova (Robertson, 1991). Glacial dispersion from further afield may be important, as most of the samples were collected below the glacial corrie moraine deposits. The one sample from outside Glen Clova with 177 ppm Ce (KLC 1563) was collected from Corwhattie Burn [335240 760910] in lower Glen Prosen and apart from zircon being noted in the pan the sample is relatively unremarkable.

Lead

Lead levels are lower than other comparable areas in the Dalradian with a median of 50 ppm. A slight population break is found at 100 ppm and this is taken as the threshold level. Positive correlations with elements such as Ce and U (Table 2) would seem to indicate that these elements are associated with the Glen Clova intrusions (Figure 10) which may be enriched in a heavy mineral such as monazite and, possibly, contain lead in K-feldspar. The granitic intrusions in the East Grampians may be enriched in lead by normal differentiation processes but evidence for the small intrusions in Glen Clova is lacking. Lead is also correlated with zinc but examination of the lead - zinc plot (Figure 11) shows that only a few samples such as KLC 146, 148, 497, 22 and 142 are enriched in both elements. Another group of samples (KLC 97, 99, 500, 155 and 1503) from the Glen Clova area, with high lead but normal zinc levels, all have high cerium values. A third group (KLC 22, 56, 72 and 112) with background levels of lead but elevated zinc contents, come from the area east of Pitlochry with high secondary oxide contents. Three influences can therefore be distinguished by this plot. Lead is enriched along with cerium and uranium in the Glen Clova area particularly in the streams draining Loch Brandy and Loch Wharral. A small group of samples is probably related to base metal mineralisation and includes samples such as KLC 142, 146 and 148 from Snow Burn in Glen Prosen.

Bismuth

Bismuth shows no significant correlations with any of the other elements. Only one sample, KLC 135 with 81 ppm, contains significantly more bismuth than the limit of detection about 2 - 3 ppm Bi. This sample was collected from a stream draining Carn Lunkard at the northwestern end of Glen Doll. The sample has a lead content of 104 ppm which just exceeds the threshold and detectable gold in the panned concentrate (26 ppb Au). Pyrite was noted in the panned concentrate and a minor source of Pb-Bi-(Au) mineralisation is probably present in the stream catchment. There is no sign of an association with gold and antimony in panned concentrate as seen in the Ochil Hills area (Coats et al., 1991).

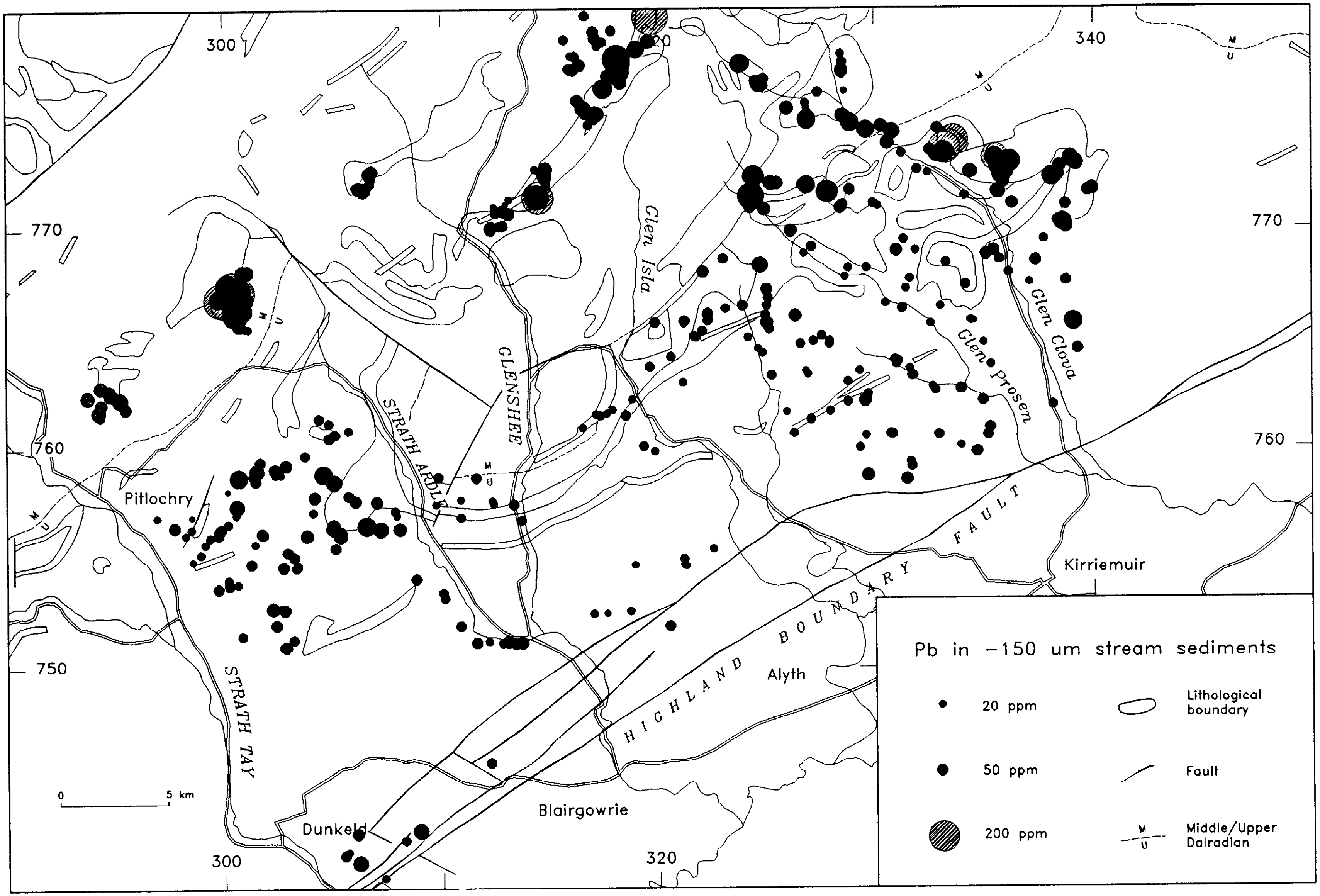

Figure 10 Distribution of lead in stream sediments

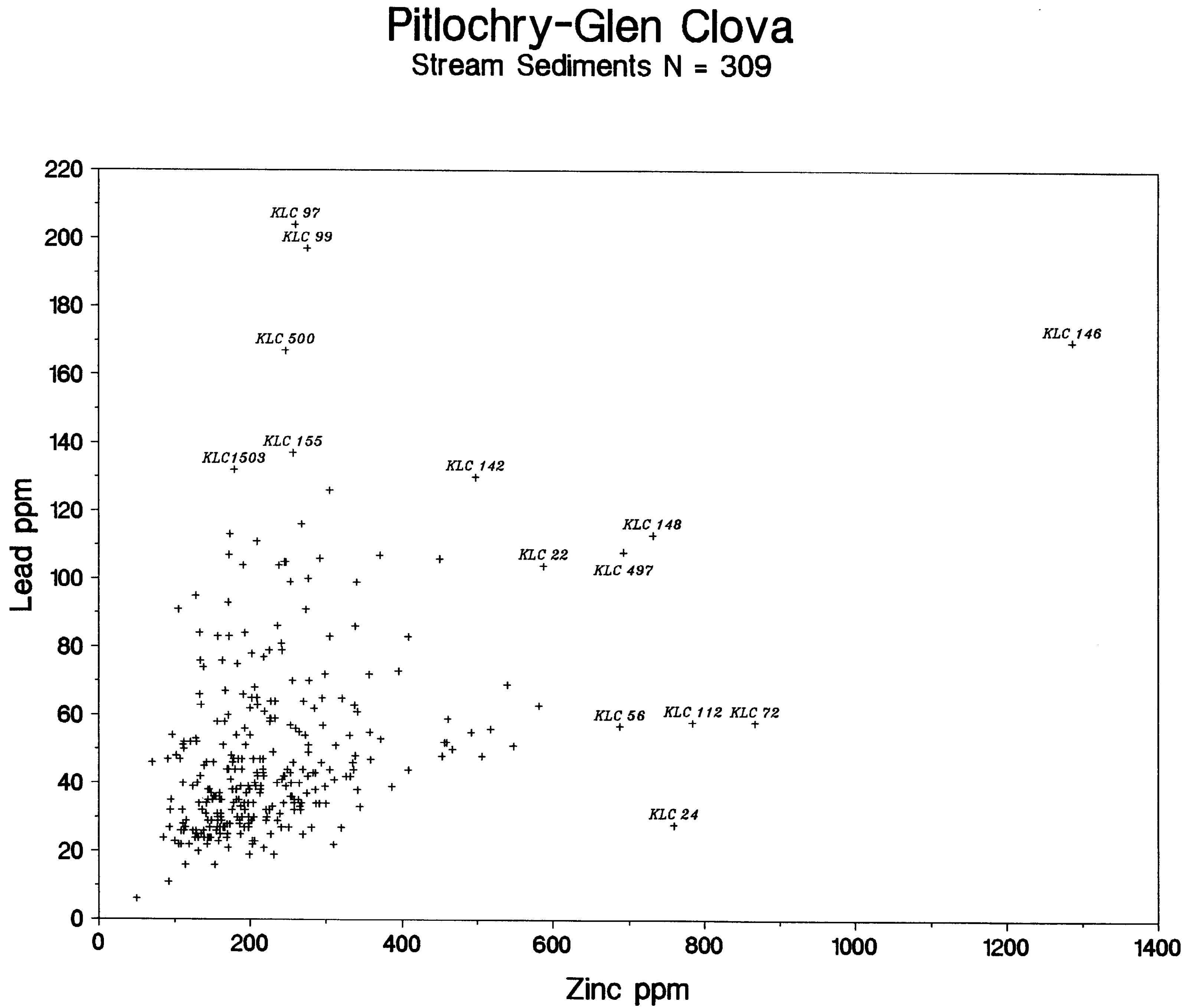

Figure 11 Plot of lead vs zinc in stream sediments

Thorium
This element shows relatively little constrast in geochemistry in this area and all the values can be considered part of one lognormal population. Higher values >25 ppm Th are centred on the northeast side of Glen Clova along with high Ce and U.

Uranium
Uranium in stream sediments shows a similar lognormal distribution to thorium but there are marked breaks at the top end of the distribution with thresholds at 10 and 17 ppm. High values are found in Glen Clova in two main areas. The first area is also anomalous in Ce and Th and is exemplified by samples such as KLC 498 and 1502 which were collected from Burn of Loch Wharral. The sediments from this area are enriched in a heavy mineral phase containing Ce, Th and U. The second area, the Burn of Heughs, is enriched in uranium but does not show high thorium. This is illustrated by sample KLC 1511, collected from Matthews Burn, one of the upper tributaries of the Burn of Heughs, which contains 34 ppm U but only 15 ppm Th and is discussed in a later section. The gold-rich gossan in the latter catchment was shown to be enriched in uranium but not in thorium. The distribution of uranium in stream sediments may indicate that this mineralisation is present over a relatively large area.

Panned concentrate samples

The summary statistics for the panned concentrate samples are given in Table 5. Compared to areas such as Aberfeldy (Coats et al., 1981) and central Argyll (Coats et al., 1982) the median element contents are similar, with only Mn and Fe having higher and Ce and Ba lower medians. This illustrates the lack of significant barium mineralisation in this area compared to Aberfeldy, which has major stratabound deposits and to central Argyll which has many small baryte vein-style occurrences. The reason for the higher Mn and Fe is unclear. The greater initial volume of material collected in this survey may have been panned down to a similar final volume to the previous surveys, thus upgrading the magnetite content in the concentrate. A constant large initial volume was collected in this survey so that the gold content would be representative at the expected concentration levels.

Calcium
There are no distinct population breaks in the log-probability plot for calcium and an arbitrary threshold of 4% Ca was taken to pick out anomalous samples. Samples above this level are concentrated in two areas, Glen Doll and Glenshee. The Glen Doll samples are all noted as containing hornblende and epidote in the field descriptions. These relatively heavy, calcium-bearing minerals are derived from the calc-alkaline dioritic intrusion in Glen Doll. The samples from Glenshee are from the Alrick Burn and Drumore Loch catchments which drain the Loch Tay Limestone near Nether Craig. The panned concentrates probably contain calcite or calc-silicate minerals such as Ca-garnet. Correlations are negative with many elements indicating that the occurrences of calcite or calc-silicates dilutes the concentrations of other elements which are predominantly in mafic phases such as spinels.

Titanium
This element shows a high positive correlation with iron (Table 6) indicating that titanium occurs predominantly with iron in oxide minerals such as ilmenite. The panned concentrates draining the Caledonian igneous rocks in upper Glen Clova show the highest levels of titanium, e.g. KLP 122

with 18% Ti and 23% Fe from Rough Burn in Glen Doll. These exceptionally high levels are caused by natural upgrading of the heavy minerals in the steep gradient of these streams. Other positive correlations with elements such as Sn (+0.29) and Ag (+0.25) are probably related to an XRF interference effect with high Fe and Ti increasing the background levels.

Table 5 Summary statistics on panned concentrate samples from the Pitlochry - Glen Clova area

	N	Mean	Median	Lower Quartile	Upper Quartile	Minimum	Maximum
Ca	347	24341	25800	15800	32700	600	52700
Ti	347	21491	12790	8180	23740	1700	183720
Cr	331	250	213	115	320	44	1370
Mn	290	10215	10180	6402	13760	830	28490
Fe	347	181489	188600	160100	208900	20600	360900
Co	155	23	21	18	25	7	83
Ni	347	16	12	3	22	0	132
Cu	347	15	13	9	19	2	95
Zn	347	104	95	75	120	37	449
As	345	7	4	1	8	0	129
Mo	346	9	5	3	16	0	24
Ag	347	4.6	4	3	6	0	13
Sn	347	3.2	2	0	4	0	95
Sb	347	1.9	1	0	3	0	13
Ba	347	217	83	56	155	18	21076
Ce	342	51	28	12	64	0	544
Au	347	300	0	0	12	0	40000
Pb	347	21	11	6	18	0	440
Bi	302	0.3	0	0	0	0	6
Th	347	9	8	5	11	1	69

1. All elements in ppm except Au in ppb.
2. Method of analysis X-ray fluorescence, except gold which was determined using an aqua regia attack, MIBK solvent extraction and atomic absorption.

Chromium

Three populations can be distinguished on the log-probability plot. The lowest population from 10 to 200 ppm Cr occurs in streams draining metasediments whereas the intermediate population from 200 to 500 ppm Cr occurs over the metabasic rocks. An anomalous group above the 500 ppm threshold mainly consists of samples from the Burn of Kilbo in Glen Doll, which were collected from the catchments underlain by ultrabasic or dioritic members of the Caledonian igneous suite. Three samples occur away from the Glen Doll area, KLP 1566 with 903 ppm Cr in Glen Prosen and two samples KLP 2511 and 2512 from Glen Ogil with 615 and 504 ppm Cr.The source of the high chromium in Glen Ogil is unknown. High correlations with Ni, Zn and Cu indicate that the association with basic and metabasic rocks is the dominant control on the distribution of chromium.

Table 6 Spearman rank correlation coefficients (>99% significance level) for panned concentrate samples

Ca	Th -0.55	Ba -0.53	Zn -0.53	Ce -0.43	Pb -0.42	Cr -0.40	Ni -0.39
	Mn +0.27	Cu -0.27	Mo -0.23	Sb +0.20	Au -0.19	Sn +0.18	Fe +0.17
	Ti +0.16						
Ti	As -0.38	Fe +0.37	Sn +0.29	Ba -0.26	Ni +0.26	Cu +0.26	Ag +0.24
	Zn +0.20	Th +0.19	Au -0.18	Mn +0.18	Ce +0.17	Sb +0.16	Ca +0.16
Cr	Mo +0.71	Ni +0.56	As -0.49	Sb -0.48	Zn +0.45	Th +0.42	Ca -0.40
	Cu +0.38	Ba +0.27	Pb +0.26	Sn -0.18			
Mn	Fe +0.59	Ba -0.50	Ni -0.36	Ce -0.33	Ca +0.27	Cu -0.21	Zn -0.21
	Th -0.20	Ti +0.18	Pb -0.18				
Fe	Ba -0.69	Mn +0.59	Ag +0.37	Ti +0.37	Sn +0.33	As -0.32	Ni -0.29
	Pb -0.26	Ce -0.23	Ca +0.17				
Ni	Cu +0.72	Zn +0.65	Ba +0.60	Cr +0.56	Th +0.51	Pb +0.44	Ca -0.39
	Mn -0.36	Ce +0.35	Mo +0.30	Fe -0.29	Sb -0.26	Ti +0.26	Sn -0.21
	Au +0.20						
Cu	Ni +0.72	Zn +0.56	Ba +0.40	Cr +0.38	Pb +0.37	Th +0.33	Ca -0.27
	Ti +0.26	Au +0.24	Ce +0.24	Mn -0.21	Bi +0.19		
Zn	Ni +0.65	Cu +0.56	Th +0.54	Ca -0.53	Cr +0.45	Ba +0.45	Ce +0.37
	Pb +0.34	Mn -0.21	Ti +0.20	Au +0.19	Mo +0.17		
As	Cr -0.49	Mo -0.39	Ti -0.38	Fe -0.32	Th -0.23	Ba +0.22	Au +0.21
	Sb +0.19	Ag -0.15					
Mo	Cr +0.71	Sb -0.50	As -0.39	Ni +0.30	Ca -0.23	Sn -0.21	Ce -0.17
	Th +0.17	Zn +0.17	Ba +0.17	Pb +0.15			
Ag	Fe +0.37	Ba -0.26	Ti +0.24	Sn +0.21	Pb -0.18	As -0.15	
Sn	Sb +0.53	Ba -0.33	Fe +0.33	Ti +0.29	Ag +0.21	Mo -0.21	Ni -0.21
	Cr -0.18	Ca +0.18	Bi +0.15				
Sb	Sn +0.53	Mo -0.50	Cr -0.48	Ba -0.27	Ni -0.26	Ca +0.20	As +0.19
	Ti +0.16						
Ba	Fe -0.69	Ni +0.60	Ca -0.53	Mn -0.50	Pb +0.50	Zn +0.45	Th +0.42
	Cu +0.40	Ce +0.35	Sn -0.33	Sb -0.27	Cr +0.27	Ti -0.26	Ag -0.26
	Au +0.24	As +0.22	Mo +0.17				
Ce	Th +0.76	Ca -0.43	Pb +0.38	Zn +0.37	Ba +0.35	Ni +0.35	Mn -0.33
	Cu +0.24	Fe -0.23	Ti +0.17	Mo -0.17			
Au	Cu +0.25	Ba +0.24	As +0.21	Ni +0.20	Pb +0.20	Ca -0.19	Zn +0.19
	Ti -0.18	Th +0.17					
Pb	Ba +0.50	Th +0.45	Ni +0.44	Ca -0.42	Ce +0.38	Cu +0.37	Zn +0.34
	Cr +0.26	Fe -0.26	Au +0.20	Ag -0.18	Mn -0.18	Mo +0.15	
Bi	Cu +0.19	Sn +0.15					
Th	Ce +0.76	Ca -0.55	Zn +0.54	Ni +0.51	Pb +0.45	Cr +0.42	Ba +0.42
	Cu +0.33	As -0.23	Mn -0.20	Ti +0.19	Au +0.17	Mo +0.17	

Manganese

Several populations can be identified in the mangansese distribution in panned concentrates and a significant break at 1.65% Mn can be distinguished. Samples above this level are recorded as containing abundant garnet and this mineral, with iron oxide phases, must be the dominant control on the element distribution. The positive correlation with calcium (Table 6) is more difficult to explain but may be related to the occurrence of hornblende or garnet in the metabasic rocks.

Iron

Iron shows a single population on the log-probablity plot and the major factor on the distribution is the availability of iron oxide minerals such as magnetite and the degree of upgrading in the pan. Panned concentrates with greater than 30% Fe occur in Glen Doll and Glen Clova and also in Glen Isla but these exceptionally high levels are related to local stream upgrading as much as to the abundance of heavy minerals.

Cobalt

Cobalt values are not very high, ranging from only 7 to 83 ppm. Two populations can be identified with a break at 20 ppm Co. Lower values are related to poorly flowing streams draining metasedimentary rocks with abundant light minerals such as mica. The higher values are found in streams draining the igneous bodies or the metabasic rocks. The good correlation with Ni, Cu and Zn (Table 6) strengthens this interpretation.

Nickel

This element shows a break in the population at 50 ppm. All the samples above this threshold come from the streams draining the Glen Doll intrusion and particularly from the Burn of Kilbo, upstream of sample KLP 486 [326790 775700] which drains the most mafic portion of the intrusion.

Copper

Copper shows a single population in this survey up to a threshold of 35 ppm Cu which is a relatively low value for panned concentrates. The regional pattern (Figure 12) is distorted by the presence of much higher values in the Argyll Group Dalradian (caused by the Pyrite Belt: Smith et al., 1977) and to the south of the Highland Boundary fault (the result of contamination), so that the local pattern is not obvious. Within the local survey, high correlations with elements such as Co, Ni and Zn indicate a source in the metabasic rocks rather than in the Caledonian igneous intrusions. Most of the high copper values are associated with visible yellow sulphides in the pan but, occasionally, metal contamination is noted in the field records and the high copper concentration may be an artifact. A positive correlation with Au is found (Table 6) indicating that copper could be used as a pathfinder element. The Spearman coefficient is only +0.25, and although not high is still statistically significant. Samples with greater than 35 ppm Cu are found in Glen Doll where pyrite is recorded in diorite clasts and, also, lower down Glen Clova in the Burn of Heughs (Figure 13). Another anomalous area is further southeast in Trusty Burn and Noran Water where pyrite and limonite, possibly after pyrite, are recorded. This area is discussed in more detail later.

