British Geological Survey

Mineral Reconnaissance Programme

Gold exploration in the Duns area, Southern Uplands, Scotland

Department of Trade and Industry

MRP Report 138

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BRITISH GEOLOGICAL SURVEY

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SUMMARY

Following promising indications during regional geochemical sampling in the Duns area of south-east Scotland, a detailed exploration programme was conducted by the Mineral Reconnaissance Programme (MRP) in order to locate and characterise the source of alluvial gold occurrences discovered in the area.

A drainage survey, involving the collection of panned concentrates and stream sediments, resulted in the identification of four areas for follow-up investigation. Close-spaced soil sampling carried out over these areas led to the recognition of markedly anomalous gold concentrations (up to 250 ppb), sometimes accompanied by, or closely-associated with enrichment in arsenic. Excavations to bedrock in two of these areas revealed localised gold mineralisation (up to 5 ppm) in hydrothermally altered greywacke, with attendant enrichment in adjacent minor intrusives, which were themselves altered.

Lithogeochemical sampling of surface outcrops revealed widespread low-tenor (10 - 100 ppb) gold enrichment in hydrothermally altered Silurian greywackes, siltstones and subordinate porphyritic intrusives. Gold values in excess of 100 ppb are associated with dilatent features in the greywacke country rock such as fracture zones, hydrothermal breccias and localised quartz veining.

Mineralisation and alteration of the greywackes is mainly developed adjacent to minor calc-alkaline intrusions of late-Caledonian age. The emplacement of these plutons at a high crustal level is believed to be associated with a previously undetected major east-south-east-trending linear structure, recognised by regional and local aeromagnetic data. Within the same area detailed gravity data revealed the presence of discrete anomalies characteristic of concealed intrusive bodies.

Petrological investigations indicate the localised hydrothermal alteration of greywacke samples collected in proximity to minor porphyritic intrusions. Pervasive propyllitic alteration of some of these intrusives is also evident. Relict sulphide mineralisation was revealed in the form of pseudomorphs after pyrite and possibly arsenopyrite, occurring as disseminations and in fracture veinlets. A later phase of mineralisation, associated with fracturing and involving the precipitation of iron oxyhydroxide minerals, suggests the invasion of high-Eh meteoric waters.

Full data listings, together with detailed logs of samples, are available from the Mineral Reconnaissance Programme Database, BGS, Keyworth, on request.

INTRODUCTION

The investigations described in this report were carried out over an area of the Lammermuir Hills, some 50 km east-south-east of the city of Edinburgh, shown on the regional geology map (Figure 1). The survey described was carried out as part of the Mineral Reconnaissance Programme (MRP), sponsored by the Department of Trade and Industry (DTI).

The dominant rocks of the Southern Uplands region are Lower Palaeozoic turbidite deposits. They are tightly folded and intruded by a series of calc-alkaline granitoid plutons of late Silurian and early Devonian age and a regional dyke swarm ranging from microgranite to lamprophyre. Regional metamorphism of the sedimentary succession to prehnite-pumpellyite facies is fairly widespread, and localised hornfelsing of the greywacke country rock around the margins of the intrusions has occurred. Outliers of Lower and Upper Devonian sedimentary rocks unconformably overlie the turbidite deposits locally.

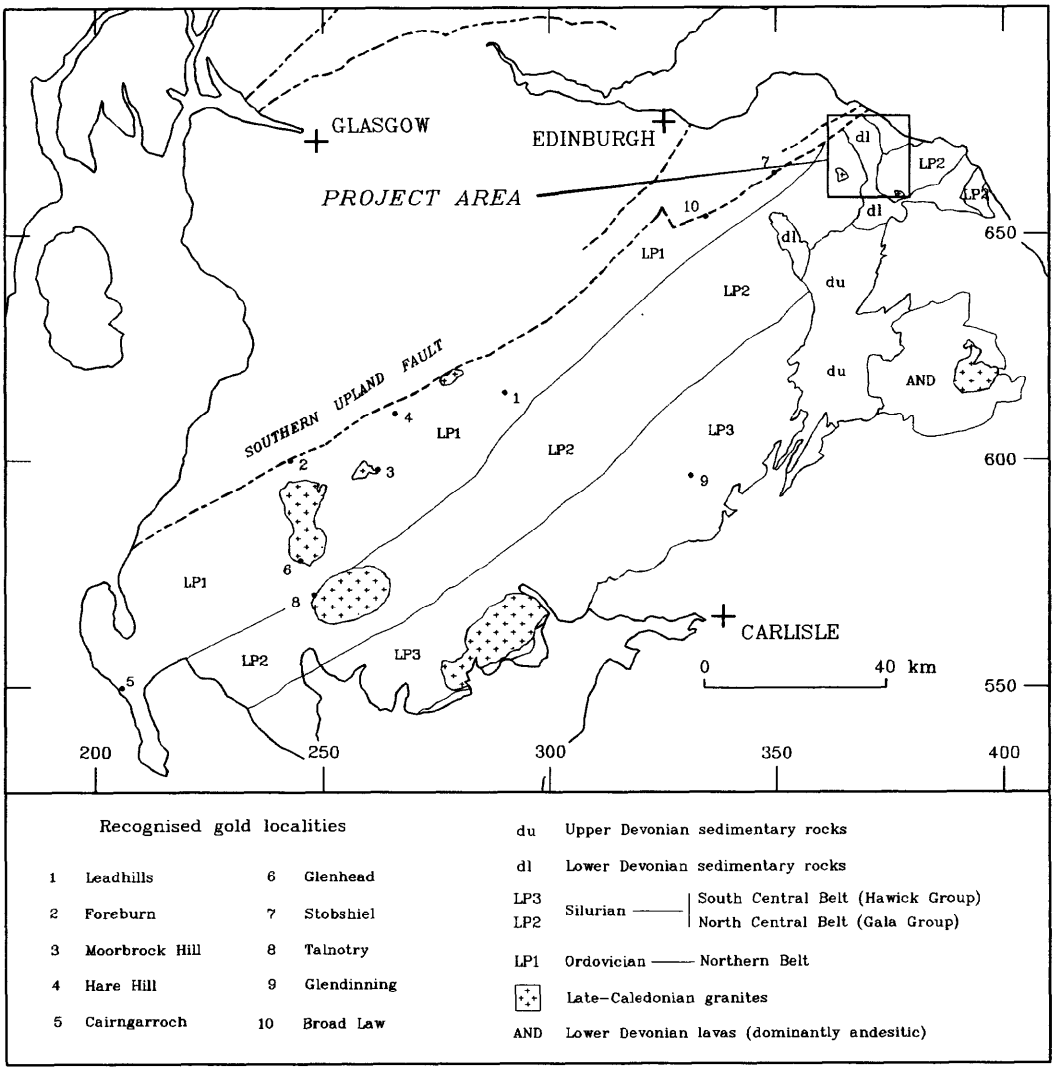

Figure 1 Regional geology of the Southern Uplands, showing location of project area and other gold occurrences

The Southern Uplands turbidite succession has broad tectono-sedimentological similarities with other Phanerozoic, turbidite-hosted gold deposits - the Meguma Group in Nova Scotia and the Lachlan Fold Belt in Australia being the most famous. Economic gold occurrences in these regions are concentrated in dilatant structures such as shear zones, concordant vein systems and saddle reefs. The latter two features occur predominantly along or near the axes of major folds and these form the main targets for potentially economic mineralisation. The apparently erratic spatial distribution of major gold occurrences in many areas of turbidite-hosted mineralisation is believed to be determined by the locations of major deep crustal structures. The proposed genetic model for the mineralisation described in this report involves the emplacement of Devonian granitoid intrusions, with resultant hydrothermal activity and gold mineralisation in shear zones. Silicification, sericitisation and arsenopyritisation at temperatures of 300-350° C commonly accompany the gold mineralisation.

PHYSIOGRAPHY

The region is sparsely-populated and the landscape is dominantly rolling hills, dissected by a small number of glacially-widened river valleys. A few small villages and farms are scattered along these valleys. The market town of Duns is the nearest main centre of population and lies 5 km south of the southern boundary of the project area.

Much of the valley and marginal hill land of the area is utilised for arable and pastoral farming. There has been significant development of commercial forestry during post-war years, and these areas now account for approximately 10% of the project area. Above 300 m elevation most of the ground is uncultivated and is largely used for free grazing and grouse shooting. In these areas the natural vegetation cover is heather or extensive upland grass, with sedge dominating the few wetland enclaves. The climate is cool temperate, with a mean annual rainfall of c. 800 mm.

PLANNING AND DEVELOPMENT FRAMEWORK

The A1 trunk road, 10 km east of the project area, provides good road communications to the area via a network of narrow rural roads. Access to the wider expanses of upland is also relatively easy due to the generally rolling landscape and good vehicle tracks, which may be used subject to the consent of landowners or forestry concerns.

There are no conservation areas close to the main zones of Au enrichment identified by this study, but some are located in the wider (reconnaissance) area. The largest occurs in the north, where the Woodhall Burn catchment [367 672] is designated a Site of Special Scientific Interest (SSSI). The nearby East Lammermuir Deans Nature Reserve [369 669] has also been given conservation status. In the vicinity of Abbey St Bathans there are small areas classified for reasons of natural or archaeological heritage.

The Tod Burn area lies within the Whiteadder Reservoir catchment and any proposals for development would have to address this constraint.

PREVIOUS WORK

Southern Uplands

The first significant recorded extraction of gold in the Southern Uplands took place in the 16th century, when several thousand ounces was worked from streams in the vicinity of Leadhills (Figure 1). The development of lead mining in the same area in the 19th century led to a revival in working the same deposits by the itinerant labour force. During this century the western half of the Southern Uplands region has been the frequent haunt of amateur prospectors and, in recent years, of geologists attempting to establish the whereabouts of bedrock sources.

Alluvial gold is widespread in the Southern Uplands region, and a number of significant bedrock sources have been identified and documented in recent years (Figure 1). In most of these localities a mesothermal style of mineralisation has been recognised. The most likely source of gold-enriched hydrothermal fluids is believed to be the turbidite pile at depth, with fluid migration dependent on protracted thermal flux as a result of granitoid emplacement. Detailed studies began in the early 1980s, with reports by BGS on gold occurrences at Loch Doon (Leake et al., 1981; Leake, 1982) and Fore Burn (Allen et al., 1982). More recently, commercial interest has prompted further detailed studies at Fore Burn (Charley et al., 1989) and Hare Hill (Boast et al., 1990). No economic occurrences of gold have been discovered during the course of these investigations.

In most cases a clear intrusion-related association has been identified. For example, the Glenhead Burn locality (Leake et al., 1981; Leake, 1982) occurs on the southern margin of the Doon granite and contains arsenopyrite, pyrite and native gold in quartz veins in hydrothermally altered Ordovician greywackes. At Moorbrock Hill (Beale, 1984; Naden and Cauldfield, 1989; Boast et al., 1990) localised Au concentrations, in the range 1-3 ppm, occur in quartz-pyrite-arsenopyrite veins in a north-east-trending zone of intense hydrothermal alteration. Investigations at Hare Hill by BP Minerals International Ltd. and Newmont Overseas Exploration Ltd. (Mineral Exploration and Investment Grants Act Open File Project No. 257) established the presence of a mesothermal Sb-Au system associated with the late-Caledonian Hare Hill granitoid intrusion. This mineralisation is concentrated in structures associated with an area of regional-scale sinistral shear. Immediately north of the Southern Uplands Fault at Fore Burn, gold mineralisation occurs in veins in brittle fracture zones and stockworks within porphyritic diorite. The alteration assemblage in the vicinity of the Au+As+Cu mineralisation at this locality is tourmaline, sericite, carbonate, chlorite and apatite.

Sampling by the Geochemical Survey Programme of BGS in the mid-1980s (British Geological Survey, 1993) identified regional enhancement of As in stream sediments across the Northern and Central belts of the Southern Uplands (Figure 1). High-tenor As enrichment occurs in proximity to the Doon and Fleet granitoid plutons in the western half of the region, sometimes coinciding with anomalous values for Au. Studies of this association have established a mesothermal signature for gold mineralisation, intimately linked with the emplacement of late-Caledonian granitoids (Naden and Cauldfield, 1989; Dullar, 1989). Fluid inclusion studies by Naden and Cauldfield on Au-As mineralisation at Glenhead, Hare Hill, Moorbrock Hill and Stobshiel identified early quartz-pyrite-arsenopyrite mineralisation and associated hydrothermal alteration within sedimentary-granitoid-hosted deposits. Pressure - temperature modelling of fluid-inclusion data indicates a near-linear trend ranging from high-temperature inclusions

(350°C, 2-3 kbar) to low-temperature inclusions (200°C, 0.5-1 kbar). Microthermometric and isotopic data indicate that the hydrothermal systems were initiated at depths of 3-5 km and that mineralisation took place over a protracted period. The source of the Au in these mesothermal systems is not yet known, although potential igneous and sedimentary sources have been suggested. The occurrence of methanoic fluid inclusions in the mineralised quartz veins indicates that fluid mobilisation occurred within the graphitic Ordovician shales.

Duns area

Accounts of past mineral extraction in the project area are sketchy. The copper mines at Ellemford [372 660] and Hoardweel [378 660] were worked in the 18th century but there are no records of production. The Hoardweel Mine workings are the more extensive, with three main adits and surface workings driven parallel to the regional strike. Spoil material is not evident and was probably dumped in the adjacent River Whiteadder. A third copper mine, reported by a local source as being located to the south-west of the Whiteadder Reservoir in the lower catchment of the Faseny Water [364 662], was not found. A small trial, possibly for copper, is located in the upper catchment of the Killmade Burn [3659 6616] but is not recorded in the literature.

