Natural Environment Research Council

Institute of Geological Sciences

Mineral Reconnaissance Programme Report

A report prepared for the Department of Industry

D. Ostle
Programme Manager
Institute of Geological Sciences
Keyworth,
Nottingham NG12 5GG

No. 28

A mineral reconnaissance survey of the Abington-Biggar-Moffat area, south-central Scotland

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A mineral reconnaissance survey of the Abington-Biggar-Moffat area, south-central Scotland.

South Lowlands Unit
J. Dawson, BSc
J. D. Floyd, BSc, PhD
P. R. Phillip, BSc

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Mineral Reconnaissance Programme Reports

1 The concealed granite roof in south-west Cornwall
2 Geochemical and geophysical investigations around Garras Mine, near Truro, Cornwall
3 Molybdenite mineralisation in Precambrian rocks near Lairg, Scotland
4 Investigation of copper mineralisation at Vidlin, Shetland
5 Preliminary mineral reconnaissance of Central Wales
6 Report on geophysical surveys at Struy, Inverness-shire
7 Investigation of tungsten and other mineralisation associated with the Skiddaw Granite near Carrock Mine, Cumbria
8 Investigation of stratiform sulphide mineralisation in parts of central Perthshire
9 Investigation of disseminated copper mineralisation near Kilmelford, Argyllshire, Scotland
10 Geophysical surveys around Talnotry mine, Kirkcudbrightshire, Scotland
11 A study of the space form of the Cornubian granite batholith and its application to detailed gravity surveys in Cornwall
12 Mineral investigations in the Teign Valley, Devon. Part 1—Barytes
13 Investigation of stratiform sulphide mineralisation at McPhun's Cairn, Argyllshire
14 Mineral investigations at Woodhall and Longlands in north Cumbria
15 Investigation of stratiform sulphide mineralisation at Meall Mor, South Knapdale, Argyll
16 Report on geophysical and geological surveys at Blackmount, Argyllshire
17 Lead, zinc and copper mineralisation in basal Carboniferous rocks at Westwater, south Scotland
18 A mineral reconnaissance survey of the Doon–Glenkens area, south-west Scotland
19 A reconnaissance geochemical drainage survey of the Criffel–Dalbeattie granodiorite complex and its environs
20 Geophysical field techniques for mineral exploration
21 A geochemical drainage survey of the Fleet granitic complex and its environs
22 Geochemical and geophysical investigations north-west of Llanrwst, North Wales
23 Disseminated sulphide mineralisation at Garbh Achadh, Argyllshire, Scotland
24 Geophysical investigations along parts of the Dent and Augill Faults
25 Mineral investigations near Bodmin, Cornwall. Part 1-Airborne and ground geophysical surveys
26 Stratabound barium-zinc mineralisation in Dalradian schist near Aberfeldy, Scotland: Preliminary report
27 Airborne geophysical survey of part of Anglesey, North Wales
28 A mineral reconnaissance survey of the Abington–Biggar–Moffat area, south-central Scotland

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CONTENTS

ILLUSTRATIONS

TABLES

SUMMARY

Panned heavy mineral concentrates, mostly obtained from stream sediments, were collected from 195 sites in the Abington-Biggar-Moffat area. The project area, which lies immediately east of the formerly important mining district of Wanlockhead-Leadhills, covers approximately 500 km^2 of the north-central sector of the Southern Uplands. It incorporates the Hart Fell range of hills, the headwaters catchment for the River Tweed and River Annan, some tributaries of the River Clyde, and, to the east, the Culter Water, Talla Reservoir, Megget Water and the head of the Ettrick valley.

Numerous new occurrences of lead, zinc, copper and barium minerals were found and nine areas are recommended for further investigation. Minor amounts of baryte and traces of cupriferous pyrite were identified in the basal breccia of the New Red Sandstone deposits in Annandale. The mercury mineral, cinnabar, was identified for the first time in Scotland, occurring in trace amounts in stream sediment concentrates in the Coulter area close to the Southern Upland Fault. Chromiferous spinel was recognised as a major constituent in the majority of panned samples. It is present as a detrital mineral in greywackes but must have been originally derived from ultrabasic rocks. An unusual mineral widely dispersed in trace amounts is corundum (including some gem-quality sapphire). Historical references (Lauder Lindsay, 1868-9, 1871) to a wide distribution for particle gold were confirmed and many new occurrences found. A local provenance for the element is now considered certain. Some placer concentration of gold and chromiferous spinel is likely in the alluvium of the valleys of the River Tweed and the Megget Water.

Six greywacke formations, previously defined in other parts of the Southern Uplands, were mapped in the project area, each distinguished by a characteristic lithology and heavy mineral content.

INTRODUCTION

Aims and objectives

This investigation was carried out from 1976 to mid-1977 by staff of the South Lowlands Unit, Institute of Geological Sciences, as part of the Mineral Reconnaissance Programme being undertaken on behalf of the Department of Industry. The aims were to select, examine and report on an area in the Southern Uplands considered to offer potential for the discovery of economic mineralisation.

The Abington-Biggar-Moffat region (Fig. 1), which lies immediately east of the formerly important base-metal mining district of Wanlockhead-Leadhills, was chosen for investigation to test for evidence of extensions of the mining field mineralisation. The area also contains a portion of the Annandale New Red Sandstone outlier, which was considered to be a potential host for strata-bound mineralisation.

Gold is known to have been won from the Leadhills area and from some northern tributaries of the Megget Water in the 16th century (Lauder Lindsay, 1868-9, 1871). Panning of stream catchments throughout the project area was expected to show this element to have a wider distribution and to be more common than had hitherto been known.

Physical description of the project area

The area lies on sheets 72, 73, 78 and 79 of the Ordnance Survey 1:50 000 map series and on sheet 16 of the one-inch to one-mile (1:63 360) geological map of Scotland.

The topography has the form of a deeply dissected plateau, with rounded, grassy hills up to 800 m above sea level (Hart Fell 808 m) separated by steep-sided valleys. A few major valleys such as Moffatdale and Tweeddale follow the NE–SW regional strike of the rocks but the courses of the majority of streams apparently bear little relation to the local geology.

The three principal river systems of the area are the Clyde, Tweed and Annan, draining the northwestern, northeastern, and southern sectors respectively. The main drainage pattern is shown in Fig. 2 (see back pocket).

Coniferous plantations cover large tracts of ground, although most are still young enough to allow easy access. Numerous reservoirs have been sited in the area, taking advantage of the relatively high rainfall and the steep-sided valleys which facilitate the construction of dams.

Geological description of the area

The geology of the Southern Uplands is described in some detail by Peach and Horne (1899), and summarised in the South of Scotland regional guide (Greig, 1971).

The project area (Fig. 1) includes parts of the Northern and Central Belts (Peach and Horne, 1899) and is composed mainly of sediments of Ordovician and Silurian age comprising thick sequences of near-vertical greywackes, siltstones and shales with occasional subsidiary belts of black shales, cherts and volcanic rocks (Fig. 3). Some of the black shale belts have been shown (e.g. in the Moffat area - Toghill, 1970) to be associated with major strike faults which have a considerable influence on the structure of the area.

Breccias and sandstones of New Red Sandstone age occur as outliers within the valley of the River Annan, generally occupying the lower ground and presenting an obvious contrast to the more rugged terrain of the Lower Palaeozoic rocks.

No major igneous intrusions occur in the area although several large NW–SE trending dolerite dykes of Tertiary age can be traced between Moffat and Abington.

FIELD SURVEYS

Field investigations

The principal technique used in the present survey to trace the distribution of economic minerals - base metals and gold in particular - was the collection of heavy mineral pan concentrates from stream catchments. The presence of glacial deposits throughout the region raises the problem that a proportion of the panned mineral assemblage at any site may be derived from areas outwith the stream catchment. This factor was minimised by the selection of sampling sites, wherever possible, far up on stream courses in the various drainage systems as glacial till is usually thickest in the lower courses of streams and thins out against higher ground. On this principle many streams were panned within a kilometre of their source thereby reducing, in follow-up operations, the area of search for the provenance of any encouraging mineral indications found.

Traversing and sampling were carried out within an area of approximately 500 km^2 incorporating the Hart Fell range of hills, the headwaters catchment for the River Tweed and River Annan, Midlock Water, Camps Water and eastward to Culter Water, Talla Reservoir,

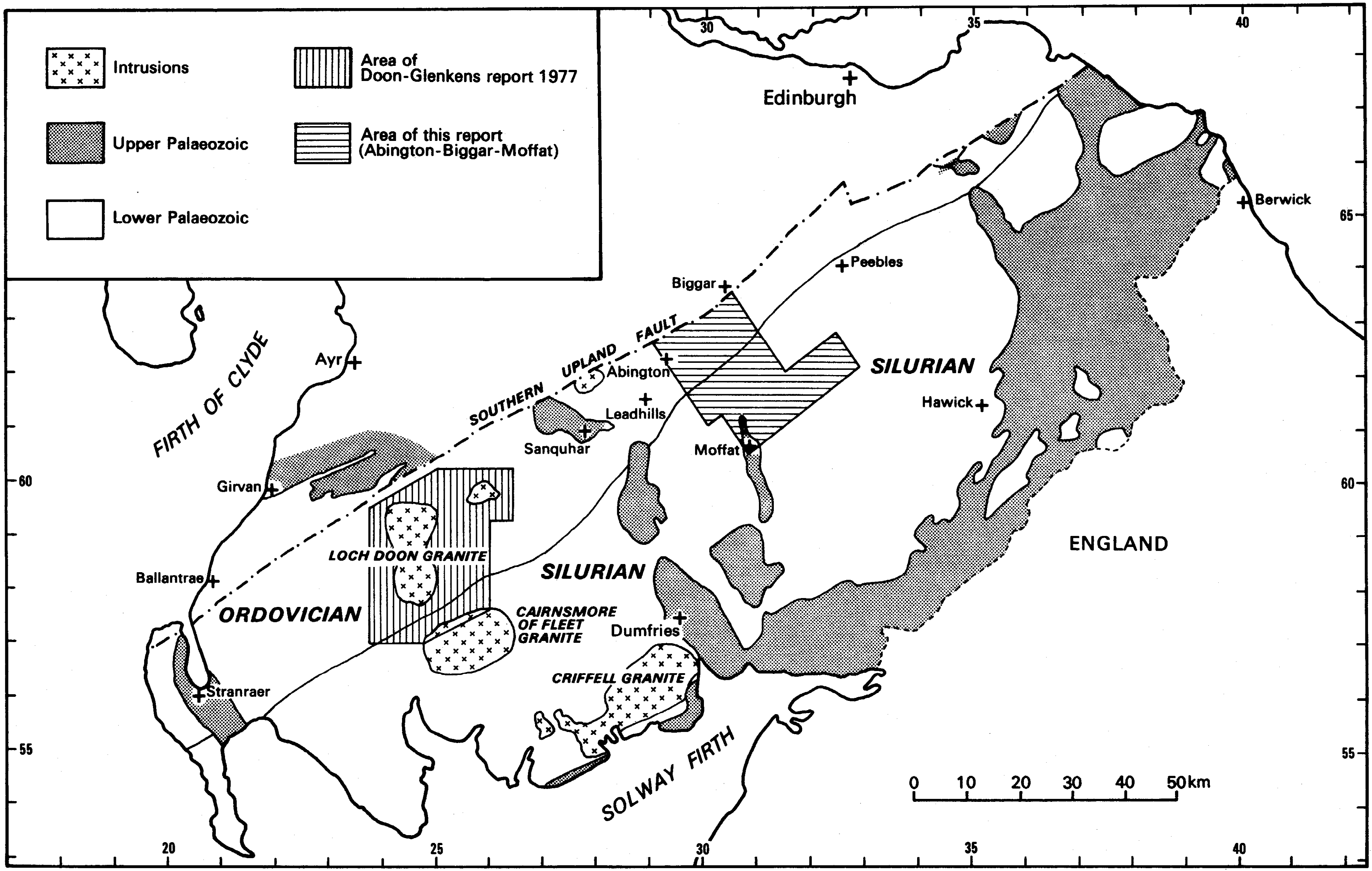

Fig.1 Outline geology of the south of Scotland

Megget Water and the head of Ettrick valley.

Superficial deposits - alluvium, eluvium, glacial drift and peat - conceal bedrock over large tracts of the project area. For the most part outcrop inspection and sediment sample collection were confined to stream courses in which earlier geological survey work showed frequent bedrock exposures.

A total of 195 heavy mineral concentrates were collected, duplicate samples for geochemical analyses being taken at 155 sites. Of the total, 182 represented stream samples; 11 were from crushed sandstone and breccia specimens from the New Red Sandstone deposits in Annandale; one was from eluvium on the flanks of Culter Craigs (reported trial for lead), and one was from a small accumulation of mineralised mine debris at a copper trial on the Auchencat Burn. The distribution of sampling sites is shown in Fig. 2.

The pan employed in the present programme is a Malayan style 'dulang', a circular dish of wood or plastic 50 cm in diameter and 10 cm deep. The procedure at each site is to extract, by sieving, the -5 mm size fraction from poorly sorted alluvium (preferably close to bedrock) in the bed of the stream. The oversize is examined for larger mineral and/or mineralised rock fragments before discard. The pan can accommodate workable amounts of sediment up to 8 kg, this weight being obtained from approximately 20 kg of alluvium. The light mineral fraction (i.e. quartz, feldspar, mica etc), which constitutes the bulk of the sieved sample, is progressively removed by the panning action until the sample is reduced to a level in which a concentration of heavy minerals can be clearly seen (usually between 25 and 50 g). Further concentration in the field is inadvisable, as it may entail some loss of heavy minerals, and the remaining light mineral components are therefore removed by heavy liquid separation (tetrabromoethane or bromoform) in the laboratory. Duplicate pan samples for geochemical analyses are reduced to approximately 50 g.

No major mineralised structures were located by outcrop inspection. Thin quartz and quartz-carbonate veins are common and usually contain minor amounts of hematite and/or pyrite. Economic minerals such as baryte, sphalerite, galena, cerussite and chalcopyrite were recorded occasionally in such veins but only in trace amounts. The few, more encouraging, examples were:-

(1) baryte-galena vein 'float' in a tributary of Swine Gill (NT 0003 2371) in the Camps Water catchment draining from Craig Hill (NT 0050 2323).

(11) baryte vein in Frazer Sike (NT 1739 1471), a tributary of the Polmoody Burn.

(111) baryte, tennantite, malachite, and chalcopyrite in a vein breccia in Red Scar (NT 1829 1818), a tributary of Garlie Cleuch in the Megget Water catchment.

Concentrations of malachite with minor chalcopyrite were recorded in a dark shale band on the south bank of the Auchencat Burn at an old mine trial (NT 0897 1104) and traces of malachite were commonly observed in the broader belt of shales well exposed in the Spa Well Burn branch and also in the neighbouring Bill's Cleuch tributary of the Lochan Burn. Lower Hartfell shale grab samples (3) from the 'Score' gully section (NT 0970 1170) above Hartfell Spa assayed (XRF) 37, 42 and 54 ppm Cu respectively. Copper and lead were the only two elements out of the group Pb, Zn, Cu, Ba, Mn and Ni showing anomalous levels in these samples. Seventeen shale grab samples were collected at Dob's Linn (NT 1961 1583) for XRF analyses. Anomalous concentrations of Cu, Ni and Pb were determined in all samples of Upper Hartfell, Lower and Upper Birkhill shales. Anomalous zinc values were recorded in some Upper Hartfell and Upper Birkhill shales. The two Lower Hartfell Shale samples contained lesser element concentrations but values were similar to those recorded in the Hartfell 'Score' samples.

No important mineralisation was observed in the fine section provided by the Frigg gas pipeline trench but the excavations afforded an apportunity to study an almost continuous succession of greywackes and other sediments. To improve stratigraphic correlations with other areas, and to augment existing knowledge on the structural controls in the region, some mapping and sampling were carried out on traverses made along the trench and also on a line from Coulter to the Megget Water at the eastern limit of the project area. Both traverses were approximately normal to the regional Caledonoid trend. The development of the concept that the greywackes in the area can be grouped into 'formations' with similar petrological characteristics involved the collection of 150 specimens on both traverses.

The New Red Sandstone deposits in the River Annan basin, north of Moffat, were examined for evidence of strata-bound mineralisation. Eleven samples, four from the basal breccia and seven from overlying sandstone beds, were collected from sections in the Tweeddale Burn, Stotfield Gill, Lochan Burn, Auchencat Burn and Mere Beck. The comparatively soft speciments were easily broken up on site and panned. Minor amounts of baryte and traces of cupriferous pyrite were identified in all heavy mineral concentrates obtained from the breccia samples but no evidence was found of disseminated mineralisation in concentrates derived from the sandstone samples.

Advances in geological information

The techniques developed in the study of the greywackes in other parts of the Southern Uplands (including the Doon-Glenkens area: Dawson et al., 1977) were utilised during the collection and microscopic examination of 150 samples of greywacke from the Frigg gas pipeline trenches and from a traverse line between Coulter and the Megget Water.

The results of this work are summarised in Fig. 4 and essentially confirm and extend the recognition of petrographic formations (see Table 1 for details) which have been erected in the Ordovician along strike to the south-west (Floyd, 1975) and in the Silurian to the north-east (Walton, 1955).

It is proposed that the northern boundary of the Silurian in this area should more appropriately be taken at the northern margin of the 'Pyroxenous Group' (as defined petrographically) than at the northern margin of the 'Queensberry Grits', which was admitted by Peach and Horne (1899) to be a less than satisfactory line. In fact the two lines are more or less coincident for much of their length, any significant disagreement being confined to the area south of Crawford where the formerly mapped Ordovician-Silurian boundary lies within the fairly homogeneous Shinnel Formation (Fig. 4) with no obvious petrographic break at that point.

The bedding throughout the area is subvertical and for the most part follows the NE–SW regional strike. The boundaries between formations are probably faulted, though field evidence for this is scanty except along the southern boundary to the prominent shale belt.

DISTRIBUTION OF ECONOMIC ELEMENTS AND MINERALS

Introduction

The elements and minerals of each element are reported on in this section and are discussed in the following order:

Gold	Nickel
Lead	Manganese
Zinc	Antimony
Copper	Arsenic
Barium	Molybdenum
Iron	Tin
Titanium	Mercury
Chromium	Uranium-Thorium

The potential of both element and mineral concentrations are considered and any pertinent associations with other elements and/or minerals are noted.