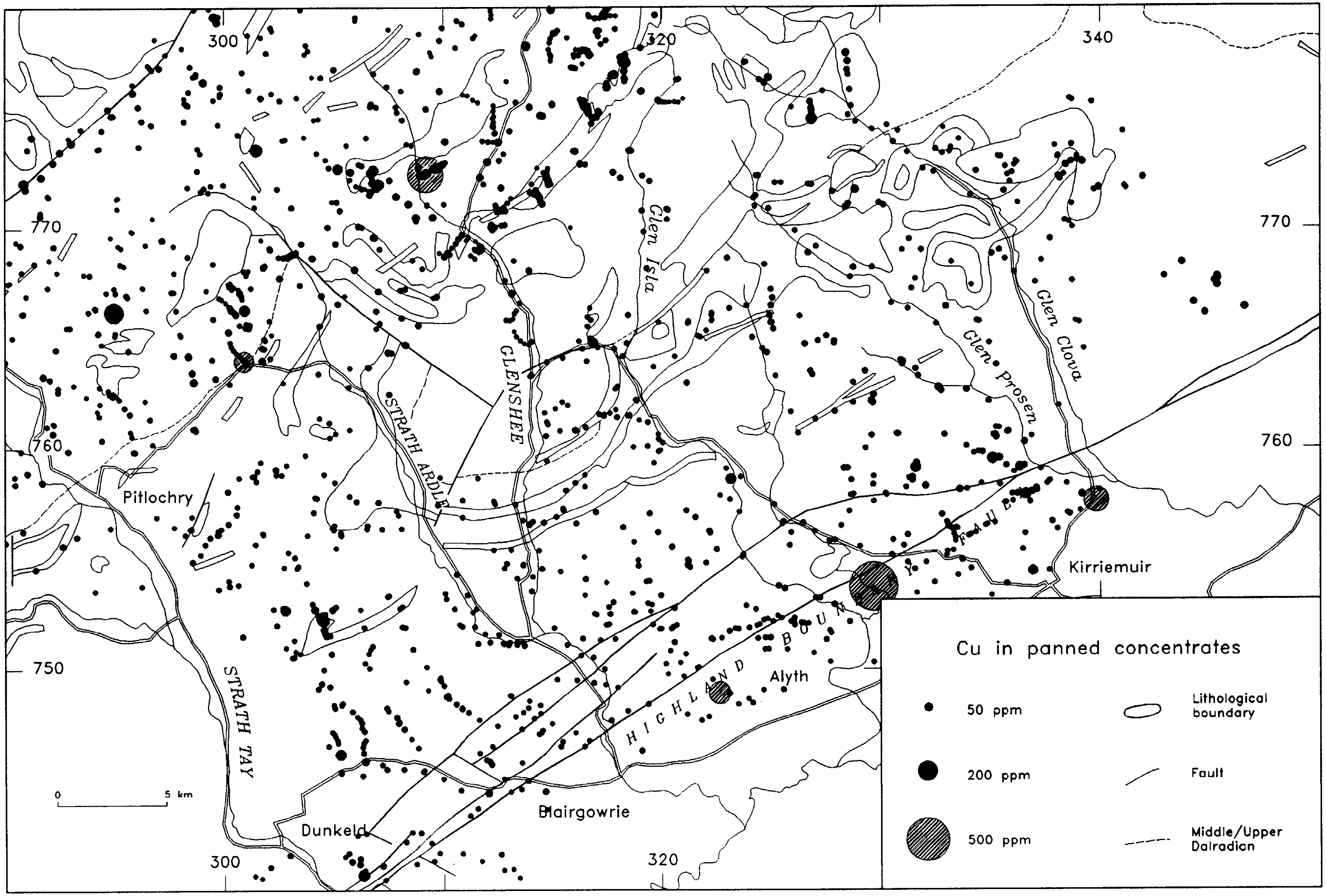

Figure 12 Regional distribution of copper in panned concentrates

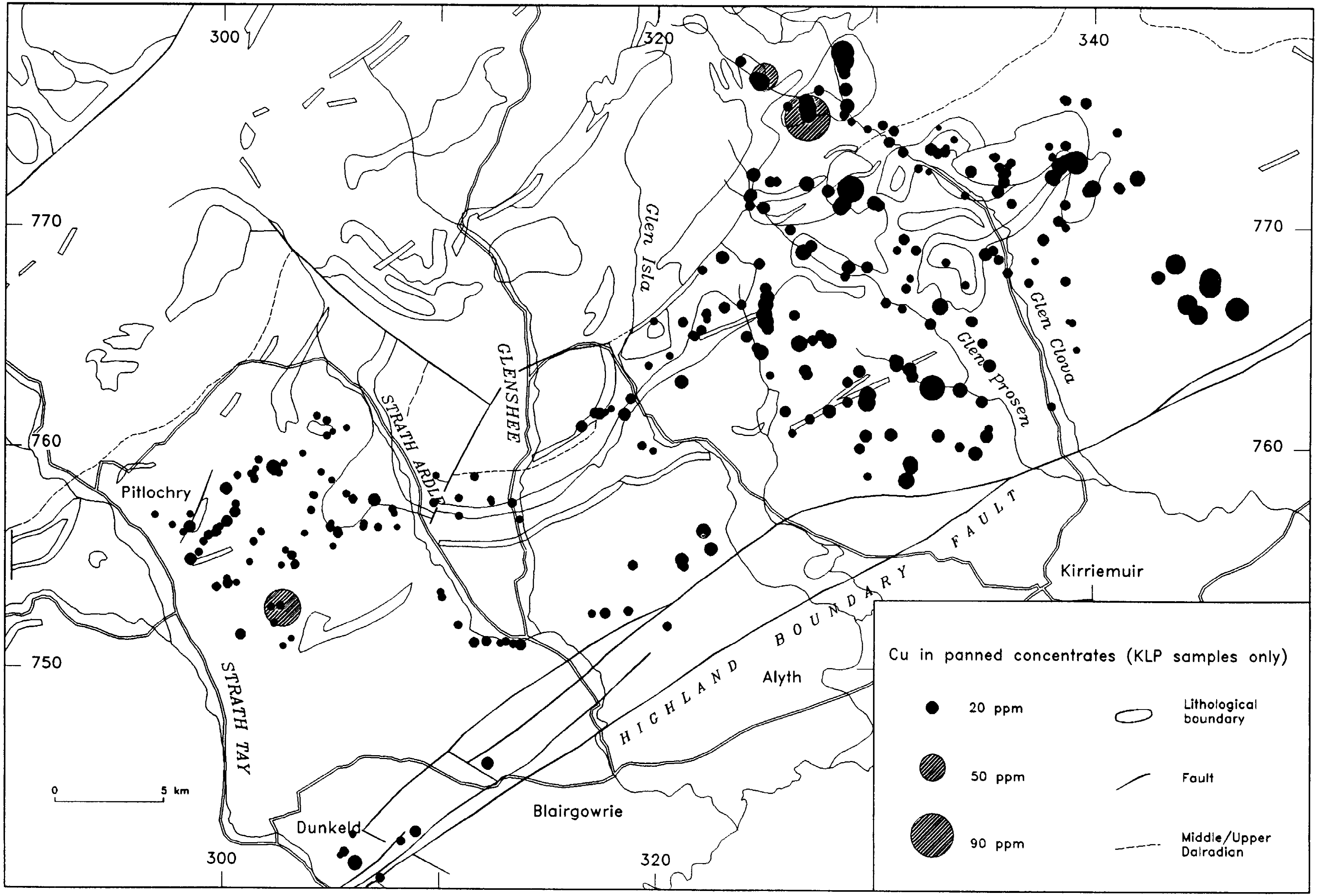

Figure 13 Local distribution of copper in panned concentrates

Zinc

Zinc shows a very linear plot on the log-probability plot with one lognormal population between 40 and 200 ppm. Above this population there are a few samples which extend up to 450 ppm Zn. Examination of the regional pattern shows that there are five main anomalous areas (Figure 14). The most distinctive anomaly is caused by the Argyll Group Dalradian Ben Eagach Schist formation which occurs from Loch Kander southwestwards to Glenshee (Gallagher et al., 1989; Coats et al., 1987). Another anomalous area occurs along the Glen Tilt fault zone in the northwest corner of Figure 14. Minor zinc-lead and fluorite mineralisation is known adjacent to the fault (Coats, unpublished information). A small group of samples from southeast of Pitlochry exceeds the 200 ppm Zn threshold but the reason for this anomaly is unclear. The anomalous samples from along the Highland Boundary fault are probably caused by contamination but some of the high values to the north of Alyth may be due to dispersion of zinc from basic and ultrabasic rocks emplaced along the fault zone. The final group of anomalous samples is found east of Glen Clova in the Water of Saughs and Noran Water catchments. This group is thought to be related to the gold mineralisation and is discussed later.

Arsenic

Arsenic in panned concentrates shows a wide concentration range from 0 to 129 ppm but the log-probability plot shows that 90% of the samples come from a background population of 0 - 15 ppm. Above this background there is a steady increase with another population break at about 50 ppm. Five of the eight samples exceeding this top threshold come from the Noran Water catchment which is discussed later (Figure 15). The other three samples are widely scattered. One (KLP 51) comes from Lochan Oisinneach Beag which also has high arsenic in the stream sediment. Another (KLP 139) from Dounalt in Glen Doll contains visible sulphide grains and is also anomalous in antimony. The third sample (KLP 1576) was collected from a stream near Auldallan [331460 758540] and this sample contained visible gold. Arsenic is positively correlated (Table 4) with Co, Ba, Au and Sb. Arsenic in pannned concentrates may therefore be effective as a pathfinder for gold. The Burn of Fleurs gold anomaly is, however, not associated with arsenic as discussed later.

Molybdenum

A bimodal distribution of this element is found in this area with the median of 5 ppm Mo being the distinguishing level. However the lower levels are near the detection level of the analytical method and an arbitrary threshold of 20 ppm Mo was chosen. Sixteen samples exceed this level and several occur in areas near the Highland Boundary Fault and Devonian andesite clasts were recorded in the streams. It is possible that the andesites have enriched levels of molybdenum in a mineral phase, such as hematite, that is upgraded by panning. Andesites from the Ochil Hills contain a median content of 6 ppm Mo (Coats et al., 1991) so that the threshold of 20 ppm Mo is not particularly high.

Silver

From the log-probability plot an effective detection limit of 3 ppm Ag can be ascertained, with 70 % of the population exceeding this value. However there seems to be little consistency in the spatial pattern of values in the range 3 - 8 ppm. A slight inflexion is present at the 8 ppm Ag level and is taken as the threshold value. Anomalous samples above this threshold are concentrated in the upper Glen Clova area, particularly in those samples draining the diorite body. There may be a XRF interference effect as all of these samples with >8 ppm Ag have >20 % Fe and also high Ti, typically >3 %. This suspicion is supported by the higher levels of other elements such as Sn and

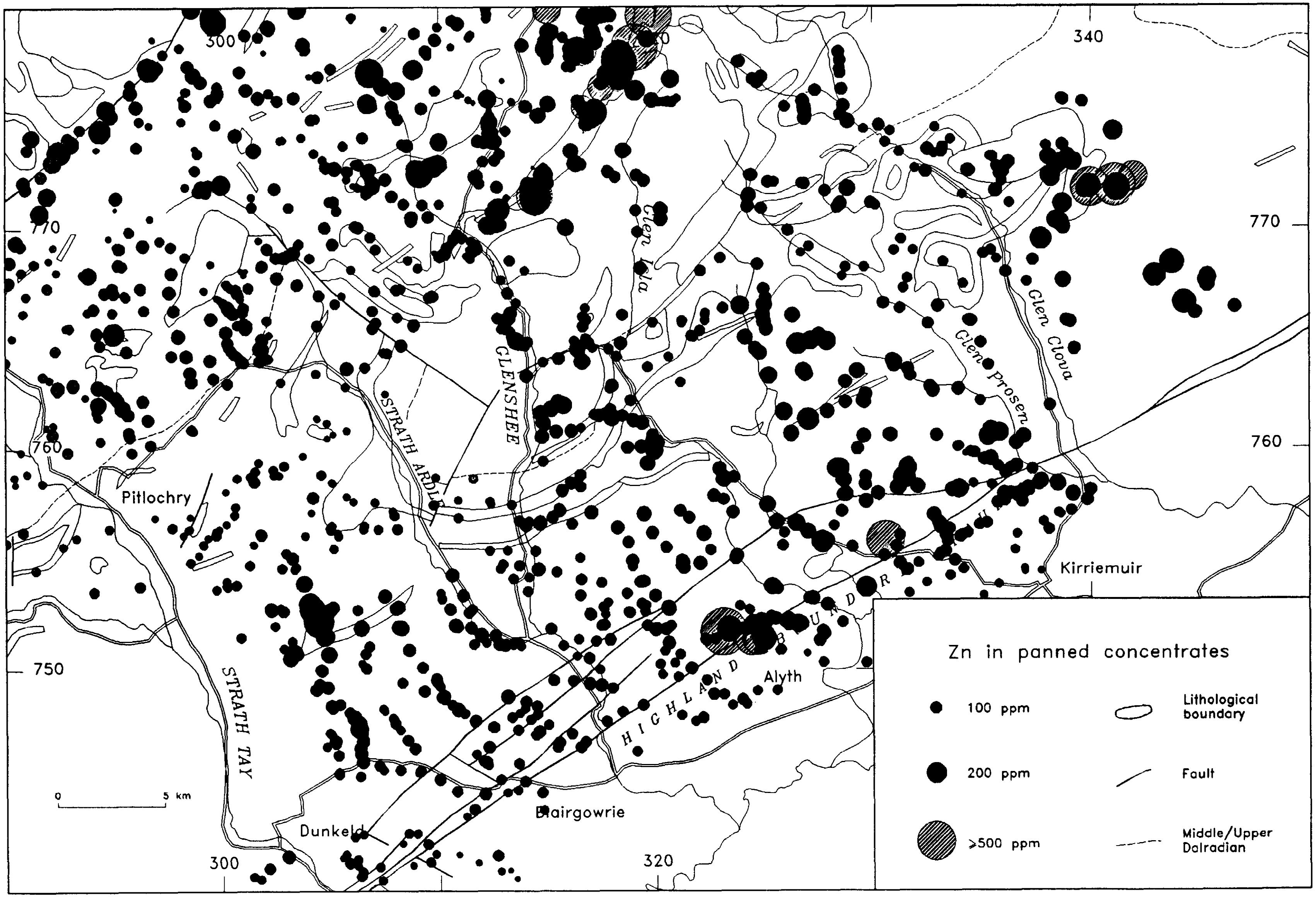

Figure 14 Regional distribution of zinc in panned concentrates

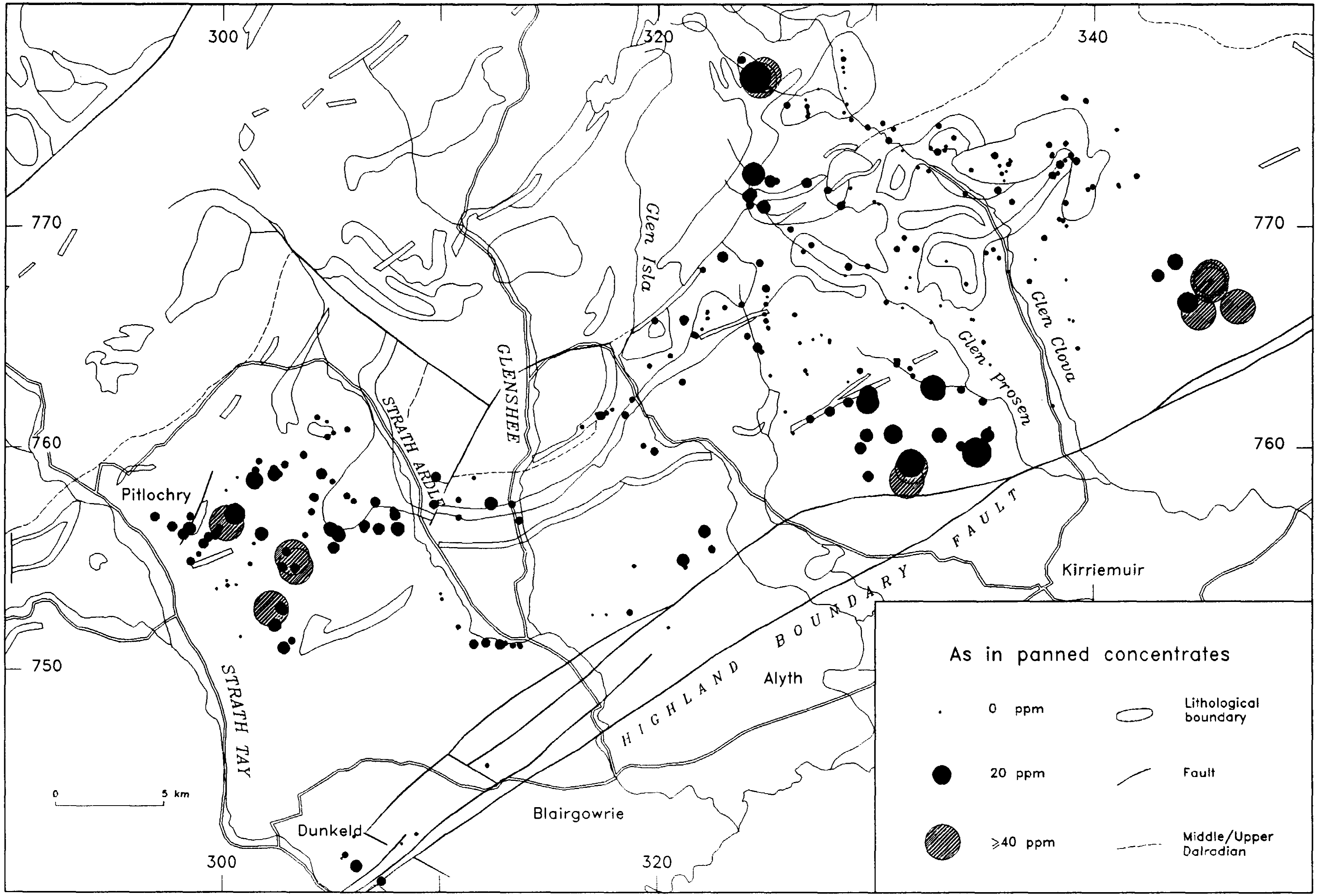

Figure 15 Distribution of arsenic in panned concentrates

Sb that occur in a similar part of the X-ray spectrum and at similar low levels. Three samples (KLP 458, 461 and 1576), however, do not exhibit high Fe contents and these are believed to have genuine enhanced silver levels. Two samples KLP 458 [313420 751100] and KLP 461 [310130 753180] were collected from Blackcraig Forest near Bridge of Cally and the former contained one visible gold grain but not a very elevated Au level on analysis (33 ppb). It is believed that this area contains gold mineralisation, possibly associated with a small outlier of Devonian lavas marked on the 1:10 000 scale geological maps but too small to show on the 1:250 000 map (Figure 2). The high silver values are believed to be associated with this gold area. Sample KLP 1576 was collected from near Auldallan [331460 758540] and contains anomalous gold levels (752 ppb Au). The silver is believed to be associated with this anomaly. One further anomalous sample (KLP 172) from Glen Damff [324990 765720] is associated with high gold levels (>10 ppm Au) but this sample also contains high Fe and Ti, so that the elevated silver content could be due to interference.

Tin

High levels of tin in panned concentrate samples are normally found in streams downstream of habitation or near roads. The tin coating of cans and the presence of Sn, Sb and Pb in solders often produces an association of these elements in panned concentrates caused by human contamination. The log-probability plot is linear up to 13 ppm which is taken as the threshold level. Samples which exceed this level were collected downstream of houses to the southeast of Pitlochry, near Dunkeld and one sample from Glen Clova. Nearly all of these samples have observed contaminants such as metal, glass or pottery in them. No tin mineralisation is recorded in the area.

Antimony

The log-probability plot shows that the antimony distribution is lognormal up to 10 ppm and only a few samples exceed this threshold. KLP 46 collected (Figure 16) at NGR [302810 752660] contains 13 ppm Sb but the tin content is high (78 ppm) and the sample description describes pottery, iron and tin can contamination. KLP 139 with 12 ppm Sb was collected at [324690 776570] near the head of Glen Doll. It has a low tin content (2 ppm), so is not obviously contaminated, and the high arsenic level (94 ppm) combined with the observation of yellow sulphides in the panned sample indicates that mineralisation is present in the catchment. KLP 484 with 12 ppm Sb was collected from a site near Bridge of Cally [313760 751050] and has high Mo (20 ppm) and Pb (144 ppm) contents. Mineralisation may be present in this catchment. There is no correlation with Au in panned concentrates and the Sb - Au association found in the Glen Devon catchment in the Ochil Hills (Coats et al., 1991) is not seen in this area. Regionally, the Argyll Group Dalradian has higher levels of antimony in panned concentrates compared to the Southern Highland Group Dalradian (Figure 16). Sporadic high values along the Highland Border zone may be due to contamination.

Barium

Barium in panned concentrates from this area shows a complex distribution with one lognormal population from 18 to 155 ppm and another from 155 to 500 ppm Ba. Only seven samples exceed this threshold in the dataset from this particular survey (Figure 9). On a regional scale (Figure 17) only the two samples collected from streams that drain Nether Craig, just east of Glenshee, contain appreciable barium contents. One sample KLP 464 from southeast of Dunkeld at [307320 740490] contains 3463 ppm Ba and baryte mineralisation must be present in the catchment. Other features shown on the regional plot (Figure 17) are the vein-style baryte mineralisation in Glenshee and Glen Tilt and the anomalies near Kirriemuir in the Devonian sediments.