It was during regional geochemical investigations by BGS in 1983 that gold was found in the Duns area in panned concentrates. The main cluster of gold-bearing sites is immediately west of the Whiteadder Reservoir, near the margin of the Priestlaw pluton. Stream-sediment and panned-concentrate samples were not routinely analysed for gold, either as a result of this survey or subsequently. However, the data for arsenic in stream-sediments show a medium-tenor enrichment in the vicinity of these gold occurrences, as well as the more distinctive regional enhancement throughout the northern part of the Southern Uplands.

REGIONAL GEOLOGY

The Lower Palaeozoic greywackes which underlie much of the Southern Uplands of Scotland can be divided into several discrete lithostratigraphical units which are fault-bounded and have and elongate, north-east trend parallel to the regional strike (Stone et al., 1987). Bedding is generally vertical or steeply inclined and, despite locally intense folding, overall younging within individual formations is towards the north-west. However, the formations themselves become sequentially younger towards the south-east such that the older, Llandeilo-Caradoc strata crop out at the north-west margin adjacent to the Southern Upland Fault, whereas the youngest, late Wenlock rocks are seen in the south-east along the Solway coast. These structural and stratigraphic relations are the result of imbricate thrusting at the Laurentian margin of the early Palaeozoic Iapetus Ocean during the development of either a forearc accretionary prism (Leggett et al., 1979) or thrust stack propagating sequentially from a back arc to foreland basin (Stone et al., 1987).

The accretionary prism model envisages the greywackes being deposited in a deep ocean trench at an active continental margin of the early Palaeozoic Iapetus Ocean where the oceanic plate was subducting north-westward. As the oceanic plate descended, its covering of sediment was scraped off and stacked at the continental margin in a series of thrust slices. Since the greywackes would only be deposited above the pelagic sediments covering the oceanic plate as it approached the trench, the age of the greywackes in each thrust slice becomes younger. The alternative model involves the initiation of the Southern Uplands within a back-arc basin, which developed into a sequential back-arc to foreland basin thrust system following continental-arc collision in the early Silurian.

Regional geochemical data for the Southern Uplands have been interpreted in support of the back-arc to foreland basin transition (Stone et al., 1993). A continuing BGS remapping programme is currently providing much new information on the regional tectonic development. However, the project area described in this report has not been significantly remapped. Whichever model is preferred, the essential thrust geometry is fundamentally the same and developed diachronously so that structures in the north-west of the Southern Uplands formed earlier than those in the south-east.

The Southern Uplands Lower Palaeozoic succession can be divided into three distinctive stratigraphic tracts, the Northern, Central and Southern Belts.

The Northern Belt comprises rocks of Ordovician age and includes distinctive graptolitic black shales (Moffat Shale group) and polymict conglomerates containing granitic clasts of cratonic origin. Floyd and Rushton (1993) identified at least eight petrographically distinct lithostratigraphic greywacke formations within this belt, with material sources from both cratonic and volcanic (probably island-arc) terranes. The volcanic-derived greywackes are noted for the abundance of fresh pyroxenes (Styles et al., 1989), but also contain significant proportions of plutonic, low-grade metamorphic and sedimentary rock fragments.

The Central Belt comprises two main lithological subdivisions. The older of these (Gala Group), comprises rocks of Llandovery age which are relatively quartz-rich, although the lower sequences contain up to 10% detrital grains of pyroxene and amphibole. The mafic constituents confirm that erosion of the volcanic source area was still taking place during the early to mid-Llandovery times. In contrast, the younger Hawick Group (late Llandovery to early Wenlock) greywackes are markedly more calcareous and devoid of a significant basic volcanic component.

The Southern Belt (Riccarton Group) succession of turbidites of mid- to late-Wenlock age incorporates Hawick Group material from the north due to uplift and erosion. The abundant shelly fragments are probably derived from reefs fringing the emerging landmass to the north (Kemp, 1986).

GEOLOGY OF THE PROJECT AREA

Silurian

The project area is underlain by the Gala Group; thickly bedded (0.2 - >3 m) quartzose greywackes form between 50 and 90 per cent of the sequence, with subordinate siltstones and silty mudstones (Figure 2). The succession is best exposed in the lower section of the Killmade Burn, immediately south-east of the Whiteadder Reservoir [366 662] and in the major streams draining northwards into the reservoir catchment. In the upper part of the Gala Group the thinner-bedded, finer-grained units are more abundant, generally in the range 0.5 - 5 m, but locally exceeding 100 m..

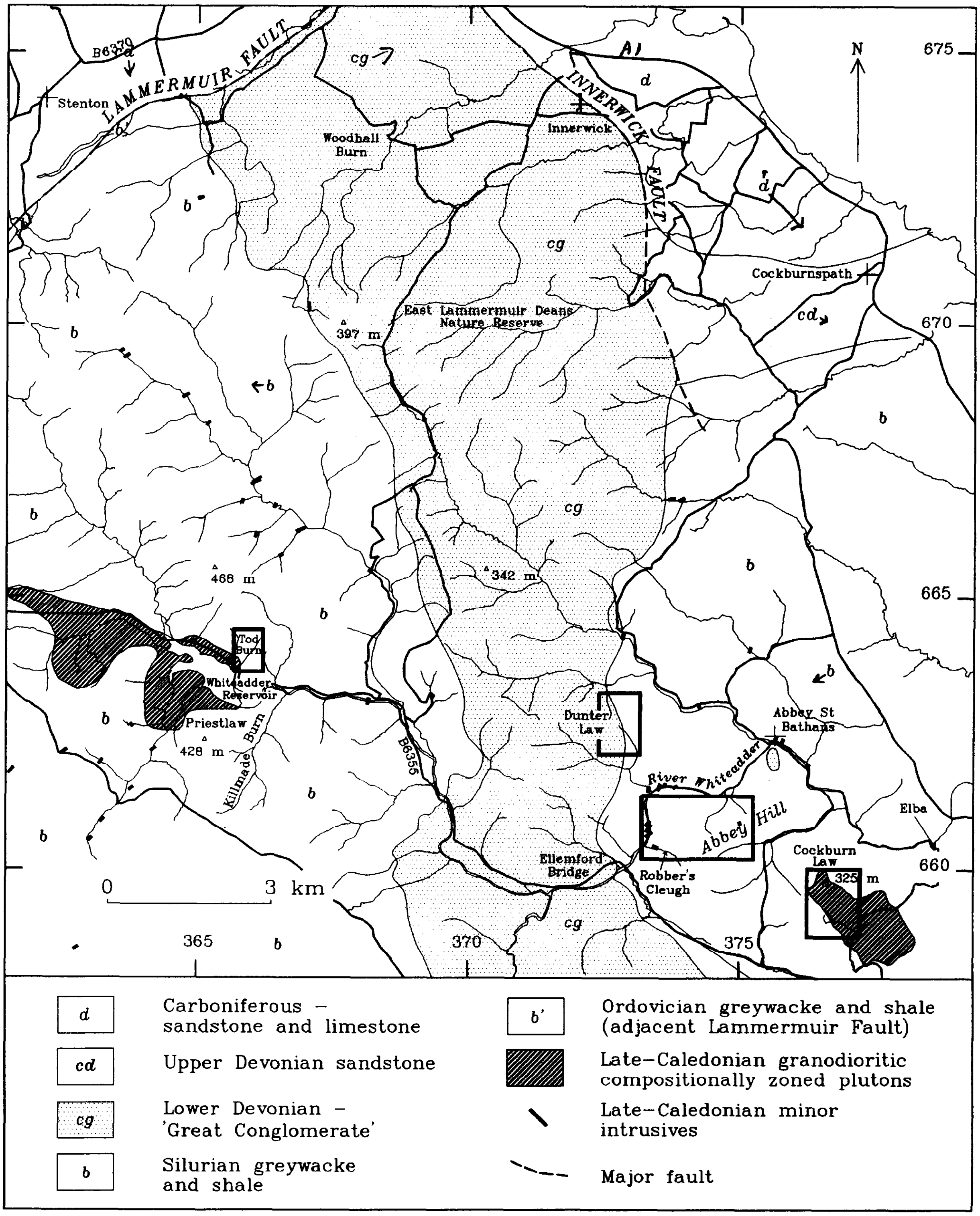

Figure 2 Locational and geological map of project area (detailed sampling areas boxed, road network marked)

Due to the absence of distinctive marker horizons within the sedimentary succession, correlation along strike between adjacent exposures is seldom possible. Only rarely do the finer-grained units attain thicknesses in the order of tens of metres and allow some measure of local structural control; one such example is exposed along the Whiteadder Forest Track east of Ellemford Bridge. The dominant strike direction is north to north-east over most of the project area. Units are generally tightly folded and rotated to a sub-vertical attitude. The dip of rocks is usually in the range 60 - 70° and mainly to the north-west. There is evidence of tight, upright folding locally and a widespread slaty cleavage has been imposed, particularly in the finer-grained lithologies. Although way-up indicators are rare, inversion of some beds can be established by flute-casting on their lower surfaces, such as in the excellent roadside exposure near Cranshaws [368 662].

The greywackes and siltstones are locally reddened, possibly as a result of the circulation of oxidised meteoric water following uplift during early Devonian times (J S Coats, oral communication). However, the proximity of the most pervasively oxidised turbidites to the Priestlaw intrusion suggests that oxidation was also influenced by hydrothermal processes.

Devonian

The Silurian turbidites are unconformably overlain by the poorly-sorted Great Conglomerate of Lower Devonian age, based on the dating of a lamprophyre which cuts the conglomerate (Rock and Rundle, 1986). These rocks form a continuous north-trending outlier within the central part of the project area (Figure 2, stippled) and a small outlier in the Abbey St. Bathans area [375 661]. A maximum thickness of several hundred metres has been estimated for the succession. Exposure of the conglomerates is generally poor, but their extent may be discerned from deeply incised steep-sided stream valleys, often dry or ephemeral, which are a characteristic weathering style. The conglomerate comprises pebbles, cobbles and boulders of greywacke in a weakly cemented matrix of finely comminuted greywacke material. Igneous clasts are rare. Deep fluvioglacial erosion of the major watercourses, such as the Monynut Water and in the East Lammermuir Deans area (Figure 2) has created the best exposure of the conglomerates, in the form of 'badlands-style' weathering.

Intrusions

A variety of late-Caledonian intrusives cut the Silurian rocks. The largest of these (Figure 2) are the two granitoid plutons of Priestlaw (c. 4 km^2) and Cockburn Law (c. 2 km^2), dated at 408.5 +/- 5.6 Ma and 413.7 +/- 4.2 Ma respectively by Thirlwall (1988). They are related to the main late-Caledonian calc-alkaline intrusive phase which took place between 430 and 390 Ma (Stephens and Halliday, 1974). Compositional zoning in the Priestlaw pluton includes distinctive noritic and basic pyroxene-mica granodiorites (Shand, 1989). Around the Cockburn Law intrusion the greywackes are hornfelsed within a zone which broadens on its north and north-east sides up to 1 km in width. A third pluton of similar age is located to the east of the project area at Lamberton Moor. It has been suggested that these intrusions are apophyses of a major intrusion - the Tweeddale Batholith. This hypothesis is based on the presence of an extensive negative north-east-trending Bouguer anomaly across much of the eastern part of the Southern Uplands (Lagios and Hipkin, 1979).

A range of late-Caledonian porphyritic dykes of acid, felsic and intermediate composition intrude the Lower Palaeozoic succession but are absent in the Great Conglomerate, suggesting that this phase of intrusive activity pre-dates deposition of the conglomerate. The majority of these are exposed to the south-west of the Priestlaw intrusion (Figure 2) and in the valleys of the River Whiteadder and Monynut Water near Abbey St Bathans, Elba [378 660] and along the Whiteadder forest track at Robber's Cleugh [373 660]. Their widths vary from <1 to 24 m, but their linear extents cannot be readily discerned. The dominantly north-east trend of these intrusions is roughly concordant with the strike of the greywackes. A number of distinctive intrusive types are locally present and include a north-south-trending quartz porphyry dyke in the Nether Monynut [372 664] and calc-alkaline lamprophyre (minette) dykes such as at Elba [378 660]. Most of the exposed dykes show only limited alteration. Evidence from pitting operations suggests that intrusions which are intensely hydrothermally altered do not readily form outcrop and so may be more abundant.

A genetic link between the minor intrusions and the Priestlaw and Cockburn Law plutons is suggested by their close proximity. Local cross-cutting relationships indicate multiple phases of intrusive activity.

A later Carboniferous suite of basaltic dykes (not shown in Figure 2) is found within the Great Conglomerate. These are discussed in greater detail in the Structural Interpretation section.

Quaternary

Superficial deposits over the project area are of two principal types. The main valleys such as that of the River Whitteadder are filled with fluvioglacial deposits, largely of Devensian age. These predominantly cobble to sand-sized deposits form broad, planar expanses of valley fill. Over almost all the higher ground the drift is dominantly of residual nature and generally less than 2.5 metres in thickness. Most of these soils are of the brown earth variety and overly C horizon material comprising fragments of bedrock with a minor matrix component of soil. A few boggy areas exist on flat-lying high ground and there thicker, gleyed soil profiles are locally developed.