Geochemical analyses

Duplicate pan samples (155) were analysed by XRF for Pb, Zn, Cu, Ba, Fe, Ni, Ti, Mn, Sb, Sn, As, Ce and Ca and by emission spectrography for Mo and Cr. The results are listed in Appendix II. Attention is drawn to possible analytical inaccuracies in the emission spectrography results caused by the difficulty in obtaining sufficient homogeneity in the sample to ensure that the small subsample used for analysis is representative - this applies particularly to chromium where the element is mainly contained in detrital spinel. It must be emphasised that background element values quoted in the text are only approximate and have been arrived at from a consideration of experience gained in similar environments elsewhere in the Southern Uplands as well as from results recorded in the project area.

Numerous element anomalies were detected by the geochemical analytical work and the good measure of agreement between these results with minerals identified in the heavy mineral concentrates provides a sound basis for consideration of prospects warranting follow-up investigation.

Distribution of elements and minerals

The results of pan concentrate examination and analyses of duplicate samples revealed a wider distribution of economic minerals and a much higher incidence of anomalous element and/or mineral concentrations than appeared likely from outcrop inspection. The texts for gold, lead, zinc, copper and barium have accompanying maps which show the distribution of minerals (both primary and secondary) and in the cases of lead, zinc, copper and barium any anomalous element concentrations. These maps are compiled from the data given in Appendix I (stream concentrates) and Appendix II (geochemical analyses). As the proportion of any element or mineral recorded in samples is influenced by so many variable and unquantifiable factors no attempt is made on these distribution maps to grade the concentration levels of minerals and elements at sites. Such values at this stage of investigation of the area give little guidance as to the number, size, nature or distance of any contributing source of mineralisation.

The principal detrital heavy mineral species found in pan concentrates and considered to be derived mainly from the Lower Palaeozoic sedimentary succession are chrome spinel, garnet, tourmaline, rutile, anatase, zircon and members of the chlorite, serpentine and epidote groups of minerals. Detrital pyrite (generally in composite rock fragments) and clinopyroxene are locally important. Minor or trace occurrences include magnetite (+chromiferous magnetite), ilmenite, hydromica, amphibole (mostly metamorphic mineral species), brookite, apatite (+fluorapatite) and corundum. Corundum, including the gem variety sapphire, merits particular mention in the following text.

Distribution of gold (Fig. 5)

Gold was discovered in the Leadhills-Wanlockhead district at the beginning of the 16th century. Mines were opened up by James IV and continued in operation during the reign of James V (Lauder Lindsay, 1868–9). Gold to the value of that time of £300,000 is reported to have been won from both vein and placer deposits. In the project area, placer gold was worked in the Glengaber Burn, a north tributary of the Megget Water (Lauder Lindsay, 1871). Though systematic

Table 1. Petrological characteristics of the greywacke formations

Formation	Major Characteristics in Thin Section	Detrital Heavy Minerals
Marchburn	Quartz averages 15% of rock. Mainly fragments of volcanic rocks present. Ferromagnesian minerals sometimes present	Chrome spinel very common Garnet common Tourmaline very common Rutile very common Zircon common Apatite common
Afton	Quartz averages 40% of rock. Metamorphic rock fragments sometimes important. Virtually no ferromagnesian minerals.	Chrome spinel common Garnet common with pink metamorphic variety Tourmaline common Rutile common Zircon very common
Scar	Quartz averages 10% of rock Volcanic rock fragments very important. Pyroxene usually common.	Chrome spinel common Garnet very common Tourmaline not common Rutile very common Zircon common
Shinnel	Quartz averages 38% of rock. Ferromagnesian minerals usually absent.	Chrome spinel common Garnet not common Tourmaline not common Rutile not common Brookite locally common Zircon common
Pyroxenous	Quartz averages 22% of rock. Volcanic rock fragments common. Pyroxene common.	Chrome spinel very common Garnet common Tourmaline common Rutile not common Zircon very common Corundum sometimes present
Intermediate	Quartz averages 39% of rock. Ferromagnesian minerals usually absent.	Chrome spinel very common Garnet very common Tourmaline common Rutile not common Zircon very common Corundum sometimes present

mining virtually ceased after the 16th century the search by prospectors throughout the Southern Uplands has continued down to the present day, with interest being mainly centred on the Leadhills-Wanlockhead district and the project area. One objective of the present investigation was to check the veracity of several claims that the panning of most streams making up the head-water catchments of the River Clyde, the River Annan, the River Tweed and the Moffat Water in the Hart Fell range of hills would yield gold.

Fine particle gold was located in 48 out of a total of 182 streams panned. Though many occurrences could be significant, in only five samples were more than two grains observed. The percentage of angular, granular grains exceeds that of flakes, a feature favouring local provenance. The majority have a 0.1 mm to 1.0 mm size range with very few examples showing a dimension over 3 mm.

As one or two pannings at any site are not adequate to establish the presence or absence of particle gold in any catchment, it is likely that the occurrence of the element is more common than is proved by this investigation. Consideration of the results permits some generalisations as regards frequency of distribution. In the Ordovician system gold is most common in the area occupied by the youngest rocks, a succession characterised by pyritous, micaceous shales and siltstones (Lowther Shales) with subordinate greywacke units and volcanic rocks (Tweeddale Volcanics) forming only minor features. Next in importance is the broad, complex belt of steeply dipping, closely folded Glenkiln-Hartfell black shales with associated mudstones, sandy shales, spilites, cherts and subordinate intercalations of greywacke that extends from Abington to the Coulter Water. Finally the metal has been found in the few streams which drain the area immediately south of the Southern Upland Fault. Here the sequence - the oldest - comprises a very diverse lithological assemblage of variegated pebbly grits with a greywacke matrix, coarse to fine greywackes and variegated cherts, shales and mudstones (commonly tuffaceous). Gold is recorded in only two streams in the sector immediately south of the prominent shale belt in which greywacke sediments predominate (Scar Formation).

Llandovery rocks of the Silurian system occupy approximately two-thirds of the project area with the major part of the succession represented by greywackes of the Pyroxenous and Intermediate formations (incorporating the Queensberry Grits of the Gala Group). The succession is characterised by rather massive bedded, gritty greywackes with subordinate intercalations of flags and shales. Coarser pebbly and conglomerate beds are quite common and locally important as in the area which extends from Pin Stane hill in the upper reaches of Clydes Burn north-eastward into the headwaters catchment of the River Tweed. By contrast with the Ordovician, gold incidence is fairly uniformly widespread and shows no preferred association with shale dominant sequences (e.g. Hartfell and Birkhill shale belts). The proportion of streams yielding gold in pan concentrate is approximately 30%.

(1) Distribution in Ordovician rocks: In the Wandel-Lamington district gold is present in both the Wandel and Lamington Burn catchments. Placer concentrations are likely to occur but would be difficult to assess due to the presence of an extensive cover of glacial drift over the area. An encouraging return was obtained in the pan sample from Berries Burn (NS 9531 2208), 1 km north of Crawford, on the south side of the prominent shale belt. In the short section to the stream source above the sampling point there is reasonable opportunity for finding in situ mineralisation, possibly in quartz veins considering the coarser form of some of the gold particles. Gold occurs in many streams which drain the belt, mainly occupied by the Lowther Shales, which extends from Rodger Law (NS 98 18), ENE from Elvanfoot, north-eastward for approximately 8 km to Hillshaw Head (NT 04 24). It was located in Glespin Burn (NS 9763 1947), Cakelaw Burn (NS 9731 1890), Reddie Grain (NS 9946 1940) and Nether Moss Cleuch (NS 9767 1661), which drain from the Rodger Law ridge; in Spout Sike (NS 9927 2066) and Whelphill Hope (NT 0082 2017) on Whelphill Farm; in Carle Gill (NT 0062 2174) and Midge Gill (NT 0119 2136) flowing into the south-west side of Camps Reservoir; and in Grains Burn (NT 0372 2440) near the old county boundary.

(2) Distribution in Silurian rocks: Above Tweedsmuir gold occurs in the River Tweed (NT 0533 1629) and in the following tributaries:-

- (i) Cor Water (NT 0819 1402), in the branch of the Whitehope Burn.
- (ii) Glencraigie Burn (NT 0769 1628).
- (iii) Hawkshaw Burn (NT 0830 1846; 0795 1984; 0808 2005) and the branch of the White Cleuch Burn (NT 0791 1864).
- (iv) Chapel Burn (NT 0858 1970), Carterhope Burn (NT 0995 1791) and Fern Hope Burn (NT 1137 1828) in the Fruid Water catchment.
- (v) Menzion Burn (NT 1028 2046).

Coarser gold present in the Hawkshaw Burn samples might indicate the presence of auriferous quartz veins. The valleys of the southern tributaries of the River Tweed, the Hawkshaw and Chapel Burns, are considered to offer the best prospects for placer concentration.

- (vi) Smid Hope Burn (NT 0464 1552; 0478 1734(?)).
- (vii) Badlieu Burn (NT 0344 1813), a branch of Shilling Cleuch.
- (viii) Glenbreck Burn (NT 0480 2230).
- (ix) Glenwhappen Burn (NT 0578 2270; 0645 2196).
- (x) Hallow Burn (NT 0720 2278).

As gold from all these streams will find its way into the River Tweed, placer concentrations can be expected in the Tweed valley alluvium below Glenbreck.

More detailed pan sampling is required in the Megget Water catchment to establish both the distribution and provenance of the metal in this important area. In this investigation, streams selected were those which crossed recognised shale belts. Gold was not found in Garlie's Cleuch below crops of Lower Birkhill Shales but is present in the small Red Scar tributary (NT 1829 1818; 1828 1821) where pebbly greywackes, containing an appreciable amount of dark pyritous shale fragments, occur intercalated with Birkhill Shales. A prominent belt of shales extends from the Shielhope Burn, by Syart Law to Craigierig Burn. Gold was not recovered in either of the samples from the Shielhope Burn or its tributary Shielhope Sike below the shale belt but a single panning above the shale belt in the Craigierig Burn (NT 2041 2349) north of Hunter Hill yielded 24 particles, some coarse. In this section of the stream, as at Red Scar, the shale belt contains and is overlain by beds of gritty to pebbly greywacke in which dark, pyritous shale fragments are a major constituent. Gold was not recovered in the nearby tributary (NT 2059 2371) which exposes a succession of blue-grey, thin bedded, fine grained greywackes, siltstones and shales. Boar Cleuch, where a fine section of shales (mainly Birkhill Shales) is succeeded by a considerable thickness of grey flaggy shales, also yielded no gold. However, towards the foot of the main stream, the Glengaber Burn, an almost continuous stream section shows a narrow band of dark pyritous shale overlain by massive bedded, quartz veined, coarse gritty greywackes. Much gold, some coarse, has been won from narrow strips of alluvium flanking the burn in this area for over 300 years. Though the placer resources are virtually exhausted here there might still be prospects for proving a viable stockwork of auriferous quartz veins and/or an enriched zone in the strata flanking the valley. Quartz veined gritty greywackes are exposed in the dry course of Bught Slack west of Hunter Hill (R. Gillanders-personal communication). Further west, gold, some coarse, was found in the Cromalt Burn above the confluence of the Stottin Cleuch tributary (Dr F. May-personal communication).

In the Annandale-Hart Fell region gold is present in Whitehope Burn (NT 0910 1252), Auchencat Burn (NT 0981 1118) and Mossgrain Burn (NT 1135 0900). In Moffatdale it was found in Frazer Sike (NT 1739 1471), a branch of the Polmoody Burn.

In consideration of the now proven wide distribution of gold in the Southern Uplands and the recognised frequent occurrence in association with silicate enriched and argillaceous-carbonaceous deposits (sedimentary facies well represented in the Lower Palaeozoic succession) there are reasonable grounds (Buryak, 1963; Buryak et al., 1966) for believing the primary provenance of most, if not all, gold in this region to be in the host sediments. Mobilisation, dispersal and redeposition of the metal has been effected by dynamic metamorphism and hydrothermal solutions. The presence or absence of particle gold throughout the region is considered to be controlled by local variations in the degree of metamorphism, on the availability and composition of hydrothermal fluids to effect solution and transport and, above all, on the auriferous tenor of the local sediments. One point emerges from the long history of prospecting in the Southern Uplands - the sparse incidence of readily identifiable auriferous quartz veins. Further evidence that quartz veins are not likely to be a major source of the metal is provided by the general fine size range (0.1 to 1.0 mm) of particles, a characteristic feature of gold-sulphide mineralisation. In this association gold is irregularly dispersed in veinlets and as impregnations along bedding planes, joints, cleavage fissures and micro-breccia structures in folded sedimentary rocks in zones of strong structural deformation. Gold tenor is considerably influenced by the primary rock composition. In the Ordovician, on distribution considerations, the richest rocks would appear to occur in belts dominated by pyritous, argillaceous-carbonaceous sediments. By contrast, the more widespread distribution of the metal in Silurian rocks is less obviously related to shale sequences which generally form only minor features in a greywacke-dominant succession. The apparent general increase in the gold tenor of the Silurian rocks in this area is attributed to the presence of pyritous shale-siltstone and pyritous phyllite-mica schist debris as a major component in many greywacke units.

What proportion of the primary metal content of the Lower Palaeozoic rocks has been mobilised and dispersed into 'enriched' zones and vein stockworks remains an open question. The tenor in greywackes, recognising their very variable composition, is, for the most part, considered to be low.

Distribution of lead mineralisation (Fig. 6)

Though the Leadhills-Wanlockhead district is only a few kilometres to the west, there is no record of lead mining in the project area. No evidence was found (590) of a reported trial on the south side of Culter Craigs (NT 0307 330).

Twenty-three new occurrences of lead minerals were identified from the examination of heavy mineral concentrate samples. Minerals recorded are galena (PbS), cerussite ($PbCO_3$), pyromorphite (PbCl) Pb_4 $(PO_4)_3$), and mimetite (PbCl) Pb_4 $(AsO_4)_3$). Over fifty element anomalies, assessed on a threshold level of around 30 ppm, were detected from XRF analyses of 155 duplicate pan concentrate samples. In only eight cases was there no supporting element anomaly where lead minerals had been recorded.

(1) <u>Distribution in Ordovician rocks</u>

(a) Sector proximate to the Southern Upland Fault:-
  - (i) Gair Gill (589), a tributary of the Culter Water: galena and chemical anomaly (69 ppm): other elements: Ba, Zn, Cu.
  - (ii) Woodend Burn and a small stream which flows northward through Hartside, both tributaries of the River Clyde draining from Devonshaw Hill (NS 9606 2865).
    Woodend Burn (588): chemical anomaly (346 ppm); other elements: Ba, Zn, Hg.
    Hartside stream (587): chemical anomaly (47 ppm); other elements: Ba, Hg.
  - (iii) Little Smagill (585): chemical anomaly (38 ppm); other elements: Ba.

(b) The prominent shale belt:-
  - (i) Raggengill Burn (484): chemical anomaly (246 ppm) but fertiliser (basic slag glass) identified in sample and may be a contributory factor.
  - (ii) Lead Burn (487): cerussite and chemical anomaly (2235 ppm) but fertiliser (basic slag glass) identified in sample may contribute to the high chemical anomaly.
  - (iii) Hawkwood Burn (490): pyromorphite, cerussite and chemical anomaly (135 ppm); other elements: Ba.
  - (iv) Deer Gill (493): pyromorphite and chemical anomaly (55 ppm); other elements: Ba, Zn, Cu.
  - (v) Yearn Cleuch (560): galena; other elements: Ba, Cu, Zn.
  - (vi) Stotlea Gutter (563): pyromorphite and mimetite (XRD): other

elements: Cu.

(vii) Barrow Cleuch (564): pyromorphite, mimetite (XRD) and chemical anomaly (31 ppm); other elements: Zn, Cu, Ba.

(c) Area immediately south from the prominent shale belt:-

(i) Normangill Burn (446): cerussite (XRD); other elements: Cu.

(ii) Reed Gill (465): chemical anomaly (42 ppm); other elements: Zn, Ba.

(iii) Swine Gill (480): galena; other elements: Ba, Zn.

(iv) Base metal mineralisation is indicated in all four of the six northern tributaries of Grains Burn from which pan samples were taken.
Linn Burn (554): galena and chemical anomaly (61 ppm); other elements: Zn, Cu.
Nightfield Burn (555): galena (XRD) and chemical anomaly (34 ppm); other elements: Zn, Cu, Ba.
Three Grains (556): galena and chemical anomaly (52 ppm); other elements: Ba, Zn, Cu.

(v) Mineralisation is indicated in several streams which flow into Culter Reservoir.
Ram Gill (568): chemical anomaly (30 ppm); other elements: Cu, Zn, Ba.
Bramble Sike (573): chemical anomaly (37 ppm); other elements: Ba.
Breeks Burn (577): chemical anomaly (55 ppm); other elements: Ba.
Knock Burn (578): chemical anomaly (41 ppm); other elements: Ba.

(d) Area proximate to the Ordovician boundary:-

(i) Lang Cleuch (481): pyromorphite and chemical anomaly (317 ppm) but phosphate fertiliser, identified in sample, may contribute to the chemical anomaly. Other elements: Ba.

(ii) Nether Moss Cleuch (482): chemical anomaly (30 ppm); other elements: Ba, Zn.

(iii) Glespin Burn (483): pyromorphite, cerussite (XRD), mimetite (XRD) and chemical anomaly (61 ppm); other elements: Ba, Zn, Cu.

(iv) Mineralisation is indicated in Whelphill Hope and its tributary Deer Gill.
Whelphill Hope (472): chemical anomaly (32 ppm); other elements: Cu.
Deer Gill (473): pyromorphite and chemical anomaly (31 ppm); other elements: Ba, Zn, Cu.

(v) Mineralisation is indicated in several streams which contribute to the catchment for Camps Reservoir.
Carle Gill (455): pyromorphite; other elements: Ba, Cu, Zn.
Midge Gill (456): chemical anomaly (135 ppm); other elements: Zn, Cu.
Hilshie Burn (449): chemical anomaly (56 ppm); other elements: Ba, Zn, Cu.
Thorter Cleuch (452): chemical anomaly (37 ppm); other elements: Ba, Zn, Cu.
Martin Cleuch (457): chemical anomaly (34 ppm); other elements: Cu.

(vi) Traces of mineralisation were identified in Holms Burn and Hare Burn, tributaries of the Holms Water.
Holms Burn (594): chemical anomaly (33 ppm); other elements: Cu, Ba.
Hare Burn (595): chemical anomaly (28 ppm); other elements: Cu, Zn, Ba.

(vii) Mineralisation is indicated in the Kingledoors Burn and its tributaries Scabmenow Burn and Glenwhappen Burn.
Kingledoors Burn (600): chemical anomaly (79 ppm); other elements: Cu, Ba, Zn.
Scabmenow Burn (599): chemical anomaly (35 ppm); other elements: Zn, Ba.
Glenwhappen Burn (601): chemical anomaly (30 ppm); other elements: Cu, Ba.