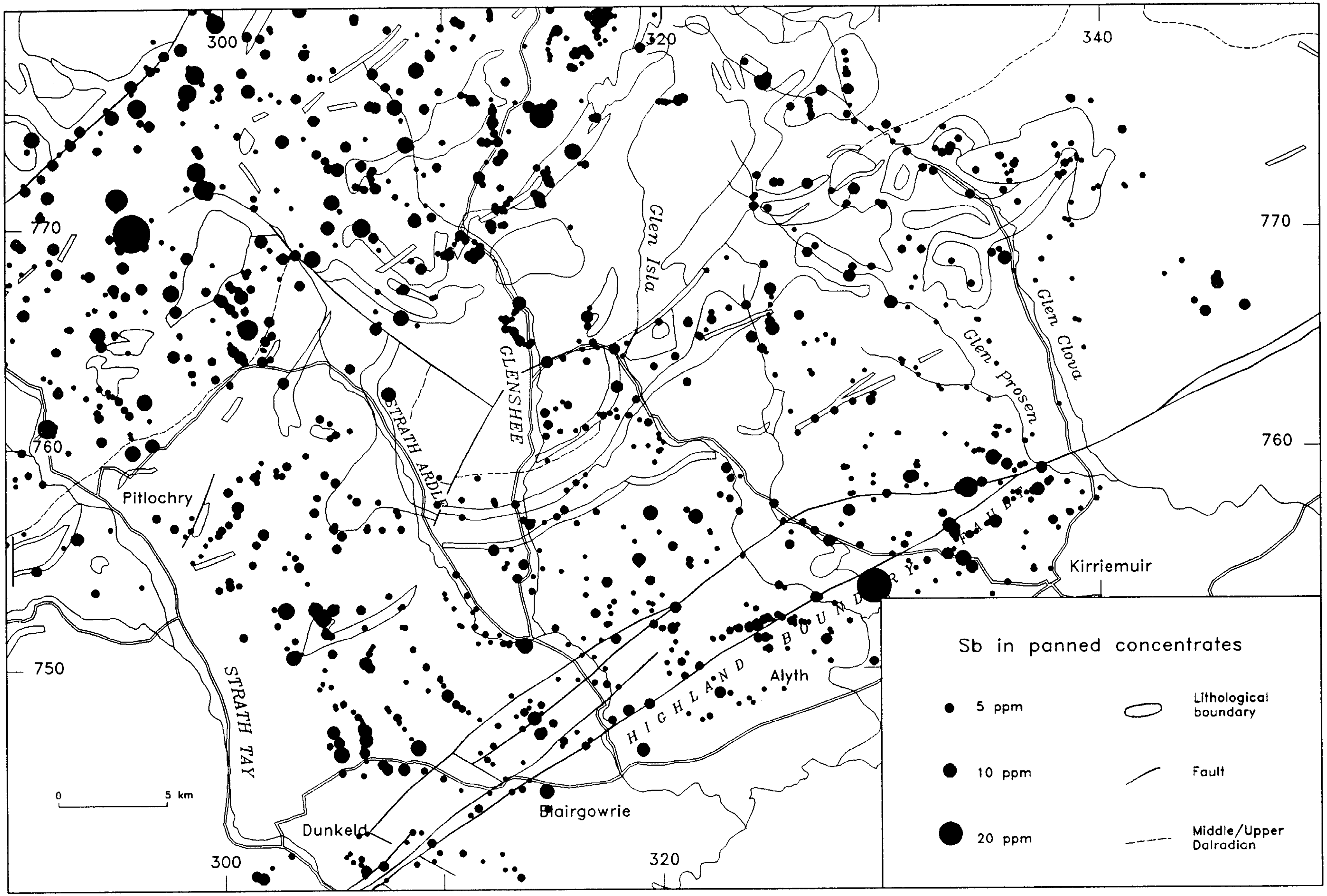

Figure 16 Regional distribution of antimony in panned concentrates

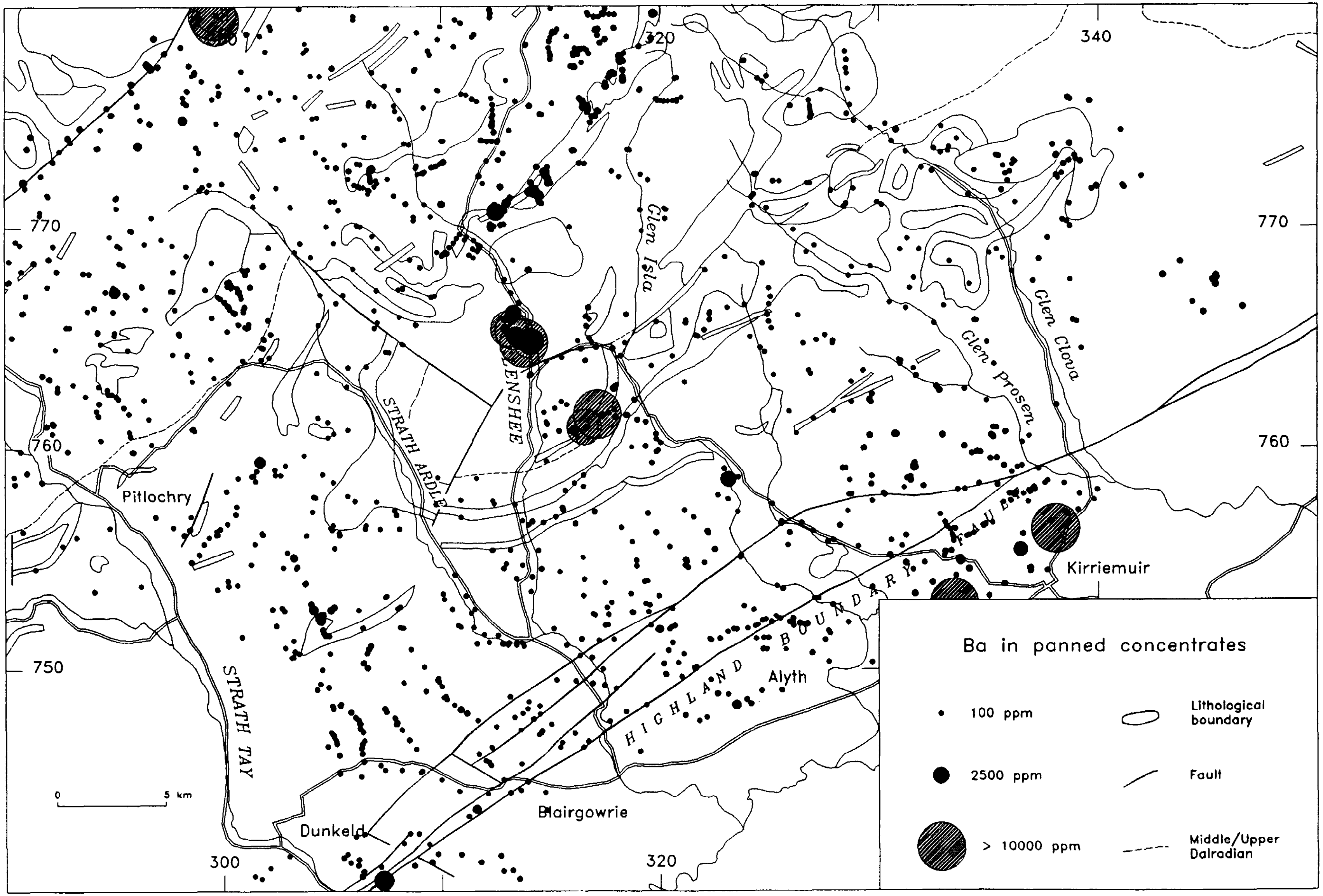

Figure 17 Regional distribution of barium in panned concentrates

Cerium

Cerium shows a ploymodal distribution but there is a clear population break at 200 ppm. Most of the anomalous samples were collected from Glen Clova, particularly on the north side of the Glen from Loch Brandy to the Burn of Eskielawn (Figure 18). This pattern is also shown by the stream sediments so that a resistate heavy mineral source such as monazite is indicated. A high correlation with Th (+0.76) also indicates a common source.

Gold

The distribution of gold in the panned concentrates is highly skewed with a large range from <10 ppb to 40 000 ppb Au. The median value is below the detection limit of 10 ppb Au, indicating that the method of analysis is not sufficiently sensitive to determine a meaningful background population. Examination of the log-probability plot shows that population breaks occur at 100 and 1000 ppb Au. Thirty one samples exceed the lower threshold and nineteen of these show visible gold grains but the correlation between the number of grains and the gold analysis is poor. Because gold occurs as a rare resistate, heavy mineral sampling error is a major cause of spatial variation. The random occurrence of a single large flake of gold in a concentrate sample can produce large anomalous levels of Au. Analytical values for gold are therefore typically 'noisy' with scattered high values which may appear to occur at random positions. Groupings of anomalies are therefore much more significant than isolated high values. This is well shown in Figure 19. The high values are scattered but there are notable groupings in Glen Clova to Noran Water and in Glen Prosen, with other, mainly single, anomalous samples at Nether Craig, Bridge of Cally and near Dunkeld. The lack of anomalous samples in the area southeast of Pitlochry is clearly shown and contrasts with the very high arsenic levels in the stream sediments from this area. Arsenic in stream sediments is therefore a poor pathfinder for gold in the upland peat environment with heavy secondary iron precipitation. Gold is significantly correlated with Cu, Ba, As and Ni in the panned concentrates (Table 6). The correlation with As is better in the Glen Prosen and Noran Water areas, which both show As anomalies in the panned concentrates (Figure 15). These areas are discussed in more detail later.

Lead

The log-probability plot shows that lead has a nearly lognormal population up to 50 ppm where there is one discontinuity and another break at 150 ppm. The regional distribution of lead (Figure 20) is dominated by high values along the Highland Boundary Fault and in the Argyll Group Dalradian. The former group is probably the result of contamination, being in the more populated agricultural ground. In the dataset collected as part of this survey the three highest lead values give the following results:

Table 7 Locations of panned concentrates with the highest lead contents

Sample	Grid Reference	Locality	Pb (ppm)	Sn (ppm)
KLP 13	[299750 753620]	Tulliemet Burn	387	11
KLP 14	[300220 754000]	West of Auchnabeich	386	14
KLP 134	[335660 768580]	Downie Burn	440	11

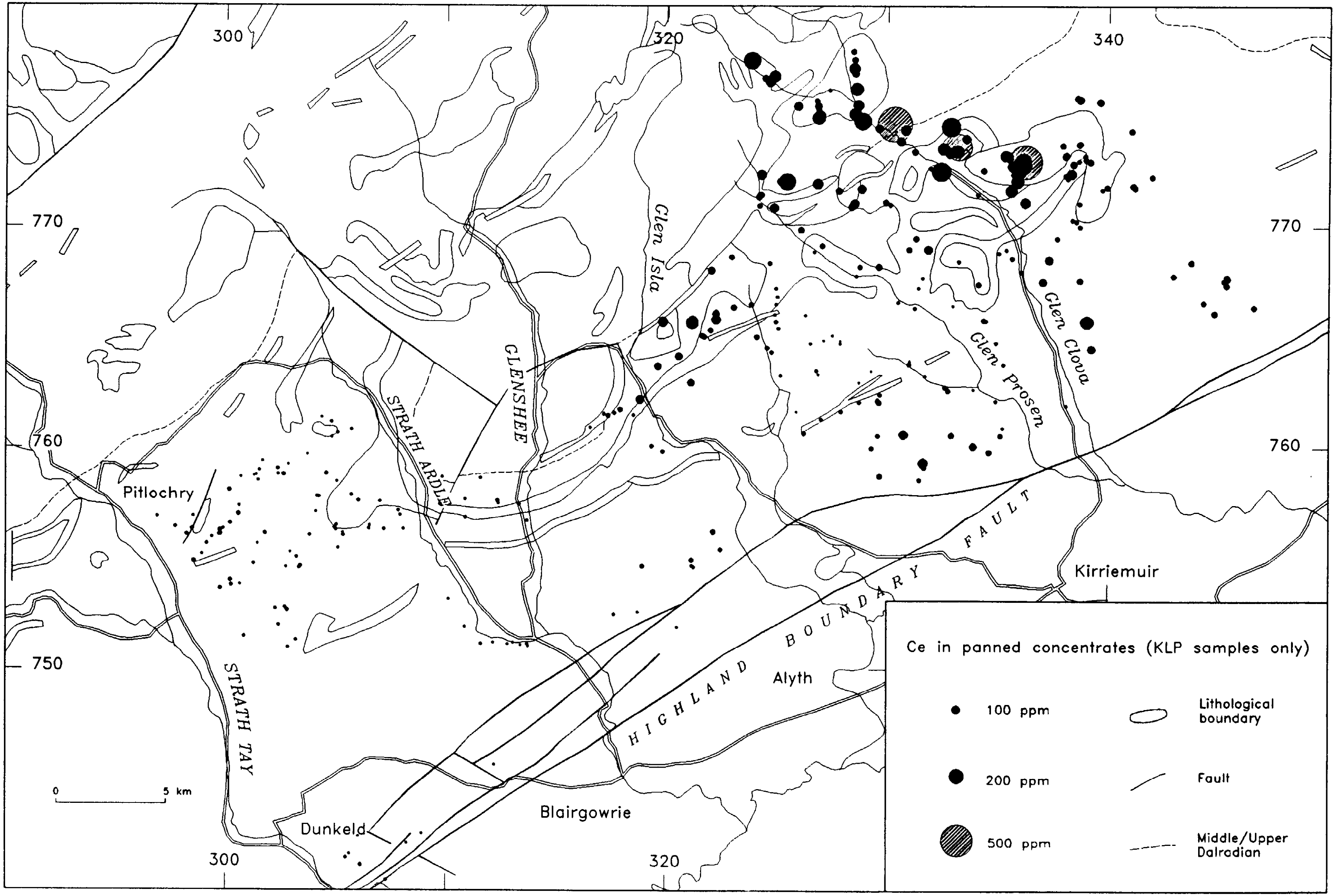

Figure 18 Distribution of cerium in panned concentrates

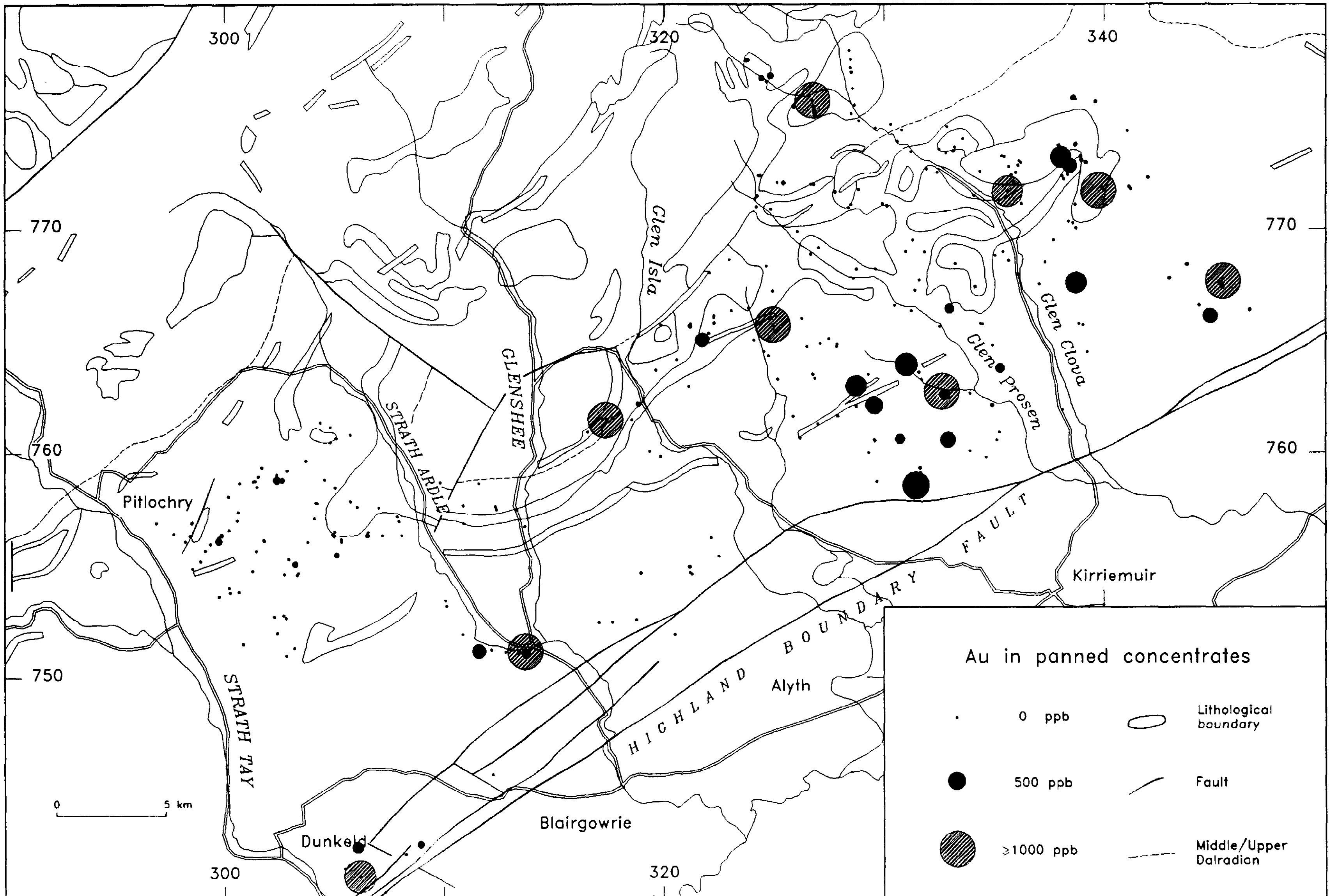

Figure 19 Distribution of gold in panned concentrates

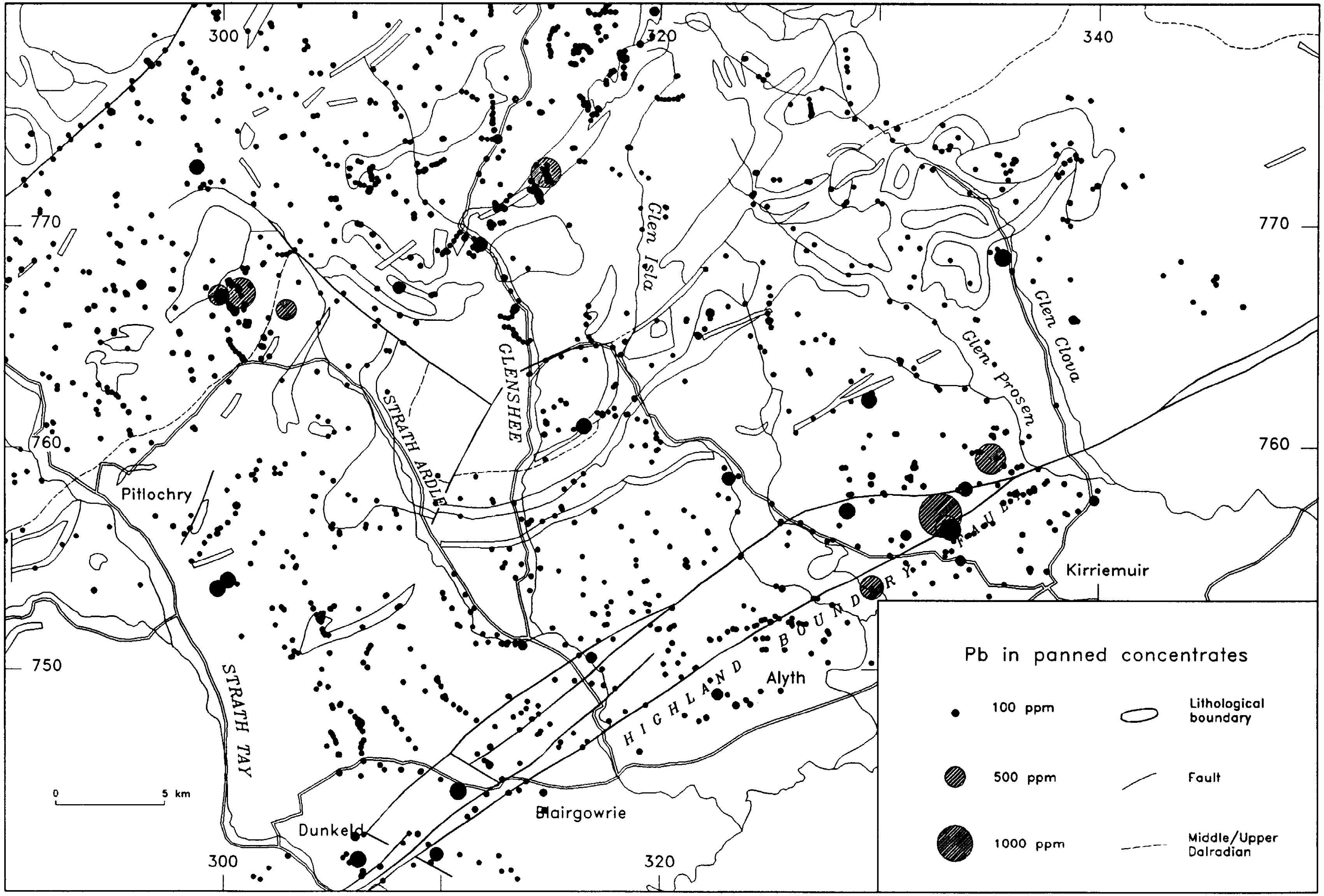

Figure 20 Regional distribution of lead in panned concentrates

These samples were collected south east of Pitlochry and in Glen Clova and are probably all contaminated as shown by the elevated tin contents. Other samples with lead above the upper threshold of 150 ppm are found at Nether Craig downstream of the baryte mineralisation and at Burn of Luthrie [329560 762130] in Glen Dye, west of Glen Prosen. One of the rock types in this catchment (Figure 2) is an acid porphyry dyke and minor lead mineralisation is possibly present at its margins. A similar paragenesis is seen at the baryte and base metal mineralisation adjacent to a felsite dyke at Meall Odhar in Glenshee (Coats et al., 1987 and unpublished work by D G Cameron 1985). The anomalies near Dunkeld, such as KLP 475 [306060 742480] with 146 ppm Pb, whilst not as high as Nether Craig, confirm earlier unpublished sampling work by BGS in this area. Galena-bearing float was discovered in a stream near Dungarthill [306160 741180] and other lead-bearing veins are probably present in this area. Several of these samples (KLP 471, 472, and 475) also have detectable gold contents in the panned concentrates which indicates that these sulphide-bearing veins also contain gold. However, no further work was carried out in this part of the area.