RECONNAISSANCE INVESTIGATIONS

Reconnaissance drainage sampling was carried out over a 150 km^2 area. Stream-sediment and panned-concentrate samples were collected from most of the sites.

Sample collection, preparation and analysis

Sampling was undertaken according to the techniques developed for precious-metal exploration as described by Gunn (1989). To prevent undue loss of gold while digging, sampling was carried out using a concave-bladed shovel with raised back edge plate. Panned-concentrate samples were collected in the field by wet screening through a nylon mesh, followed by washing to remove clays and reduction by panning to a standard final volume. Four litres of <2 mm fraction material was panned down to 150 ml final volume. Stream-sediment samples were obtained by wet screening to <150 μm. The sediment was allowed to settle prior to pouring off excess water and decanting into a Kraft bag.

Moderate-density sampling of low-order streams (c. 1 site per km^2) was used to facilitate discrimination of discrete source areas of Au. Care was taken to avoid winnowed fine sediment and pool sections to reduce the potential for sampling bias as the result of poor site selection.

In the laboratory, panned-concentrates were dried at low temperature and then milled using a chrome - steel Tema mill down to 100 µm. Stream-sediment samples were dried, disaggregated and homogenised prior to sub-sampling for analysis. Both sample types were analysed for a range of elements by X-ray fluorescence spectometry (XRF) at BGS, Keyworth using a 12 g subsample with 3 g 'elvacite' binder. Analysis for Au was carried out by lead fire assay of 30 g followed by inductively coupled plasma mass spectometry (ICP) or atomic absorption spectometry (AAS) techniques at Acme Analytical of Vancouver. This method provides a lower detection limit of 1 ppb.

Panned-concentrates

Panned-concentrates were collected from a total of 181 sites. Gold grains, generally in the size range 0.1 to 0.3 mm, were found at approximately 40% of sites draining Lower Palaeozoic rocks. With the exception of one site [367 671] no gold grains were found at sites over the Devonian conglomerate or downstream of the unconformity on its western margin.

Summary statistics for panned-concentrates (Table 1) indicate the high 75 percentile value of Au (335 ppb). There are no Spearman Rank Correlation Coefficients significant at the 99% confidence level between Au and other elements.

Table 1 Summary statistics for panned concentrates
n=181
Values in ppm except for Au and Hg in ppb

	Minimum	25%	Median	75%	90%	Maximum
Au	1	3	6	335	1706	105400
Hg	5	5	15	20	45	705
Ca	500	1000	1200	2000	3160	141900
Ti	1830	3865	4250	5335	6760	43100
V	33	72	89	112	173	351
Cr	15	201	336	655	1034	3545
Mn	230	435	600	800	978	4070
Fe	13100	37900	45600	66050	89560	187200
Ni	8	25	31	40	48	82
Cu	5	13	16	21	28	66
Zn	28	61	81	96	118	293
As	5	17	31	73	133	424
Ag	0	0	0	2	4	15
Sn	0	0	1	4	9	148
Sb	0	3	4	8	13	250
Ba	117	292	429	827	8514	98699
Ce	27	41	51	63	109	480
Pb	0	10	16	29	53	461
Bi	0	0	0	0	1	5

The distribution of gold in panned concentrates is shown in Figure 3. Most of the elevated Au values lie in an east-south-east-trending zone, close to the Priestlaw and Cockburn Law intrusions. Between these two areas, streams draining the Great Conglomerate, to the north-west of Ellemford Bridge, contain uniformly low Au levels. To the west of this, Silurian rocks are also gold-deficient. Atypically, the streams in this area drain gently sloping, undulating ground, and the drift thickens markedly. The potential for upgrading of gold, and other heavy minerals, in these streams will be influenced by this factor.

The median Au value of 6 ppb is close to the level expected for greywacke - siltstone sequences. The highest Au value (>100 ppm) was from the Killmade Burn [366 661] near the southern margin of the Priestlaw intrusion. Seven grains of gold were identified in the pan, up to a maximum size of 0.5 mm. The majority of streams immediately north of the Priestlaw intrusion also show medium to high tenor Au enrichment. Multiple gold grains were also observed in streams draining the Abbey Hill area, in particular the Robber's Cleugh [373 660] and Steele Burn [374 661] and in the Dunter Law area (Philip Burn) [372 663]. Two samples with elevated Au were also found over the northern part of the Great Conglomerate.

The spatial distribution patterns for Au and As (Figure 4) are similar, with the majority of anomalous sites lying in an east-south-east-trending belt, between the Priestlaw and Cockburn Law intrusions. Au shows only a weak association with Ag and the base metals. The distribution pattern for Pb (Figure 5) indicates sporadic enrichment at sites in the vicinity of the Whiteadder Reservoir, Ellemford Bridge and Abbey St. Bathans. However, the most conspicuous cluster of values exceeding 200 ppm occurs in the northern part of the area, to the west of Innerwick. This zone also contains elevated levels of Ag (Figure 6) and As, suggesting the presence of a number of mineralised bedrock sources.

There is no evidence for the glacial transport of mineralised material from adjacent areas, although localised marked fluvial upgrading may account for some of these anomalies. The occurrence of enhanced Hg in panned-concentrates (Figure 7), in a zone overlapping the Ag and base-metal anomalies supports a local derivation.

Stream sediments

A total of 149 <150 μm stream-sediment samples were collected during the reconnaissance phase of investigations. The median Au concentration in stream sediments is 4 ppb (Table 2), within the range typical for greywacke-shale sequences.

In common with panned concentrates, Au shows consistent enrichment in streams draining the margins of the Priestlaw intrusion, with the highest values (up to 1180 ppb, in a sample from the Tod Burn [365 663] occurring near its northern boundary (Figure 8). In this area the majority of Au values >100 ppb occur in streams immediately north of the mapped northern margin of the intrusion, over a distance of approximately 4 km. To the north of this an abrupt change to values close to the minimum detection limit is seen.

An area containing enhanced Au values occurs near the south-eastern corner of the project area, stretching from Cockburn Law to the eastern unconformity of the Great Conglomerate. In contrast with the Whiteadder Reservoir occurrences, the distribution of the anomalous sites in this area is more sporadic, and a number of the sites occur along the eastern margin of the Great Conglomerate.