(2) <u>Distribution in Silurian rocks</u>

(e) Sector proximate to the Silurian boundary and incorporating the headwaters catchment of the River Tweed.

(i) Mineralisation is indicated in the East Water catchment.
Thorter Gutter (466): pyromorphite (XRD); other elements: Ba.
Martin Cleuch (467): chemical anomaly (29 ppm); other elements: Ba, Zn, Cu.
Ramsey Gill (469): chemical anomaly (35 ppm); other elements: Cu.

(ii) Crinshie Burn (454): chemical anomaly (29 ppm); other elements: Ba.

(iii) Mineralisation is indicated in several tributaries of the River Tweed.
Shilling Cleuch (515): pyromorphite (XRD) and cerussite (XRD).
Old Burn tributary (529): chemical anomaly (265 ppm); other elements: Ba, Zn, Cu.
Peddirie Burn (532): cerussite (XRD) -no geochemical sample; other elements: Ba, Cu.
Glenbreck Burn (536): chemical anomaly (30 ppm); other elements: Ba, Cu.

Old Burn (534): chemical anomaly (30 ppm); other elements: Ba, Cu, Zn.
Glenwhappen Burn (537, 538): chemical anomalies (42 and 45 ppm) at both sample sites; other elements: Ba, Zn, Cu.
Hallow Burn (539): chemical anomaly (34 ppm).
Rigs Burn (501): chemical anomaly (29 ppm); fertiliser (basic slag glass) identified in sample and may contribute to chemical anomaly.
Glencraigie Burn (512): chemical anomaly (63 ppm).
Carterhope Burn (498): galena (XRD); other elements: Ba, Zn, Cu.
Logan Burn (596): chemical anomaly (94 ppm); other elements: Ba.

(iv) Mineralisation is indicated in the Codleteth Burn and Talla Cleuch which flow into the Talla Reservoir.
Codleteth Burn (437): galena (XRD) and pyromorphite - no geochemical sample: other elements: Ba, Cu, Zn.
Talla Cleuch (438): pyromorphite - no geochemical sample: other elements: Cu, Ba, Zn.

(f) Southern sector of project area incorporating parts of Annandale, Moffatdale, Ettrick valley and Megget Water.

(i) In Annandale mineralisation is indicated in the following streams:-
Bill's Cleuch (504): chemical anomaly (52 ppm); other elements: Cu
Spa Well Burn (525): chemical anomaly (29 ppm); other elements: Cu, Ba.
Birnock Water (541): chemical anomaly (49 ppm); other elements: Ba, Zn, Cu.

(ii) In Moffatdale mineralisation is indicated in the following streams:-
Hang Burn (519): chemical anomaly (282 ppm); other elements: Ba, Zn, Cu.
Craigie Burn (507): chemical anomaly (35 ppm); other elements: Ba, Zn, Cu.

(iii) In the Ettrick valley mineral traces were found in Range Cleuch.
Range Cleuch (407): pyromorphite - no geochemical sample; other elements: Ba, Zn, Cu.

Qualitative XRF analyses of thirteen samples of Glenkiln, Hartfell and Birkhill Shales collected from Dob's Linn and Hartfell 'Score' gave indications of Pb values in excess of 30 ppm in all samples.

Distribution of zinc mineralisation (Fig. 7)

Forty-seven new occurences of the ore mineral sphalerite (ZnS) were established by identification of the mineral in pan concentrates and fifty-six zinc anomalies, assessed on a threshold level of around 130 ppm, were detected from XRF analyses of 155 duplicate pan samples. In only nine cases where sphalerite has been identified was no corresponding element anomaly recorded in the duplicate sample. The presence of sphalerite in twice the number of samples in which lead minerals have been found can be attributed to the superior detrital properties of the mineral. Distribution is widespread and shows no marked concentration in any sector of the project area. To emphasise this feature, and recognising the common association of zinc, lead and barium minerals, it is considered useful to include in this section many localities listed in the previous section.

(1) Distribution in Ordovician rocks

(a) Sector proximate to the Southern Upland Fault:-

(i) Gair Gill (589): significant amounts of sphalerite with chemical anomaly (425 ppm); other elements: Ba, Pb, Cu.

(ii) Hartside Burn (586): sphalerite; other elements: Ba.

(iii) Woodend Burn (588): significant amounts of sphalerite with chemical anomaly (175 ppm); other elements: Ba, Pb, Hg.

(b) The prominent shale belt:-

(i) Berries Burn (444): sphalerite.

(ii) Mineralisation is indicated in several tributaries of the Wandel Burn.
Ragged Gill (488): chemical anomaly (133 ppm); other elements: Ba, Cu.
Rough Grain (492): sphalerite and chemical anomaly (234 ppm); other elements: Ba, Cu.
Deer Gill (493): sphalerite and chemical anomaly (153 ppm); other elements: Ba, Pb, Cu.
Rein Gill (489): significant amounts of sphalerite; other elements: Ba, Cu.

(iii) Horse Grain (559): sphalerite and chemical anomaly (132 ppm); other elements: Ba, Cu.

(iv) Yearn Cleuch (560): chemical anomaly (162 ppm); other elements: Ba, Cu, Pb.

(v) Big Smagill (561): sphalerite and chemical anomaly (158 ppm); other elements: Cu.

(vi) Mineralisation is indicated in Duncan Gill and its tributary The Grip.
Duncan Gill (557): sphalerite; other elements: Ba, Cu.
The Grip (558): sphalerite - no geochemical sample; other elements: Ba.

(vii) Barrow Cleuch (564): sphalerite and chemical anomaly (147 ppm); other elements: Cu, Ba, Pb.

(c) Area immediately south from the prominent shale belt:-
  (i) Mineralisation is indicated in several tributaries of the Camps Water which flow into the river below Camps Reservoir.
  Earns Gill (464): chemical anomaly (143 ppm); other elements: Ba.
  Reed Gill (465): chemical anomaly (190 ppm); other elements: Pb, Ba.
  Swine Gill (480), tributary of Cowhill Burn: chemical anomaly (187 ppm); other elements: Ba, Pb.
  (ii) Mineralisation is indicated in all four of the six northern tributaries of Grains Burn from which pan samples were taken.
  Howe Cleuch (479): sphalerite (XRD); other elements: Ba, Cu.
  Linn Burn (554): sphalerite (XRD) and chemical anomaly (204 ppm); other elements: Pb, Cu.
  Nightfield Burn (555): sphalerite and chemical anomaly (174 ppm); other elements: Pb, Cu, Ba.
  Three Grains (556): sphalerite and chemical anomaly (182 ppm); other elements: Ba, Pb, Cu.
  (iii) Ram Gill (568): sphalerite and chemical anomaly (137 ppm); other elements: Cu, Pb, Ba.

(d) Area proximate to the Ordovician boundary:-
  (i) Nether Moss Cleuch (482): chemical anomaly (127 ppm); other elements: Ba, Pb.
  (ii) Glespin Burn (483): sphalerite (XRD) and chemical anomaly (143 ppm); other elements: Ba, Pb, Cu.
  (iii) Cakelaw Burn (476): chemical anomaly (140 ppm); other elements: Ba, Cu.
  (iv) Shalf Grain (470), tributary of the Midlock Water: chemical anomaly (130 ppm); other elements: Ba, Cu.
  (v) Mineralisation is indicated in Spout Sike and Deer Gill, both tributaries of Whelphill Hope.
  Deer Gill (473): sphalerite and chemical anomaly (191 ppm); other elements: Ba, Pb, Cu.
  Spout Sike (475): sphalerite (XRD) and chemical anomaly (135 ppm).
  (vi) Mineralisation is indicated in several streams in the catchment for Camps Reservoir.
  Risingclaw Burn (448): sphalerite (XRD); other elements: Ba, Cu.
  Carle Gill (455): chemical anomaly (131 ppm); other elements: Ba, Cu, Pb.
  Midge Gill (456): chemical anomaly (197 ppm); other elements: Pb, Cu.
  Hilshie Burn (449): chemical anomaly (165 ppm); other elements: Ba, Pb, Cu.
  Thorter Cleugh (452): chemical anomaly (137 ppm); other elements: Ba, Pb, Cu.
  (vii) Grains Burn (553), source branch: sphalerite; other elements: Cu, Ba.
  (viii) Culter Water (572), source branch: sphalerite and chemical anomaly (125 ppm); other elements: Cu, Ba.
  (ix) Hare Burn (595), tributary of Holms Water: sphalerite and chemical anomaly (136 ppm); other elements: Cu, Ba, Pb.
  (x) Mineralisation is indicated in the Kingledoors Burn and its tributary Scabmenow Burn
  Kingledoors Burn (600): chemical anomaly (192 ppm); other elements: Cu, Ba, Pb.
  Scabmenow Burn (599): chemical anomaly (130 ppm); other elements: Ba, Pb, Cu.

(2) <u>Distribution in Silurian rocks</u>

(e) Sector proximate to the Silurian boundary including the headwaters catchment of the River Tweed.
  (i) Mineralisation is indicated in the Aller Cleuch and in Stock Cleuch, both tributaries of Clydes Burn.
  Aller Cleuch (459): chemical anomaly (133 ppm); other elements: Pb.
  Stock Cleuch (460): chemical anomaly (133 ppm); other elements: Ba.
  (ii) Martin Cleuch (467), in the East Water catchment: significant amounts of sphalerite (XRD) and chemical anomaly (192 ppm); other elements: Ba, Cu, Pb, As.
  (iii) Mineralisation is indicated in many of the streams in the River Tweed catchment.
  Smid Hope Burn tributary (495): chemical anomaly (177 ppm).
  Old Burn tributary (527): chemical anomaly (137 ppm); other elements: Ba, Cu.
  Old Burn tributary (529): sphalerite (XRD) and chemical anomaly (132 ppm); other elements: Ba, Pb, Cu.
  Glenwhappen Burn (537, 538): sphalerite and geochemical anomalies (170 and 153 ppm); other elements: Ba, Cu, Pb.
  Glenbreck Burn (536): chemical anomaly (125 ppm); other elements: Ba, Cu, Pb.
  Old Burn (534), tributary of Glenbreck Burn: chemical anomaly (146 ppm); other elements: Ba, Cu, Pb.
  River Tweed (510): sphalerite; other elements: Ba.
  Fingland Burn (542, 543): significant amounts of sphalerite and chemical anomaly (615 ppm) in 542; other elements: Ba, Cu.
  Fingland Burn tributary (543): sphalerite (XRD); other elements: Cu.

White Cleuch (544): chemical anomaly (146 ppm); other elements: Cu.
Carterhope Burn (498), tributary of Fruid Water: sphalerite (XRD); other elements: Ba, Cu, Pb.
Priesthope Burn (499), tributary of Fruid Water: sphalerite (XRD) and chemical anomaly (180 ppm); other elements: Ba, Cu, Pb.
Fern Hope Burn (548), tributary of Fruid Water: sphalerite; other elements: Cu.
Fruid Water tributary (549): chemical anomaly (137 ppm); other elements: Ba, Cu.

(iv) Mineralisation is indicated in the Codleteth Burn and Talla Cleuch in the catchment for the Talla Reservoir.
Codleteth Burn (437): sphalerite (XRD) - no geochemical sample: other elements: Ba, Cu, Pb.
Talla Cleuch (438): sphalerite - no geochemical sample; other elements: Ba, Cu, Pb.

(f) Southern sector of project area incorporating parts of Annandale, Moffatdale, Ettrick valley and Megget Water.

(i) Mineralisation is indicated in several streams in Annandale.
Tweedhope Burn (503): sphalerite (XRD) and chemical anomaly (188 ppm); other elements: Ba, Cu.
Whitehope Burn (505): chemical anomaly (351 ppm); other elements: Ba, Cu.
Auchencat Burn (526): sphalerite (XRD) and chemical anomaly (139 ppm); other elements: Ba, Cu.
Birnock Water (541): chemical anomaly (135 ppm); other elements: Ba, Cu, Pb, As.
Frenchland Burn (552): sphalerite and chemical anomaly (149 ppm); other elements: Cu, Ba.

(ii) Mineralisation is indicated in several streams in Moffatdale.
Craigie Burn (507): sphalerite and chemical anomaly (130 ppm); other elements: Ba, Cu, Pb.
Roundstonefoot Burn (520): sphalerite and chemical anomaly (188 ppm); other elements: Ba, Cu.
Black Hope Burn (422): sphalerite - no geochemical sample; other elements: Ba, Cu.
Carrifran Burn (423): sphalerite (XRD) - no geochemical sample; other elements: Ba, Cu.
Hang Burn (519): chemical anomaly (141 ppm); other elements: Pb, Ba, Cu.

(iii) In the Megget Water catchment indications of mineralisation were found in the following streams:-
Garlie Cleuch (411,412): sphalerite (XRD) - no geochemical sample; other elements: Ba, Cu.
Shielhope Burn (413): sphalerite (XRD) - no geochemical sample; other elements: Ba, Cu.
How Cleuch (419): sphalerite - no geochemical sample; other elements: Ba.

(iv) In the Ettrick valley indications of mineralisation were found in Range Cleuch.
Range Cleuch (407): sphalerite - no geochemical sample; other elements: Ba, Pb, Cu.

Quantitative XRF analyses were carried out on twenty grab shale samples collected from Dob's Linn and Hartfell 'Score'. Values determined range from 18 to 47 ppm in the Glenkiln (1) and Lower Hartfell (5) groups with a mean of 25 ppm for the Lower Hartfell Shales; from 129 to 211 ppm in the Upper Hartfell (4) group with a mean of 161 ppm; from 35 to 117 ppm in the Lower Birkhill (7) group with a mean of 76 ppm and from 150 to 166 ppm in the Upper Birkhill (3) group.

Distribution of copper mineralisation (Fig. 8)

Evidence of copper mineralisation is widespread. Mineral and/or element anomalies (assessed on a threshold level of 25 ppm) were detected in over half the pan samples. However, in the majority of samples, the level of concentration indicated by both minerals and chemical anomalies is considered too low to warrant further investigation except in cases where the element is associated with anomalous concentrations of other important economic elements (see the accompanying sections on lead and zinc mineralisation).

Chalcopyrite ($CuFeS_2$) is the principal mineral found in pan concentrates but malachite ($CuCO_3.Cu(OH)_2$), usually in trace amounts, is also quite common. Cupriferous pyrite (pyrite with a few per cent of chalcopyrite) constitutes a variable proportion of determined pyrite and is considered to account for many of the smaller element anomalies indicated by XRF analyses in samples where no positive mineral identification has been made. Cupriferous pyrite, like pyrite, occurs both as discrete grains and as disseminated particles in greywacke rock fragments (often in phyllite and mica schist debris). There is a marked concentration of mineral/element anomalies in the sector occupied by the Ordovician-Silurian boundary sequence of rocks, and, in particular, the Lowther Shales group of the Ordovician. An interesting occurrence of the mineral tennantite ($(CuFe)_{12}As_4S_{13}$) was recorded from Red Scar (NT 1829 1818) in the Megget Water catchment.

At the adit portal of an abandoned trial on the south bank of the Auchencat Burn (NT 0898 1104) in Annandale a vertically dipping band of dark grey shale is conspicuously impregnated with malachite. The band, one metre wide and trending N 80° E, can be traced for nearly ten metres along the bank of the stream. The adit was driven on a bearing of 145° on no obvious mineralised structure. Pan samples, taken from a small accumulation of mine debris near the adit portal, yielded large amounts of malachite and some chalcopyrite. A very high element anomaly (12621 ppm) was determined in the XRF sample. Chalcopyrite, malachite and anomalous element concentations (306 ppm) were identified in samples collected upstream in the Spa Well Burn tributary (525) at a point where the stream passes through a gully exposing faulted and brecciated grey clay shales. Traces of malachite and a chemical anomaly (39 ppm) were recorded in samples from a site on the main stream (526) outwith the shale belt. Chalcopyrite and a chemical anomaly (80 ppm) was recorded in samples taken from the adjacent tributary, the Lochan Burn (504). Some 5 km further south chalcopyrite and a chemical anomaly (180 ppm) was determined in samples taken from the Frenchland Burn (552). Here again the stream course follows a belt of faulted shales.

In the prominent shale belt, cupriferous pyrite and chalcopyrite with supporting element anomalies were recorded from Rough Grain (492), tributary of the Wandel Burn and from Barrow Cleuch (564), a Shank Houp tributary.

In the area to the south of the shale belt cupriferous pyrite and chalcopyrite were found in samples from Grains Burn (553) and its tributaries Linn Burn (554), Nightfield Burn (555), Three Grains (556) and Howe Cleuch (479). All streams, with the exception of Howe Cleuch, show small element anomalies. In the Culter Reservoir catchment cupriferous pyrite and chalcopyrite with traces of malachite were recorded from Ram Gill (568) and Snow Gill (569). A chemical anomaly (109 ppm) was determined in the XRF sample from Ram Gill. In the Camps Reservoir catchment cupriferous pyrite and chalcopyrite with supporting element anomalies were identified in samples from Hilshie Burn (449), Thorter Cleuch (452), Carle Gill (455), Midge Gill (456) and Martin Cleuch (457). The largest chemical anomaly (160 ppm), recorded from Martin Cleuch, is attributed mainly to pyritous Hartfell Shales which crop out from sample point to source in the stream.

In the Tweed valley cupriferous pyrite, chalcopyrite and traces of malachite with supporting element anomalies were proved in the following tributaries:-

- (i) Peddirie Burn (531, 532) and in two branches of its tributary Old Burn (529, 530). The largest chemical anomaly (118 ppm) was recorded in a sample from a branch of Old Burn (530).
- (ii) Glenwhappen Burn (537, 538).
- (iii) Glenbreck Burn (535, 536) and its tributary Old Burn (534).
- (iv) Hallow Burn (539).
- (v) Pipershole Burn (496).

Element anomalies are indicated in samples from Martin Cleuch (467), Ramsey Gill (469), and another small East Water tributary (468) flowing off Broad Hill.

In Moffatdale cupriferous pyrite and chalcopyrite were identified in samples from Black Hope Burn (422) and Carrifran Burn (423) and, in the Ettrick valley, from Range Cleuch (407). Geochemical samples were not taken at these sites.

In the Megget Water catchment tennantite, chalcopyrite and cupriferous pyrite were recorded from Red Scar (410, 421), a small south tributary of Garlie Cleuch. The provenance of these minerals may be a quartz-veined breccia, approximately 1 m wide and trending N 30°E along the west side of the burn. Cupriferous pyrite and chalcopyrite were also found in samples from Garlie Cleuch (412) and Shiel Hope Burn (413). In the latter stream traces of sulphides were identified in a thin, quartz-carbonate cemented breccia which crosses the stream at NT 1945 2171 on a bearing of N 30°E.