Thorium

A high correlation with cerium (Table 6) indicates that both these elements are present in the same heavy mineral, such as monazite, or alternatively are derived from the same host rock type. The similar pattern shown by the stream sediments also indicates that the elements are present in a resistate heavy mineral phase and that the element distribution is little affected by secondary processes.

DETAILED INVESTIGATIONS

Drainage samples

Glen Clova to Noran Water Area

Detailed investigations were carried out in this area following the recognition of gold anomalies in the drainage and the anomalous gold concentrations in rocks collected in collaboration with the geological remapping of the area (Redwood, 1988a).

Detailed sampling involving the collection of a further 22 panned concentrates was undertaken upstream of the sites where anomalous concentrations of Au had been recorded in 1987. Figure 21 shows the distribution of Au in panned concentrates in this area. High values are seen in the Burn of Adielinn, Burn of Heughs, Burn of Fleurs, Kennel Burn and Noran Water. The erratic nature of the Au distribution is well shown with several anomalies not being repeated upstream of the original sites and little evidence for smooth dispersion trains downstream of anomalies. This is partly the result of the scarcity of the gold grains but is also related to the collection method. Digging of stream sediment and preparation of a panned concentrate loses a considerable proportion of the fine-grained sediment and the contained gold (Petts et al., 1991). Another factor in the distribution of gold in gravel bed streams is the sedimentological character of the substrate, with coarse grained, well sorted sediments having enhanced gold levels compared to those with a poorly sorted immature matrix.

Arsenic is often used as a pathfinder for gold and its distribution in panned concentrates is shown in Figure 22. The most notable feature is the high values in Noran Water and adjacent catchments

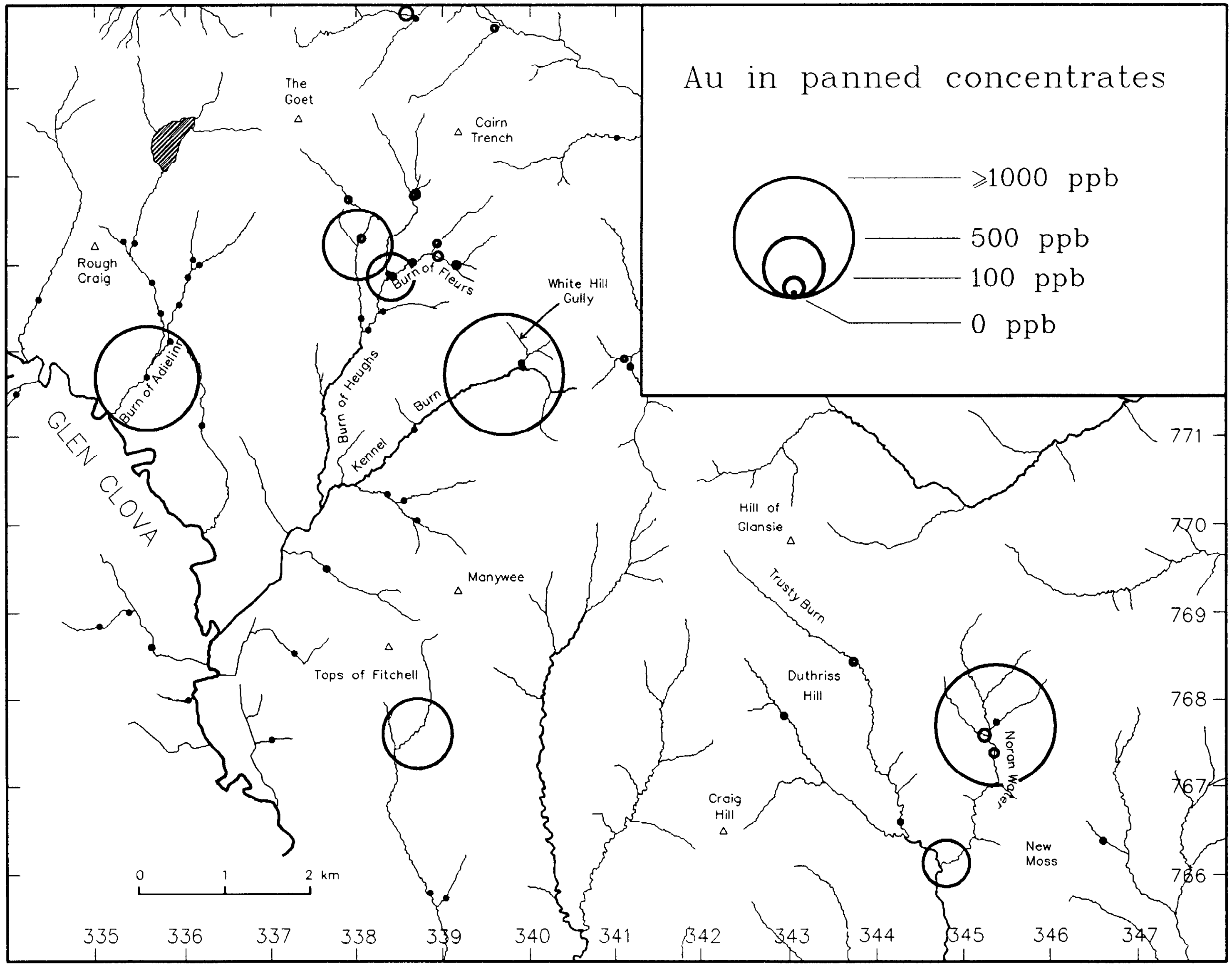

Figure 21 Distribution of gold in panned concentrates from Glen Clova

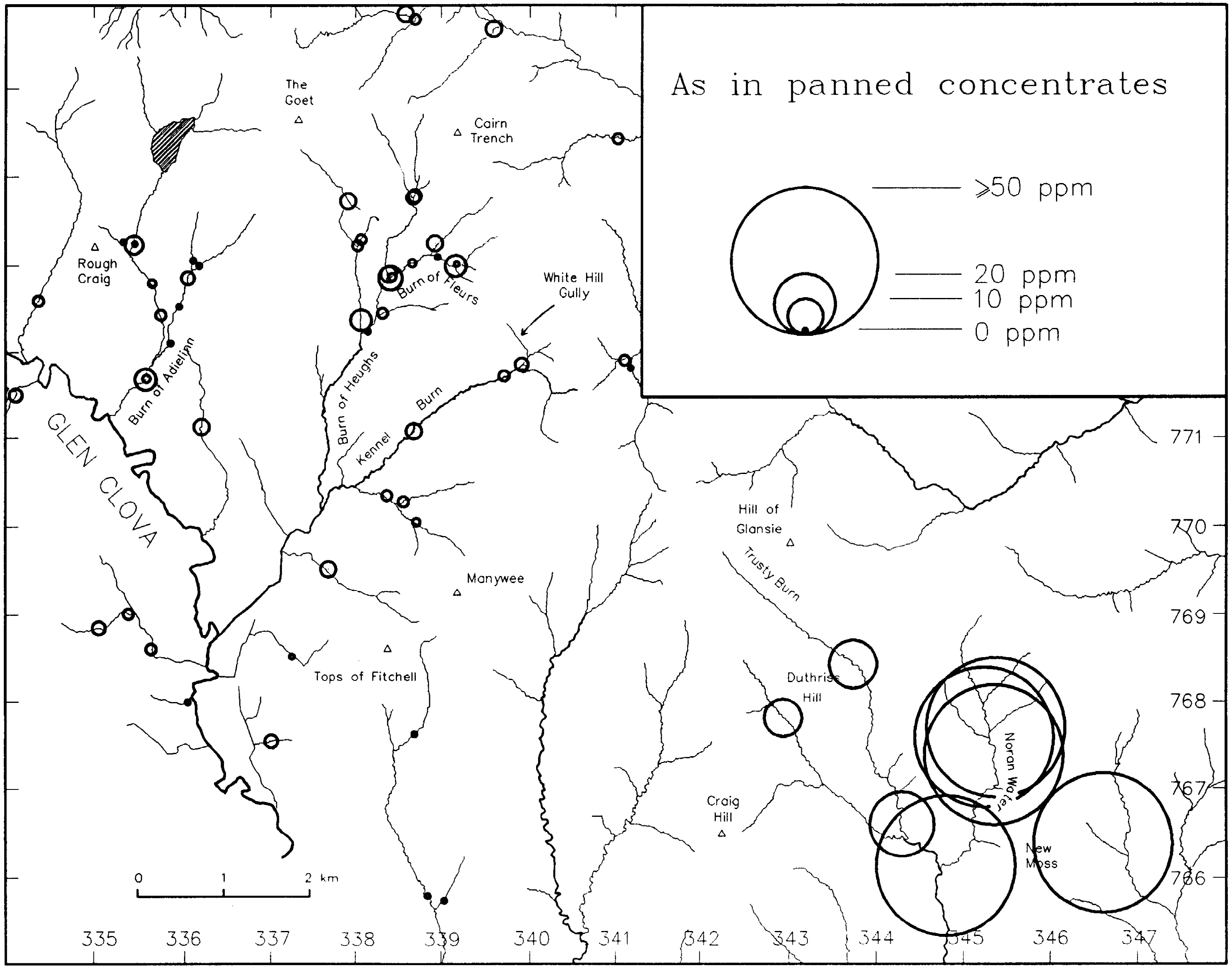

Figure 22 Distribution of arsenic in panned concentrates from Glen Clova

such as Trusty Burn and the stream east of New Moss. Arsenic is much lower in the Burn of Heughs and Kennel Burn catchments and is not a very good pathfinder in this area.

Copper shows a similar pattern (Figure 23) to arsenic in the Noran Water catchments but is also high in the Burn of Fleurs and Kennel Burn. The levels of copper in excess of 40 ppm normally indicate minor sulphide mineralisation with copper being associated with pyrite. Lead in panned concentrates is slightly enriched in the Burn of Adielinn, Kennel Burn and east of New Moss (Figure 24). The high values found in the lower streams of Glen Clova are probably caused by contamination.

Glen Uig Area

Drainage reconnaissance sampling observations of gold in panned concentrates were recorded in the vicinity of Glen Uig, to the west of Glen Prosen. Little extra drainage sampling was carried out except to slightly increase the density of coverage. Enhanced Au values of >200 ppb were found in ten of the forty samples from this area. The anomalous sites form a cluster around the headwaters of Glen Quharity and Glen Uig (Figure 25a) with the highest recorded value of 14000 ppb occuring in the Burn of Heughs [332640 762760]. It should be noted that this stream is different from one of the same name in Glen Clova. The sample also gave slightly enhanced values of Cu (49 ppm), As (27 ppm) and Bi (5 ppm). The second highest Au value in the Uig area (752 ppb), was found to the south of the main cluster in the Burn of Auldallan [331460 758540]. This is also associated with enhanced As (64 ppm). The three panned concentrate samples from this catchment were weakly enriched in Cu (21 - 28 ppm).

There appears to be no association between Au and Pb from the panned concentrate data, the three highest values of >300 ppm Pb being attributed to the lead shot contamination recorded on field cards. However, the distribution patterns of Pb and U in stream sediments may indicate a weak enrichment over the anomalous Au area. A Spearman rank correlation coefficient of 0.5 between Pb and U, significant at the 99% confidence level, suggests a possible link between these two elements.

Significant Spearman rank correlation coefficients above +0.4 were recorded between Au and Ca, Ti, Fe and Th in panned concentrate data. Despite this, the distribution patterns of the four elements do not show the same clustering as Au or As. An explanation for this association is that gold grains are concentrated by fluvial processes along with other high density minerals, such as oxides and amphiboles, in sites of alluvial upgrading. This pattern is consistent with observations recorded elsewhere by the authors (Coats et al., 1991).

A distribution map for As in panned concentrates (Figure 25b) reflects a similar distribution to Au. A comparable but lower contrast distribution is shown by As in stream sediments. The southern part of the Glen Uig area has higher arsenic levels which seem to be displaced from the anomalous Au area slightly to the north. This contrast may be the result of different arsenic concentrations in the metasedimentary rock units or relate to hydrothermal activity. A widespread association with Au in the form of mineralised bedrock is as yet unproven.

The distribution of Au may be spatially related to the outcrop of a quartz feldspar porphyry dyke as shown in Figure 25a. A brief examination of the dyke revealed minor clay alteration but no sulphide mineralisation. The Au may also be associated with a suite of northwest - southeast