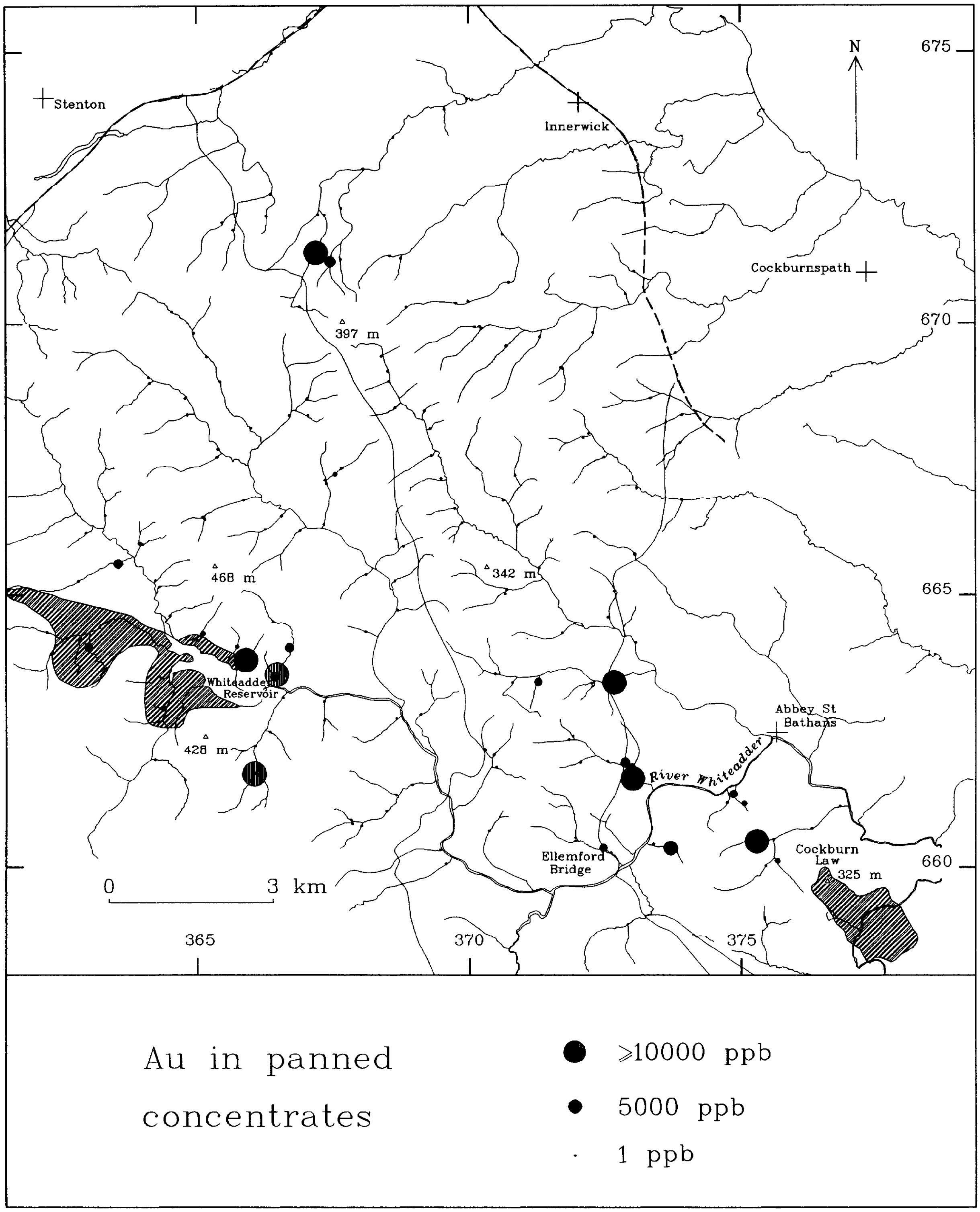

Figure 3 Distribution of Au in panned concentrates

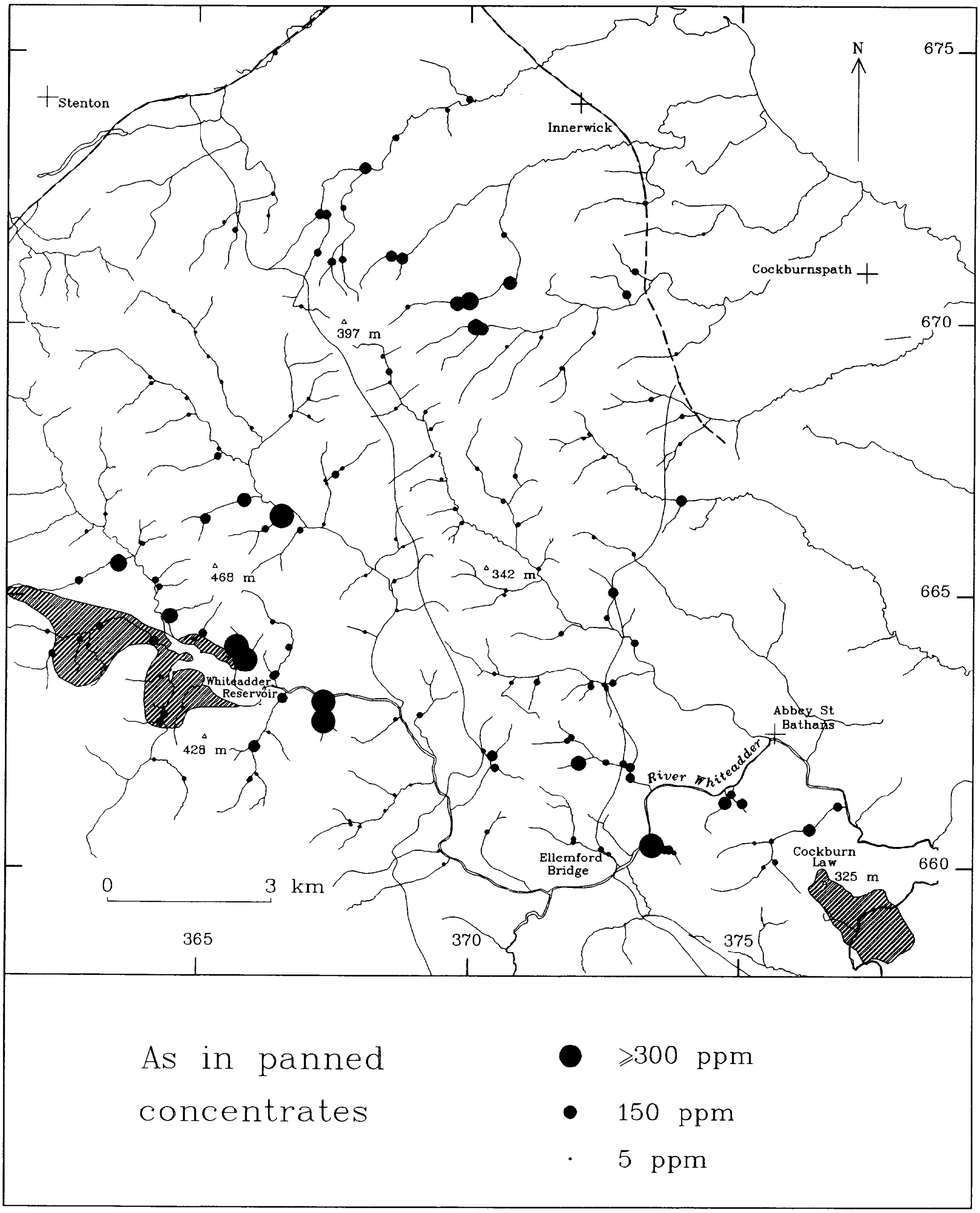

Figure 4 Distribution of As in panned concentrates

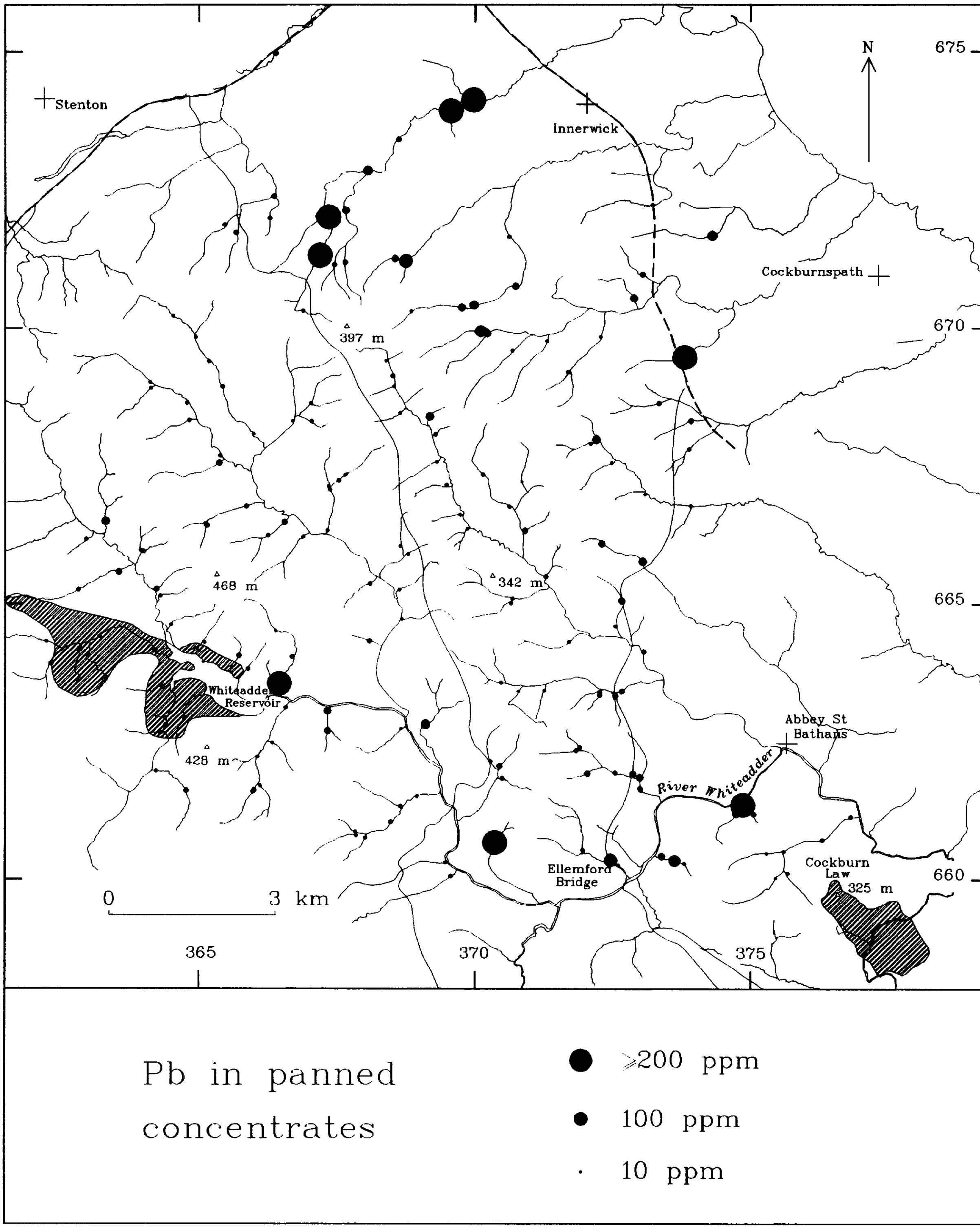

Figure 5 Distribution of Pb in panned concentrates

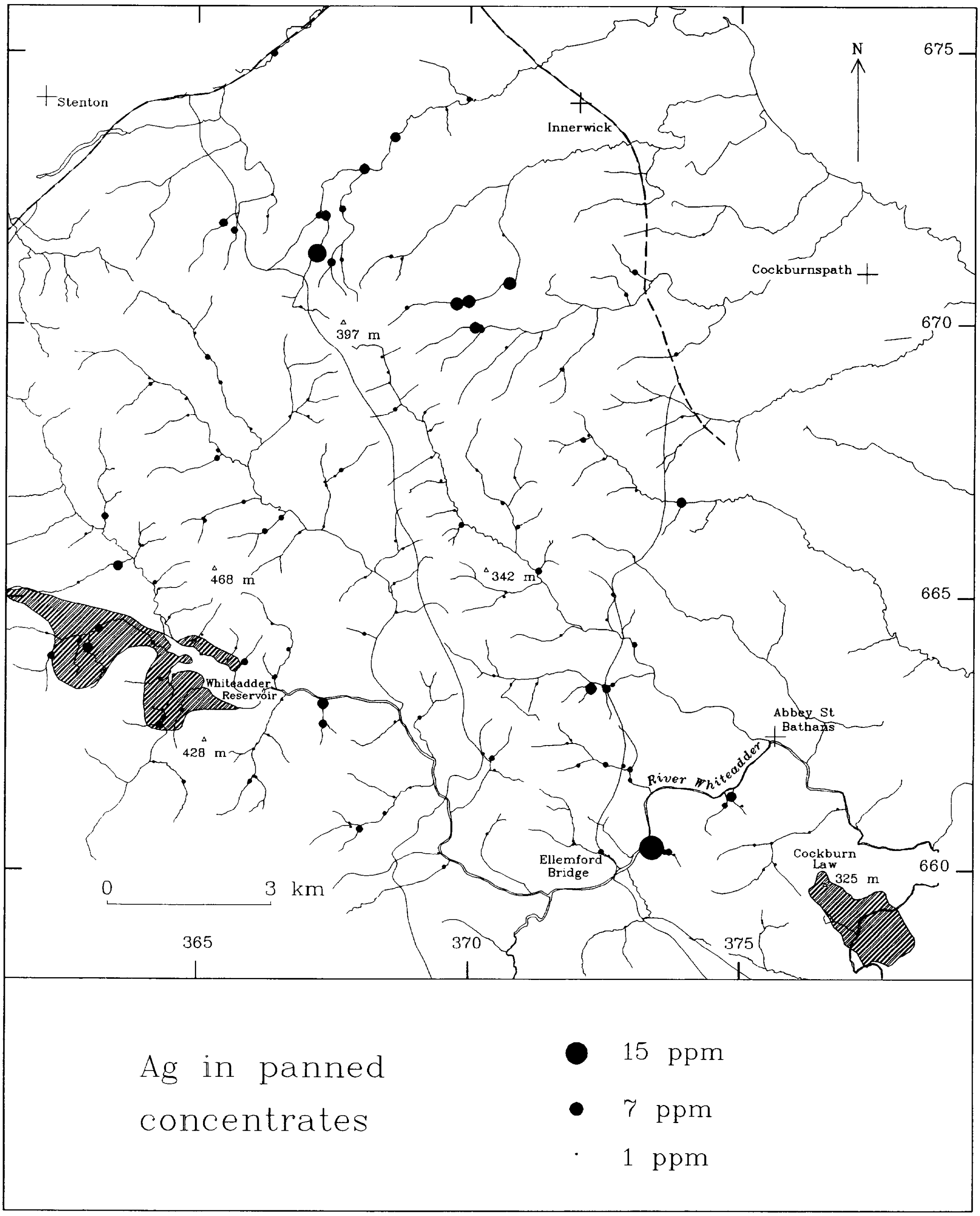

Figure 6 Distribution of Ag in panned concentrates

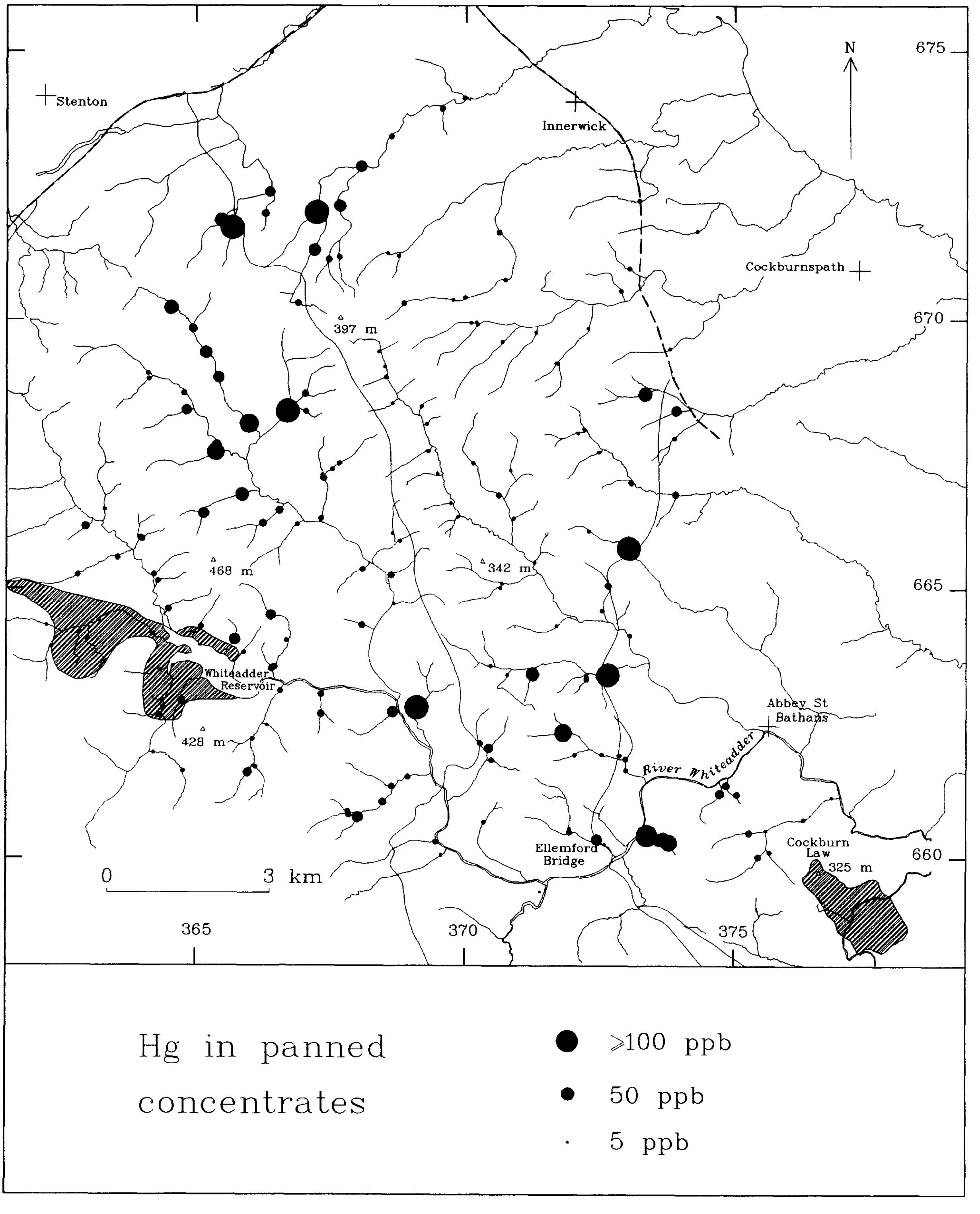

Figure 7 Distribution of Hg in panned concentrates

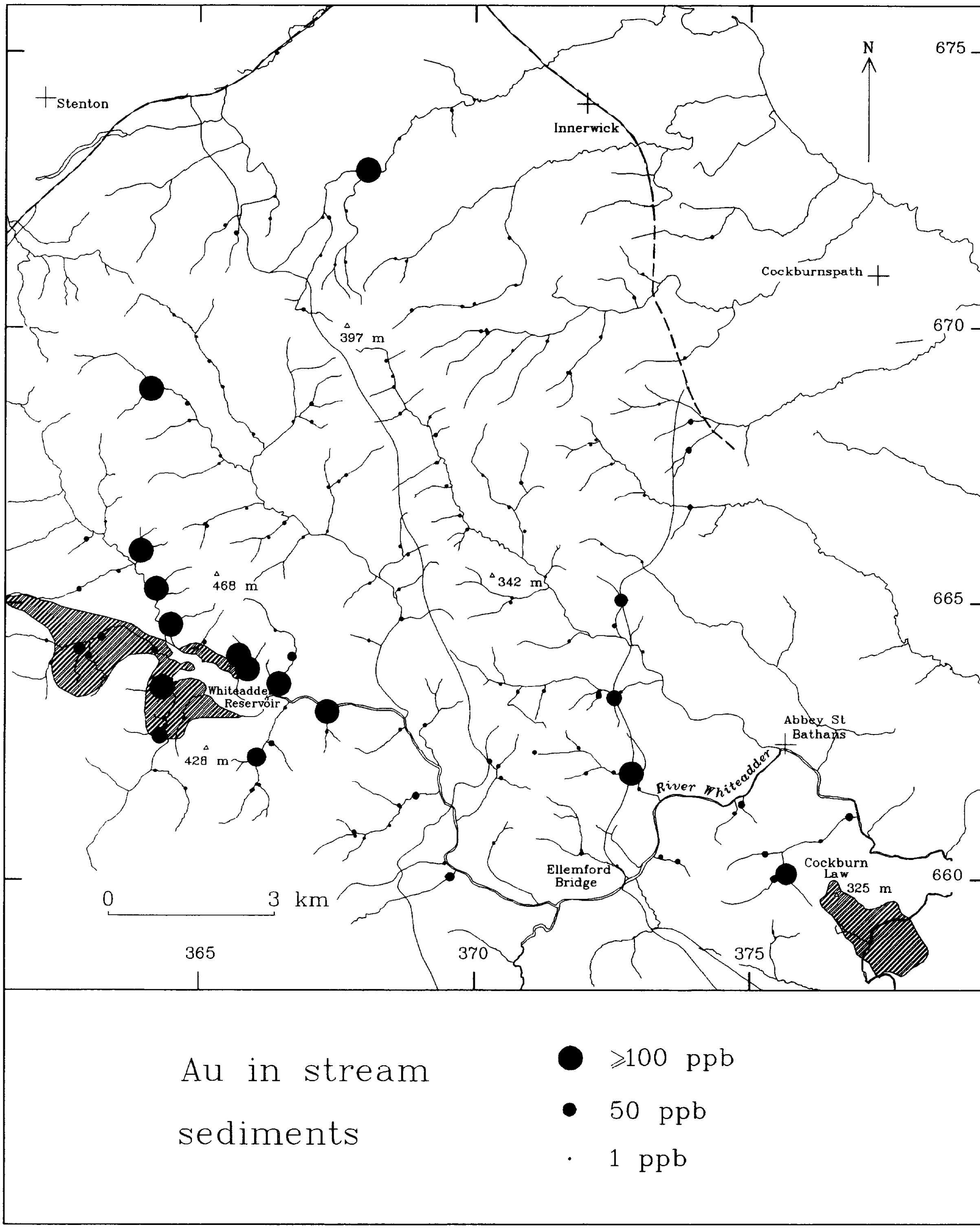

Figure 8 Distribution of Au in stream sediments

Table 2 Summary statistics for stream sediments
n=149
Values in ppm except for Au - ppb

	Minimum	25%	Median	75%	90%	Maximum
Au	1	2	4	7	22	1180
Ca	1400	2500	3300	4100	5400	23800
Ti	4130	4710	4980	5370	5680	6700
Mn	320	1280	1980	3080	6020	18300
Fe	31900	45000	48200	53500	61400	135500
Co	12	18	20	26	31	101
Ni	26	38	46	53	68	93
Cu	8	16	20	26	31	110
Zn	52	101	128	169	211	537
As	2	9	15	25	46	217
Mo	0	0	0	1	2	7
Ag	0	0	0	1	1	3
Sb	0	0	2	3	4	16
Ba	300	441	532	682	1122	6633
Ce	51	62	67	72	79	150
W	0	0	0	1	2	4
Pb	10	19	23	27	34	63
Bi	0	0	1	1	2	3
U	0	2	3	5	6	14

Within the Great Conglomerate only a single highly elevated Au value was determined. The site occurs 1.5 km downstream of two Au-in-panned-concentrate anomalies, and these anomalies are probably linked to a common, localised source. Streams draining the western margin of the Great Conglomerate are not enriched in Au. It is therefore summised that the basal part of the Great Conglomerate contains no significant placer accumulations of gold.

Arsenic shows a similar distribution pattern to gold, with the main cluster of anomalous values occurring near over and to the north of the Priestlaw Intrusion (Figure 9). Markedly elevated values also occur over a limited along the eastern margin of the Great Conglomerate [372 664]. In the vicinity of Cockburn Law an As-anomalous zone extends north-west into the Great Conglomerate, although levels diminish markedly in this direction. The distribution of Sb (figure not shown) shows sporadic enrichment, up to a maximum of 16 ppm, at two sites near the Priestlaw Intrusion. To the north-west of Cockburn Law minor enrichments are also found.