Heavy mineral residues obtained by panning crushed sandstone and breccia grab samples from the New Red Sandstone deposits in Annandale, north of Moffat, were examined for copper minerals. Possible traces of cupriferous pyrite were identified in breccia residue samples from Lochan Burn (430), Auchencat Burn (433) and Mere Beck (434). Large concentrations of rounded, ferruginous grains recorded in some samples were shown by X-ray powder photographs to be coated particles of hematite, clay mineral-quartz, magnetite or ilmenite.

Quantitative XRF analyses were carried out on twenty shale grab samples collected from Dob's Linn and Hartfell 'Score'. Values determined for the Glenkiln (1) and Lower Hartfell (5) groups were in the range 25 to 54 ppm with a mean of 47 ppm for the Lower Hartfell Shales. Mean figures for the Upper Hartfell and Lower and Upper Birkhill shales at 96 ppm, 81 ppm and 100 ppm respectively shows an approximate doubling of the element tenor in these younger shale groups.

Distribution of barium mineralisation (Fig. 9)

Barium mineralisation, as represented by the mineral baryte ($BaSO_4$), is widespread and very common. The mineral has been identified in 125 out of a total of 182 pan concentrates, and, at 28 sites, the proportion by weight in the heavy mineral separate exceeds 1%. Element anomalies, assessed on a threshold level of around 450 ppm, were recorded at 35 sites. There is no instance of an element anomaly determined by XRF analyses where baryte was not identified in the duplicate pan sample.

Baryte, in heavy mineral concentrate, occurs as white, sub-angular, rather tabular grains of an average size usually larger than that of the other minerals present. The pinkish variety is not common, occurring in notable amounts only in samples from the River Tweed tributaries, Glenbreck Burn (535) and Glenwhappen Burn (538).

Few samples show high enough concentrations to justify further investigation for baryte alone. Attention has already been drawn in the sections on lead and zinc to the likely occurrence of baryte (often in significant amounts) as a component of composite ores. Consideration is given in this section to sites at which comparatively high mineral and/or element concentrations were detected.

(1) Distribution in Ordovician rocks

(a) Sector proximate to the Southern Upland Fault:-

(i) Gair Gill (589), tributary of the Culter Water: baryte (3.5% by weight of heavy mineral concentrate) and chemical anomaly (1981 ppm); other elements: Pb, Zn, Cu.

(ii) Woodend Burn (588): baryte (1.5% by weight of heavy mineral concentrate).

(b) The prominent shale belt:-

(i) Coldchapel Burn (485): baryte (0.5% by weight of heavy mineral concentrate) and chemical anomaly (583 ppm); other elements: Cu.

(ii) William Gill (445), tributary of Camps Water: baryte (1% by weight of heavy mineral concentrate) and chemical anomaly (538 ppm); other elements: Zn, Cu.

(iii) Rough Grain (492), tributary of the Wandel Water: baryte (1.5% by weight of heavy mineral concentrate) and chemical anomaly (858 ppm); other elements: Zn, Cu.

(iv) Deer Gill (493), tributary of the Wandel Water: baryte (0.5% by weight of heavy mineral concentrate) and chemical anomaly (807 ppm); other elements: Pb, Zn, Cu.

(v) Mineralisation is indicated in several streams around the Cow Gill reservoirs.
Horse Grain (559): baryte (3% by weight of heavy mineral concentrate): other elements: Zn, Cu.
Yearn Cleuch (560): baryte (4% by weight of heavy mineral concentrate and chemical anomaly (479 ppm); other elements: Zn, Cu.
Wind Gill (566): baryte (2% by weight of heavy mineral concentrate).

(c) Area immediately south from the prominent shale belt:-

(i) Swine Gill (480), a branch of Cowhill Burn which joins Camps Water below the reservoir: baryte (14% by weight of heavy mineral concentrate) and chemical anomaly (11474 ppm); pieces of baryte mineralised 'float' observed in stream above sampling site; other elements: Zn, Pb, Cu.

(ii) Mineralisation is indicated in Grains Burn and some of its tributaries.
Grains Burn (553): baryte (traces); other elements: Cu.
Nightfield Burn (555): baryte (traces); other elements: Pb, Zn, Cu.
Three Grains (556): baryte (1% by weight of heavy mineral concentrate) and chemical anomaly (630 ppm); other elements: Pb, Zn, Cu.
Howe Cleuch (479): baryte; other elements: Zn, Cu.

(d) Area proximate to the Ordovician boundary:-

(i) Glespin Burn (483): baryte (5% by weight of heavy mineral concentrate) and chemical anomaly (731 ppm); other elements: Pb, Zn, Cu.

(ii) Deer Gill (473), a tributary of Whelphill Hope: baryte (1% by weight of heavy mineral concentrate) and chemical anomaly (468 ppm); other elements: Pb, Zn, Cu.

(iii) Carle Gill (455), in the Camps Reservoir catchment: baryte (2% by weight of the heavy mineral concentrate) and chemical anomaly (1785 ppm); other elements: Pb, Zn, Cu.

(2) Distribution in Silurian rocks

(e) Sector proximate to the Silurian boundary and including the headwaters catchment of the River Tweed.

(i) Martin Cleuch (467), an East Water tributary: baryte (1.5% by weight of heavy mineral concentrate) and chemical anomaly (477 ppm); other elements: Zn, Cu, Pb.

(ii) Crinshie Grain (454), a tributary of Fopperbeck Burn: baryte (0.5% by weight of the heavy mineral separate) and chemical anomaly (855 ppm).

(iii) Mineralisation is indicated in the River Tweed and many of its tributaries.
River Tweed (510): baryte (1% by weight of heavy mineral concentrate); other elements: Zn, Cu.
Badenhay Burn (509), tributary of the Cor Water: baryte (2% by weight of the heavy mineral concentrate) and chemical anomaly (453 ppm).
Wills Cleuch (528): baryte (1% by weight of heavy mineral concentrate).
Old Burn (529): baryte (0.5% by weight of heavy mineral concentrate) and chemical anomaly (1443 ppm); other elements: Pb, Zn, Cu.
Glenbreck Burn (535, 536): baryte (1% and 0.5% respectively by weight in heavy mineral concentrates); other elements: Pb, Zn, Cu.
Old Burn (534), tributary of Glenbreck Burn: baryte (0.5% by weight of heavy mineral concentrate) and chemical anomaly (569 ppm); other elements: Pb, Zn, Cu.

Glenwhappen Burn (538): baryte (2.5% by weight of heavy mineral concentrate) and chemical anomaly (7357 ppm); other elements: Pb, Zn, Cu.
Fingland Burn (542): baryte (5% by weight of heavy mineral concentrate) and chemical anomaly (8127 ppm); other elements: Zn, Cu.
Hawkshaw Burn (545): baryte and chemical anomaly (2768 ppm).
Carterhope Burn (498): baryte (1% by weight of the heavy mineral concentrate) and chemical anomaly (417 ppm); other elements: Zn, Cu, Pb.
Priesthope Burn (499): baryte (0.5% by weight of heavy mineral concentrate); other elements: Zn, Cu, Pb.
Fruid Water tributary (549): baryte (1% by weight of heavy mineral concentrate) and chemical anomaly (463 ppm); other elements: Zn, Cu.

(iv) Codleteth Burn (437), in catchment for the Talla Reservoir: baryte (6% by weight of heavy mineral concentrate) - no geochemical sample; other elements: Zn, Cu, Pb.

(f) Southern sector of project area incorporating parts of Annandale, Moffatdale, Ettrick valley and Megget Water.

(i) Baryte was identified in nearly all pan samples taken in Annandale.
Whitehope Burn (505): baryte and chemical anomaly (1274 ppm); pieces of baryte mineralised 'float' were found in river bank alluvium near the sample site; other elements: Zn, Cu.
Grey Gill (436): baryte (2% by weight of heavy mineral concentrate) - no geochemical sample.

(ii) Baryte was identified in nearly all pan samples taken in Moffatdale.
Hang Burn (519): baryte (0.5% by weight of heavy mineral concentrate) and chemical anomaly (606 ppm); other elements: Pb, Zn, Cu.
Roundstonefoot Burn (520): baryte (3% by weight of heavy mineral concentrate) and chemical anomaly (944 ppm); other elements: Zn, Cu.
Black Hope Burn (422): baryte (1% by weight of heavy mineral concentrate) - no geochemical sample; other elements: Zn, Cu.
Frazer Sike (424): baryte (9% by weight in heavy mineral concentrate) - no geochemical sample.

(iii) In the Megget Water catchment significant amounts of baryte were found in the following streams:-
How Cleuch (419): baryte (20% by weight of the heavy mineral concentrate) - no geochemical sample; other elements: Zn.
Red Scar (410, 421), tributary of Garlie Cleuch: baryte (3% and 4% respectively by weight of the heavy mineral concentrates) - no geochemical samples; other elements: Cu.
Garlie Cleuch (411): baryte (0.75% by weight of heavy mineral concentrate) - no geochemical sample; other elements: Zn, Cu.

In Annandale interesting amounts of baryte were identified in the heavy mineral residues obtained from panning crushed breccia samples collected from the New Red Sandstone deposits in Lochan Burn (430), Mere Beck (435), Tweedhope Burn (425) and Auchencat Burn (433).

Barium levels indicated by quantitative XRF analyses of twenty shale grab samples taken at Dob's Linn and Hartfell 'Score' showed no significant variations between Glenkiln, Hartfell and Birkhill shale groups. Mean values determined ranged from 420 to 580 ppm.

Distribution of iron mineralisation

Magnetite (Fe_3O_4) is present in most pan concentrates, usually in small amounts (less than 1% by weight). Geoscan electron microprobe analyses indicate that chromium bearing varieties may be present.

The commonest iron mineral is hematite (Fe_2O_3) which is present in every stream concentrate and in over 20% of samples constitutes more than 50% by weight of the heavy mineral separate. Specular and micaceous varieties were identified in over 50% of samples collected from the area south of the prominent shale belt, and occur, often in significant amounts, in all samples derived from the area occupied by the Llandovery portion of the Ordovician-Silurian boundary rock sequence. In the area between the Southern Upland Fault and the southern margin of the prominent shale belt these hematite varieties have not been found, but limonite, the hydrous ferric oxide, was noted in over 50% of samples in small amounts. South of the prominent shale belt limonite is a rare constituent in pan concentrates and has not been identified in samples from the Silurian sector. Minor amounts of goethite (FeO(OH) - XRD) occur in samples from Barrow Cleuch (564) and Crinshie Grain (454). Siderite, iron carbonate, was only recorded in one sample, that from Hare Burn (597), a tributary of Kingledoors Burn.

No important hematite veins were located in this survey. The high concentration of the mineral in most pan samples is thought, for the most part, to be derived from innumerable minor mineralised structures. Only a small proportion is considered to have a detrital provenance in the sedimentary rocks of the project area.

Pyrite is present in all heavy mineral pan concentrates but occurs in only minor amounts in approximately 70% of samples. A notable increase was recorded in the majority of samples collected from the Ordovician-Silurian boundary sector. Pyrite occurs both as discrete, euhedral to anhedral grains and as disseminated particles in shale, siltstone, phyllite and mica schist rock fragments in greywackes. Such pyritous rock fragments were noted to be particularly common in samples taken in the Ordovician-Silurian boundary sector and the generally higher XRF copper values determined in many of the duplicate samples is attributed to the presence of a proportion of cupriferous pyrite.

Pyrrhotite is a trace constituent in several pan concentrates and is present in minor amounts in samples from Redshaw Burn (443), a tributary of the Evan Water; Glenwhappen Burn (537), tributary of the River Tweed; and in Fingland Burn (598) and Glenwhappen Burn (601), tributaries of the Kingledoors Burn. Marcasite was only identified in one sample, that from Mossgrain Burn (540), a tributary of Birnock Water.

In Annandale, crushed and panned samples of New Red Sandstone breccia and sandstone (425 - 435) yielded, in all cases, fairly large heavy mineral concentrates. These were shown (XRD) to be composed essentially of hematite and Fe-coated grains of clay mineral-quartz, magnetite and ilmenite. Small amounts of pyrite were determined in samples from Auchencat Burn (433), Mere Beck (434, 435) and Lochan Burn (430).

Emission spectrograph and XRF analyses of duplicate pan samples show high levels of iron (over 9% Fe) in over 20% of all samples, with the majority of these being located in the area which extends from the southern boundary of the prominent shale belt to the Ordovician-Silurian boundary zone.

Distribution of titanium mineralisation

Titanium minerals account for between 0.5% and 5% of the heavy mineral content of most pan concentrates. The principal minerals are ilmenite ($FeO.TiO_2$), rutile (TiO_2) and its other polymorph oxides anatase and brookite. Sphene ($CaTiSiO_5$), rare in samples from the Ordovician sector, is quite common in trace amounts in samples derived from the Silurian sector. An unexpected feature is the general low ilmenite tenor (less than 2% by weight) in most heavy mineral concentrates. By comparison the proportion of rutile, and in a lesser degree anatase, is much higher than expected, particularly in samples from the Ordovician sector. In the area occupied by the youngest group of Ordovician rocks anatase is common and anomalous concentrations were noted in samples from Hare Burn (595); Kingledoors Burn (600) and its tributaries Hare Burn (597), Fingland Burn (598) and Glenwhappen Burn (601). In the same sector, brookite, which is rare in the area occupied by older rocks, is quite common. Anomalous concentrations were recorded in samples taken from Thorter Cleuch (452); Midge Gill (456); Reddie Grain (463); Whelphill Hope (472) and its tributary Deer Gill (473); Cakelaw Burn (476); Whitelaw Burn (478) and Glespin Burn (483). Data indicate that brookite, in trace amounts, has a wider distribution and has been more commonly identified in samples derived from the Silurian sector.

XRF analyses of duplicate pan samples show the average titanium figure for Ordovician samples to be approximately 30% higher than that for the Silurian samples. Values range from around 0.3% to almost 2%. Eight samples with over 1% Ti are all located within the Ordovician sector.

Notable concentrations of rutile were recorded in most of the heavy mineral residues obtained by panning crushed sandstone grab samples from the New Red Sandstone deposits in Annandale. The best results, between 2% and 6% by weight, pertain to samples from Tweedhope Burn (426, 427), Stotfield Gill (428, 429), Lochan Burn (431) and Mere Beck (434). Only one breccia sample, that from the Auchencat Burn (433), contained equivalent amounts of rutile. Traces of anatase and sphene were found in a few samples. Ilmenite is present in all samples but not in anomalous amounts.

Distribution of chromium mineralisation

Chromiferous spinel is the most abundant of the detrital economic mineral species so far found in the Southern Uplands. It has been detected in all heavy mineral concentrates from the project area and, in the majority of cases, is present as a major constituent. The mineral occurs as a detrital mineral in greywackes. Variations in the proportion of the mineral recorded in pan samples across the project area normal to the Caledonoid trend are considered to be directly related to belts occupied by greywackes with distinctive compositional features i.e. the Marchburn, Afton, Scar, Shinnel, Pyroxenous and Intermediate formations (Floyd, 1975). The mean weight percentages of chromiferous spinel in the 142 pan samples that can be allocated with some confidence to areas occupied by these greywacke formations are listed in Table 2 below. To achieve a more reliable estimate of the chromiferous spinel proportion that can be expected in detrital heavy mineral residues derived from the various greywacke formations, hematite has been subtracted from the weight of each pan concentrate and the remaining assemblage recalculated to 100%.

The figures show a substantial drop in content from the Marchburn, the oldest greywacke formation, passing into the younger Ordovician formations followed by an equally substantial rise in content in the Silurian formations.

Most of the chromiferous spinel grains are in the form of small (0.1 - 0.5 mm diameter) subhedral to euhedral octahedra. Coarser (up to 3 mm diameter) euhedral grains are not uncommon but rarely constitute a notable proportion of the

Table 2. Distribution of chromium spinel derived from areas occupied by various greywacke formations

Formation	Location	No. of Samples	Mean Weight %
N Marchburn	Ordovician sector proximate to the Southern Upland Fault	2	40
Afton	Ordovician sector north of the prominent shale belt	20	20
Scar	The area immediately south of the prominent shale belt	23	19
Shinnel	The Ordovician sector proximate to the Ordovician-Silurian boundary	17	18
Pyroxenous	The Silurian sector proximate to the Ordovician-Silurian boundary	30	28
S Intermediate	The Silurian sector including parts of Annandale, Moffatdale, Megget Water and Ettrick valley	50	36

mineral population. The form and size of mineral grains indicates a disseminated ore provenance in ultrabasic rocks or in serpentine derived from them (Thayer, 1960).

Commonly associated with chromiferous spinel, usually in minor amounts, is a distinctive green pyroxene which has been shown by the Petrological Department to be a chromiferous augite (electron microprobe analysis) with a Cr content of approximately 1%. Chromium bearing magnetite (electron microprobe analysis) has also been identified and is considered to constitute a proportion of the magnetite fraction in many concentrates.

As ultrabasic rocks represented in the Ballantrae Complex could be a possible provenance for the chromium minerals identified, samples of both vein (S 6449) and disseminated ore (S 6429 - serpentinised dunite) from occurrences in the Knockdaw area (NX 16 88) were analysed by the Petrological Department. The results indicate that the chromiferous spinel mineral in both samples is similar in composition (Cr_2O_3 : 35%; Al_2O_3 : 32%; MgO : 17%; FeO : 11%; Fe_2O_3 : 5%), approximating in composition to the mineral picotite($(Cr, Al, Fe)_2O_4$ (Fe, Mg)) one of the less common chrome ores. With a Cr/Fe ratio of less than 3:1 this mineral would be classed as a refractory grade ore.

The few analyses of chromiferous spinel grains from stream concentrates so far carried out show a spread of Cr_2O_3 values between 30% and 56%. It is therefore possible that additional sources of chrome ore other than the Ballantrae Complex exist beneath a cover of younger rocks in the South Scotland region.

Some placer concentration of chromiferous spinel can be expected in alluvium in valleys throughout the project area, particularly in the valley of the River Tweed where there are extensive spreads of alluvial deposits.

Distribution of nickel mineralisation

A trace of niccolite (NiAs-XRD) in the heavy mineral concentrate from Raggengill Burn (484) was the only indication of nickel mineralisation located. As pyrrhotite was identified in only trace amounts in a few samples (see iron mineralisation) no analyses for Ni content were made.

The Ni tenor in most analysed (XRF) duplicate samples is below 80 ppm. The sixteen samples with concentration levels above 80 ppm and ranging up to 161 ppm (headwaters catchment for the Kingledoors Burn (600)) are all located in the Ordovician-Silurian boundary sector of the project area.