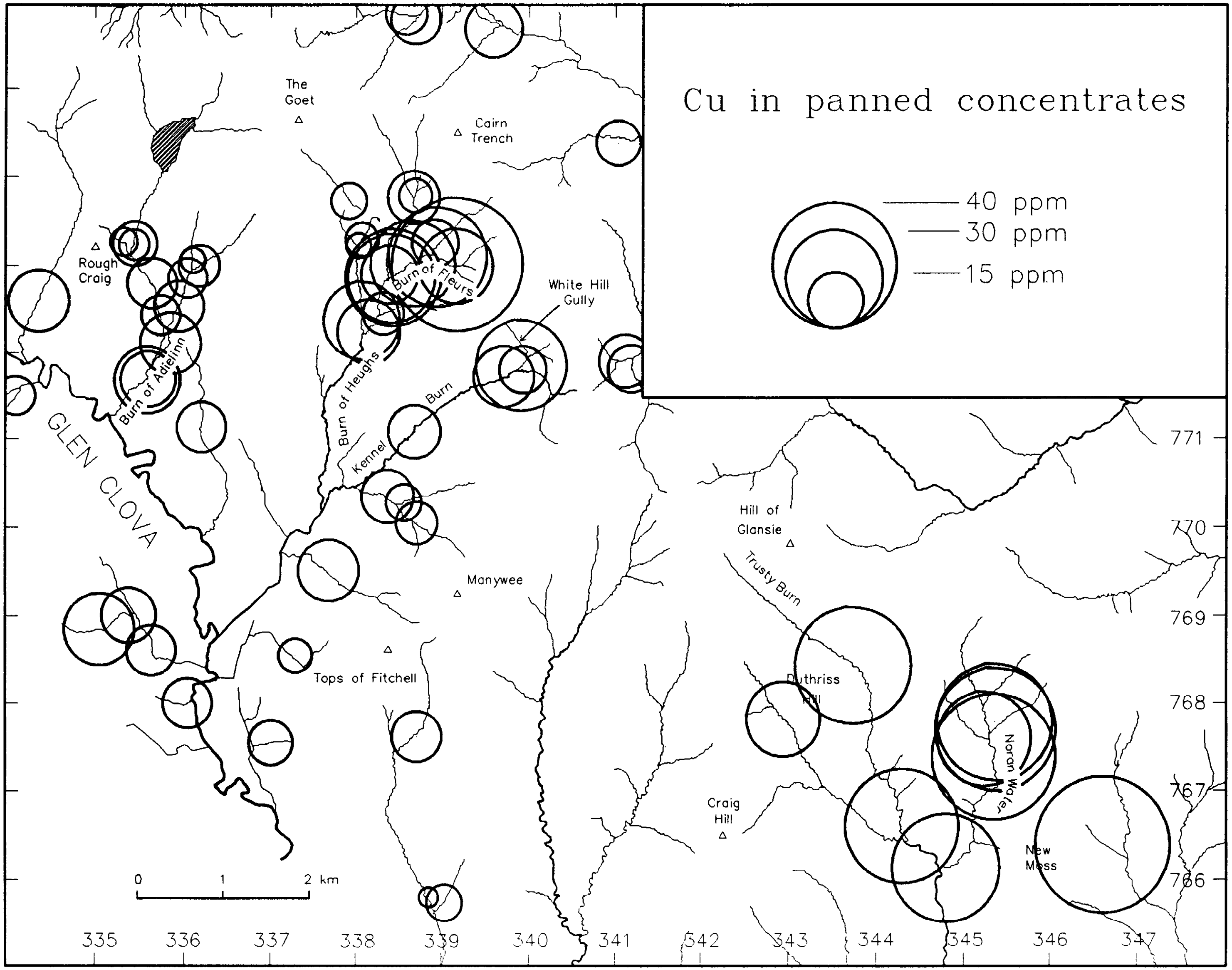

Figure 23 Distribution of copper in panned concentrates from Glen Clova

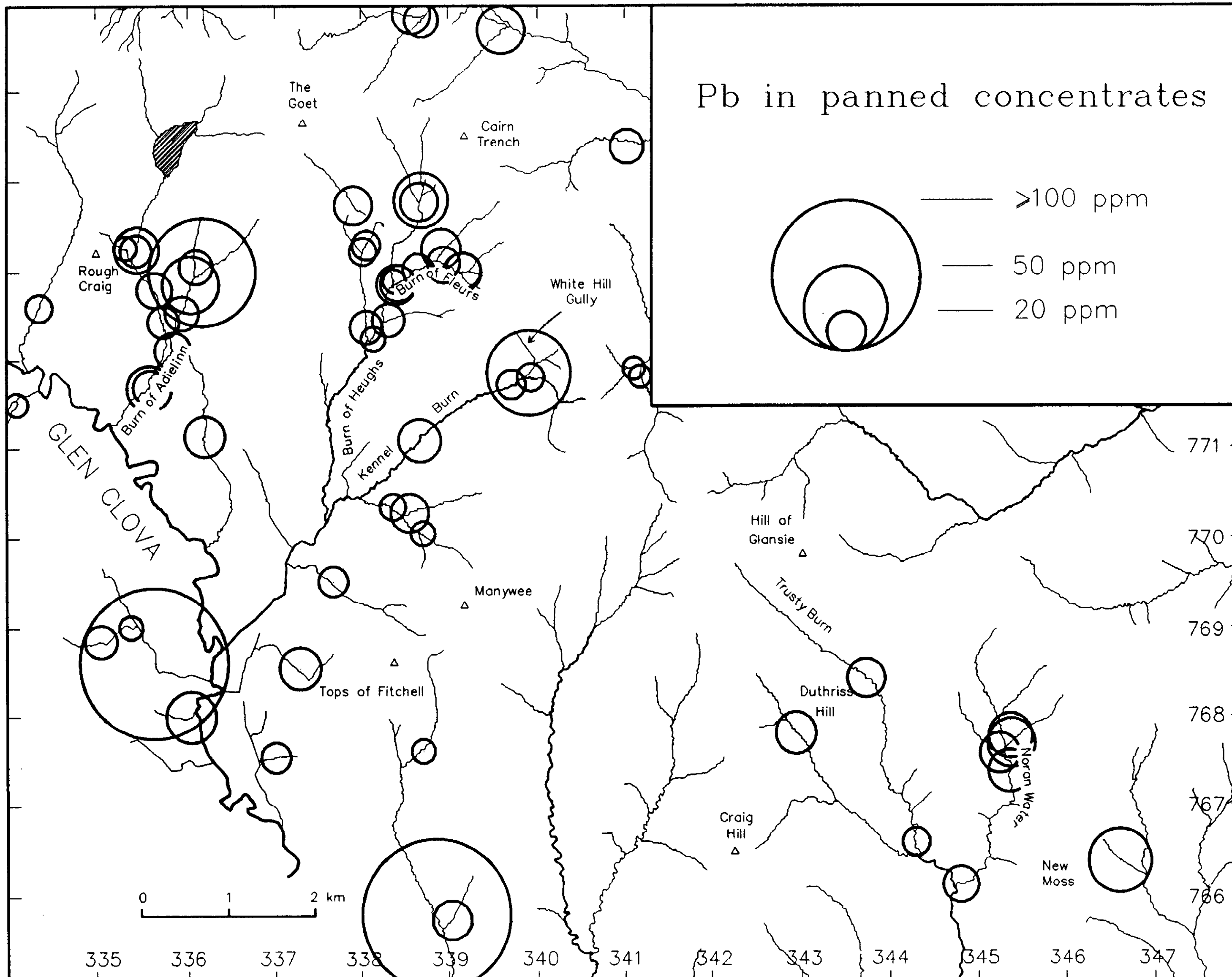

Figure 24 Distribution of lead in panned concentrates from Glen Clova

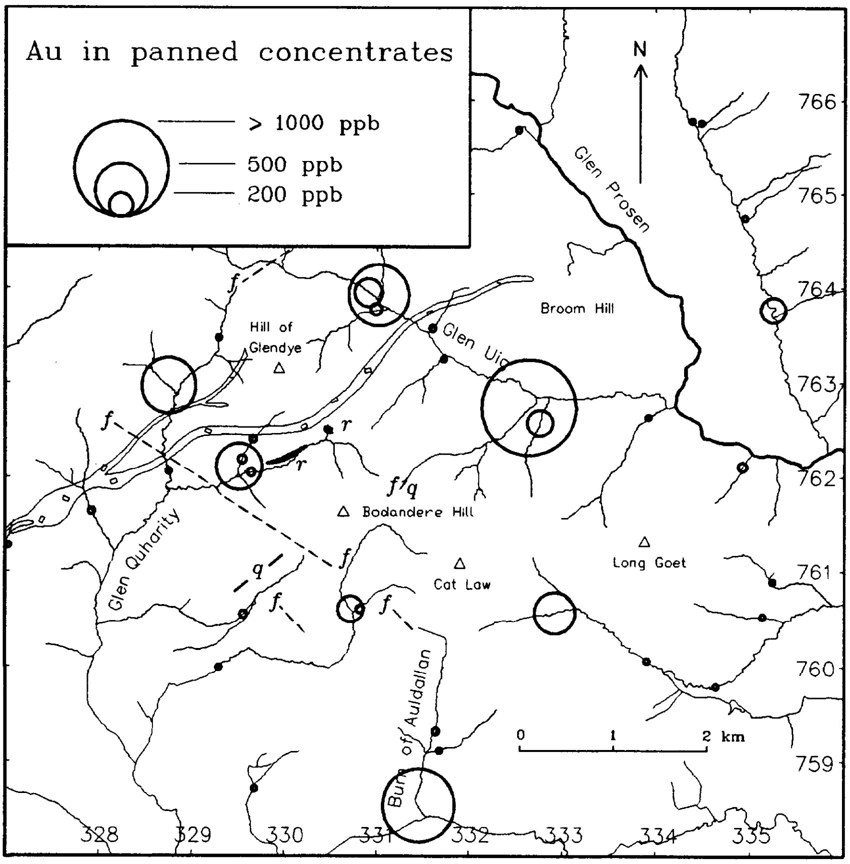

Figure 25a. Distribution of gold in panned concentrates from Glen Uig

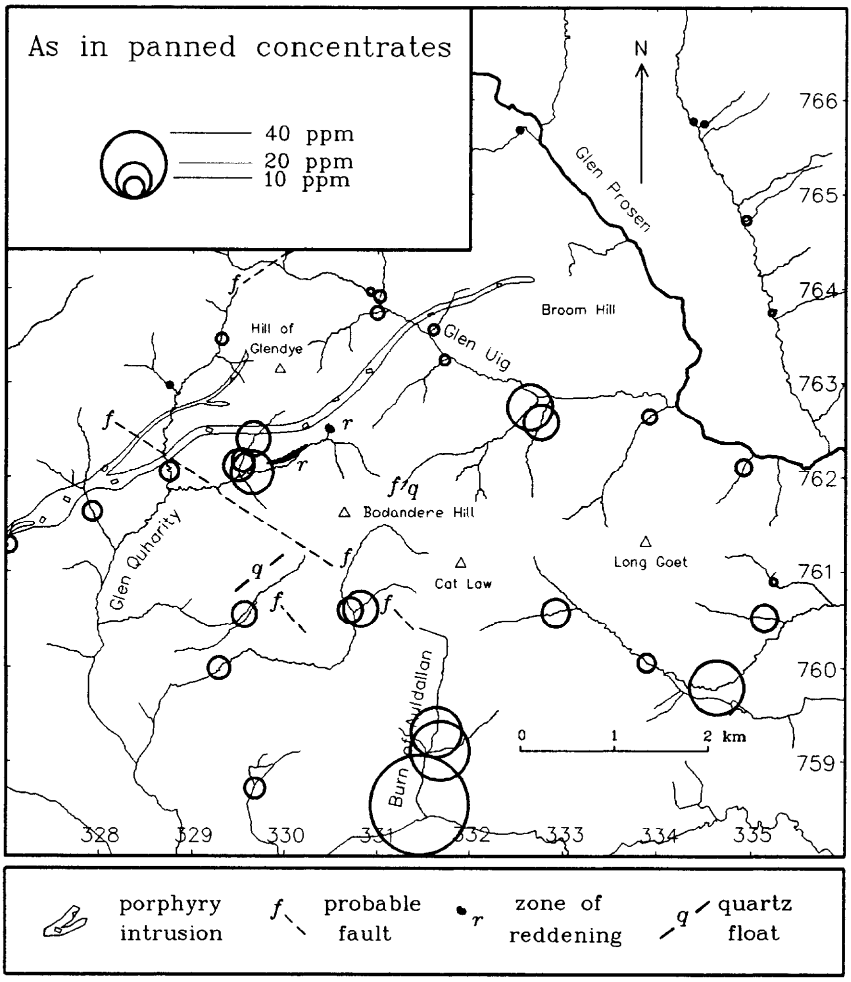

Figure 25b. Distribution of arsenic in panned concentrates from Glen Uig

striking faults in the area, giving it a similar paragenesis to the Glen Clova mineralisation. An area of reddening reported in the headwaters of Glen Quharity [3305 7624] (S Robertson, personal communication) is another similarity with the Burn of Fleurs and Kennel Burn areas in Glen Clova.

Shallow overburden samples

Following the identification of Au-bearing mineralisation in the Burn of Fleurs section and anomalous Au values in panned concentrates in the Kennel Burn and Burn of Heughs catchments, a limited shallow overburden sampling programme was undertaken along the postulated strike of the Burn of Fleurs fault southeast to White Hill Gully. The aim of this sampling was to identify any extension of Au mineralisation between the two catchments, over an area with no rock exposure.

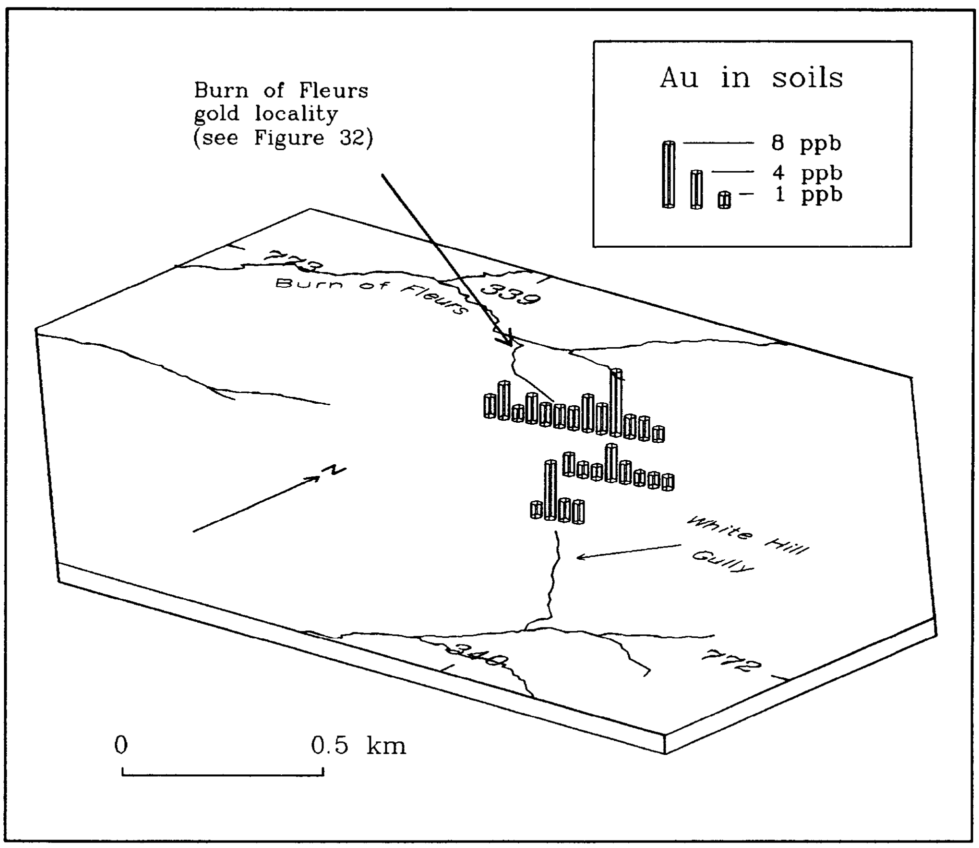

Figure 26 Distribution of gold in shallow overburden samples from Glen Clova

A total of 25 soils was collected using conventional hand augers. Sample sites were positioned at 25 m intervals along three east-west traverses, 200 m apart (Figure 26). In order to obtain a representative sample of mineral soil of adequate size, a cluster of auger holes was sampled at each site, from within a 0.5 m radius. The presence beneath the peat of buried scree or larger rock fragments up to boulder size hindered sample collection and retrieval. Sample quality was also affected by the organic-rich nature of the soil, often with little or no mineral component within augerable depth. In an attempt to maintain sample consistency it was therefore necessary to profile holes, in order to locate pockets of mineral soil within the peat. Nevertheless, at half the sites sampled only trace amounts of mineral constituents were present. Due to the problems encountered sample coverage was reduced and rockhead was reached at only three sites. Samples were collected from depths ranging from 0.1 to 1.3 m, the latter being the maximum attainable with the conventional auger.

The samples were oven dried and sieved through 180 micron nylon mesh and sub-samples of each analysed for Au by Acme Analytical of Vancouver, using an aqua regia attack, MIBK extraction and an AAS finish. A detection limit of 1 ppb for Au is achieved by this method. Trace elements were determined using XRF by the Analytical Geochemistry Group of BGS.

Table 8 Summary statistics on shallow overburden samples from the Fleurs area

Element	N	Median	Lower Quartile	Upper Quartile	Minimum	Maximum
Au(ppb)	25	2	1	3	1	8
Ca	25	3000	2350	3700	1000	6500
Ti	25	5880	5375	6825	3190	7700
V	25	88	74	102	42	118
Cr	25	84	67	101	32	113
Mn	25	350	250	465	170	820
Fe	25	36300	29350	43600	14600	56600
Co	25	13	9	17	3	19
Ni	25	20	15	26	3	50
Cu	25	21	9	33	0	54
Zn	25	76	48	93	25	160
As	25	7	5	9	1	13
Sr	25	101	85	117	50	155
Zr	25	400	342	445	196	515
Mo	25	0	0	1	0	2
Ag	25	2	1	2	0	3
Sn	25	1	0	2	0	3
Ba	25	561	468	646	267	680
Ce	25	90	63	99	32	156
Pb	25	40	33	50	22	60
Sb	25	1	0	1	0	2
Bi	25	0	0	1	0	2
Th	25	12	10	14	7	18
U	25	2	1	3	0	4

1. All elements in ppm except Au in ppb.
2. Method of analysis X-ray fluorescence except for Au determined by AAS after MIBK extraction.

Summary statistics for the soils are shown in Table 8. Au shows minor enrichment, up to a maximum of 8 ppb. There appears to be a linear trend to the enhanced Au values as shown in Figure 26. However, it should be noted that samples containing a high organic component gave consistently low Au values, and the composition of the samples influences the distribution pattern more than the underlying bedrock. The majority of Au values fall at or close to the detection limit of 1 ppb. There are no positive Spearman rank correlation coefficients with other elements significant above the 99% confidence level. Levels of the potential pathfinder elements Sb and Bi are at or close to their detection limits of 1 ppm. Although slightly enhanced Au levels are widespread along line 1200 N there was no clear association with Cu, Pb, Zn or U, as observed in the Burn of Fleurs rocks. Strong positive correlations of between 0.63 and 0.78 were obtained between Fe and Mn, Co, Ni, V, Cu, Ba and Zn . The trend reflects the proportions of ferromagnesian and micaceous minerals to organic material in the shallow overburden.

Geophysics

Survey area and methods

A phase of geophysical survey was undertaken in June 1989 in the Burn of Heughs catchment area in Glen Clova, to examine anomalous Au concentrations in drainage samples and the disposition of the magnetic lithologies. Total magnetic field and very low frequency (VLF) magnetic field were measured using the Scintrex IGS-2 equipment with automatic digital data capture. Regional lithological strike varies significantly across the catchment from northwest through west then northeast. This made selection of a single traverse line orientation difficult, especially considering the limitations of the available VLF transmitters. Traverse lines should preferably be approximately normal to the direction of the VLF transmitting station. The significance of northwest trending stuctures such as the Fleurs Fault and the preference for VLF station GBR were the main criteria for selecting the baseline orientation. The primary grid was surveyed from a baseline with an origin at [337550 770880] and a bearing of 342 degrees grid. Traverse lines were surveyed at intervals of 200 m from this baseline along a heading 072 degrees grid. These lines formed the primary grid and were surveyed by tape and compass and caned at intervals of 50 m. Total field magnetic data and VLF data were observed on the primary grid. To complement data collected along the primary grid, magnetic observations were also made along a few lines orthogonal to the primary grid and a tertiary grid with traverse lines running approximately north-south. Supplementary magnetic observations were made along paced traverses with variable orientations and using navigation points taken from the 1:10 000 OS map. All these data are described here. All magnetic and VLF data were collected at a nominal interval of 12.5 m. Approximately 50 line-km of total field magnetic data and 18 line-km of VLF data were collected.

Magnetic data

All magnetic data collected in 1989 were approximately corrected for diurnal change in total field by periodic monitoring of four field bases. All field bases were linked and all data finally adjusted with respect to the primary field base located at 400N on the baseline. The estimated field value for this base was 49320 nT. Supplementary magnetic data was also linked to this base. Figure 27 shows an amplitude trace plot of all total field magnetic data for the Burn of Heughs catchment, plotted to a datum of 49500 nT. Areas where the total field exceeds 49500 nT are shaded black, those with a field less than 49500 are shown by the trace only.

The key features of the data are: a zone of positive magnetic anomaly around and east of the baseline between 700N and 1000N; west-north-west trending anomalies observed in the data on the tertiary grid to the west; north-north-west anomalies in the northeast part of the primary grid.

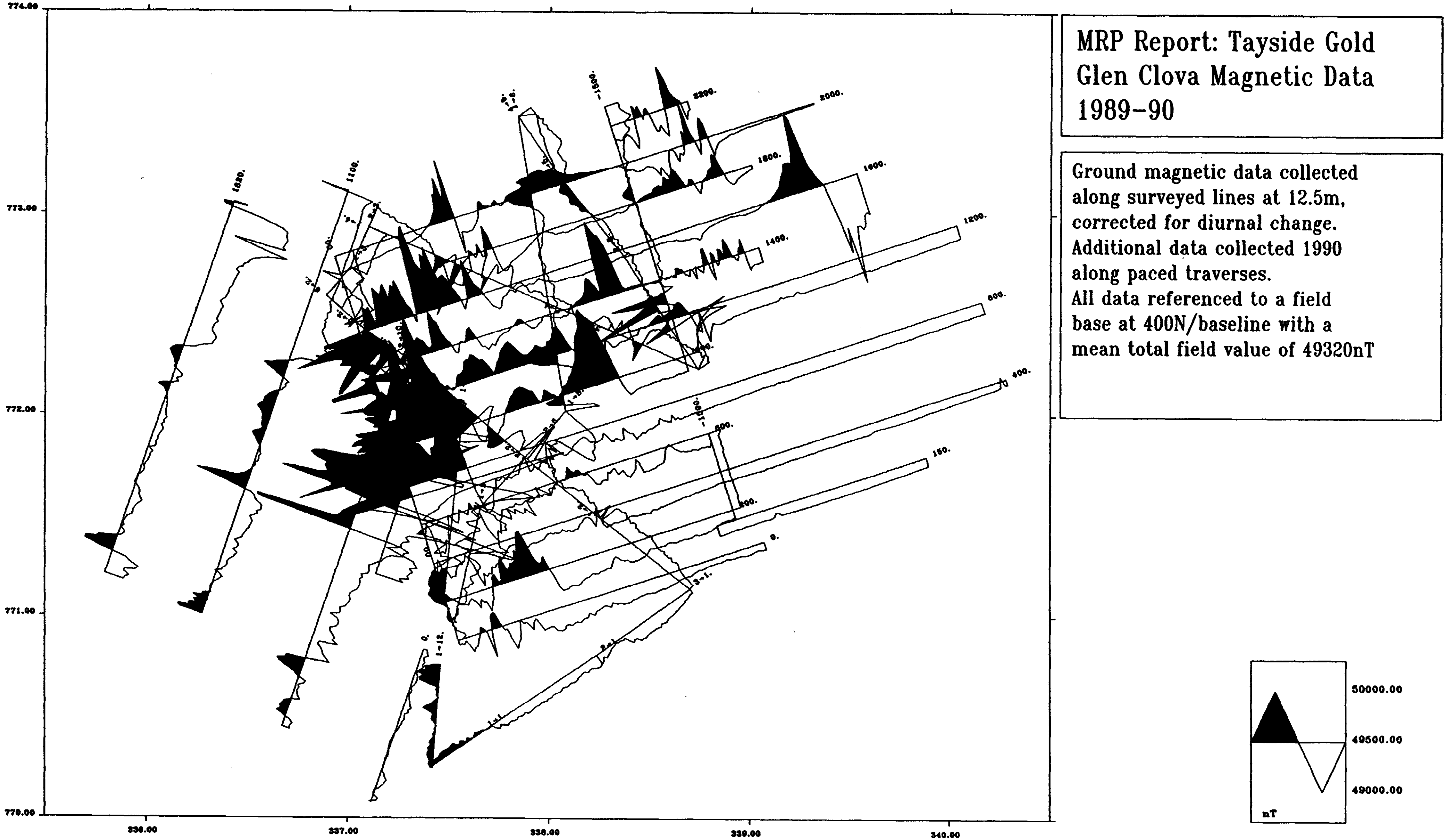

Figure 27 Plot of ground magnetic data in Glen Clova

Individual anomalies are not easily correlated to adjacent lines across the primary grid, for example the large anomaly on line 1000N at 1000E. Some of these features are due to cross cutting late dykes with an east-north-east trend.

Figure 28 shows all the magnetic data not observed on the primary grid. This helps to identify better the easterly trending structures.

Susceptibility data

Outcrop is limited across much of the surveyed area and no new susceptibility data were collected at the time of geophysical survey. Some outcrops had been sampled during the geological mapping programme and these results are also displayed in Figure 28. Field susceptibilities of the Green Beds reach 0.030 SI against background values less than 0.001 SI.

VLF data

VLF data were collected along the primary grid lines using the GBR transmitter (16 kHz) and the FUO Bordeaux station (15.1 kHz) while the former was not transmitting. The data are shown in Figure 29 as amplitude trace plots showing both real and imaginary components of the field. Typically the in-phase anomaly shows amplitudes up to about 50% and is largely positive, with occasional sharp local minima which have corresponding inflexions in the out-of-phase component. The correlation of these anomalies between lines 400 m apart is not simple.

On lines 1200N and 1600N matching anomalies and cross-overs at about 800E and 900E respectively imply a north-trending resistivity boundary which might represent the edge of thick drift deposits. At about 2100E on line 1600N a sharp minimum in the in-phase anomaly identifies the position of the Fleurs Fault, further north on line 2000N the same feature occurs at about 1950E. The inferred strike of the structure is about 325 degrees grid. On line 1200N along this strike only a very subdued anomaly can be identified although a very strong feature can be seen on line 800N at about 2100E. Matching the latter anomaly with a feature on line 1200N at 1950E also suggests a northwest strike. However the two anomalies on lines 800N, 1200N can be matched in general terms with features on the VLF data for lines 0N, 150N, 400N to suggest a north-north-east strike of structures up to at least the Fleurs Fault. This correlation would reflect lithological contacts in the Dalradian rather than faulting.

Figures 30 and 31 show the calculated current density models in the sub-surface for lines 800N, 1600N using the BGS program VLFCDI. The current density modelling suggests a southwesterly dip of the Fleurs Fault.

Lithogeochemistry

Lithogeochemical sampling was undertaken in 1988 (Redwood, 1988a) and 1989, based on the results of reconnaissance stream sampling in order to investigate potential sources of Au mineralisation. The area of particular interest was Glen Clova because of the cluster of Au anomalies in the Burn of Fleurs and Burn of Heughs catchments (Figure 21). Drainage anomalies were also followed up in the nearby catchments of the Kennel Burn and the Burn of Adielinn. At the northern end of Glen Clova enhanced Au in panned concentrates was followed up in the Kilbo and Fee Burn catchments (Redwood, 1988b). The Trusty Burn and Noran Water catchments to the south-east of Glen Clova were also investigated in the later stages of the detailed sampling.