Base-metal levels in stream sediments are generally low. Although a maximum Cu value (110 ppm) was reported from the upper section of Robber's Cleugh, in general distribution terms higher Cu and Pb levels occur in the northern part of the area. Similar distribution patterns are seen for Ni (Figure 10) and for Ba. This geochemical contrast distribution pattern of these elements, diminishing from north-west to south-east, reflects the greater abundance of mafic volcanogenic detritus in the northern part of the Gala Group,

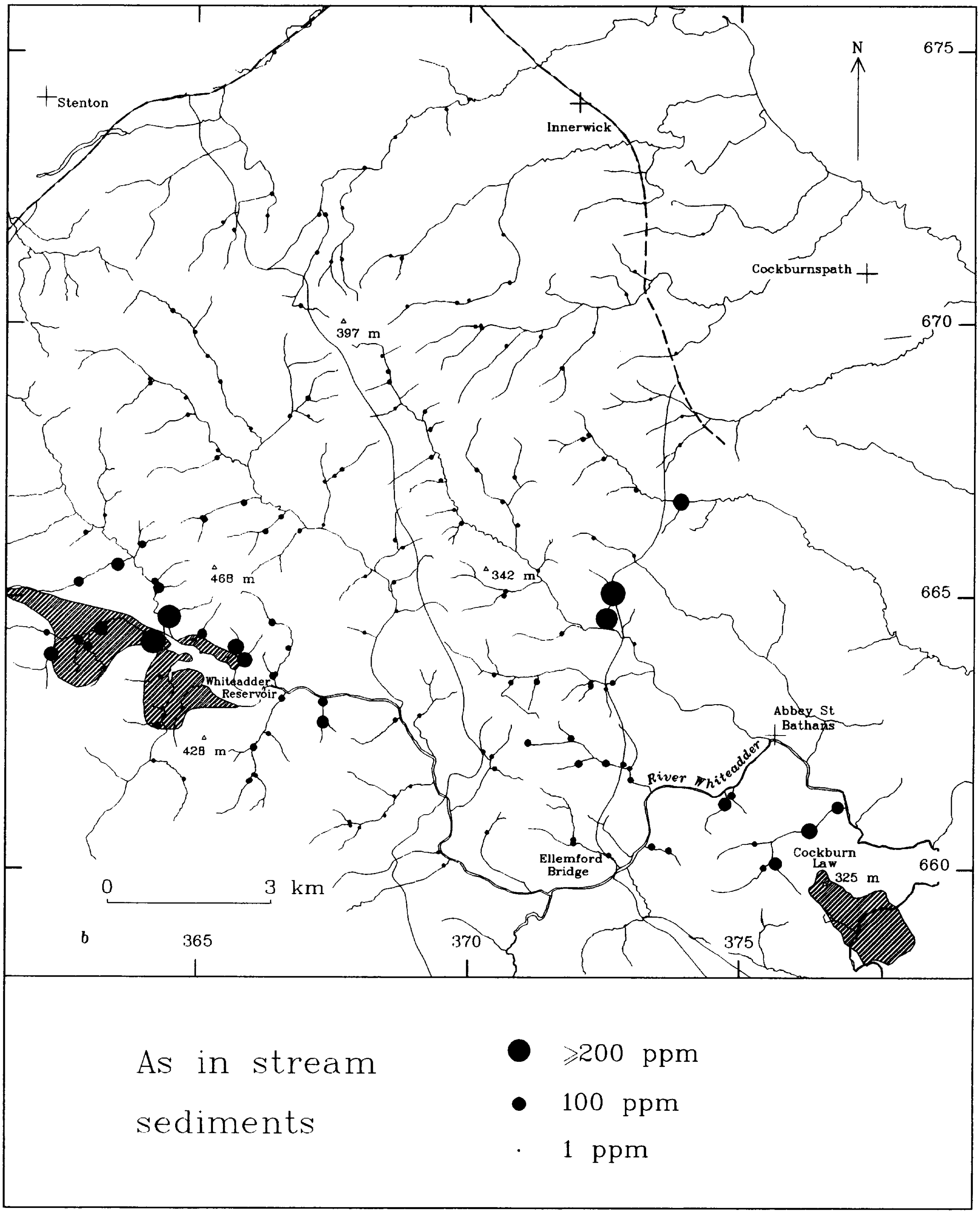

Figure 9 Distribution of As in stream sediments

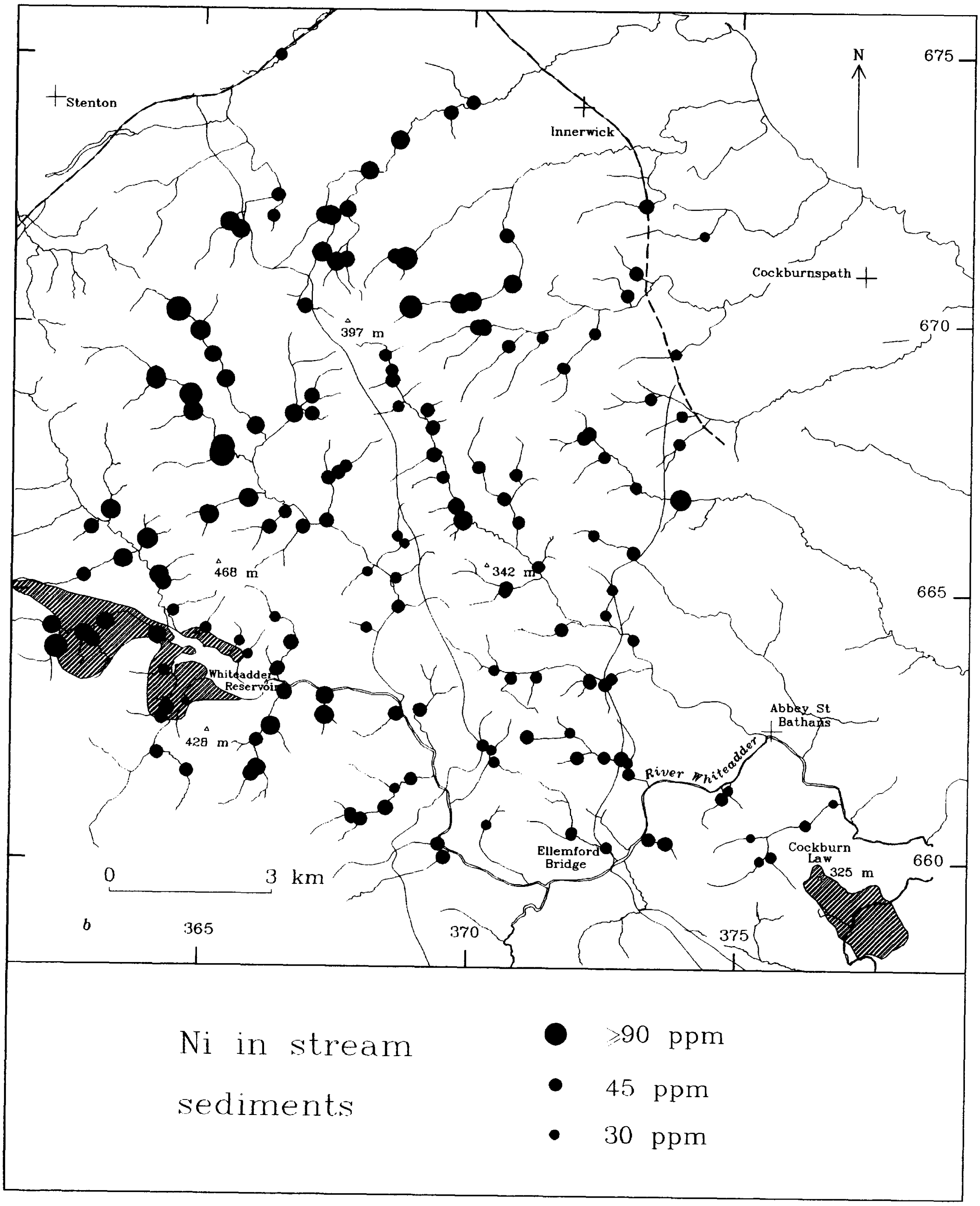

Figure 10 Distribution of Ni in stream sediments

and coincides with the projected trend of the Moffat Valley Lineament (Stone et al., in press), which is believed to define the transition from back-arc to foreland basin deposition.

Discussion

The distribution patterns of Au in panned concentrates and stream sediments indicate a close spatial association with the two main granitoid intrusions in the project area. The main areas of enhanced Au lie close to the main Priestlaw and Cockburn Law intrusions, displaced to the north of the mapped outcrops of these bodies. Evidence of Au enrichment in the southern sector of the project area, close to the eastern unconformity of the Great Conglomerate is more extensive in <150 µm stream-sediment samples than in panned-concentrates. This anomalous zone appears to be truncated by the Innerwick Fault, although sample coverage in the north-east part of the project area is sparse.

A summary map of the panned concentrate data is shown in Figure 11. Areas of elevated Ag and As are associated with all sites containing >10000 ppb Au. Enrichment in Hg occurs in two zones, marginal to the main areas of Au enrichment in panned-concentrates but encompassing some of the outliers of Au in stream-sediments. Within the Great Conglomerate areas of Hg, Ag, As, Cu and Pb (not shown) overlap the small area of Au enrichment.