Twenty shale grab samples taken from sections at Dob's Linn and Hartfell 'Score' were analysed quantitatively by XRF for nickel. The average tenor in the Upper Hartfell, and Lower and Upper Birkhill shale groups at 117, 89 and 93 ppm respectively is more than double the mean value (40 ppm) recorded for the Lower Hartfell samples.

Distribution of manganese mineralisation

Manganese minerals have not been identified in any of the heavy mineral stream concentrates. The low tenor of the element, less than 0.1% in all but five analysed (XRF) pan samples, indicates that it is unlikely that significant mineral concentrations will be found in the project area. In the sector between the prominent shale belt and the Southern Upland Fault the average element value for samples, at 0.04%, is somewhat higher than that for samples collected from the remainder area occupied by younger rocks (0.025 - 0.03%).

The highest values, at 0.36% and 0.25%, were respectively recorded in samples taken from Rough Grain (492) and Deer Gill (493), both tributaries of the Wandel Burn.

Twenty shale grab samples from Dob's Linn and Hartfell 'Score' were quantitatively analysed by XRF for their manganese content. Again the results confirm the low tenor of the element in the rocks of the project area. No detectable levels (ie above 0.01%) were recorded in any of the Glenkiln or Lower Hartfell samples. Higher concentrations of the element were only found in samples of Upper Hartfell and Upper Birkhill shales (0.52% maximum in the former and 0.44% maximum in the latter groups) with values in the range 0.04 to 0.06% determined for all Lower Birkhill samples.

Distribution of antimony mineralisation

No antimony minerals were identified. The majority of analysed (XRF) duplicate pan samples contain less than 10 ppm Sb. In only ten samples is the concentration level greater than 25 ppm but it is perhaps significant to note that seven of these are from tributaries of the River Tweed, respectively Pipershole Burn (496) with the maximum recorded value of 45 ppm, Peddirie Burn (531), Glenwhappen Burn (538), Hallow Burn (539), Fingland Burn (542), Hawkshaw Burn (545) and Kingledoors Burn (600) - the sample from this last locality being the only one with an associated major lead anomaly.

Distribution of arsenic mineralisation

Arsenic mineralisation, as represented by the mineral arsenopyrite (FeAsS), has been identified only in trace amounts in a few concentrates. Duplicate samples were analysed for element content by XRF and of these 41 contained anomalous concentrations (based on a threshold of 30 ppm). Arsenic values exceeded 90 ppm at 10 localities with a maximum of 207 ppm being recorded in the sample from Ramsey Gill (469), a tributary of East Water. The distribution of anomalies, however, may be significant since all but five are located within the Ordovician-Silurian boundary sector.

There does not appear to be any consistent relationship between the occurrence of particle gold and arsenic anomalies, gold having been identified at less than half of the arsenic anomaly sites.

Distribution of molybdenum mineralisation

There is little evidence of molybdenum mineralisation. The principal ore mineral, molybdenite (MoS_2), was recorded in only one pan sample, that from Stot Grain (477 - XRD), a tributary of Whitelaw Burn. The several flakes identified in the heavy mineral separate may be derived from a small, altered 'microgranite' intrusion exposed in the upper reaches of the stream. One hundred and thirty five of the duplicate pan samples (155) were analysed for molybdenum by emission spectrography but no significant concentrations were determined. The highest values, 20, 25 and 23 ppm, were recorded respectively in samples collected from Earns Gill (464), tributary of Camps Water; Spa Well Burn (525), tributary of Auchencat Burn and Barrow Cleuch (564), a Shank Houp tributary.

Distribution of tin mineralisation

Tin minerals were not identified in any of the heavy mineral pan concentrates and analyses of duplicate samples show an Sn tenor of less than 10 ppm in all but three samples. The highest value, 91 ppm was recorded in a sample taken from a stream flowing off Devonshaw Hill (587), close to the Southern Upland Fault. Another unusual feature in this stream is that the heavy mineral separate sample contains traces of the very rare mineral cinnabar (HgS).

Distribution of mercury mineralisation

Cinnabar (HgS), the ore mineral of mercury, was identified (XRD) for the first time in Scotland in trace amounts in pan concentrate samples taken from a small stream at Hartside (587B) and from Woodend Burn (588), both tributaries of the River Clyde draining from Devonshaw Hill (NT 9606 2865) near the Southern Upland Fault. A fine section of massive bedded, variegated gritty to pebbly greywackes of the Marchburn formation is exposed along the west bank of the former stream. It includes examples of greywacke facies similar to the 'Haggis Rock' as described by Peach and Horne in 'The Silurian Rocks of Britain' (p. 51).

Distribution of uranium-thorium mineralisation

No uranium or thorium minerals were identified in pan concentrates.

1413A scintillometer traverses along the Frigg Gas pipeline showed low levels of radioactivity (up to 80 μr/hr) at a few points in a fault zone on the south side of the prominent shale belt.

Grab samples of dark shales, collected from sections at Dob's Linn and from the 'Score' gully at Hartfell Spa, were analysed for uranium with the following results:-

Glenkiln Shales	(1 sample) : 11 ppm
Lower Hartfell Shales	(6 samples): mean tenor - 9 ppm
Upper Hartfell Shales	(3 samples): mean tenor - 10 ppm
Lower Birkhill Shales	(7 samples): mean tenor - 10 ppm
Upper Birkhill Shales	(3 samples): mean tenor - 7 ppm

The Glenkiln Shale sample, taken at Dob's Linn, was selected, by 1413A scintillometer survey, as the most radioactive horizon in the outcrop of this shale group. Maximum values of 16 and 17 ppm were determined in Upper Hartfell and Lower Birkhill horizons respectively.

Distribution of corundum

The mineral corundum was identified (XRD) in twenty pan concentrates, several of which contained examples of gem quality sapphire. Of these occurrences fifteen were from streams in the area occupied by Silurian rocks, two in the Ordovician sector of the Ordovician-Silurian boundary zone, and three from the north-west sector of the project area draining from the prominent Ordovician shale belt. In the Silurian the majority of sites were in the River Tweed catchment, respectively Smid Hope Burn (495), Hawkshaw Burn (497, 546), Priesthope Burn (499), Priest Burn (511), Glencraigie Burn tributary (512), Wills Cleuch (528), Peddirie Burn (531), Old Burn (534), Fingland Burn (542) and Ellers Cleuch (550). The mineral species was also found in Thorter Gutter (466) and Martin Cleuch (467), both tributaries of the East Water and in the River Annan tributaries, Tweedhope Burn (503) and Lochan Burn (506). In the Ordovician sector of the Ordovician-Silurian boundary zone it was identified in samples from Shalf Grain (470), tributary of the Midlock Water and from Cakelaw Burn (476), a River Clyde tributary. Elsewhere in the Ordovician sector it is perhaps significant that occurrences are restricted to samples collected from the headwaters catchment of the Coldchapel Burn (485, 486) and William Gill (445), streams draining a part of the prominent shale belt in which there are several earlier Geological Survey records of porcelainised shale outcrops.

Mineral grains are generally anhedral but a few subhedral to euhedral forms are recorded. The number of grains identified per pan sample is usually only one or two, with an average size of just under 1 mm and an occasional crystal having a maximum dimension around 2 mm. Colour is very variable ranging from dull, cloudy or patchy, pale mauve-blue to clear, pale purple-blue and deep ultramarine-blue in the gemstone examples.

Distribution of artificial fertilisers

Crushed phosphate rock from North Africa has been extensively employed by the Forestry Commission and other forestry groups. There is also evidence of the use of a basic slag type dressing on some farms in the northern part of the project area. Particles of both fertilisers survive panning and heavy liquid separation processes. Their distinctive colour and form properties makes microscope identification comparatively easy. Their identification in heavy mineral pan concentrate provides a useful check in the case of the duplicate samples collected for geochemical analyses where such contaminants might pass undetected and give rise to inaccurate estimates of important economic elements. Any pertinent examples are reported in text.

CONCLUSIONS AND RECOMMENDATIONS

This survey has identified many new indications of base metal mineralisation and established that particle gold has a wide distribution. The results suggest that collection of pan samples from the drainage system of a project area is an effective reconnaissance technique for determining the distribution of economic minerals.

As placer gold concentrations are likely to be too small and too localised to support major exploitation, any future potential for the element appears to lie in the identification of enriched zones in the sedimentary rocks. Should payable values be proved in greywacke units, detrital chromiferous spinel could provide an important byproduct.

Though hematite is a very prominent constituent in the majority of pan samples no major vein or strata-bound concentrations of this mineral have been located during the survey.

It is difficult to make a selection from the large number of lead, zinc, copper and barium element and mineral anomalies for follow-up investigations, as the level of concentration in any sample is influenced by many unquantifiable factors. A seemingly impressive assemblage of minerals supported by element values could be derived from minor mineralisation close to the panning site while traces could originate from important distant mineralisation. While it is recommended that all indications of economic minerals and chemical anomalies be investigated in due course, the following areas, selected on a basis of numerical incidence of anomalous mineral and element concentrations, are put forward for initial follow-up study:-

<u>Principally Pb-Zn-Ba mineralisation with possible Cu</u>

(i) The numerous tributaries of the Wandel Burn, the headwaters catchment of the Coldchapel Burn, the Raggengill Burn and the northern tributaries of Camps Water which drain from the prominent shale belt. Samples: 444, 445, 484, 485, 487, 490, 492, 493.

(ii) In the area close to the Southern Upland Fault: Woodend Burn and drainage from Devonshaw Hill (a provenance for the mercury mineral cinnabar should be sought for in this area); Gair Gill and its tributaries in the Culter Water catchment. Samples: 587, 588, 589.

(iii) All streams draining northward into the Upper Cowgill Reservoir from the prominent shale belt. Samples: 557, 558, 559, 560.

(iv) Grains Gill and its tributaries which feed into the north side of Camps Reservoir. Samples: 479, 553, 554, 555, 556. Carle Gill and Midge Gill which feed into the south side of Camps Reservoir. Samples: 455, 456.

Mineralisation, if proved in Carle Gill and Midge Gill, may extend southward into the headwaters catchment of the Whelphill Hope. Sample: 473.
Swine Gill, a tributary of Cowhill Burn which joins Camps Water below the reservoir. Sample: 480.

(v) The River Clyde tributaries Lang Cleuch and Glespin Burn. Samples: 481, 483.

(vi) The Codleteth Burn and Talla Cleuch which feed into the Talla Reservoir. Samples: 437, 438.

(vii) Blackhope Burn, Carrifran Burn, Frazer Sike and Hang Burn in Moffatdale. Samples: 422, 423, 424, 519.

The potential prospects in the River Tweed catchment are not included due to the difficulty of tracing mineralisation in an area with widespread and often thick accumulations of superficial deposits.

Principally Cu mineralisation

(i) Dispersions of both primary and secondary minerals have been recorded in outcrop and in pan samples from the Hartfell 'Score' broad belt of shales which extends up the Auchencat Burn into the Spa Well Burn branch and finally across into Bill's Cleuch Burn, a tributary of Lochan Burn. Mineral traces were also identified in associated sediments, mainly gritty greywackes, which crop out along the course of the Auchencat Burn for nearly 3 km to its source near Hart Fell. Samples: 504, 524, 525, 526.
Both primary and secondary mineral traces were identified in pan samples taken from the Frenchland Burn, nearer Moffat. Here again the stream course, for the most part, is contained within a belt of shales. Sample: 552.

(ii) Primary minerals identified in heavy mineral pan concentrates from the Red Scar tributary of Garlie Cleuch in the Megget Water catchment is considered to be derived from a vein breccia structure flanking the stream above both sampling points. Samples: 411, 421.

It is further recommended that, in areas where encouraging mineral/element concentrations have been proved, pan samples be collected from streams omitted in this reconnaissance.

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APPENDIX I Mineralisation in pan concentrates

No	Locality	Grid Ref	Ba	Pb	Zn	Cu	Au
406	Entertrona Burn	NT 1831 0807	-	-	-	•	-
407	Range Cleuch	NT 1964 1006	●	•	•	•	-
408	Glengaber Burn	NT 2175 2346	●	-	-	-	-
409	Talla Water	NT 1432 2001	•	-	-	-	-
410	Red Scar, Garlie Cleuch tributary	NT 1829 1818	●	-	-	●	•
411	Garlie Cleuch tributary	NT 1737 1795	●	-	•	-	-
412	Garlie Cleuch	NT 1763 1814	-	-	•	-	-
413	Shiel Hope Burn	NT 1953 2136	●	-	●	-	-
414	Shiel Hope Burn tributary	NT 1940 2120	-	-	-	-	-
415	Craigierig Burn	NT 2041 2349	●	-	-	-	●
416	Craigierig Burn tributary	NT 2059 2371	●	-	-	-	-
417	Glengaber Burn tributary	NT 2122 2424	●	-	-	-	-
418	Glengaber Burn	NT 2173 2350	●	-	-	-	-
419	How Cleuch	NT 2272 2363	●	-	•	-	-
420	Henderland Burn	NT 2329 2463	●	-	-	-	-
421	Red Scar, Garlie Cleuch tributary	NT 1828 1821	●	-	-	●	•
422	Black Hope Burn	NT 1320 1221	●	-	●	-	-
423	Carrifran Burn	NT 1511 1341	●	-	●	-	-
424	Polmoody Burn tributary	NT 1739 1471	●	-	-	-	•
425	Tweedhope Burn: basal breccia (R)	NT 0793 1245	●	-	-	-	-
426	Tweedhope Burn: sandstone (R)	NT 0794 1243	-	-	-	-	-
427	Tweedhope Burn: sandstone (R)	NT 0789 1238	-	-	-	-	-
428	Stotfield Gill: sandstone (R)	NT 0819 1218	-	-	-	-	-
429	Stotfield Gill: sandstone (R)	NT 0780 1202	-	-	-	-	-
430	Lochan Burn: basal breccia (R)	NT 0818 1124	●	-	-	-	-
431	Lochan Burn: sandstone (R)	NT 0818 1125	-	-	-	-	-
432	Auchencat Burn: sandstone (R)	NT 0820 1048	-	-	-	-	-
433	Auchencat Burn: basal breccia (R)	NT 0827 1054	●	-	-	-	-
434	Mere Beck: sandstone (R)	NT 0832 0977	-	-	-	-	-
435	Mere Beck: basal breccia (R)	NT 0843 0994	●	-	-	-	-

APPENDIX I continued Mineralisation in pan concentrates

No	Locality	Grid Ref	Ba	Pb	Zn	Cu	Au
436	Grey Gill	NT 0892 0877	●	-	-	-	-
437	Codleteth Burn	NT 1383 2080	●	•	•	-	-
438	Talla Cleuch	NT 1217 2168	•	•	•	-	-
439	Glencotho Burn	NT 0884 2932	●	-	-	-	-
440	Willow Wand Burn	NT 0907 2967	-	-	-	•	-
441	March Burn	NT 0378 1336	•	-	-	-	-
442	Hassockwell Burn	NT 0390 1317	•	-	-	-	-
443	Redshaw Burn	NT 0307 1298	●	-	-	-	•
444	Berries Burn	NS 9531 2208	-	-	●	-	•
445	William Gill	NS 9682 2319	●	-	●	-	-
446	Normangill Burn	NS 9818 2348	-	•	-	-	-
447	Raecleuch Burn	NT 0394 1179	-	-	-	-	-
448	Risingclaw Burn	NT 0330 2119	●	-	•	-	-
449	Hilshie Burn	NT 0334 2173	●	-	-	-	-
450	Blackcleuch Burn	NT 0233 2073	●	-	-	•	•
451	Davies Burn	NT 0243 2071	●	-	-	-	-
452	Thorter Cleuch	NT 0281 2235	-	-	-	-	-
453	Clerk Grain	NT 0341 1552	-	-	-	-	•
454	Crinshie Grain	NT 0356 1593	●	-	-	-	-
455	Carle Gill	NT 0062 2174	●	●	-	-	•
456	Midge Gill	NT 0119 2136	-	-	-	-	•
457	Martin Cleuch	NT 0199 2320	-	-	-	-	-
458	Clydes Burn	NT 0185 1620	-	-	-	-	-
459	Aller Cleuch	NT 0093 1639	-	-	-	-	-
460	Stock Cleuch	NT 0040 1638	•	-	-	-	-
461	West Water	NT 0050 1825	-	-	-	-	-
462	Malls Cleuch	NS 9973 1829	-	-	-	-	-
463	Reddie Grain	NS 9946 1840	•	-	-	-	•
464	Earns Gill	NS 9876 2193	●	-	-	-	-
465	Reed Gill	NS 9900 2279	•	-	-	-	-
466	Thorter Gutter	NT 0189 1757	●	•	-	-	-

APPENDIX I continued Mineralisation in pan concentrates

No	Locality	Grid Ref	Ba	Pb	Zn	Cu	Au
467	Martin Cleuch	NT 0197 1808	●	-	●	-	-
468	East Water tributary	NT 0170 1836	-	-	-	-	-
469	Ramsey Gill	NT 0111 1933	-	-	-	-	-
470	Shalf Grain	NS 9943 1912	-	-	-	-	-
471	Kess Cleuch	NS 9857 1969	-	-	-	-	-
472	Whelphill Hope	NT 0082 2017	-	-	-	-	•
473	Deer Gill	NT 0032 2053	●	•	●	•	-
474	Little Tinnan	NS 9935 2063	●	-	-	-	-
475	Spout Sike	NS 9927 2066	-	-	•	-	•
476	Cakelaw Burn	NS 9731 1890	•	-	-	-	•
477	Stot Grain	NT 0301 2380	-	-	-	-	-
478	Whitelaw Burn	NT 0302 2369	-	-	-	-	-
479	Howe Cleuch	NT 0111 2427	●	-	•	•	-
480	Swine Gill	NT 0003 2371	●	•	-	-	-
481	Lang Cleuch	NS 9946 1651	●	•	-	-	-
482	Nether Moss Cleuch	NS 9767 1661	•	-	-	-	•
483	Glespin Burn	NS 9763 1947	●	●	•	-	•
484	Raggengill Burn	NS 9480 2338	-	-	-	-	-
485	Coldchapel Burn	NS 9603 2475	●	-	-	-	-
486	Wood Gill	NS 9522 2414	-	-	-	-	-
487	Lead Burn	NS 9849 2528	-	•	-	-	•
488	Ragged Gill	NS 9829 2507	●	-	-	-	-
489	Rein Gill	NS 9808 2588	●	-	●	•	•
490	Hawkwood Burn	NS 9175 2548	●	●	-	-	-
491	Birnock Burn	NS 9956 2602	●	-	-	-	-
492	Rough Grain	NS 9952 2609	●	-	●	•	-
493	Deer Gill	NS 9900 2563	●	•	•	-	-
494	Bog Grain	NT 0464 1552	-	-	-	-	•
495	Smid Hope Burn tributary	NT 0478 1734	-	-	-	-	-
496	Pipershole Burn	NT 0579 1860	-	-	-	-	-
497	Hawkshaw Burn	NT 0808 2005	●	-	-	-	•
498	Carterhope Burn	NT 0995 1791	●	•	•	-	•