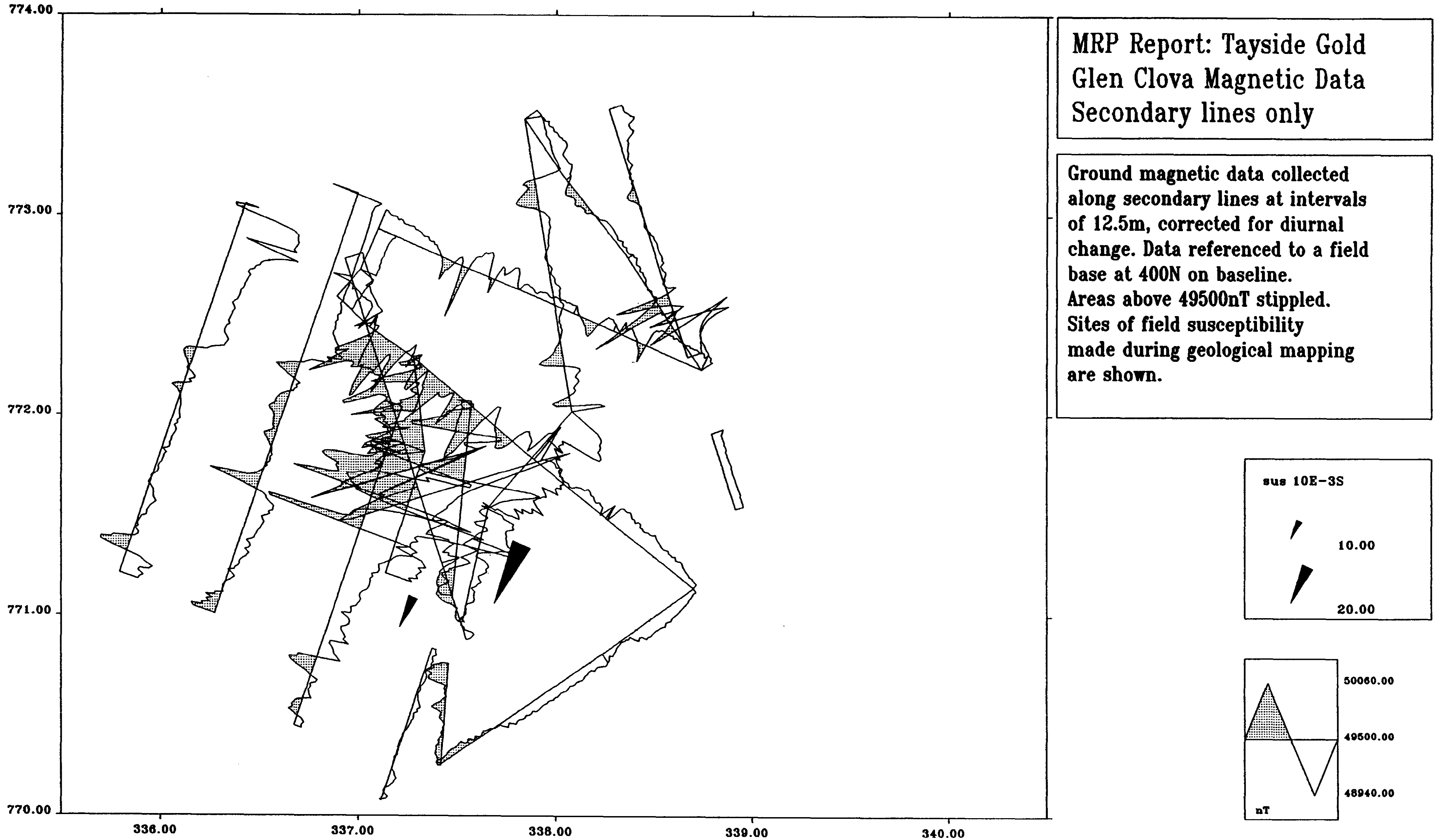

Figure 28 Plot of ground magnetic data in Glen Clova, secondary lines only

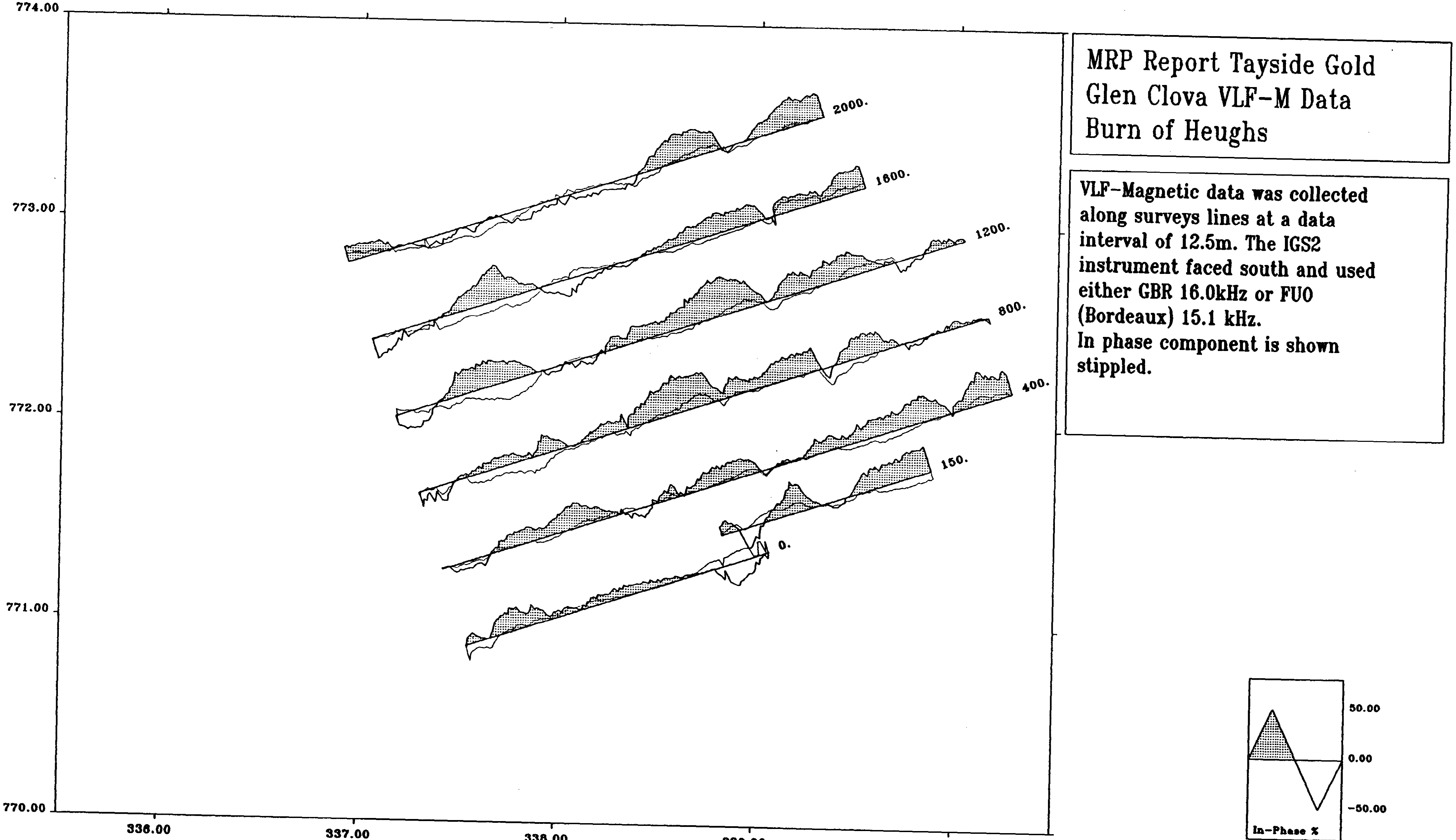

Figure 29 Plot of VLF-M data in Glen Clova

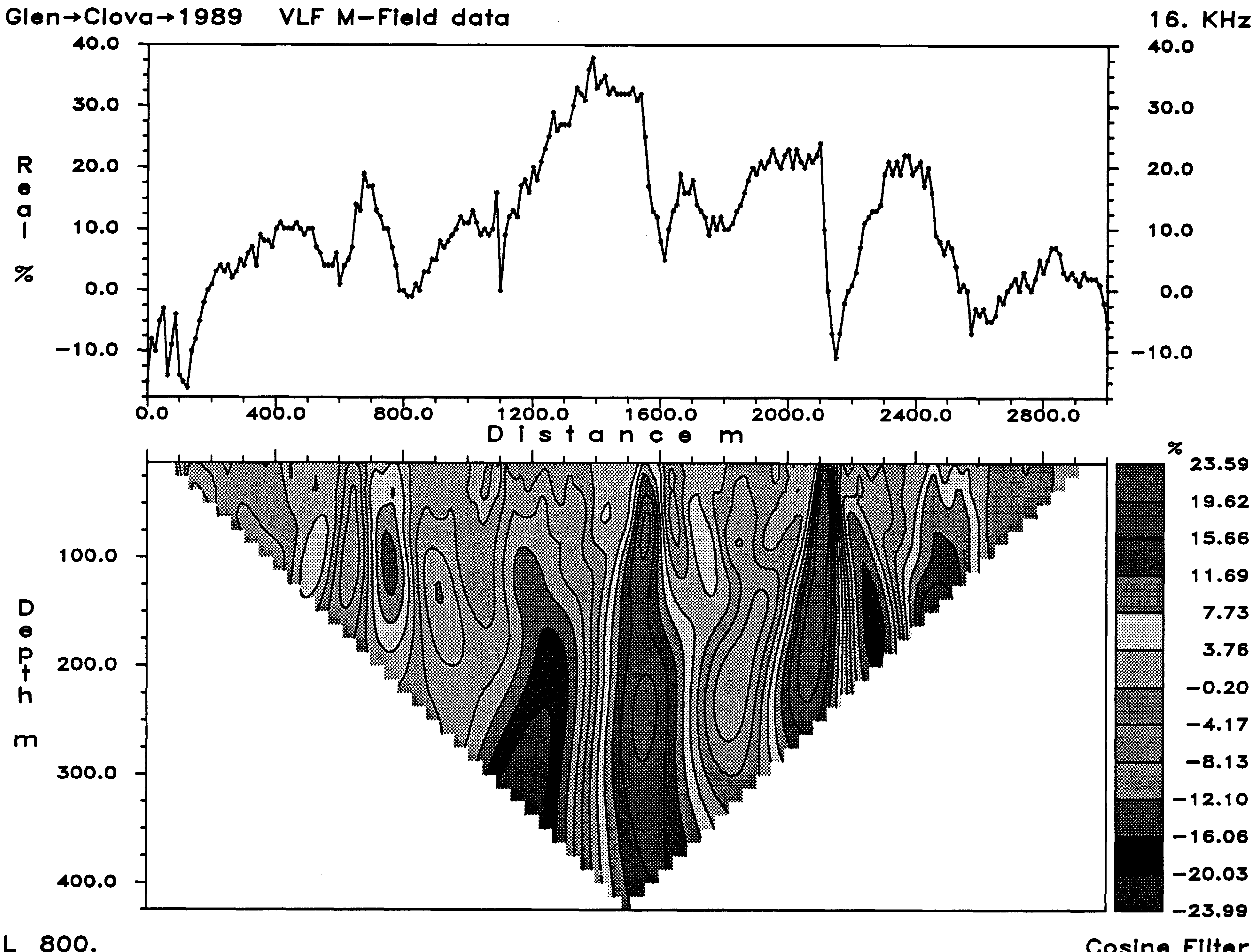

Figure 30 Calculated sub-surface current density model for line 800N Glen Clova

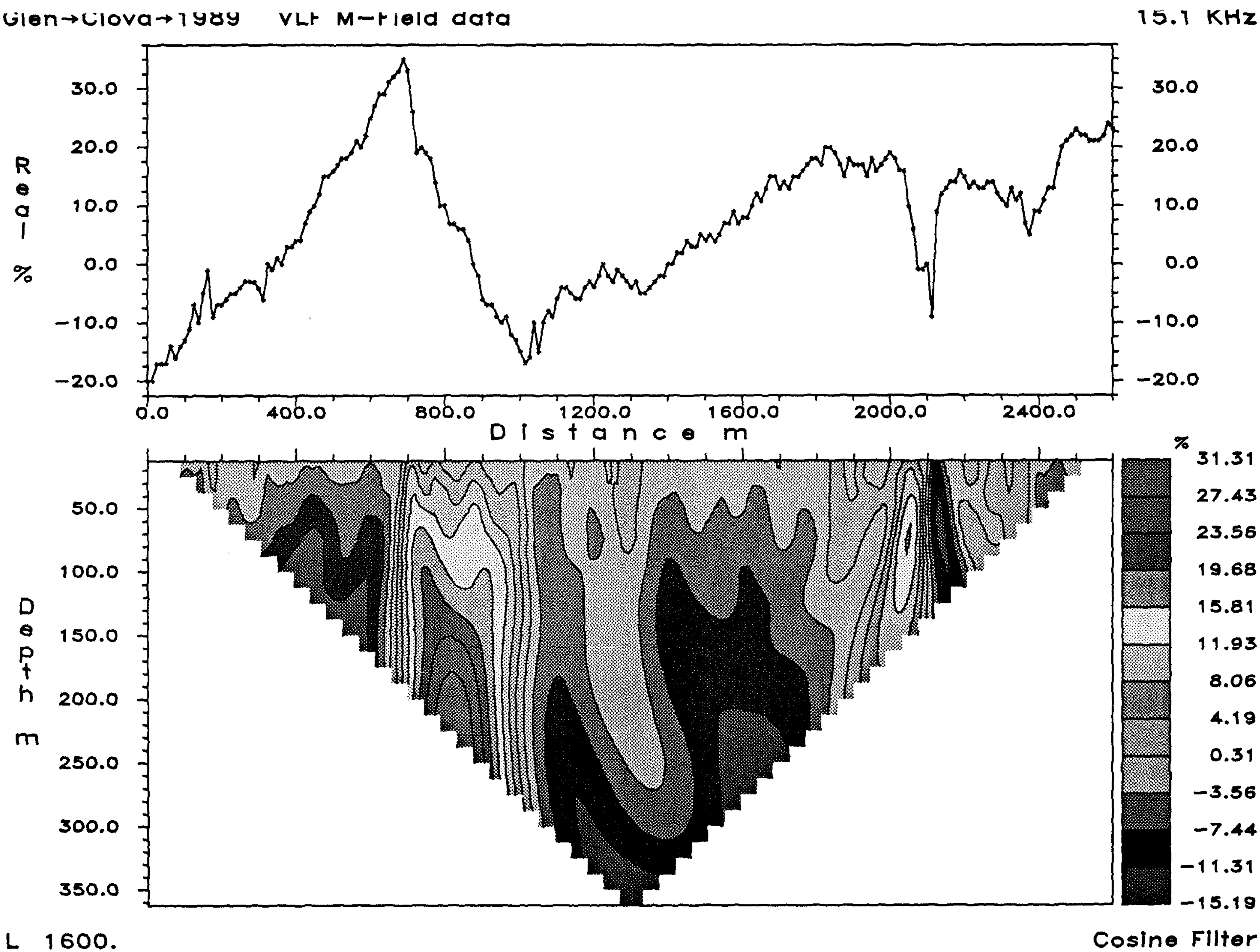

Figure 31 Calculated sub-surface current density model for line 1600N Glen Clova

Au determinations were made by digestion in aqua regia, MIBK extraction and AAS using commercial laboratories. Trace element analyses were produced by XRF at BGS laboratories, Keyworth. Summary statistics for the 56 samples collected within the project area are shown in Table 9 and Spearman rank correlation coefficients in Table 10.

Table 9 Summary statistics on rocks from the Pitlochry - Glen Clova area

	N	Median	Lower Quartile	Upper Quartile	Minimum	Maximum
Au	56	5	2	17	0	6850
Ca	56	5000	600	34350	0	82700
Ti	56	3705	2093	5365	70	16280
V	56	70	37	109	1	412
Cr	37	271	143	351	46	779
Mn	56	900	333	1280	40	3600
Fe	56	43600	24575	59525	5000	89200
Co	56	17	7	32	1	62
Ni	56	28	10	45	0	180
Cu	56	23	10	55	0	269
Zn	56	52	28	85	2	408
As	37	1	0	3	0	235
Rb	56	66	27	124	10	234
Sr	56	148	66	243	15	780
Y	56	17	11	20	3	31
Zr	56	130	88	232	20	472
Mo	56	4	2	9	0	22
Ag	56	1	0	2	0	21
Ba	56	222	155	432	34	855
La	56	21	15	34	2	68
Ce	56	37	22	56	0	111
Pb	56	13	8	25	2	241
Sb	56	1	0	4	0	35
Bi	37	0	0	1	0	93
Th	56	6	3	8	0	35
U	56	2	1	4	0	63

1. All elements in ppm except Au in ppb.
2. Method of analysis X-ray fluorescence except for Au determined by AAS after MIBK extraction.

The range of lithologies sampled included metasedimentary rocks composed mainly of semipelites and psammites and metabasic rocks, including banded hornblende schists, forming part of the Rottal Formation of the Southern Highland Group. In northern Glen Clova samples were collected from late-Caledonian diorite intrusions and marginal or intercalated metasedimentary rocks, together with minor intrusions. Within this suite of varied lithologies attention was focused on outcrops containing sulphides and/or displaying alteration or pervasive oxidation. Minor quartz veins and gossans were also sampled.

Background levels of Au in many of the psammites, semipelites and metavolcanic rocks are close to the lower detection limit of 1 ppb. The late Caledonian intrusive rocks are weakly enriched in Au (2 - 17 ppb) but this is a fairly typical range for Caledonian igneous rocks (Coats et al., 1991).

Table 10 Spearman rank correlation coefficients (>99% significance level) for rock samples							
Au	U+0.49	Pb+0.38					
Ca	Co+0.79	Mn+0.74	Sr+0.71	V+0.67	Ni+0.64	Zn+0.56	Cu+0.55
	Fe+0.52	Ti+0.51	Bi+0.45	Cr+0.34	Th-0.44	Sb-0.43	Rb-0.40
Ti	V+0.92	Sr+0.70	Zn+0.69	Fe+0.67	Co+0.64	Ni+0.62	Ca+0.51
	Mn+0.50	Y+0.45	Zr+0.41				
V	Ti+0.92	Co+0.78	Fe+0.78	Sr+0.76	Ni+0.72	Zn+0.68	Ca+0.67
	Mn+0.59	Cu+0.52	Y+0.36				
Cr	As+0.81	Bi+0.68	Mo+0.55	Mn+0.42	Ca+0.34		
Mn	Ca+0.74	Co+0.69	Zn+0.59	V+0.59	Ni+0.58	Fe+0.50	Ti+0.50
	Sr+0.48	Bi+0.45	Cr+0.42	As+0.39	Y+0.36	Cu+0.35	
Fe	V+0.78	Co+0.73	Ti+0.67	Ni+0.64	Ag+0.62	Cu+0.60	Ca+0.52
	Zn+0.50	Mn+0.50	Sr+0.47	Sb-0.49			
Co	Ni+0.83	Ca+0.79	V+0.78	Fe+0.73	Mn+0.69	Sr+0.66	Cu+0.64
	Ti+0.64	Zn+0.61	Ag+0.42	Sb-0.48			
Ni	Co+0.83	V+0.72	Fe+0.64	Ca+0.64	Ti+0.62	Mn+0.58	Cu+0.57
	Sr+0.56	Zn+0.55	Sb-0.39				
Cu	Co+0.64	Fe+0.60	Ni+0.57	Ca+0.55	V+0.52	Sr+0.40	Ag+0.40
	Mo+0.36	Mn+0.35	Ce-0.37	Sb-0.59			
Zn	Ti+0.69	V+0.68	Co+0.61	Mn+0.59	Ca+0.56	Ni+0.55	Sr+0.52
	Fe+0.50	Y+0.45	Ba+0.40				
As	Cr+0.81	Bi+0.72	Mo+0.45	Mn+0.39	Ce-0.37		
Rb	Th+0.77	Ba+0.54	Ce+0.50	U+0.50	La+0.40	Pb+0.40	Sr-0.37
	Ca-0.40						
Sr	V+0.76	Ca+0.71	Ti+0.70	Co+0.66	Ni+0.56	Zn+0.52	Mn+0.48
	Fe+0.47	Cu+0.40	Rb-0.37	U-0.38			
Y	La+0.62	Ce+0.52	Zn+0.45	Zr+0.45	Ti+0.45	Th+0.45	Mn+0.36
	V+0.36						
Zr	La+0.66	Ce+0.61	Y+0.45	Ti+0.41	Th+0.38		
Mo	Cr+0.55	As+0.45	Bi+0.37	Cu+0.36	Ba-0.42		
Ag	Fe+0.62	Co+0.42	Cu+0.40	Sb-0.41			
Ba	Rb+0.54	Th+0.45	Pb+0.44	La+0.42	Ce+0.41	Zn+0.40	Y+0.36
	Mo-0.42						
La	Ce+0.91	Zr+0.66	Th+0.65	Y+0.62	Ba+0.42	Rb+0.40	
Ce	La+0.91	Th+0.70	Zr+0.61	Y+0.52	Rb+0.50	Ba+0.41	U+0.35
	Bi-0.34	Cu-0.37	As-0.37				
Pb	U+0.56	Ba+0.44	Rb+0.40	Au+0.38			
Sb	Ni-0.39	Ag-0.41	Ca-0.43	Co-0.48	Fe-0.49	Cu-0.59	
Bi	Cr+0.68	As+0.72	Mn+0.45	Ca+0.45	Mo+0.37	Ce-0.34	
Th	Rb+0.77	Ce+0.70	La+0.65	U+0.48	Ba+0.45	Y+0.45	Ca+0.44
	Zr+0.38						
U	Pb+0.56	Rb+0.50	Au+0.49	Th+0.48	Ce+0.35	Sr-0.38	

Au shows positive Spearman rank correlation coefficients with U (+0.48) and Pb (+0.36), significant at the 99% confidence level (Table 10).

Burn of Fleurs

The upper part of the stream section contains exposures of shattered schistose micaceous psammites. The rocks contain abundant lenticular quartz segregations which show no mineralisation but are sometimes cavernous (after calcite?). Within a 30 m long streambank section, a 0.5 - 1.0 m wide fault zone with 1 m wide marginal alteration zones, striking 126° and dipping steeply to the southwest, is exposed near [338990 773040]. A central clay-rich gouge contains both green and red clay alteration with shattered quartz (Figure 32). Marginal limonite alteration is extensive forming a saprolitic country rock in places. Within the fault zone the sulphides are absent and limonitic colouration is pervasive.

The highest Au values in KLR 1155 and 2558 were samples from the hard, green, soapy clay (pyrophyllite?) containing quartz-rich stringers and which forms the main fault gouge. Adjacent samples (KLR 2555 and 2558) of strongly limonitic material were enriched up to 1600 ppb Au. The psammite which forms the country rock shows less alteration and the gold levels are close to background (Table 11).

Comparison of the gold and base metal values shows that copper is not significantly enhanced with the gold (Figure 33) with samples KLR 1155, 2558, 2557 and 2554 having only 27 to 49 ppm Cu. Lead shows a different pattern, the two limonitically altered rocks marginal to the fault zone having over 200 ppm Pb (Figure 34) and the fault zone itself still being enriched with around 50 ppm. Uranium is enriched in many of the rocks but high levels are found in the same marginal rocks (Figure 35).