The distribution patterns of Au and associated pathfinders suggest that Au mineralisation at surface is focused in two principal areas within Silurian rocks. It is possible that these areas are part of a continuous gold-mineralised zone which extends beyond the geographical limits of these investigations.

Minor enrichment in Au and associated pathfinder elements also occurs along the eastern margin of the Great Conglomerate. These occurrences form part of the zone of sporadic Au distribution stretching north-west from the Cockburn Law area. These gold occurrences are frequently coincident with zones of brecciation of the country rock, and pebble-sized barite clasts are also common in streams in this area. It seems likely that the localised occurrence of gold in drainage samples over a relatively short length of the eastern margin of the Great Conglomerate is related to these manifestations of breccia-hosted mineralisation. The absence of visible (or analytically determined) gold in drainage samples from streams draining westwards from the western unconformable margin of the Great Conglomerate suggests that there is no placer-style gold accumulation near the base of this lithology.

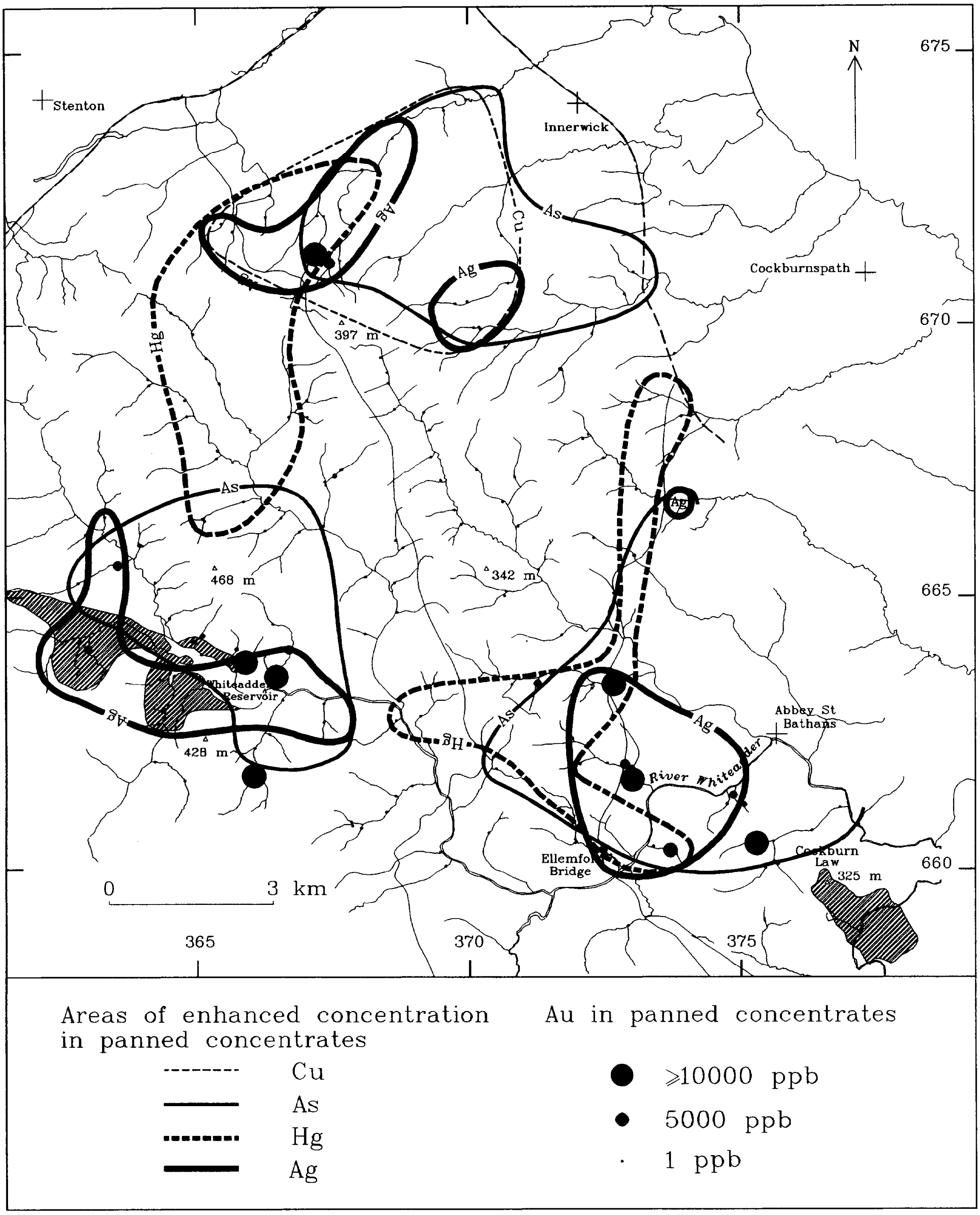

Figure 11 Relationship between Cu, As, Hg, Ag and Au in panned concentrates

SOIL SAMPLING

Soil sampling was conducted to identify the source of Au anomalies found in reconnaissance drainage sampling. Four areas, Abbey Hill, Cockburn Law, Dunter Law and Tod Burn (Figure 2) were selected because of the occurrence of high Au values within relatively small, discrete catchment areas. Thin soil cover and low levels of entrainment of transported material in these areas permitted the collection of C-horizon soil samples by shallow pitting or conventional hand-augering.

Abbey Hill

The Abbey Hill grid lies along the summit and northern flank of the north-east-trending Abbey Hill ridge, to the south-west of Abbey St Bathans. Much of the higher ground is gently to moderately sloping but the gradients steepen markedly on its northern flank adjacent to the River Whiteadder flood plain. Most of the land has been ploughed and replanted within the last 50 years, transforming it from a natural cover of heather to improved grassland.

There is very little exposure within the gridded area, although sporadic outcrop occurs within stream sections and in cuttings along the forest track running parallel to the River Whiteadder. In the west greywacke and greywacke siltstones dominate, the latter being locally pervasively reddened and highly fractured. Minor intrusions of feldspar porphyry poorly exposed in places. In the east the greywackes become highly quartzose, very pale grey and contain only a small proportion of detrital mafic minerals.

Soil sampling was carried out in two phases. During the first phase, sample traverses were selected at 200 m spacings and surveyed by tape and compass, with verification using measurement along field boundaries. The second phase of sampling involved infill of the more promising zones with sites spaced at either 25 or 10 m intervals. A total of 540 samples were collected.

Table 3 Summary statistics for soil samples from the Abbey Hill area
n=540 for all elements except Ti (400) and Bi (140)
Values in ppm except for Au - ppb

	Minimum	25%	Median	75%	90%	Maximum
Au	1	1	2	3	5	250
Ti	4430	9988	6463	6774	7176	9988
Mn	62	217	294	472	748	3160
Cu	0	8	13	17	21	74
Zn	14	35	46	55	65	116
As	6	18	23	31	46	220
Ba	281	418	473	528	632	7641
Pb	2	8	11	14	19	147
Sb	0	2	3	5	6	12
Bi	0	0	1	1	2	3

Gold enrichment, in the range 10 - 250 ppb, occurs in a zone 150 m long in the central part of the sampling area (Figure 12). Outside this area there are few elevated Au values. At one site near the western

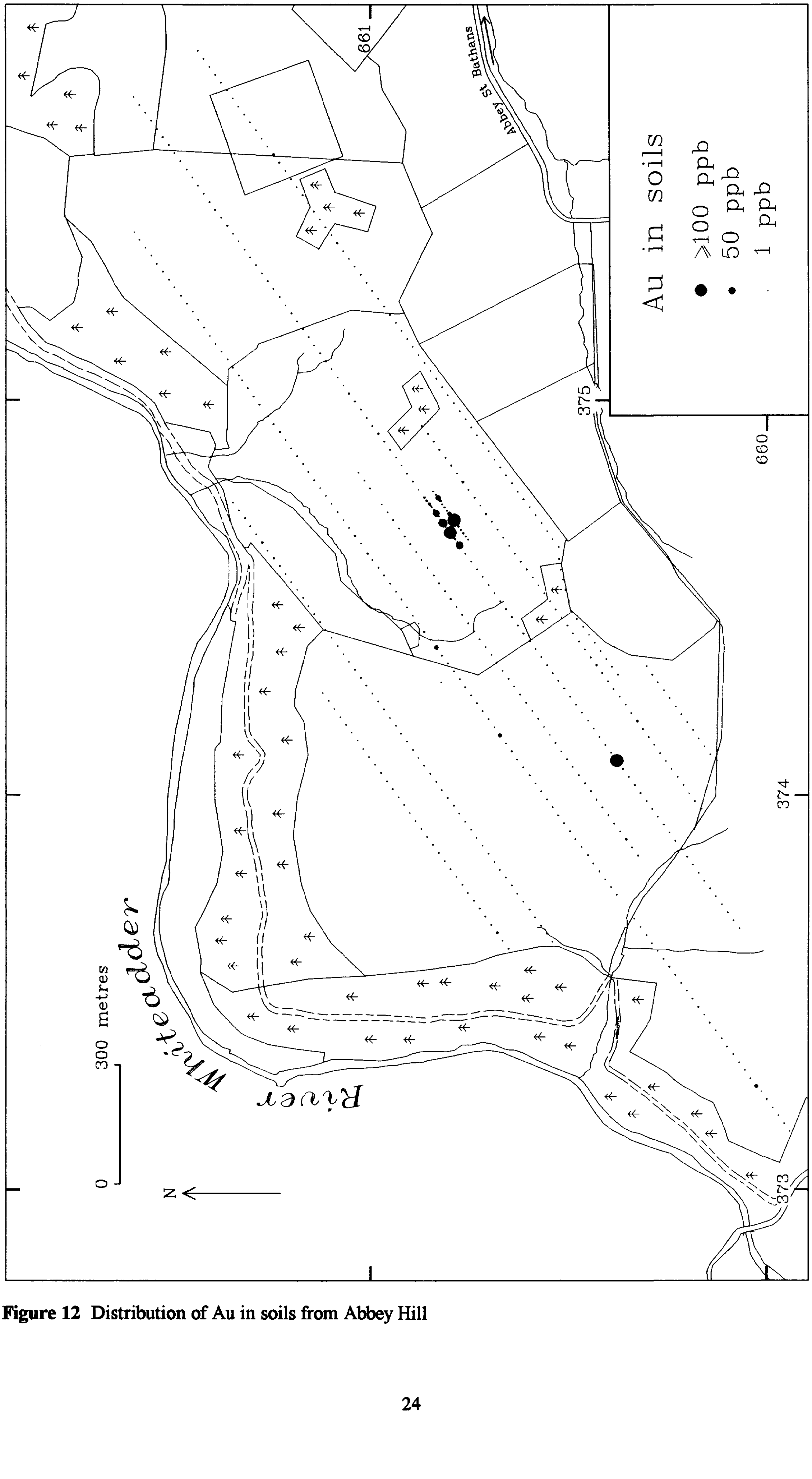

Figure 12 Distribution of Au in soils from Abbey Hill

margin of the grid a value of 110 ppb was reported. A broad, irregular zone of As enrichment (Figure 13) occupies a large part of the central section of the gridded area, marginal to the main Au-enriched zone. Within this area, to the north and east of the mapped L-shaped wood, small, shallow pits with associated spoil-heaps containing quartz-veined greywacke are found. Similar pits of quartz-veined greywacke are also present near the western margin of the sampled area. These are probably mineral trials and are of considerable age.

Sporadic enrichment in Cu occurs over a broad zone stretching south-westwards from the main Au anomalous area (Figure 14). This distribution pattern cannot be explained by secondary processes such as hydromorphic enrichment and it is probable that a number of small bedrock sources occur in this area.

Dunter Law

This area was selected on the basis of enhanced Au in drainage samples along the eastern margin of the Great Conglomerate (Figures 3 and 8). The presence of brecciated, barite-mineralised highly reddened greywacke siltstone outcropping in the Glen Cleugh catchment was seen as a favourable indicator of mineralisation. Samples were collected at 10 m intervals along seven east-trending traverses within the fault-controlled Glen Cleugh catchment. Three additional traverses were surveyed within the Shorthope Cleugh catchment, with sample-site spacings of 25 m (Figure 15).

Soil geochemistry shows only minor enrichment in Au, up to a maximum of 16 ppb (Table 4). The highest values occur in the vicinity of the Glen Cleugh, where quartz-veined reddened medium-grained greywacke float is locally present. As shows the closest spatial association with Au, with a maximum value of 126 ppm. There is also a close spatial association with elevated levels of Ti and slightly enhanced Sb in the Glen Cleugh catchment (Figure 15). However, there are no Spearman Rank Correlation Coefficients between Au and the other elements significant at the 99% confidence level.