APPENDIX I continued Mineralisation in pan concentrates

No	Locality	Grid Ref	Ba	Pb	Zn	Cu	Au
499	Priesthope Burn	NT 0989 1833	●	•	●	-	-
500	Chapel Burn	NT 0858 1970	-	-	-	-	•
501	Rigs Burn	NT 0769 2325	-	-	-	-	-
502	Mire Gill	NT 0632 1291	-	-	-	-	-
503	Tweedhope Burn	NT 0819 1324	●	-	●	-	-
504	Bill's Cleuch Burn	NT 0918 1207	-	-	-	•	-
505	Whitehope Burn	NT 0910 1252	●	-	-	-	•
506	Lochan Burn	NT 0923 1252	●	-	-	-	-
507	Craigie Burn	NT 1165 0610	●	-	●	●	-
508	Shortwoodend Burn	NT 1337 0812	-	-	-	-	-
509	Badenhay Burn	NT 0613 1591	●	-	-	-	-
510	River Tweed	NT 0533 1629	●	-	●	-	•
511	Priest Burn	NT 0721 1563	-	-	-	-	-
512	Glencraigie Burn tributary	NT 0769 1628	-	-	-	-	-
513	Glencraigie Burn	NT 0765 1619	•	-	-	-	•
514	Muckle Powskein Burn	NT 0394 1879	●	-	-	-	-
515	Shilling Cleuch	NT 0344 1813	-	•	-	-	•
516	Badlieu Burn	NT 0339 1704	-	-	-	-	-
517	Black Craig Burn	NT 0373 1715	-	-	-	-	-
518	Tweed's Well	NT 0560 1456	●	-	-	-	-
519	Hang Burn	NT 1419 0979	●	-	-	•	-
520	Roundstonefoot Burn	NT 1390 0863	●	-	●	-	-
521	Member Burn	NT 0643 1392	-	-	-	-	-
522	Powskein Burn	NT 0803 1451	●	-	-	-	-
523	Whitehope Burn	NT 0819 1402	●	-	-	-	•
524	Auchencat Burn: mine debris (M)	NT 0898 1104	-	-	-	●	-
525	Spa Well Burn	NT 0971 1164	•	-	-	●	-
526	Auchencat Burn	NT 0981 1118	●	-	•	•	•
527	Old Burn tributary	NT 0469 1994	●	-	-	•	-
528	Wills Cleuch	NT 0463 2027	●	-	-	•	-
529	Old Burn tributary	NT 0419 2013	●	-	●	●	-

APPENDIX I continued Mineralisation in pan concentrates

No	Locality	Grid Ref	Ba	Pb	Zn	Cu	Au
530	Old Burn	NT 0420 1978	•	-	-	●	-
531	Peddirie Burn	NT 0528 2057	●	-	-	•	-
532	Peddirie Burn: mineralised vein	NT 0533 2054	●	•	-	•	-
533	River Tweed tributary	NT 0579 2006	●	-	-	-	-
534	Old Burn	NT 0551 2166	●	-	-	-	-
535	Glenbreck Burn	NT 0548 2198	●	-	-	•	•
536	Glenbreck Burn	NT 0480 2230	●	-	-	-	-
537	Glenwhappen Burn	NT 0578 2270	●	-	•	•	•
538	Glenwhappen Burn	NT 0645 2196	●	-	•	•	•
539	Hallow Burn	NT 0720 2278	●	-	-	•	•
540	Mossgrain Burn	NT 1135 0900	-	-	-	-	•
541	Birnock Water	NT 1076 0927	●	-	-	-	-
542	Fingland Burn	NT 0719 1939	●	-	●	●	-
543	Fingland Burn tributary	NT 0655 2004	-	-	•	•	-
544	White Cleuch Burn	NT 0791 1864	-	-	-	-	•
545	Hawkshaw Burn	NT 0830 1846	●	-	-	-	•
546A	Hawkshaw Burn	NT 0795 1984	●	-	-	-	•
547	Menzion Burn	NT 1028 2046	-	-	-	-	•
548	Fern Hope Burn	NT 1137 1828	-	-	●	-	•
549	Fruid Water tributary	NT 1125 1618	●	-	-	-	-
550	Ellers Cleuch	NT 1168 1644	-	-	-	-	-
551	Garelet Cleuch	NT 1144 1697	-	-	-	•	-
552	Frenchland Burn	NT 1068 0624	●	-	●	●	-
553	Grains Burn	NT 0372 2440	•	-	●	•	•
554	Linn Burn	NT 0223 2547	-	-	●	•	-
555	Nightfield Burn	NT 0192 2538	•	•	•	•	-
556	Three Grains	NT 0125 2522	●	-	●	●	-
557	Duncan Gill	NT 0084 2701	●	-	•	-	•
558	The Grip	NT 0076 2746	●	-	•	-	-
559	Horse Grain	NT 0150 2755	●	-	●	-	-
560	Yearn Cleuch	NT 0132 2708	●	•	-	-	-

APPENDIX I continued Mineralisation in pan concentrates

No	Locality	Grid Ref	Ba	Pb	Zn	Cu	Au
561	Big Smagill	NT 0028 2851	-	-	•	-	-
562	Harklaw Gutter	NT 0174 2901	-	-	-	-	-
563	Stotlea Gutter	NT 0202 2846	-	•	-	-	-
564	Barrow Cleuch	NT 0200 2931	•	•	●	●	-
565	Howe Gill	NT 0164 3059	●	-	-	-	-
566	Wind Gill	NT 0207 3091	●	-	•	-	•
567	Kings Beck	NT 0383 3034	●	-	-	•	-
568	Ram Gill	NT 0387 2690	•	-	●	●	•
569	Snow Gill	NT 0346 2688	●	-	-	•	•
570	Stone Gill	NT 0329 2770	-	-	-	-	-
571	Lea Gill	NT 0314 2832	●	-	-	•	-
572	Culter Water	NT 0550 2659	●	-	●	•	-
573	Bramble Sike	NT 0491 2703	-	-	-	-	-
574	Whitelaw Burn	NT 0469 2716	•	-	-	-	-
575	Back Burn	NT 0476 2617	•	-	-	-	-
576	Coal Heuch	NT 0464 2641	•	-	-	•	-
577	Breeks Burn	NT 0427 2767	●	-	-	-	-
578	Knock Burn	NT 0374 2867	●	-	-	-	-
579	Cow Gill	NT 0304 2938	●	-	-	-	-
580	Nisbet Burn	NT 0505 3129	●	-	-	-	-
581	Nisbet Burn	NT 0463 3193	-	-	-	-	-
582	Peat Burn	NT 0429 3153	•	-	-	-	-
583	Nisbet Burn	NT 0372 3246	●	-	-	-	-
584	Eask Gill	NS 9910 2805	-	-	-	-	-
585	Little Smagill	NS 9930 2871	●	-	-	-	•
586	Hartside Burn	NS 9746 2839	•	-	•	-	-
587B	River Clyde tributary	NS 9653 2887	●	-	-	-	-
588	Woodend Burn	NS 9541 2811	●	-	●	-	•
589	Gair Gill	NT 0250 3222	●	●	●	-	-
590B	Culter Craigs: (E)	NT 0302 3331	-	-	-	-	-
591	Glencotho Burn	NT 1090 2130	●	-	-	-	•

APPENDIX I continued Mineralisation in pan concentrates

No	Locality	Grid Ref	Ba	Pb	Zn	Cu	Au
592	Hope Burn	NT 0720 2961	-	-	-	-	-
593	Glenharvie Burn	NT 0644 2869	-	-	-	-	-
594	Holms Burn	NT 0667 2777	•	-	-	-	-
595	Hare Burn	NT 0720 2826	•	-	•	-	-
596	Logan Burn	NT 1077 2980	●	-	-	-	•
597	Hare Burn	NT 0818 2660	●	-	-	•	-
598	Fingland Burn	NT 0550 2448	-	-	-	•	-
599	Scabmenow Burn	NT 0546 2413	•	-	-	•	-
600	Kingledoors Burn	NT 0551 2404	●	-	-	•	-
601	Glenwhappen Burn	NT 0681 2525	●	-	-	•	-

Explanation

Pan concentrate	from stream alluvium unless otherwise indicated in brackets.
(R)	heavy mineral residue from crushed rock sample.
(M)	heavy mineral residue from crushed mine trial debris.
(E)	heavy mineral residue from hillside eluvium.
Grid Ref	National Grid Reference to eight figures.
Ba	Barium as represented by the mineral baryte.
Pb	Lead as represented by undifferentiated lead minerals.
Zn	Zinc as represented by the mineral sphalerite.
Cu	Copper as represented by undifferentiated copper minerals.
Au	gold as represented by particle gold.
●	mineral grains present in readily recognisable amounts.
•	only one or two mineral grains present.
-	no mineral(s) detected.

APPENDIX II Analytical results for duplicate pan concentrates

Samples (155) were analysed by Emission Spectroscopy (Mo, Cr) and XRF (all other elements) by the Analytical and Ceramics Unit of IGS in London. There are no results for samples 406 - 440, 451, 532, 533, 535, 558 and 576 as no duplication material was collected in these cases.

KEY
ppm = parts per million
% = percentage
* = arsenic only - indicates that interference by uranium and/or tungsten was detected and allowed for.
N.D. = not detected.
N.A. - no analysis

Sample No.	ppm								%			%	ppm
	Pb	Zn	Cu	Ba	Ni	Sb	As	Sn	Fe	Ti	Mn	Cr	Mo
441	5	103	7	182	26	6	26*	ND	3.7	0.46	0.01	0.19	2
442	7	84	10	235	26	9	16*	7	3.0	0.31	0.03	0.07	1
443	ND	129	17	373	43	12	29*	3	5.8	0.40	0.04	0.12	2
444	24	90	13	170	36	20	ND	28	3.9	0.64	0.01	0.38	2
445	17	286	47	538	79	7	53	2	5.6	0.36	0.16	0.02	6
446	19	74	29	270	43	3	23*	ND	6.7	0.45	0.02	0.11	1
447	14	110	13	314	41	2	18*	3	4.0	0.36	0.02	0.17	1
448	21	103	25	213	41	ND	20*	3	5.1	0.48	0.01	0.18	1
449	56	165	50	318	83	10	64	4	11.2	0.58	0.03	0.10	ND
450	14	85	29	343	31	6	43*	ND	6.6	0.41	0.02	0.10	1
452	37	137	48	474	97	5	58	6	9.6	0.74	0.06	NA	NA
453	11	70	15	241	35	5	23*	1	4.2	0.43	0.01	0.06	2
454	29	120	23	855	54	13	50*	ND	10.9	0.42	0.04	0.07	3
455	19	131	48	1785	95	ND	38	2	9.2	0.68	0.05	0.03	ND
456	129	197	39	245	102	ND	22	ND	9.7	1.26	0.06	0.26	ND
457	34	84	160	274	77	19	111	2	14.2	0.76	0.04	NA	NA
458	16	91	22	260	42	1	20*	1	6.0	0.41	0.05	0.06	1
459	29	144	23	248	43	1	1	4	4.6	0.48	0.02	0.11	1
460	19	133	13	200	42	ND	22*	ND	5.2	0.72	0.01	0.14	1
461	19	116	21	187	40	ND	16*	7	5.9	0.54	0.01	0.20	ND
462	16	95	10	171	41	2	15*	3	3.7	0.73	ND	0.36	ND
463	25	103	27	302	78	6	73*	7	7.1	0.64	0.02	0.10	ND
464	18	143	5	433	57	1	20	ND	26.7	0.53	0.06	0.14	20

APPENDIX II continued

Sample No.	ppm								%			%	ppm
	Pb	Zn	Cu	Ba	Ni	Sb	As	Sn	Fe	Ti	Mn	Cr	Mo
465	42	190	3	157	48	ND	21*	3	17.7	1.92	0.03	NA	NA
466	26	98	18	333	38	7	22*	1	8.4	0.63	0.02	0.14	2
467	29	192	46	477	56	ND	20*	1	7.0	0.61	0.01	0.35	ND
468	22	119	59	369	64	4	7	1	6.2	0.51	0.03	0.02	ND
469	35	56	54	210	57	19	207	ND	13.1	0.53	0.01	0.12	2
470	22	130	52	484	90	5	69	1	7.9	0.61	0.03	0.03	8
471	15	110	19	230	45	2	43*	3	4.4	0.62	0.01	0.13	ND
472	32	119	44	388	88	6	30	ND	6.8	0.60	0.02	0.04	ND
473	31	191	46	468	102	6	12	2	7.5	0.60	0.02	0.02	ND
474	9	91	16	332	53	2	16*	5	4.2	0.47	0.02	0.07	1
475	19	135	19	229	44	3	20*	1	5.3	0.59	0.03	0.16	1
476	21	140	26	375	65	4	14	7	5.9	0.52	0.02	0.04	1
477	11	93	32	191	48	1	22*	1	4.4	0.84	0.02	0.04	2
478	28	103	34	317	88	5	152	2	12.0	0.70	0.04	0.05	3
479	17	116	20	292	48	ND	5	5	5.2	0.61	0.02	0.14	2
480	23	187	14	11474	42	1	3	8	4.8	0.49	0.02	0.04	1
481	317	112	18	240	40	ND	8*	3	3.9	0.44	0.03	0.04	ND
482	30	127	17	306	59	3	25	2	6.4	0.52	0.02	0.11	ND
483	61	143	32	731	81	9	36	7	7.6	0.61	0.02	0.18	ND
484	246	100	15	178	31	3	10*	ND	3.8	0.45	0.03	0.02	ND
485	12	80	21	583	36	1	18*	ND	6.5	0.49	0.04	0.04	3
486	23	101	20	184	46	2	30*	4	12.8	1.19	0.08	0.11	3
487	2235	99	30	222	50	8	14	ND	7.2	0.54	0.04	NA	NA
488	17	133	37	299	58	4	14	4	5.4	0.45	0.05	NA	NA
489	12	119	49	234	39	ND	5	ND	6.6	0.48	0.04	0.04	4
490	135	75	23	357	39	ND	21*	2	5.9	0.61	0.05	0.10	ND
491	11	121	30	358	61	ND	6	ND	6.2	0.51	0.04	0.07	ND
492	16	234	69	858	77	ND	17	2	9.0	0.52	0.36	0.01	6
493	55	153	40	807	65	10	28	5	10.8	0.53	0.25	NA	NA
494	1	84	3	213	33	1	15*	ND	3.6	0.39	0.01	0.32	ND

APPENDIX II continued

Sample No.	ppm								%			%	ppm
	Pb	Zn	Cu	Ba	Ni	Sb	As	Sn	Fe	Ti	Mn	Cr	Mo
495	9	177	5	167	45	5	27*	2	6.7	0.62	ND	0.73	ND
496	13	126	67	155	76	45	160	ND	10.9	0.46	0.03	0.05	10
497	19	117	16	451	55	18	58*	ND	12.8	0.41	0.06	0.27	ND
498	9	109	17	417	38	ND	14*	1	3.9	0.40	0.02	0.42	ND
499	17	180	15	401	43	20	16*	ND	4.5	0.38	0.05	0.10	ND
500	11	75	23	319	50	19	43*	ND	7.1	0.44	0.02	0.04	ND
501	29	89	35	221	43	7	24*	3	6.7	0.49	0.01	0.40	ND
502	16	57	11	278	26	2	11*	ND	2.5	0.32	0.01	0.17	ND
503	6	188	26	287	29	4	29*	ND	6.5	0.49	0.08	0.34	1
504	52	119	80	206	63	4	76*	ND	12.2	0.66	0.01	0.56	12
505	17	351	27	1274	51	2	27*	ND	7.1	0.54	0.02	NA	NA
506	18	99	16	398	52	3	14*	ND	5.3	0.45	0.01	0.21	1
507	35	130	33	406	45	ND	14*	8	4.4	0.45	0.04	0.14	1
508	6	91	13	440	48	2	8*	ND	3.8	0.40	0.03	0.05	ND
509	10	109	3	453	31	ND	16*	ND	2.7	0.62	ND	0.40	ND
510	12	105	15	203	26	ND	13*	7	3.2	0.48	0.01	0.28	1
511	23	116	14	300	30	8	32*	ND	6.2	0.36	0.06	0.36	1
512	63	76	7	292	24	10	25*	ND	4.7	0.34	0.03	0.15	ND
513	9	52	7	254	19	2	15*	ND	1.8	0.39	0.01	0.15	1
514	9	93	25	329	74	ND	5	ND	5.6	0.51	0.03	0.06	ND
515	12	95	22	257	55	3	30*	3	5.2	0.57	0.01	NA	NA
516	4	91	18	207	39	ND	12*	ND	4.7	0.56	0.01	0.21	ND
517	ND	65	13	208	33	ND	24*	ND	6.2	0.43	0.02	0.07	ND
518	13	122	12	249	49	ND	16*	ND	3.6	0.78	ND	NA	NA
519	282	141	23	606	66	ND	10	ND	8.1	0.47	0.05	NA	NA
520	9	188	27	944	41	1	7*	4	3.3	0.48	0.02	0.64	ND
521	9	95	6	318	31	ND	15*	1	2.7	0.36	0.03	NA	NA
522	10	110	13	355	34	ND	17*	3	3.5	0.51	0.03	NA	NA
523	ND	84	14	392	31	ND	12*	5	2.8	0.38	0.02	0.20	ND
524	25	16	12621	390	69	5	27	ND	7.1	0.45	0.05	0.03	2