Table 11 Selected rock analyses from the Burn of Fleurs section (Figure 32)

Sample Number	Rock type	Au (ppb)	Cu	Pb	Zn	U
KLR 2553	Limonitic psammite	2	6	8	40	4
KLR 2554	Limonitic quartz rock	300	49	12	18	5
KLR 2555	Yellow saprolitic clay	160	16	241	73	22
KLR 2556	Mica psammite	11	6	25	30	8
KLR 2557	Limonitic brown clay	1600	34	236	59	63
KLR 2558	Green clay+quartz	4690	28	49	28	13
KLR 1155	Green clay	6853	27	58	20	4

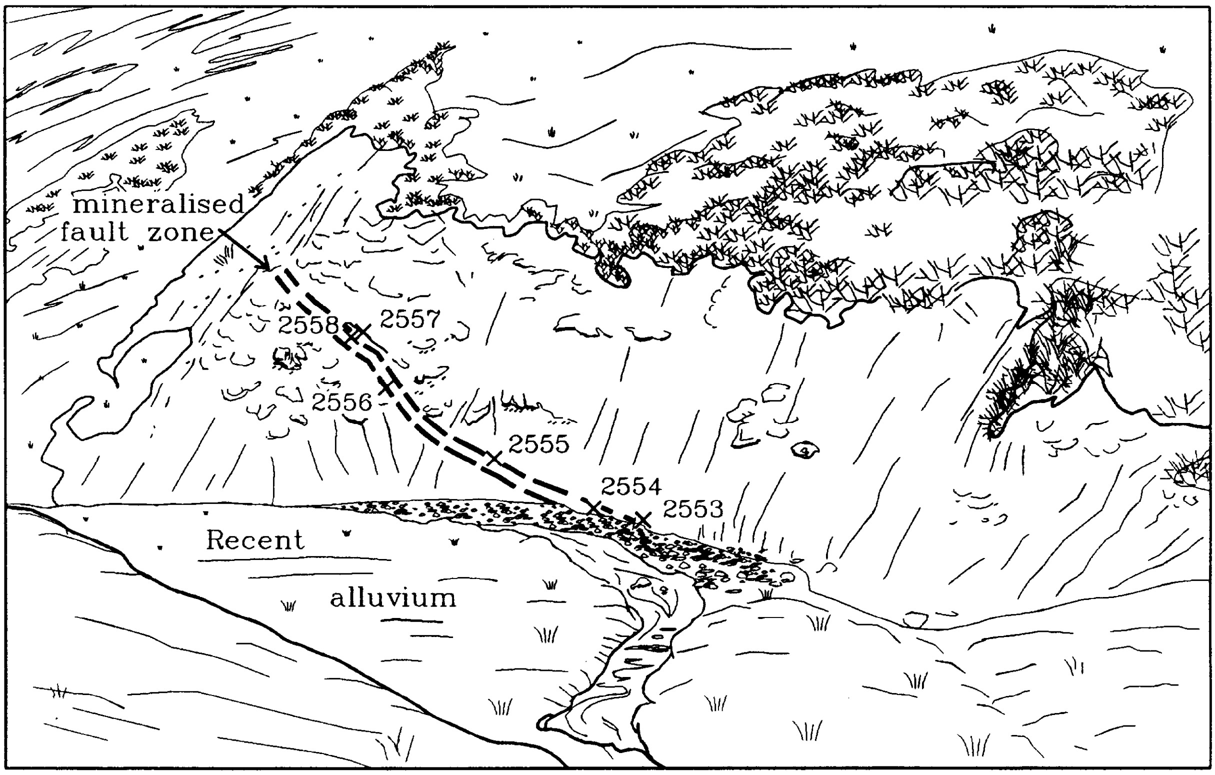

Figure 32 Exposure of mineralised fault zone in Burn of Fleurs showing location of analysed rock samples (sketch from photograph)

White Hill Gully

The south-easterly continuation of the Fleurs fault is expressed as a 400 m long headwater gully of the Kennel Burn (Figure 36), averaging 10 m in depth. Granite on the east side of the gully is faulted against schistose psammites to the west. The metasediments are intruded by granite sheets and quartz and granite pegmatite veinlets.

The gully shows a conspicuous development of red clay soil in the lower section [340000 771990]. However on sampling, the red clay (KLR 2551) showed only 33 ppb Au but is enriched in uranium (27 ppm) like the marginal limonitic rocks in the Fleurs section (Figure 36). The fault with its associated alteration and mineralisation can best be seen in the middle to upper reaches of the gully. Alteration similar to that seen in the Burn of Fleurs is exposed along a 10 m length of the gully chute, where a 0.3 m thick, central zone of ferruginous clay gouge locally contains thin irregular quartz veining. A marginal alteration zone of purple-brown hematite staining extends several metres westwards into the gully wall. A sample (KLR 2540) of ferruginous fault gouge [339810 772230] gave an Au value of 761 ppb, with enhanced U (9 ppm), Pb (68 ppm), Cu (98 ppm), Zn (100 ppm) and Mo (16 ppm). The calcium value of 50100 ppm is anomalous for this area. Other samples from this fault zone KLR 1156 and 2552, which were collected from the upper part of the gully, are not anomalous in gold or base metals.

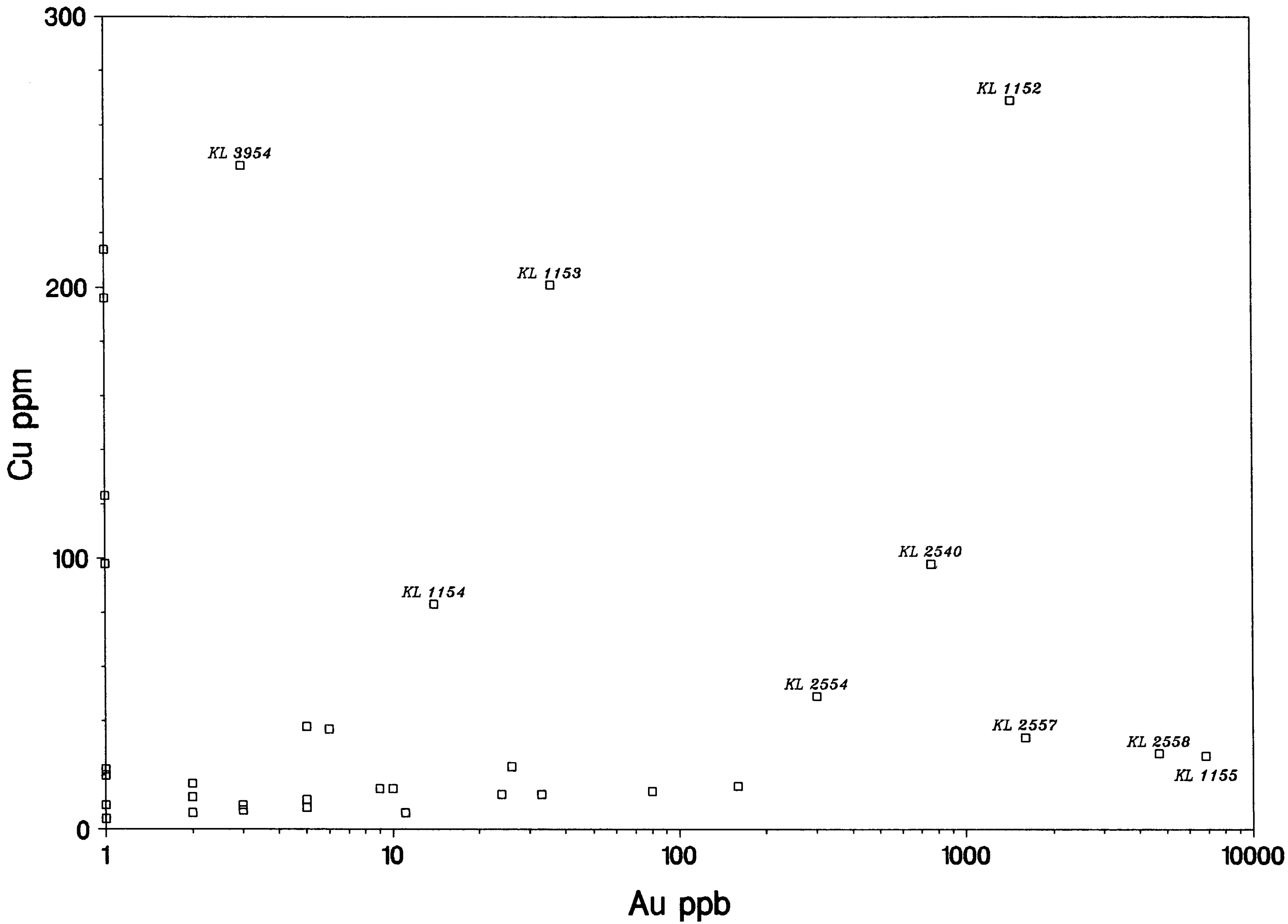

Figure 33 Plot of copper vs gold in analysed rock samples

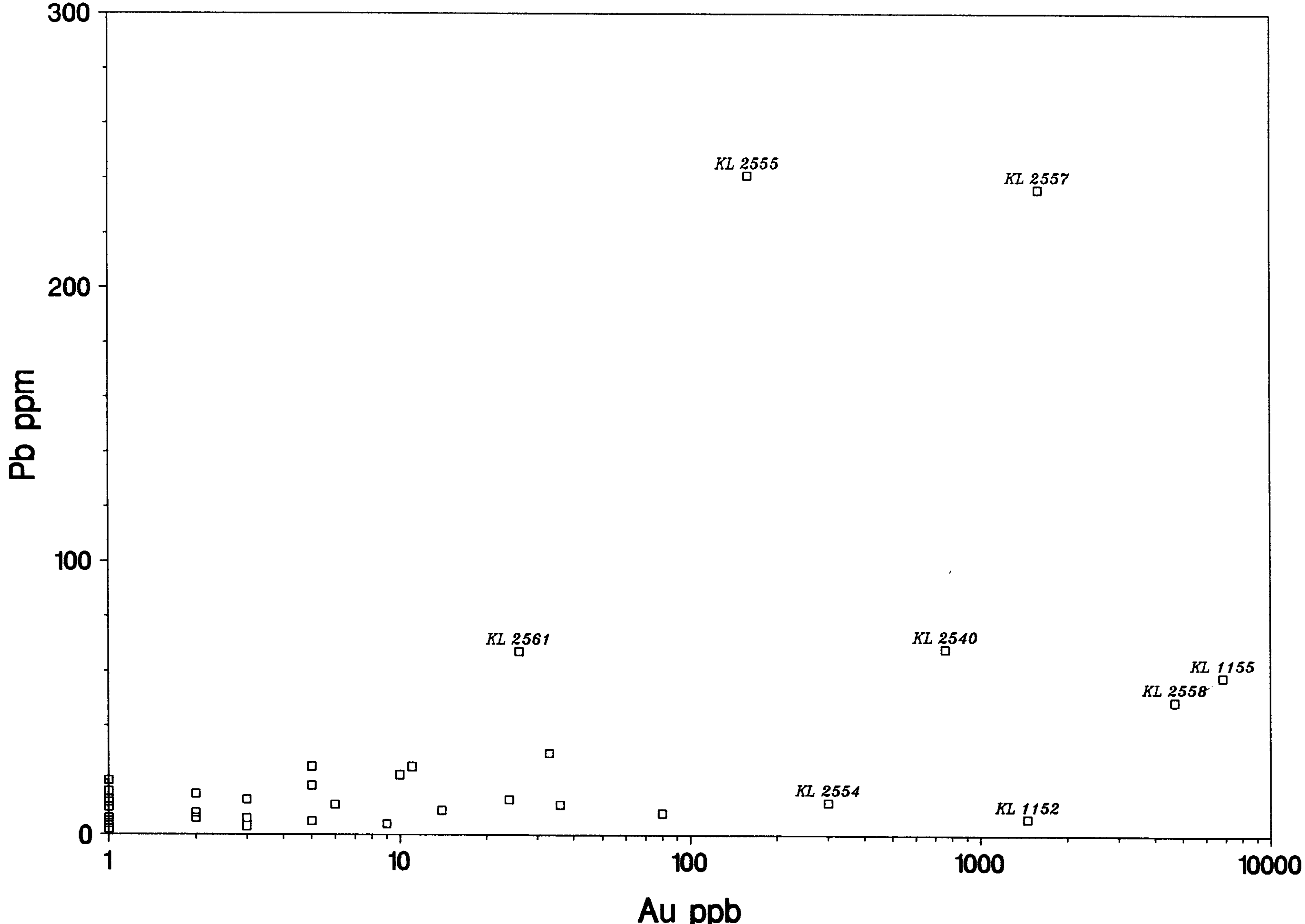

Figure 34 Plot of lead vs gold in analysed rock samples.

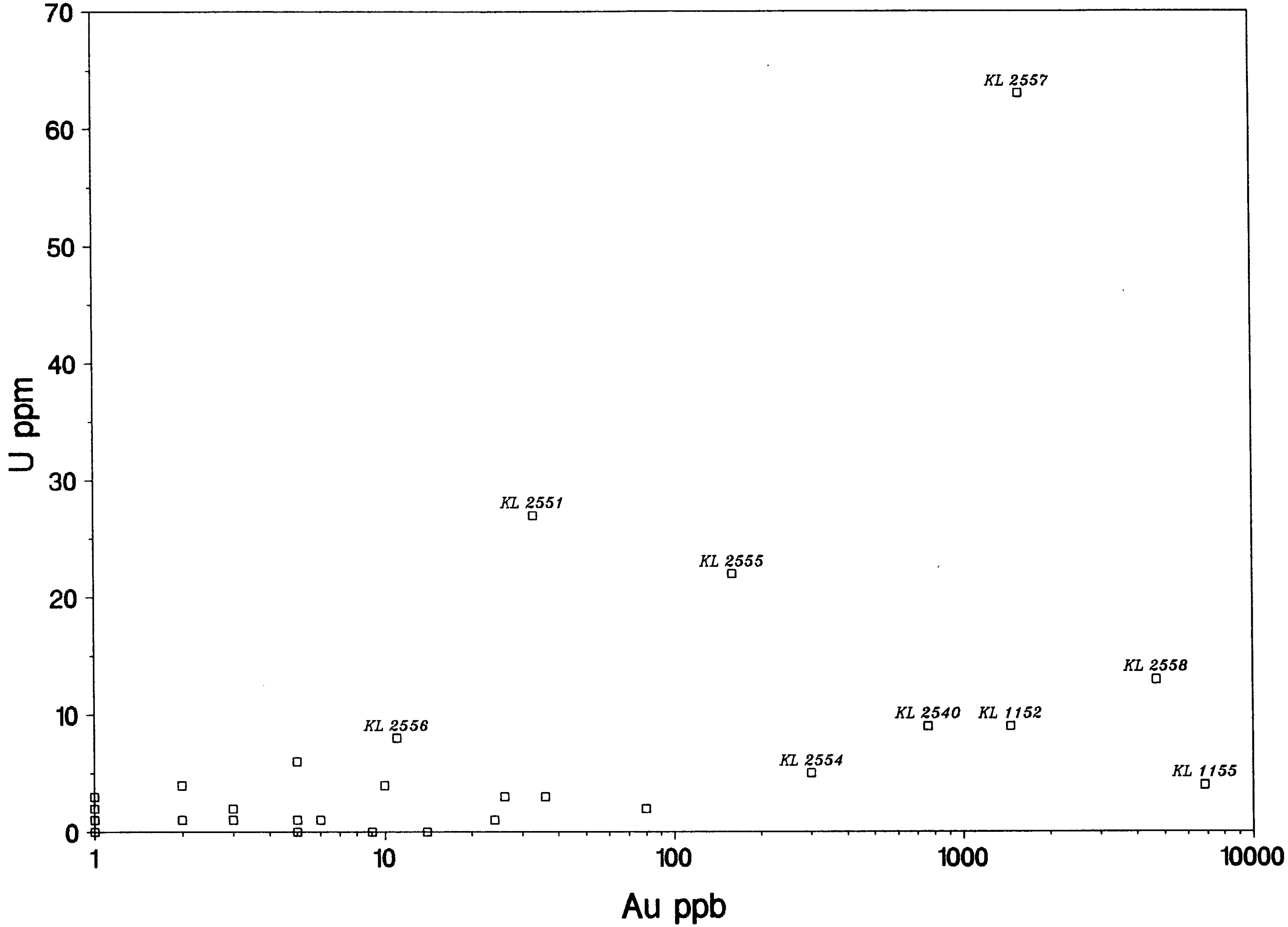

Figure35 Plot of uranium vs gold in analysed rock samples

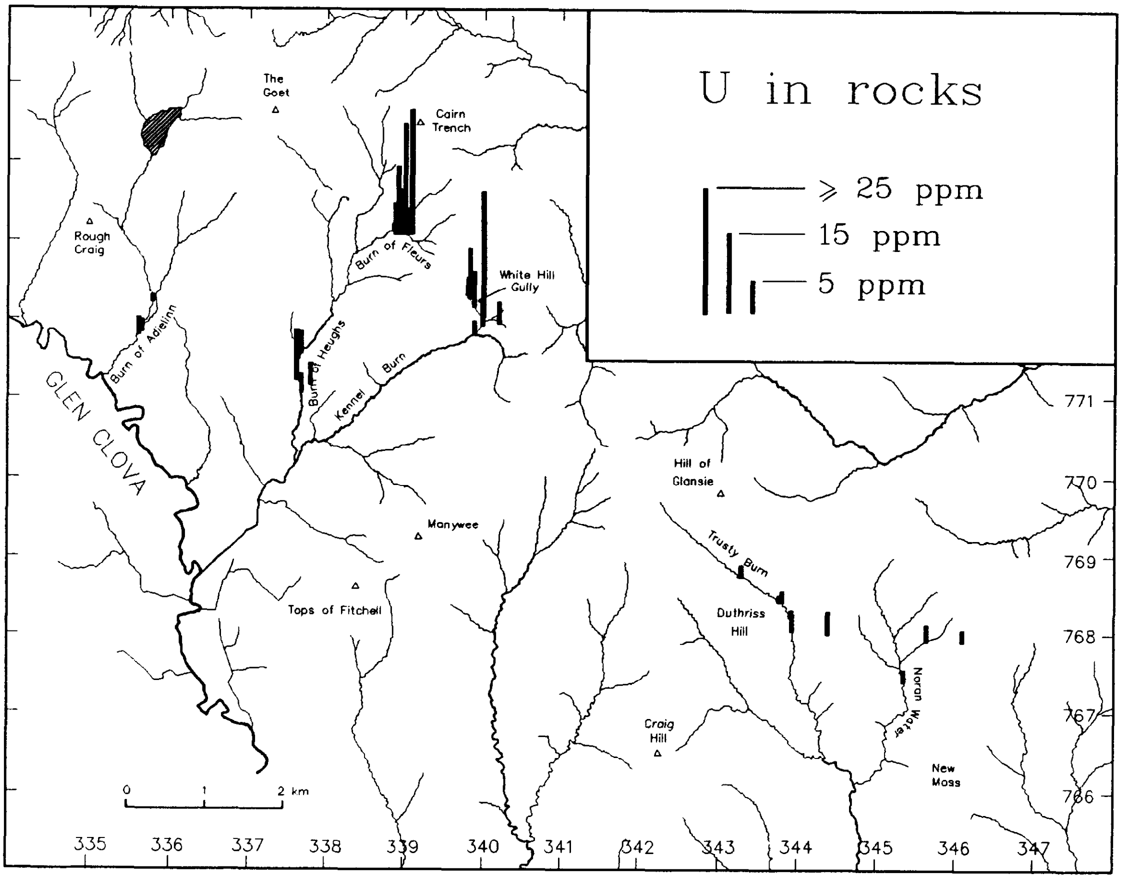

Figure 36 a. Distribution of uranium in rocks in Glen Clova

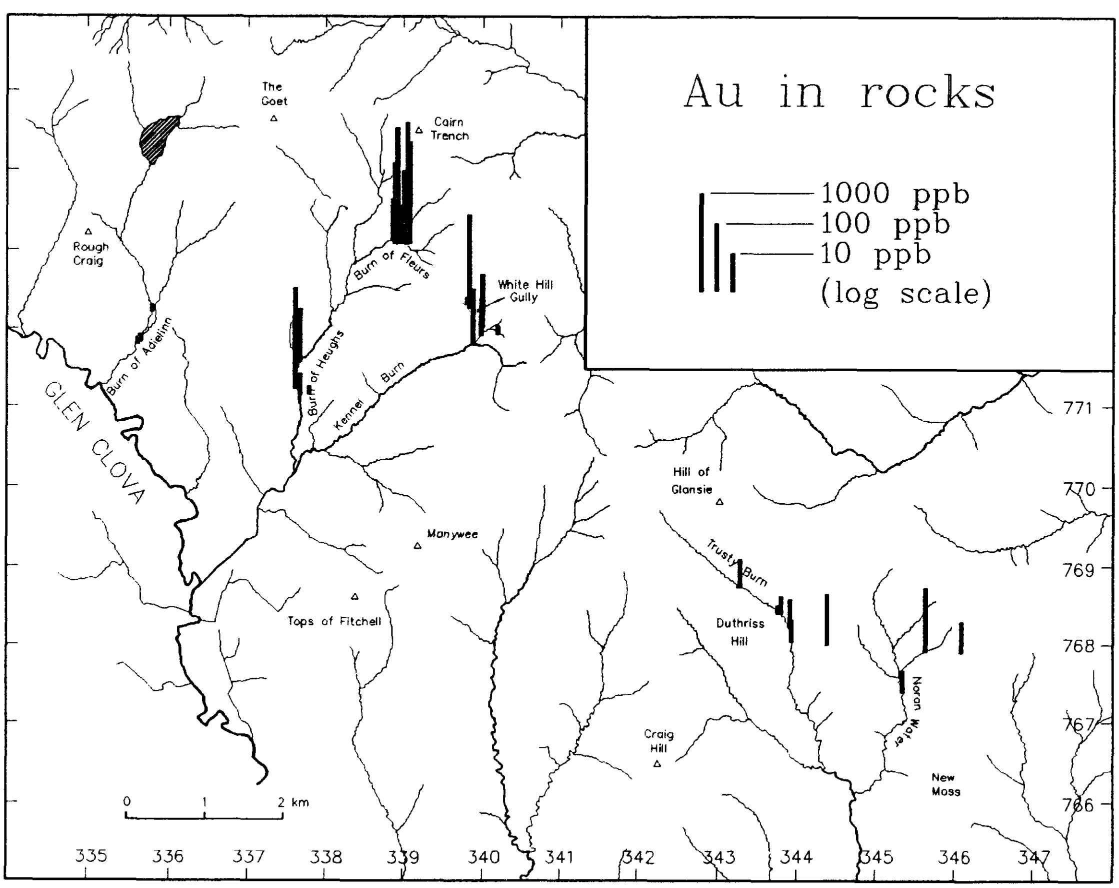

Figure 36 b. Distribution of gold in rocks from Glen Clova

Lower Burn of Heughs
Hornblende schist passing into garnet-staurolite schist of the Rottal Formation is patchily exposed over a distance of 550 m in the stream and in rare outcrops on the flanks of the valley side.