Table 4 Summary statistics for soil samples from the Dunter Law area
n=187 for all elements
Values in ppm except for Au - ppb

	Minimum	25%	Median	75%	90%	Maximum
Au	1	1	2	3	6	16
Mn	147	325	403	620	953	2331
Cu	4	10	12	14	17	37
Zn	21	43	53	63	74	89
As	8	19	28	35	47	126
Ba	329	440	467	514	582	1594
Pb	7	11	14	18	27	89
Sb	1	3	4	5	6	8
Bi	0	0	1	1	2	3

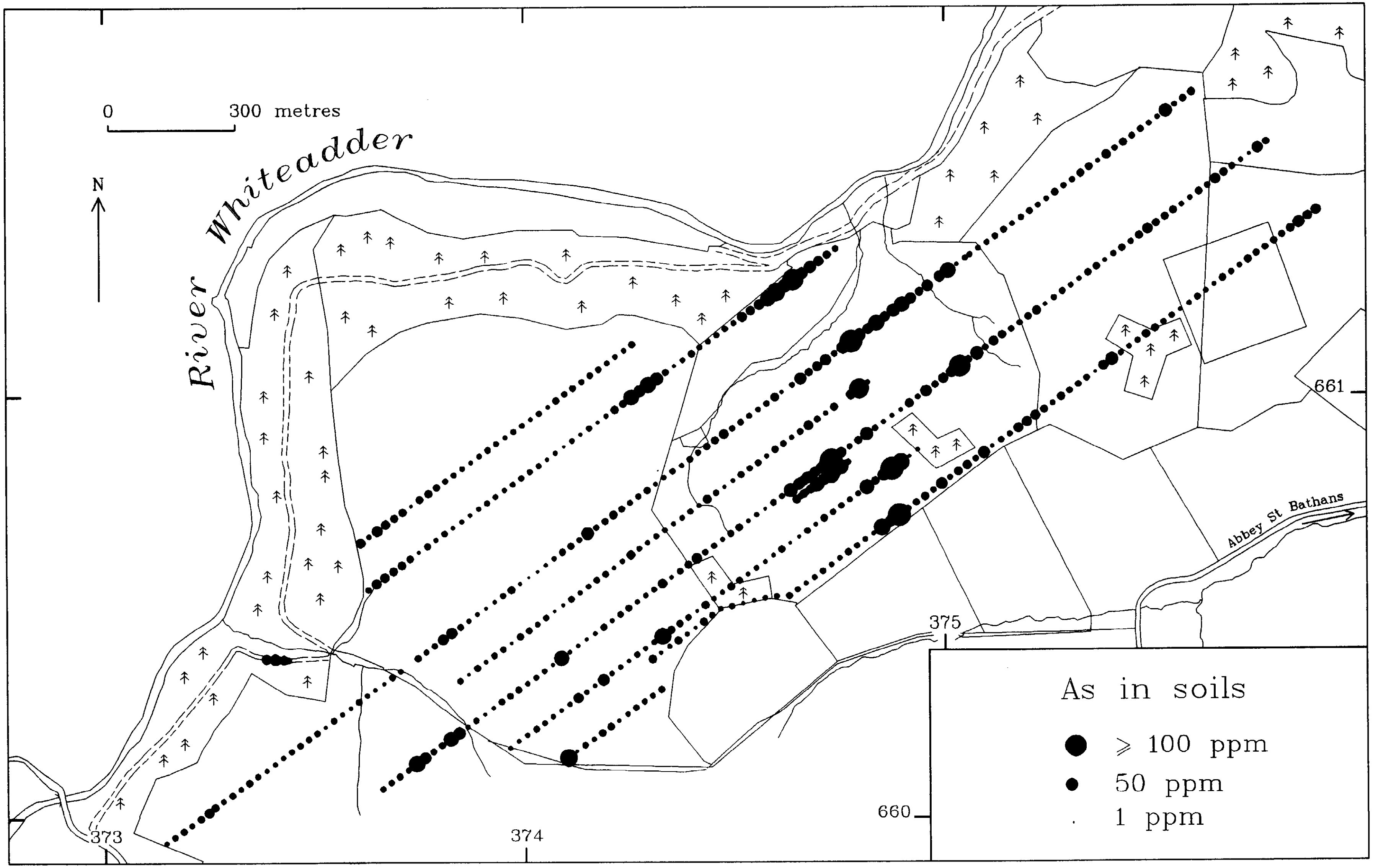

Figure 13 Distribution of As in soils from Abbey Hill

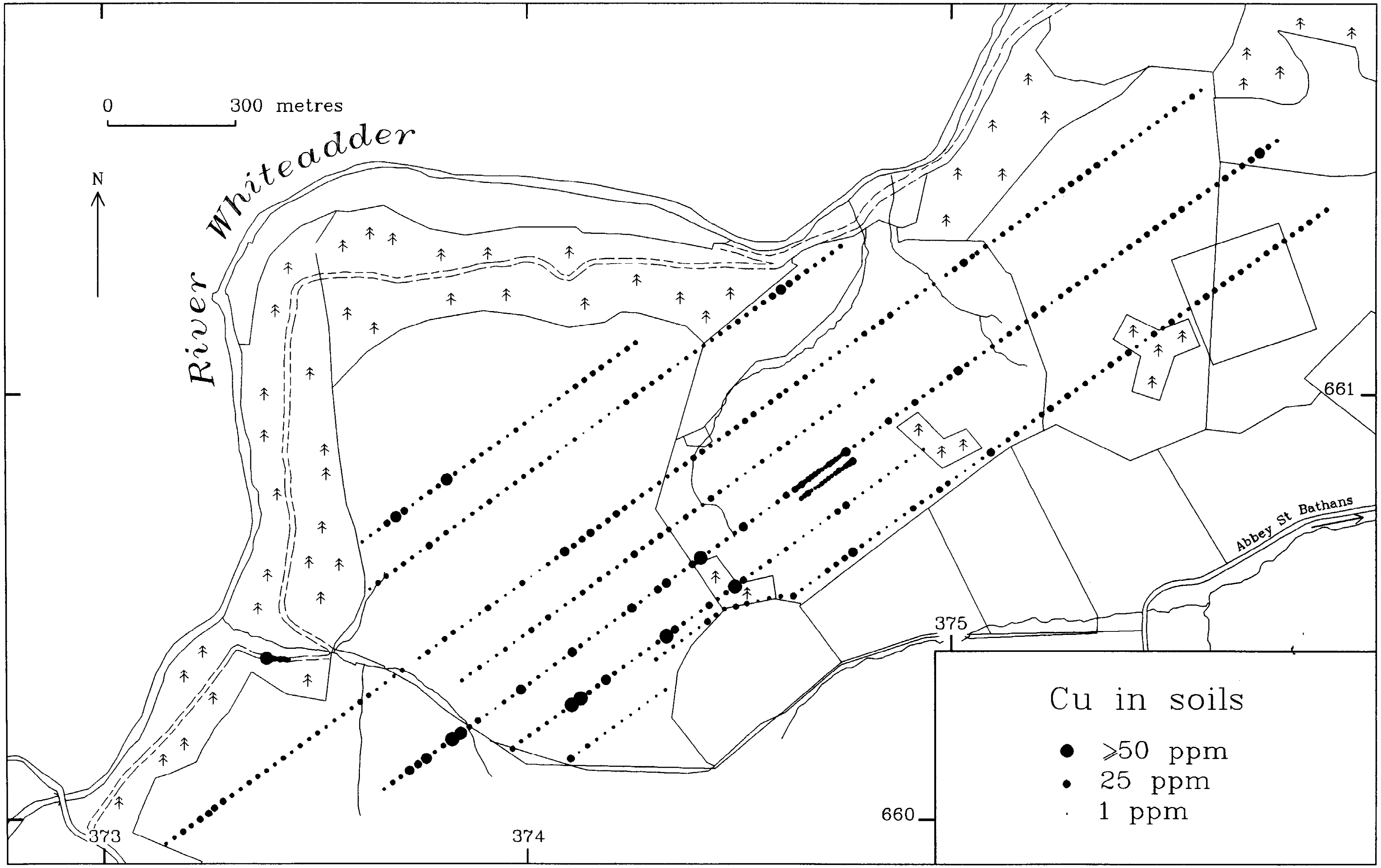

Figure 14 Distribution of Cu in soils from Abbey Hill

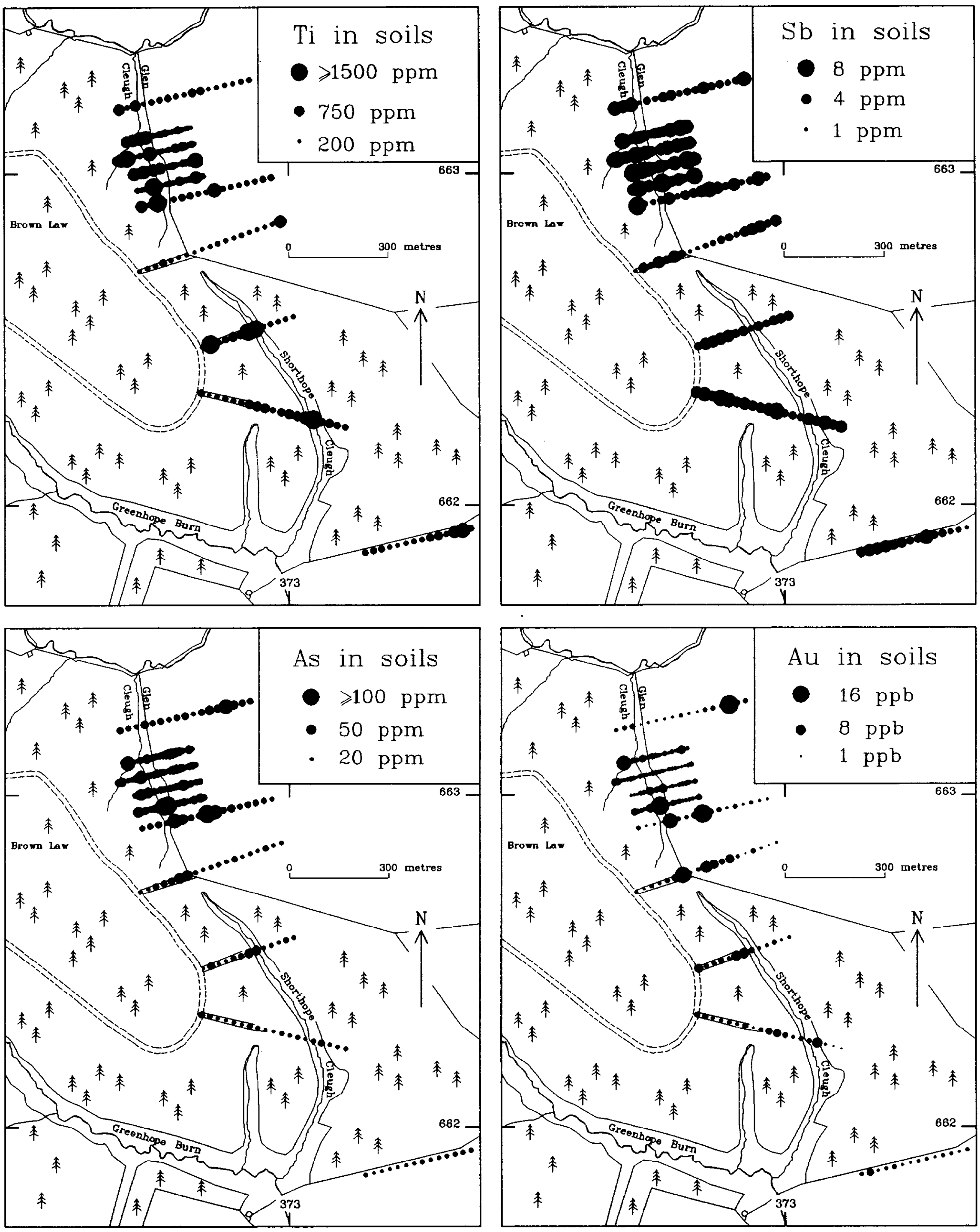

Figure 15 Distribution of Ti, Sb, As and Au in soils from Dunter Law

Cockburn Law

The soil grid lies over the mapped area of the Cockburn Law intrusion close to its south-western margin. The land use is improved grassland and the topography smooth to gently undulating, with slight to moderate gradients. An inconspicuous outcrop of reddened intrusive breccia occurs near the north-west corner of the sampling area, and two piles of mainly similar material are also present.

Soil profiles are generally light, well-drained and stony. As a result, collection of samples by soil auger was difficult and manual pitting was preferred at most sites. The area was selected for detailed sampling because of a number of elevated Sb values in bedrock and panned concentrate samples around the Cockburn law body identified during MRP investigations in the early 1980s Initially, four trial pits were dug, two of which gave Au values of 14 and 40 ppb in C-horizon soil. Further sampling, comprising the collection of 51 soils by hand-auger, was then carried out. Results from both phases of investigation are illustrated in Figure 16 and the data are summarised in Table 5.

The enrichment of Au in soils is sporadic, with the majority of sites showing Au values close to the minimum detection limit. The highest value of Au (88 ppb) is not accompanied by enrichment in As or base metals. Localised enrichments in Cu and Ba occur in different parts of the grid but their bedrock sources remain obscure. Minor enrichment in Sb occurs in the south-eastern corner of the sampling area. However, no clear association of Au with the other elements determined is apparent.

Table 5 Summary statistics for soil samples from the Cockburn Law area
n=55 for all elements except Bi (51)
Values in ppm except for Au - ppb

	Minimum	25%	Median	75%	90%	Maximum
Au	2	4	5	6	14	88
Mn	403	922	1177	1495	1681	2548
Cu	19	14	29	34	50	102
Zn	42	71	75	82	87	107
As	18	27	32	38	41	45
Ba	480	555	587	662	835	1039
Pb	13	21	22	26	31	38
Sb	2	4	6	7	8	13
Bi	0	0	1	1	2	2

Tod Burn

The Tod Burn catchment lies immediately north of the northern margin of the Priestlaw granodiorite. Exposures of medium-grained reddened greywackes occur on the steeply sloping valley sides of the lower catchment area. The area was selected because of the presence of high Au values in drainage samples (up to 15 ppm in panned concentrates and 1.18 ppm in stream sediments). Six north-west-trending traverses were surveyed, with 75 samples collected from sites spaced at 25 m intervals.