APPENDIX II continued

Sample No.	ppm								%			%	ppm
	Pb	Zn	Cu	Ba	Ni	Sb	As	Sn	Fe	Ti	Mn	Cr	Mo
525	29	67	306	377	60	13	84	ND	13.0	0.47	0.01	0.09	25
526	15	139	39	408	53	ND	4	9	4.9	0.49	0.02	0.28	1
527	18	137	31	308	56	ND	9*	ND	5.9	0.49	0.06	0.24	2
528	18	97	16	246	36	13	13*	2	4.5	0.47	0.01	0.63	ND
529	265	132	50	1443	73	5	11	2	13.4	0.67	0.02	0.31	2
530	21	76	118	237	51	6	27*	3	6.0	0.60	0.01	0.23	2
531	27	119	45	265	66	25	29*	3	9.8	0.67	0.02	0.50	1
534	30	146	40	569	74	17	33	ND	13.6	0.39	0.06	0.12	1
536	30	125	47	347	113	5	71	46	10.5	0.62	0.04	0.15	ND
537	42	170	45	440	126	14	97	1	12.9	0.53	0.06	0.07	ND
538	45	153	36	7357	115	29	90	ND	17.1	0.59	0.06	0.45	1
539	34	87	13	270	55	27	46	ND	22.6	0.48	0.04	0.26	ND
540	12	96	9	192	34	3	16*	4	3.4	0.72	ND	0.48	ND
541	49	135	29	515	68	ND	1	3	5.6	0.48	0.03	0.07	ND
542	12	615	31	8127	41	39	50*	ND	8.5	0.53	0.03	NA	NA
543	13	99	21	201	50	21	28*	3	12.1	0.43	0.02	0.38	1
544	13	146	23	324	60	5	27*	4	8.1	0.43	0.09	NA	NA
545	16	100	14	2768	70	31	34	1	18.6	0.40	0.04	0.13	4
546B	15	114	22	453	48	12	39*	4	8.6	0.39	0.06	0.20	2
547	9	66	15	377	44	3	21*	2	4.3	0.41	0.01	0.23	ND
548	10	123	17	435	49	ND	11*	ND	3.8	0.43	ND	NA	NA
549	17	137	21	463	54	1	5	5	5.1	0.41	0.06	0.17	ND
550	12	107	9	253	40	1	11*	2	3.2	0.45	ND	0.31	ND
551	13	100	18	306	40	1	10*	4	3.7	0.38	0.02	0.12	ND
552	16	149	180	433	69	6	20*	3	4.9	0.39	0.10	NA	NA
553	5	116	50	315	61	8	37*	3	5.7	0.82	0.04	NA	NA
554	61	204	66	248	54	8	17*	3	12.9	0.72	0.02	NA	NA
555	34	174	44	375	63	8	9	3	9.3	0.45	0.05	0.08	ND
556	52	182	38	630	54	1	8	3	6.2	0.56	0.03	0.22	ND
557	20	116	48	347	56	ND	21	ND	9.4	0.51	0.07	0.14	ND

APPENDIX II continued

Sample No.	ppm								%			%	ppm
	Pb	Zn	Cu	Ba	Ni	Sb	As	Sn	Fe	Ti	Mn	Cr	Mo
559	16	132	37	422	55	3	17	3	6.1	0.72	0.03	0.05	ND
560	13	162	47	479	69	ND	11	3	7.5	0.60	0.05	0.03	ND
561	25	158	29	265	41	2	3	3	6.2	0.62	0.04	0.03	ND
562	4	48	16	135	23	2	15*	1	5.6	1.12	0.03	0.02	ND
563	7	112	49	388	62	6	24	6	7.2	0.58	0.02	0.05	1
564	31	147	93	402	60	34	152	ND	9.6	0.43	0.07	0.02	23
565	6	76	11	186	37	ND	12*	ND	4.3	0.69	0.03	0.19	ND
566	7	71	13	258	36	4	11*	6	3.6	0.53	0.04	0.26	ND
567	18	78	26	244	51	9	7	1	9.2	0.53	0.03	0.30	ND
568	30	137	109	231	63	2	33*	ND	10.5	0.74	0.01	0.41	ND
569	20	74	47	267	46	7	17*	3	11.3	0.55	0.01	0.49	ND
570	18	79	37	250	46	ND	3	ND	7.1	0.48	0.01	0.42	ND
571	6	71	15	198	35	ND	9*	1	5.0	0.64	ND	0.35	ND
572	10	125	25	323	82	ND	14	ND	6.2	0.62	0.03	0.10	ND
573	37	108	ND	159	41	29	29*	1	21.9	1.22	0.06	0.59	ND
574	27	64	ND	174	32	30	17	ND	25.0	0.45	0.03	0.36	7
575	21	121	25	241	68	1	41*	1	9.0	0.92	0.02	0.27	1
577	55	66	10	217	34	24	12*	6	17.0	0.64	0.01	0.42	1
578	41	110	10	186	37	18	14	ND	25.6	0.45	0.02	0.27	5
579	9	102	28	530	55	ND	13	2	5.6	0.51	0.04	0.01	1
580	18	101	24	400	41	ND	3	1	5.2	0.44	0.02	0.07	ND
581	10	76	23	217	38	4	13*	ND	5.6	0.66	0.02	0.30	ND
582	12	81	12	276	37	ND	8*	2	4.4	0.56	0.03	0.15	ND
583	13	82	20	307	45	ND	1	2	5.7	0.51	0.05	0.15	ND
584	15	73	17	173	26	ND	6*	ND	4.1	0.75	0.02	0.03	ND
585	38	101	5	153	39	3	24*	ND	14.6	1.74	0.09	0.39	1
586	7	59	12	177	23	1	13*	ND	3.5	0.57	0.02	0.11	ND
587A	47	71	3	143	38	1	12*	91	2.4	0.61	ND	0.39	ND
588	346	175	8	399	40	ND	19*	ND	13.4	1.56	0.07	0.28	2
589	69	425	38	1981	50	ND	16*	ND	7.3	0.59	0.04	0.09	ND

APPENDIX II continued

Sample No.	ppm								%			%	ppm
	Pb	Zn	Cu	Ba	Ni	Sb	As	Sn	Fe	Ti	Mn	Cr	Mo
590A	18	62	21	222	40	3	6*	ND	7.0	1.14	0.04	0.13	ND
591	18	94	15	329	44	5	58*	ND	6.8	0.44	0.01	0.38	1
592	15	70	15	310	46	ND	ND	1	4.6	0.46	0.02	0.12	ND
593	17	84	31	304	46	ND	ND	6	5.2	0.42	0.03	0.14	ND
594	33	106	32	325	78	ND	21	1	6.7	0.63	0.03	0.25	ND
595	28	136	36	421	86	3	9	4	7.1	0.58	0.04	0.02	ND
596	94	105	19	349	62	3	36	37	5.5	0.61	0.02	NA	NA
597	24	136	48	481	107	6	53	ND	8.1	0.63	0.03	0.03	ND
598	21	115	35	457	99	8	91	ND	9.8	0.68	0.03	0.05	2
599	35	130	22	305	73	9	54	3	9.2	0.70	0.02	0.22	2
600	79	192	44	534	161	30	132	2	17.9	0.59	0.10	0.03	2
601	30	100	36	440	104	3	136	ND	10.6	0.65	0.04	NA	NA