Sampling of the hornblende schists, which are apparantly of Green Bed affinity, indicated the widespread occurrence of minor sulphide mineralisation. A hornblende schist KLR 1150 [NGR 337690 771050] contained up to 1% pyrite and chalcopyrite disseminated through the rock and also in lenticular quartz segregations. A value of 214 ppm Cu was reported but Au was below the detection limit (Figure 33). Two specimens of garnet-staurolite schist also contained pyrrhotite and chalcopyrite or pyrite in veinlets, blebs and quartz segregations (KLR 1151 and 1153). KLR 1153 is from a mineralised boulder of garnet-staurolite-schist. The directions of stream flow and former ice movement, being identical, indicated a source area to the north. They were also enriched in Cu with 123 and 201 ppm respectively. Au values are low in KLR 1151 but KLR 1153 contains 36 ppb Au (Figure 33). Both samples contain low concentrations of U (3 ppm) and Pb (11-16 ppm), illustrating the differences with the Burn of Fleurs gossan (Figures 34 and 35).

At one locality [337680 771200] a granitic layer occurs parallel to the foliation in the garnet-staurolite schist and contains pyrite, chalcopyrite and molybdenite in a vuggy quartz segregation. Other nearby segregations are barren of sulphides. A sample KLR 1152 contained Au (1458 ppb), Cu (269 ppm), Mo (17 ppm), Bi (93 ppm) but low levels of U and Pb (Figures 34 and 35).

The style of mineralisation seen in the lower part of the Burn of Heughs is very different to that observed in the Burn of Fleurs. There is localised enrichment in copper and gold but not in lead or uranium. The mineralisation is not fault controlled but related to pegmatitic segregation and irregular granite veins and sheets. The copper and gold may be derived from the nearby hornblende schists which are commonly slightly enriched in these elements in much of the Southern Highlands. However, the association with Bi and Mo is unusual and could be related to metamorphic processes or granite intrusion.

Burn of Adielinn
This catchment [3358 7718] lies 1.5 km north-west of the Burn of Heughs and is underlain by Green Beds within the Rottal Formation. Three hornblende schist samples (KLR 1160, 1161 and 1162) collected from sites along a 400 m stream section contained pyrite and chalcopyrite as disseminations and in leucocratic laminae. The copper contents are variable from 20 to 196 ppm, similar to but slightly lower than the range of 123 - 269 ppm Cu seen in the Burn of Heughs. No Au was detected in any of the samples and U levels were lower than in the Heughs hornblende schists and granite segregations.

Trusty Burn - Bettywharran Ridge
The upper 2 km of Trusty Burn follows the southeastern continuation of the Fleurs fault but over most of this section no bedrock is exposed. Five samples collected from the more southeasterly part of the area [343 768] comprise psammites and semipelites. One contains minor disseminated pyrite, the others display minor disruption or limonitic staining associated with quartz segregations. No other sulphides were seen in these samples. Low levels of Au (2-5 ppb), U (0-2 ppm) and Pb (3-18 ppm) were recorded.

On Bettywharran Ridge [34438 76798], 500 m southeast of the Trusty Burn sites, quartzite subcrop is brecciated and silicified along the line of the Fleurs fault. One sample (KLR 2539) contained trace amounts of finely disseminated sulphide, possibly arsenopyrite, within a single clay-chlorite cavity. A determination of 235 ppm confirmed the presence of As, with the value for Au being 9 ppb. A second sample (KLR 2561) contained slightly enhanced values for Au (26 ppb), Pb (67 ppm) and U (3 ppm). The sample was not analysed for As.

Noran Water

Two samples of heavily fractured semipelite were collected from the Fleurs fault in Noran Water [3453 7679]. They show enhancement in Sb (5 and 7 ppm) and As (157 and 163 ppm), whereas Au values in these samples are low (2 and 3 ppb).

A stream boulder at [34563 76789], some 600 m upstream of the fault contains 80 ppb Au. The sample (KLR 2560) comprised brecciated, altered quartz mica schist with quartz cementation and patchy limonite staining. An Sb value of 35 ppm was also recorded but As was not determined. The situation of this boulder precludes any likely transportation from the Fleurs fault line.

A fourth sample from New Moss [34608 76788], of psammite containing disseminated sulphide, gave a Au value of 6 ppb but no significant enhancements of base metals or pathfinder elements.

Burn of Kilbo - Fee Burn

Minor Au anomalies were found in panned concentrates collected from these two streams which drain the southern part of the Glen Doll diorite. Reconnaissance mapping and lithogeochemical sampling was undertaken by S D Redwood and C G Smith (Redwood, 1988b). The diorite contains 2-4% pyrite, and minor chalcopyrite and pyrrhotite, as disseminations, veinlets and patchy fracture coatings. The two samples analysed contain low levels of gold (1 and 6 ppb) and copper (34 and 40 ppm). One sample (KLR 1184) has elevated Zn (408 ppm) and Pb (149 ppm) indicating that some of the mineralisation is base metal enriched.

Only one sample (KLR 1167), a dark hornblende-rich rock, of the ultramafic portion of the intrusion was sampled. This has high Fe (6.4%) and Ca (6.0%) and a slightly enhanced Au level which averages 32 ppb. This sample has been used as an internal standard and gives reasonably consistent analyses around this level. Levels of chalcophile elements are not very high (Cu 32 ppm, Zn 78 ppm, Co 30 ppm and Ni 38 ppm). Chromium is not very high, 176 ppm, and the rock may be a hornblende-rich variant of the diorite.

Six samples of fine grained basic dykes with minor disseminated pyrite were collected and these show background gold contents (median 5 ppb, range 2-9 ppb) similar to the range found in minor intrusions from the Ochil Hills (Coats et al., 1991). The dykes are relatively mafic with median contents of 6.0% Fe and 6.1% Ca, and trace element contents of Cu (55 ppm), Co (42 ppm) and Ni (70 ppm).

Four samples of quartz feldspar porphyry dyke intrusions were collected. The gold contents range from <1 to 13 ppb and the transition elements are also low (medians: Cu <1 ppm, Zn 22 ppm, Co 2 ppm, Ni 2 ppm, Fe 0.9%, Ti 0.06%, and V 3 ppm) as normal in acid differentiates. The Rb/Sr ratio of 2.0 is also typical of such intrusions. One sample contains 200 ppm Zn and this may contain traces of sphalerite.

Three lamprophyric rocks were sampled and these show background levels of Au (2-12 ppb) and of the other trace elements that were determined. The rocks appear to be be more differentiated than the fine grained basic rocks and are probably fine grained intermediate rocks transitional to the porphyry dykes. There is no evidence of unusual gold or base metal contents.

Other trace elements such as As, Bi, Ag, Mo, Th and U are low in all the rocks collected from the intrusion. Antimony is the only pathfinder element that shows a minor enrichment (median 4 ppm) in the quartz feldspar porphyry dykes.

Near the southern contact of the diorite in the Burn of Kilbo at [327050 774910] a 40 mm thick quartz vein (KLR 1179) cutting semipelitic gneiss contains patchy pyrite, chlorite and rare pink feldspar and gave the highest Au value in the area of 1690 ppb. In contrast with the highly anomalous Au localities in the Fleurs area, levels of U, Pb, Cu and Zn are relatively low. The high Cr (383 ppm) content is unusual and minor amounts of Cr-mica may be present.

Apart from this quartz vein, gold occurs at background concentrations in the Glen Doll intrusion. The more mafic parts of the intrusion show slightly elevated levels but at most a ten-fold enrichment over background. If the quartz vein is part of a larger hydrothermal vein system the Glen Doll intrusion has some potential for economic gold mineralisation but this was not further investigated.

CONCLUSIONS AND RECOMMENDATIONS

Reconnaissance drainage sampling has identified several areas as having potential for economic gold mineralisation. These areas in order of potential are:

1. Burn of Fleurs to Noran Water
2. Glen Uig
3. East of Dunkeld
4. Bridge of Cally
5. Burn of Kilbo

Detailed sampling and follow-up investigations, using lithogeochemistry and geophysics, were only completed in the Burn of Fleurs area. Enhanced levels of Au in rock up to a maximum of 6.8 ppm and 4.7 ppm respectively were found in clay fault gouge and limonitic (formerly sulphide-rich) gossan in the Burn of Fleurs catchment of Glen Clova. Visible free gold was also observed in one specimen. A similar style of mineralisation is recognised further southeast along the line of the Fleurs fault. Also associated with this fault is sporadic enrichment in Pb and U. This fault structure, probably extending for 1.6 km, is believed to have high economic potential. Structures with a similar trend can be identified for 10 km to the southeast towards Noran Water and the Highland Boundary Fault.

The original fault zone may have been sulphide-bearing but at surface is now thoroughly oxidised to limonite, and gold may have been upgraded in this gossanous material. Other metals such as copper and zinc may have been removed. The extent of this reddening, both in the Burn of Fleurs to Noran Water and the Glen Uig areas suggests that it is related to the circulation of oxidising groundwater beneath the Devonian land surface. A proposed origin for the gold is in mesothermal, sulphide-bearing quartz veins which were emplaced in northwest - southeast fault zones. Circulation of meteoric fluids below the Devonian land surface was probably an important factor in upgrading the gold to potentially economic levels. A similar origin is proposed for the gold in the Glen Uig area but the work carried out was not sufficient to identify specific targets. The relative sequence of the events is as follows:

1. Sulphide-bearing quartz veins emplaced along northwest - southeast faults possibly coeval with quartz porphyry intrusions.
2. Uplift and erosion.
3. Circulation of oxidising groundwater beneath the Devonian unconformity. Upgrading of Au and U, removal of carbonates, Cu and Zn.

A quartz vein cutting gneiss near the Glen Doll diorite intrusion also contains high gold values (1.7 ppm) and this vein may have been formed by hydrothermal systems associated with the later phases of that intrusion and leaching metals such as Au and Cr from the more mafic portions. Other veins are probably present in this part of the area as shown by As, Sb and Bi drainage anomalies in Glen Doll. The extent of the veins has not been fully investigated and may deserve further attention.

A very different style of mineralisation is also found in Glen Clova with gold being associated with an irregular granite sheet cutting the metasedimentary rocks. Pyrite, chalcopyrite and molybdenite occur in vuggy pegmatite and migration of the metals from adjacent metasedimentary rocks or from sulphide rich layers in the metavolcanic Green Beds is envisaged. The role of the nearby older granites (Robertson 1991) is unclear and they may have provided both the mineralising fluids and some of the metals such as the molybdenum. The economic potential of these granite sheets is difficult to assess but their lack of continuity is a negative factor.

The gold occurrences near Dungarthill, east of Dunkeld, have some potential. The gold appears to be associated with small galena veins and a similar origin to the Calliachar Burn deposit near Aberfeldy is proposed. Exposure in the area is poor with areas of farmland and mature forest so the gold occurrences may be more extensive. This part of the area was only covered at reconnaissance level and conclusions can only be tentative.

A small outlier of ?Devonian lavas is seen near Bridge of Cally, and gold was observed in the panned concentrates. Exploration is hindered by forestry but a detailed overburden study may be merited if the alluvial gold can be confirmed. An origin comparable to that of the widespread gold in the Ochil Hills (Coats et al., 1991) is possible.

Other areas with the potential for gold mineralisation are the baryte occurrences at Nether Craig and Meall Odhar in Glenshee. Minor sulphides, such as galena, are present at both localities and gold was observed in drainage at the former locality. The baryte at Nether Craig occurs as a metasomatic replacement of the Loch Tay Limestone and features, such as the presence of K-feldspar, indicate a low-temperature hydrothermal origin. The baryte at Meall Odhar occurs in a vein parallel to a northwest - southeast trending Caledonian felsite dyke. This may be related to the focussing of hydrothermal fluids along the fractured dyke margin.

The potential of most of the area for base metal deposits is low; the few sulphide-bearing veins being relatively thin and poorly mineralised. Compared with the stratabound mineralisation in the Argyll Group Dalradian, which has been the subject of intensive MRP studies, they are of lesser economic significance. Some of the metavolcanic rocks in the Southern Highland Group Dalradian have elevated copper contents which may be concentrated in sulphide-rich bands as a result of metamorphism but their areal extent and size is small. On present evidence, the Pitlochry to Glen Clova segment of the Southern Highland Group Dalradian is deficient in mineral veins and it may be that this segment or 'domain' (Fettes et al., 1986) has a different basement structure. The eastern extent of this segment may be the northwest - southeast line of Glen Clova. The apparent lack of mineralisation may, however, be related to the very low level of exploration activity over the area.

The Highland Boundary Fault zone was not extensively covered by this survey and there is still some unexplored potential for gold and base metal deposits along this zone. The original MRP survey carried out in 1977 did not record which minerals were present in the panned concentrates nor were the samples analysed for gold, so that further gold occurrences may remain undiscovered. The existence of a large fault zone which has been active over a long period of geological time and the presence of ultramafic rocks makes it a favourable target area which should be further explored. The zone is largely drift covered farmland so exploration is difficult and deep overburden sampling may be the most appropriate technique.

One of the reasons for exploring the Pitlochry to Glen Clova area was the possibility of locating similar structural settings to those in the Aberfeldy district and the gold deposit at Calliachar Burn. The marked arsenic anomaly in stream sediment samples east of Pitlochry was another encouraging feature. However, no gold mineralisation was located in this part of the area, despite the confirmation of very high levels of arsenic. These high levels are associated with elevated manganese and iron precipitated as secondary oxides within the sediment. The sluggish nature of the streams, flowing from artificially dammed lochs, and the low relief of the peaty uplands, has resulted in a lack of bed turnover, allowing these secondary oxides to build up to unusually high percentages with associated high values of elements such as arsenic, cobalt and barium. Arsenic in stream sediments is not therefore a good pathfinder for gold mineralisation in this environment.

No extensive arsenic, bismuth and antimony anomaly is associated with the Glen Clova gold anomaly and pathfinders for that mineralisation style are copper, uranium and lead.

Further work in the area is recommended, as follows:

1. Shallow drill the observed fault structure in the Burn of Fleurs to find the true thickness and grade beneath the surface gossan and a further two holes along strike to the southeast.

2. Deep overburden sample the extension towards White Hill Gully and further to the southeast.

3. Carry out further drainage and lithogeochemical sampling from White Hill Gully to the southeast towards the Highland Boundary Fault. Extend the geophysical survey to the southeast, with systematic VLF and magnetic surveys across a detailed grid.

4. Extend the reconnaissance drainage survey to the northeast towards Glen Mark and Glen Esk.

5. Further detailed drainage and lithogeochemical surveys in the Glen Uig, Bridge of Cally and Dungarthill areas.

6. Detailed geological mapping and lithogeochemical sampling of the Glen Doll diorite.

This work would have been carried out in 1990 but for the change in emphasis in the MRP away from drilling detailed targets and, also, the change in exploration focus from gold to base metals.

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REFERENCES

ADAMSON, G F S. 1979. *At the End of the Rainbow. The Occurrence of Gold in Scotland.* (Haddington: Albyn Press.)

ATKINSON, S. 1619. *Discoverie and Historie of the Gold Mynes in Scotland.* (Reprinted by the Bannatyne Club, Edinburgh, 1825.), pp 84.

BRITISH GEOLOGICAL SURVEY. 1991 *Regional geochemistry of the East Grampians area.* (Keyworth, Nottingham: British Geological Survey.)

COATS, J S, SMITH, C G, GALLAGHER, M G, MAY, F, MCCOURT, W J, PARKER, M E and FORTEY, N J. 1981. Stratabound barium-zinc mineralisation in Dalradian schist near Aberfeldy, Scotland: Final report. *Institute of Geological Sciences, Mineral Reconnaissance Programme Report 40.*

COATS, J S, TANDY, B C and MICHIE, U MCL. 1982. Geochemical drainage survey of central Argyll, Scotland. *Institute of Geological Sciences, Mineral Reconnaissance Programme Report 50.*

COATS, J S, FORTEY, N J, GALLAGHER, M J, GREENWOOD, P G and PEASE, S F. 1987. Mineral exploration for zinc, lead and baryte in Middle Dalradian rocks of the Glenshee area, Grampian Highlands. *British Geological Survey Technical Report WF/87/1 (BGS Mineral Reconnaissance Programme Report 88).*

COATS, J S, SHAW, M H, GALLAGER, M J, ARMSTRONG, M, GREENWOOD, P G, WILLIAMSON, J P and FORTEY, N J. 1991. Gold in the Ochil Hills, Scotland. *British Geological Survey Technical Report WF/91/1 (BGS Mineral Reconnaissance Programme Report 116).*

CURRY, G B BLUCK, B J, BURTON, C J, INGHAM, J K, SIVETER, D J and WILLIAMS, A. 1984. Age, evolution and tectonic history of the Highland Border Complex, Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **75**, 113-133.

DEMPSTER, T J and HARTE, B. 1986. Polymetamorphism in the Dalradian of the central Scottish Highlands. *Geological Magazine*, **123**, 95-104.

FETTES, D J, GRAHAM, C M, HARTE, B and PLANT, J A. 1986. Lineaments and basement domains: an alternative view of Dalradian evolution. *Journal of the Geological Society, London*, 143, 453-464.

GALLAGHER, M J, MICHIE, U McL, SMITH, R T and HAYNES, L. 1971. New evidence of uranium and other mineralization in Scotland. *Transactions of the Institution of Mining and Metallurgy (Section B: Applied Earth Science)*, 80, B150-B173.

GALLAGHER, M J, SMITH, C G, COATS, J S, GREENWOOD, P G, CHACKSFIELD, B C, FORTEY, N J and NANCARROW, P H A. 1989. Stratabound barium and base-metal mineralisation in Middle Dalradian metasediments near Braemar, Scotland. *British Geological Survey Technical Report WF/89/12 (BGS Mineral Reconnaissance Programme Report 104).*

HALLIDAY, A N, GRAHAM, C M , AFTALION, M and DYMOKE, P. 1989. The depositional age of the Dalradian Supergroup: U-Pb and Sm-Nd isotopic studies of the Tayvallich Volcanics, Scotland. *Journal of the Geological Society, London*, **146**, 3-6.

HARTE, B. 1979. The Tarfside succession and the structure and stratigraphy of the eastern Scottish Dalradian rocks. In *HARRIS, A.L., HOLLAND, C.H. and LEAKE, B.E.* (editors) The Caledonides of the British Isles: Reviewed. *Special Publication of the Geological Society*, **8**, 221-228.

HARTE, B, BOOTH, J E, DEMPSTER, T J, FETTES, D J, MENDUM, J E and WATTS, D. 1984. Aspects of the post-depositional evolution of Dalradian and Highland Border Complex rocks in the Southern Highlands of Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **75**, 151-163.

HENDERSON, W G and ROBERTSON, A H F. 1982. The Highland Border rocks and their relation to marginal basin development in the Scottish Caledonides. *Journal of the Geological Society, London*, **139**, 433- 450.

KNELLER, B C and AFTALION, M. 1987. The isotopic and structural age of the Aberdeen Granite. *Journal of the Geological Society, London*, **144**, 717-721.

MASON, J, PATTRICK, R A D and GALLAGHER, M J. 1991 Auriferous structures in the Upper Dalradian near Aberfeldy, Scotland. (abstract) In *Prospecting in areas of glaciated terrain*, (IMM).

MENDUM, J R and FETTES, D J. 1985. The Tay Nappe and associated folding in the Ben Ledi-Loch Lomond area. *Scottish Journal of Geology*, **21**, 41-56.

PANKHURST, R J. 1970. The geochronology of the basic igneous complexes. *Scottish Journal of Geology*, **6**, 83-107.

PANKHURST, R J and PIDGEON, R T. 1976. Inherited isotope systems and the source region pre-history of early Caledonian granites in the Dalradian series of Scotland. *Earth and Planetary Science Letters*, **31**, 55-68.

PARKER, R T G, CLIFFORD, J A and EARLS, G. 1991. Exploration techniques at Cononish gold-silver deposit, Scotland. (abstract) In *Prospecting in areas of glaciated terrain*, (IMM).

PEASE, S F, COATS, J S and FORTEY, N J. 1986. Exploration for sediment-hosted exhalative mineralization in the Middle Dalradian at Glenshee, Scotland. In *Prospecting in areas of glaciated terrain* (London: IMM), 95-107.

PETTS, G E, COATS, J S and HUGHES, N. 1991. Freeze-sampling method of collecting drainage sediments for gold exploration. *Transactions of the Institution of Mining and Metallurgy (Section B: Applied Earth Science)*, 100, B28-B32.

PLANT, J A, SMITH, R T, STEVENSON, A G, FORREST, M D and HODGSON, J F. 1984. Regional geochemical mapping for mineral exploration in northern Scotland. In *Prospecting in areas of glaciated terrain* (London: IMM), 103-120.

ROBERTSON, S. 1991. Older granites in the south-eastern Scottish Highlands. *Scottish Journal of Geology*, **27**, 21-26.

REDWOOD, S D. 1988a Report on fieldwork in Glen Clova. Unpublished report, BGS Highlands and Islands Group, SDR/88/7

REDWOOD, S D. 1988b Note on sampling in Glen Doll, October 1988. Unpublished report, BGS Highlands and Islands Group, SDR/88/8

ROGERS, G, DEMPSTER, T J, BLUCK, B J and TANNER, P W G. 1989. A high precision U-Pb age for the Ben Vuirich granite: implications for the evolution of the Scottish Dalradian Supergroup. *Journal of the Geological Society, London*, **146**, 789-798.

SMITH, C G, PITFIELD, P E J, BURLEY, A J, HOWARD, S H D, PARKER, M E, MICHIE, U MCL and FORTEY, N J. 1977. Investigation of stratiform sulphide mineralisation in parts of central Perthshire. *Institute of Geological Sciences, Mineral Reconnaissance Programme Report 8.*

SMITH, C G, GALLAGHER, M J, COATS, J S and PARKER, M E. 1984. Detection and general characteristics of strata-bound mineralization in the Dalradian of Scotland. *Transactions of the Institution of Mining and Metallurgy (Section B: Applied Earth Science)*, 93, B125-B132.

WATKINS, K P. 1984. The structure of the Balquidder-Crianlarich region of the Scottish Dalradian and its relation to the Barrovian garnet isograd surface. *Scottish Journal of Geology*, **20**, 53-64.

WILSON, G V and FLETT, J S. 1921. Special reports on the mineral resources of Great Britain. Volume 17 The lead, zinc, copper and nickel ores of Scotland. *Memoir of the Geological Survey, Scotland.*