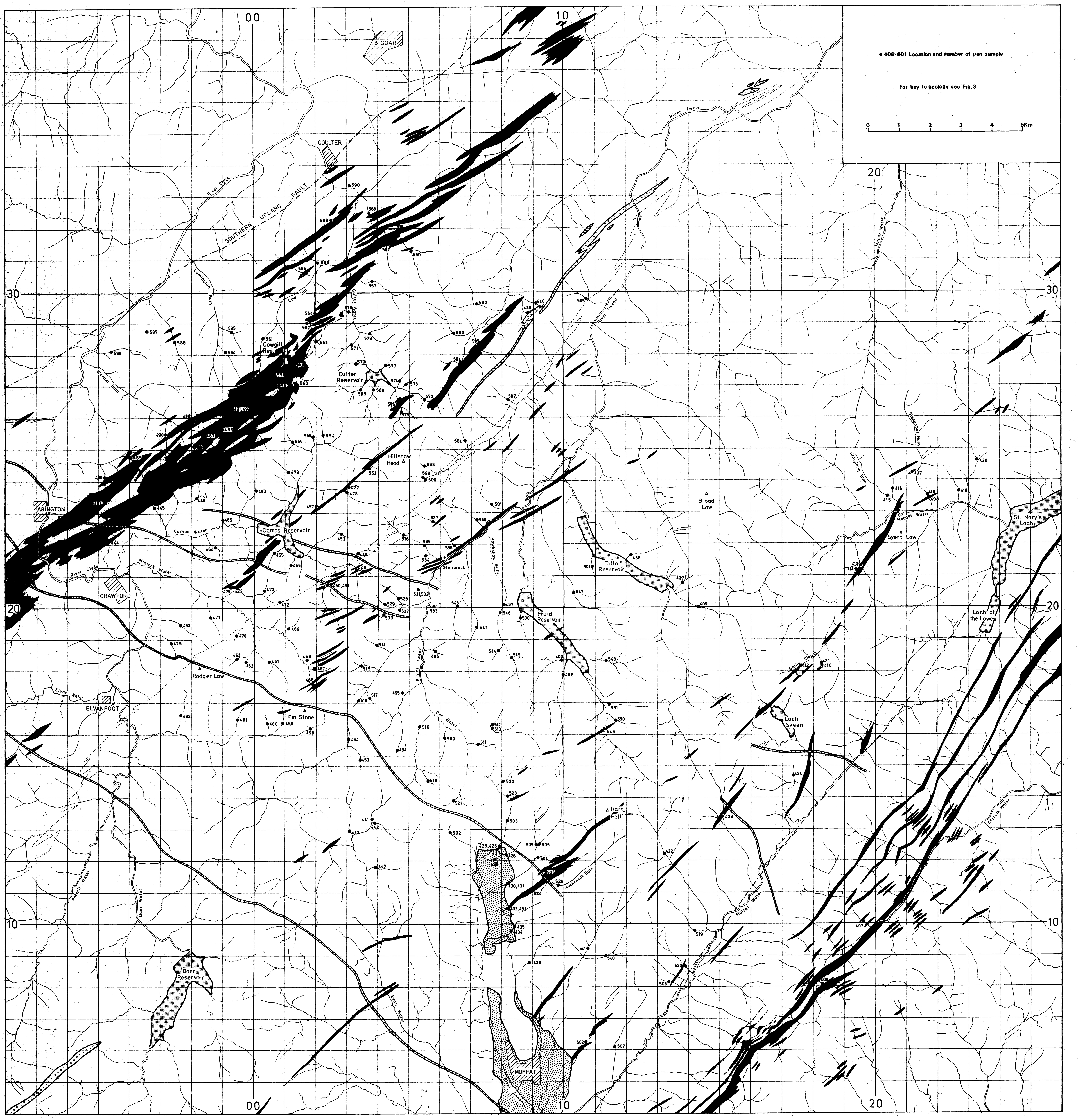

Fig.2 Map of drainage and stream sampling points

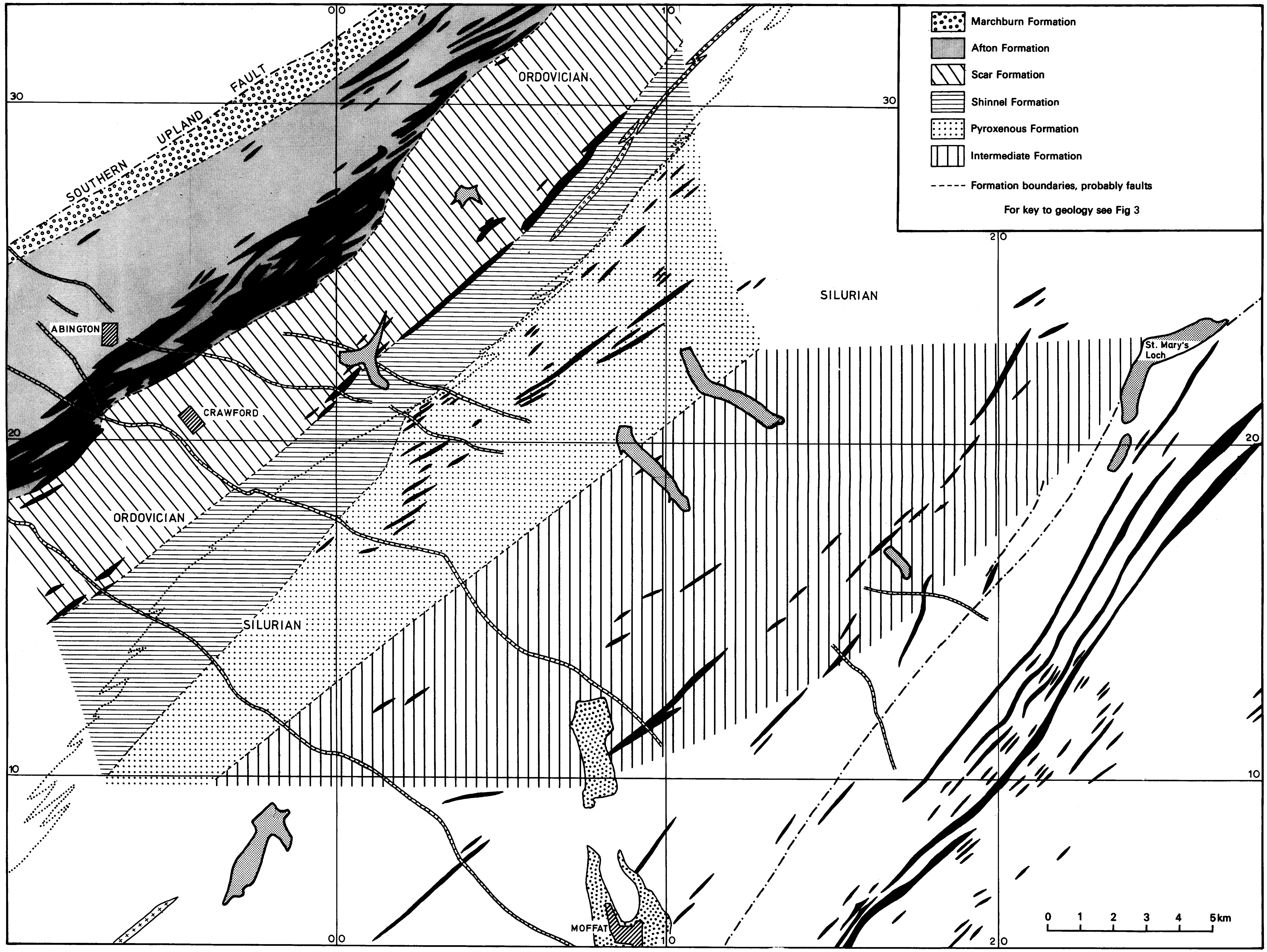

Fig. 4 Distribution map of greywacke formations

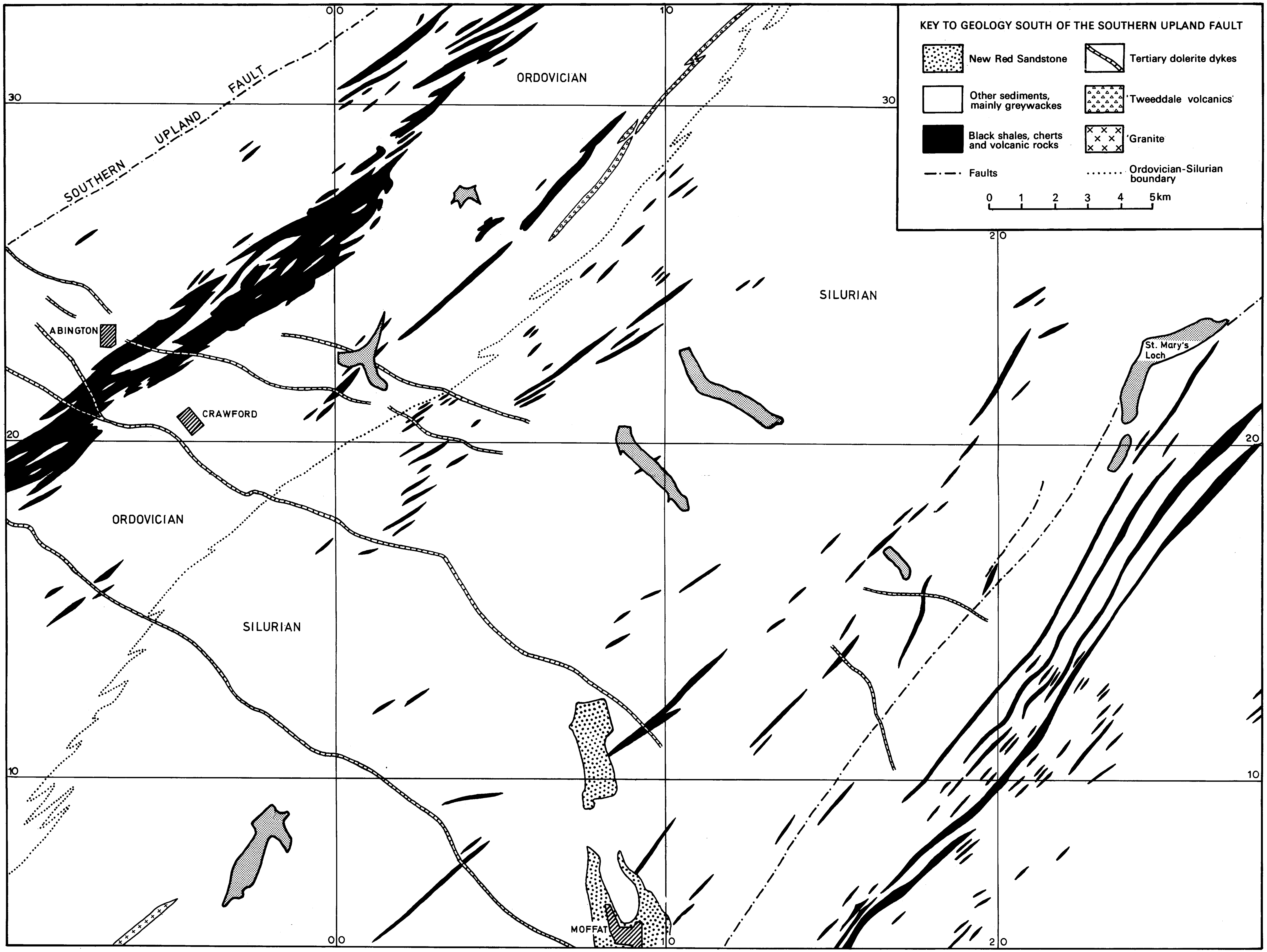

Fig. 3 Geology of the Abington-Biggar-Moffat area

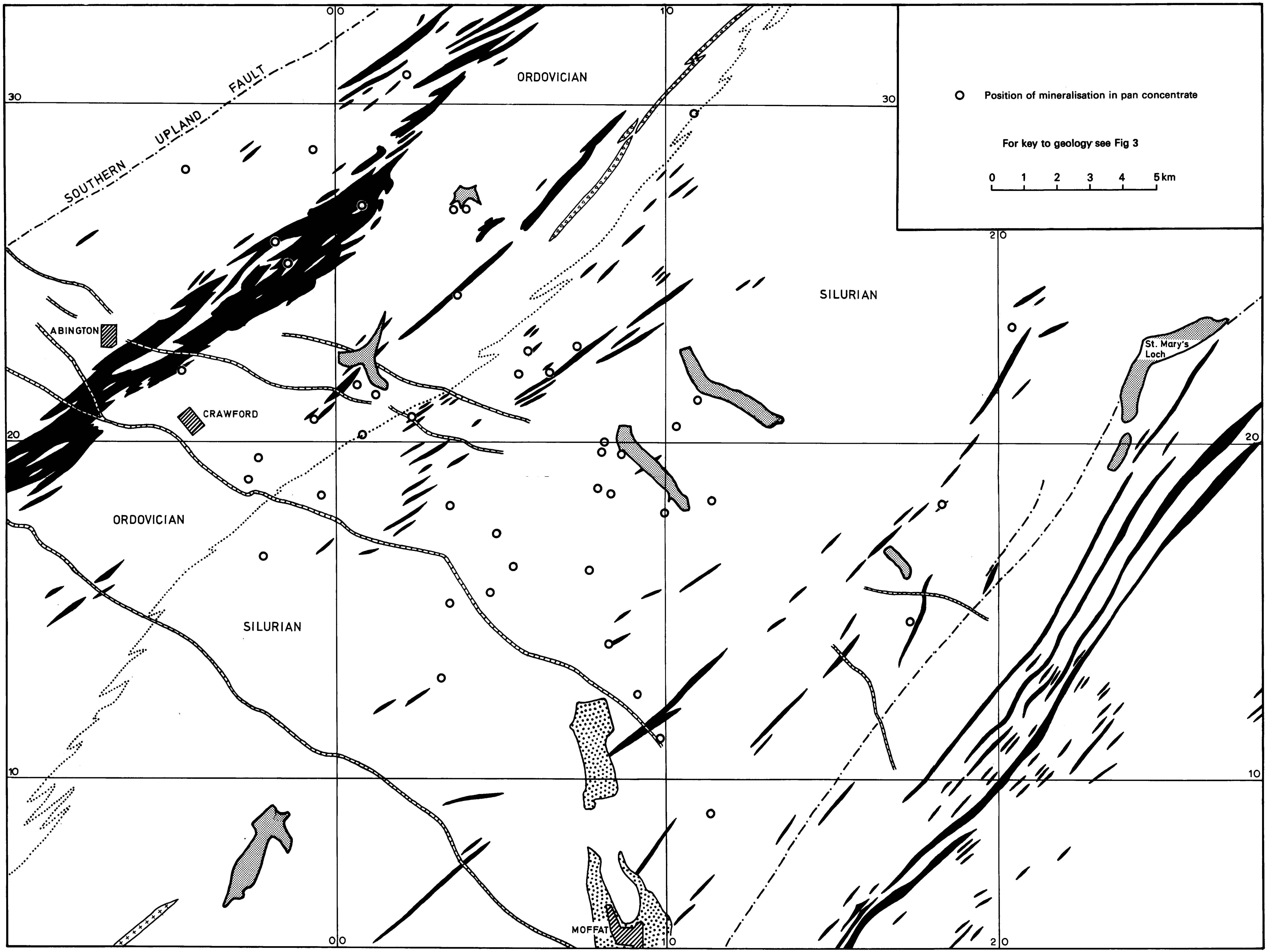

Fig. 5 Distribution of gold

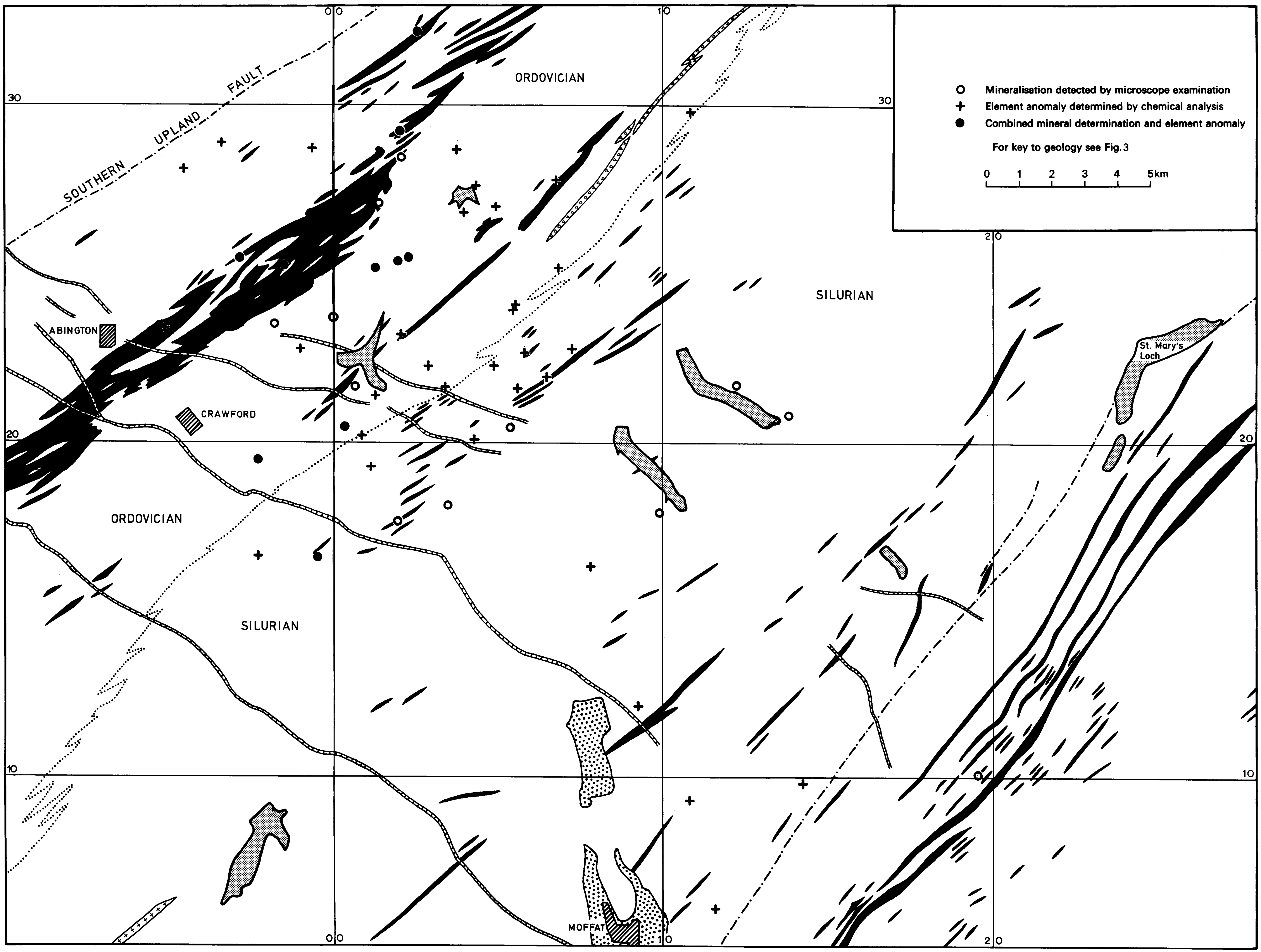

Fig. 6 Distribution of lead

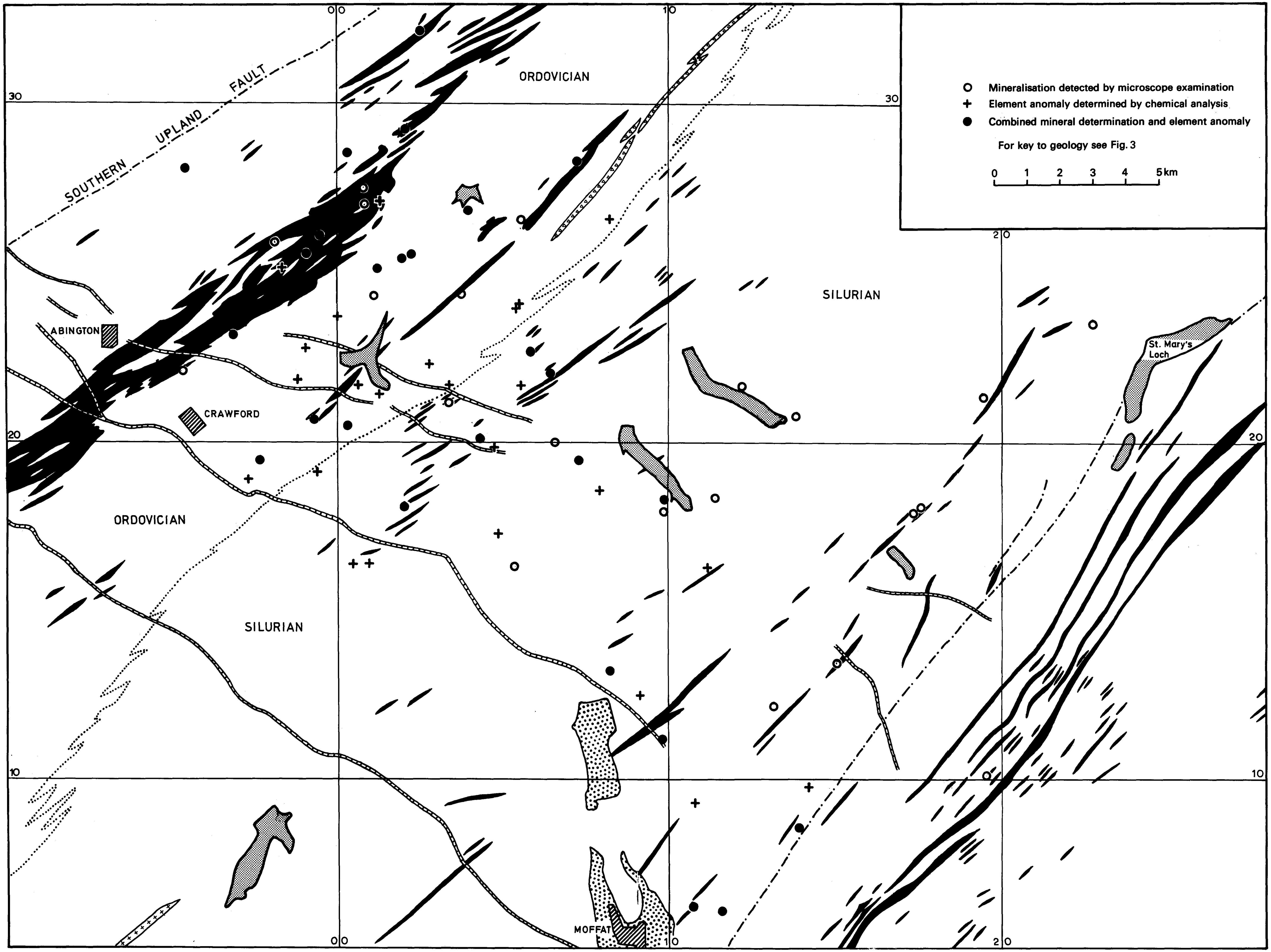

Fig. 7 Distribution of zinc

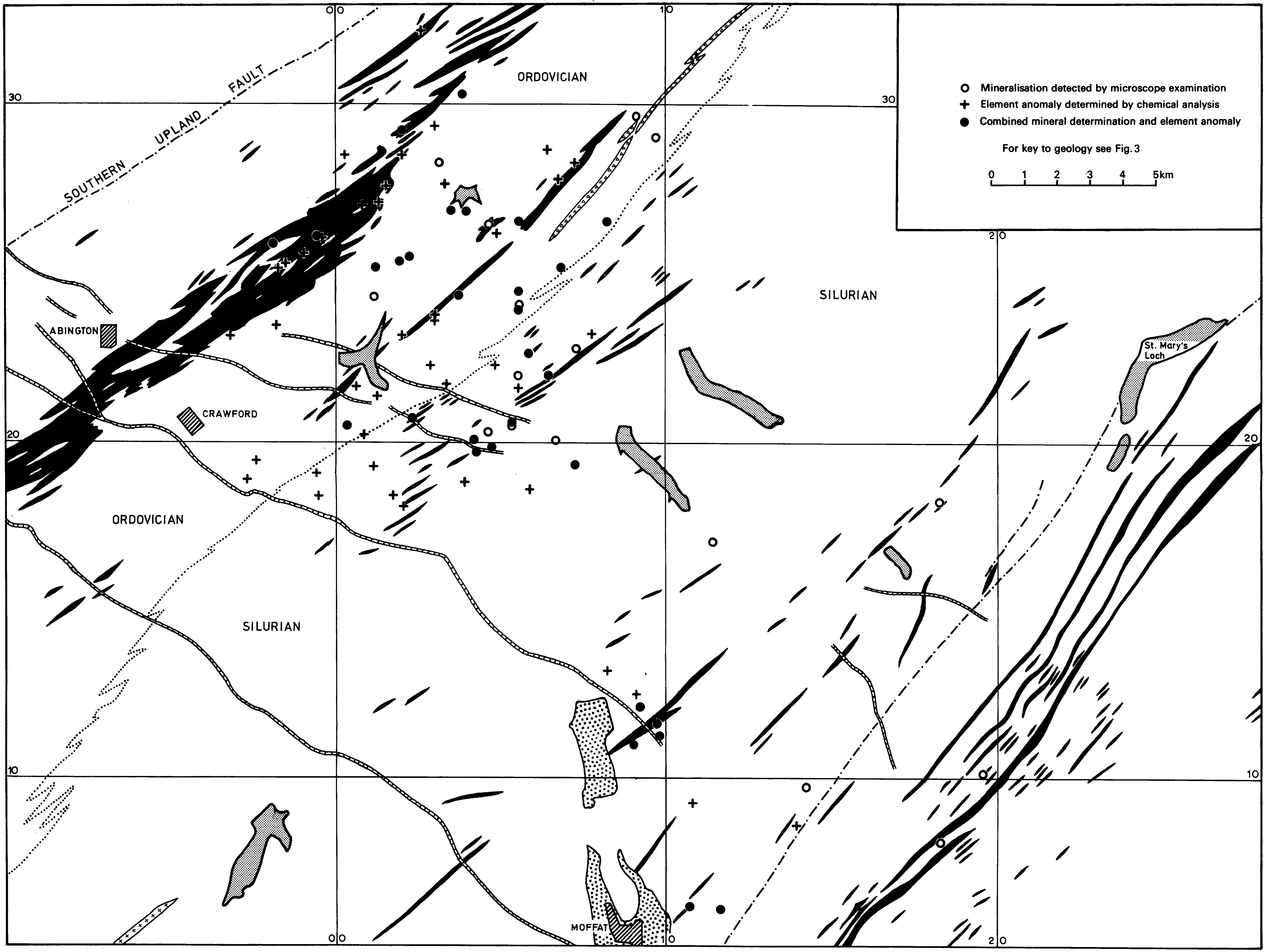

Fig. 8 Distribution of copper

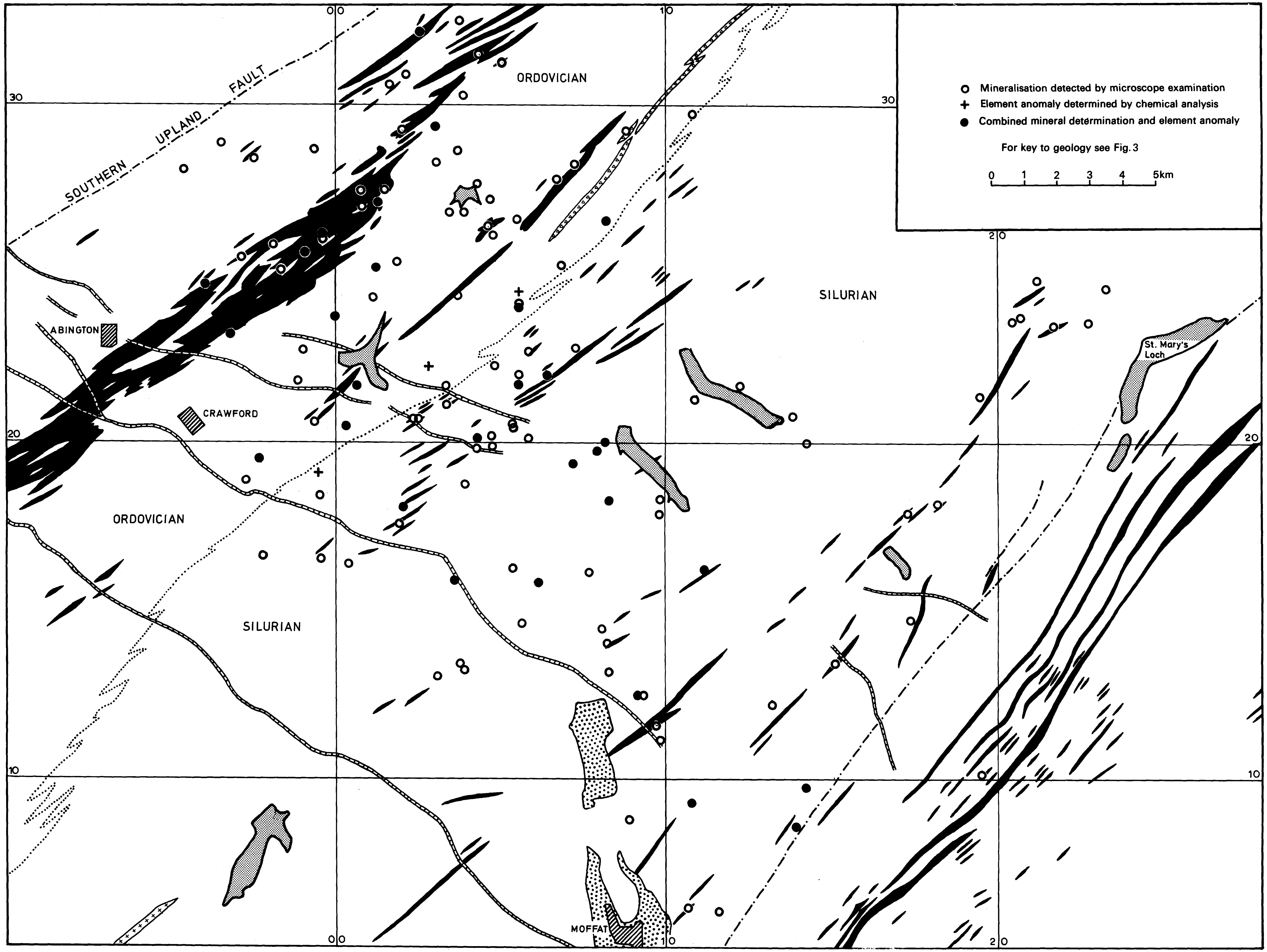

Fig. 9 Distribution of barium