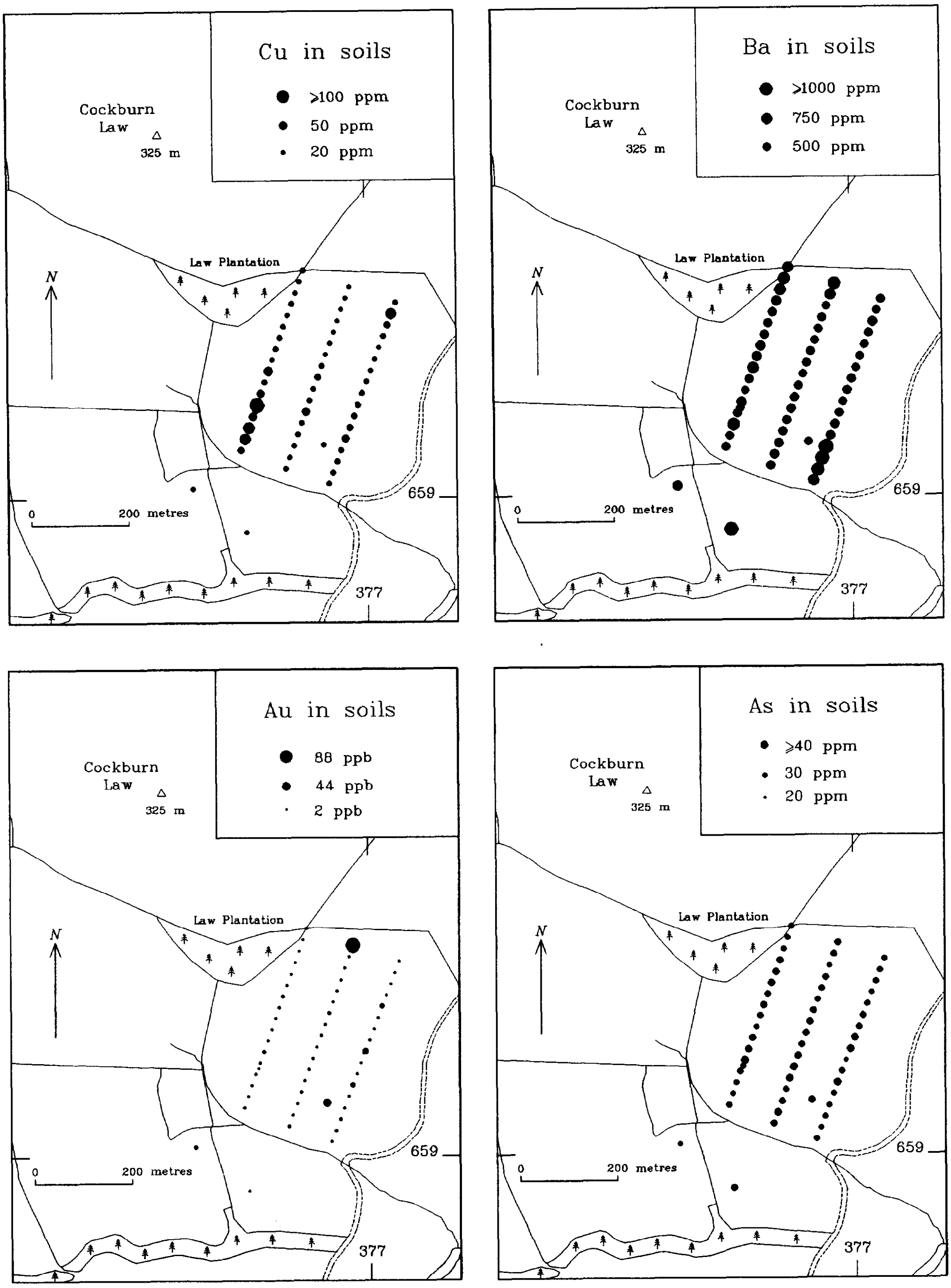

Figure 16 Distribution of Cu, Ba, Au and As in soils from Cockburn Law

The distributions of Au, As, Cu and Pb in soils are shown in Figure 17. The pattern of elevated Au values may be broadly compared to that of As. The highest values of Au are found along the western margin of the grid, while low-tenor enrichments occur in the central part of the area. Figure 17 also shows the distribution of Cu and Pb, which show little variation over the grid area.

The summary statistics table for Tod Burn soils (Table 6) indicates a medium to high-tenor Au enrichment in this area, with a maximum value of 190 ppb. As levels in soils were the highest of the four areas sampled, with a median value of 71 ppm and a maximum of 337 ppm. Maximum values of 41 ppm for Cu and 23 ppm for Pb indicates that no significant enrichment occurs in the area. Low-tenor enrichment in Zn is unusual compared with the other localities and may be due to either the presence of a higher mafic detrital component in the greywackes or else the greater abundance of mafic minerals in the intrusive rocks in this area.

Table 6 Summary statistics for soil samples from the Tod Burn area
n=75 for all elements
Values in ppm except for Au - ppb

	Minimum	25%	Median	75%	90%	Maximum
Au	2	5	9	16	31	190
Mn	271	403	503	596	689	1580
Cu	10	14	17	22	25	41
Zn	28	51	58	64	68	158
As	24	48	71	99	144	337
Ba	250	418	467	522	545	723
Pb	8	13	14	15	16	23
Sb	0	2	3	4	5	7
Bi	0	0	1	1	1	2

Discussion

Localised enrichment of Au in soils occurs in all the areas sampled in detail. Notably, the Abbey Hill and Tod Burn areas contain enrichments up to 250 and 190 ppb respectively. The enrichment in As over these areas suggests that this element provides an appropriate pathfinder for the Au mineralisation. Significantly, base-metal levels in the same areas are not markedly enriched, although sporadic elevated Cu in the Abbey Hill area indicates the likely presence of a large number of weakly-mineralised sources. It is likely that the soil values reflect Cu mineralisation of the type exposed as malachite-stained siltstone, which occurs sporadically along the Whiteadder forest track section between Robber's Cleugh [3735 6603] and Ellemford Bridge. Gold anomalies in soils at Cockburn Law and Dunter Law occur in close proximity to zones of intensive brecciation and cementation of the country rock. At Tod Burn also, a zone of intensely shattered siltstones occurs adjacent to the highest Au value in soil. The significance of these features in relation to regional structures is discussed in the structural interpretation section.

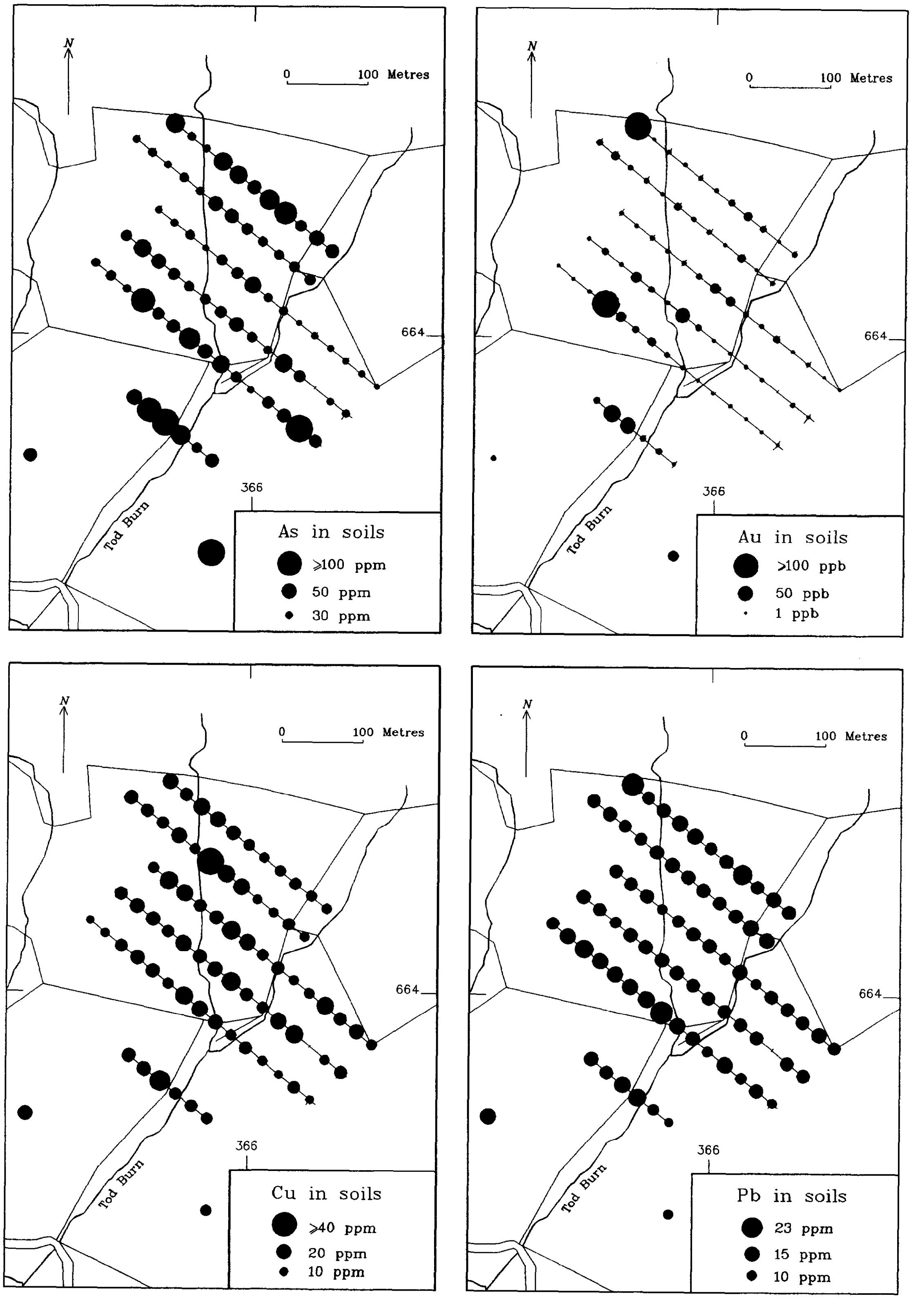

Figure 17 Distribution of As, Au, Cu and Pb in soils from Tod Burn

DETAILED SAMPLING OF GOLD ANOMALIES IN SOIL

A programme of excavation to bedrock was carried out by mechanical digger in order to establish the sources of soil Au anomalies at Abbey Hill and Tod Burn.

Pit profiles were logged in detail and bedrock and deep overburden samples collected to compare Au and trace-element distributions with the values in shallower soils. Bedrock samples, c. 2 kg in weight, were prepared by careful washing, with the exception of the highly altered and friable types. After drying, the samples were ground in a chrome-steel Tema mill. Sample splits were analysed for Ca, Fe, Mn, Cr, Cu, Pb, Ba, As, Zr, Mo, W, Pb, Bi, U by XRF on pressed powder pellets. Au was determined by lead fire assay on 30 g samples followed by ICP. Overburden samples were prepared in the same manner as soil samples, and analysed for the same elements by XRF and for Au by lead fire assay and ICP.

Abbey Hill

A total of 52 rocks and 38 overburden samples were collected from 28 pits in the main area of Au anomalies in soil (Figure 18a). The rocks included 27 greywackes 11 siltstone and 3 felsic porphyry, and the remainder were clay fault gouge or quartz vein material. Due to the variety of rocks sampled and the marked variations in alteration, summary statistics are not shown.

Two distinctive soil profiles types were identified. Profiles overlying greywacke bedrock comprised a thin (< 20 cm) dark-brown organic A horizon, with a B horizon of similar thickness above a well-drained silty loam in the C horizon. In contrast, those overlying siltstone or porphyry bedrock were more clay-rich or micaceous. Notably, pits 23 and 24 became waterlogged during excavations and for this reason pitting was not carried out over a 25 m interval section north-west of pit 24. Depths to bedrock were generally 1 - 1.5 m, with a maximum of 1.75 m.

In the majority of pits reddened greywackes are finely interbedded with subordinate finely banded red and pale grey siltstone or silty mudstone. Repetition of these rock types prevented correlation between pits on djacent traverses. Hydrothermal alteration of the country rock is suggested by the pervasive reddening and clay alteration of feldspar clasts within the greywacke matrix. In pits 3, 5 and 28, narrow dykes of altered, decomposed feldspar porphyry were encountered. These samples are characteristically lower in Cr (2 - 33 ppm), than the greywackes, which generally contain between 100 and 150 ppm Cr.

Median levels of Au were 8 ppb for siltstones (n=11) and 4 ppb in greywackes (n=27). The highest Au value in bedrock (98 ppb) was obtained from quartz-veined medium-grained altered greywacke in Pit 15 and from a hydrothermally altered feldspar porphyry in Pit 3. The former sample was also enriched in As (88 ppm) and Sb. Two other samples enriched in Au were a banded light grey siltstone (Pit 7) containing 96 ppb Au and a highly altered feldspar porphyry (Pit 5) also containing 96 ppb Au.

Comparisons of Au levels in soils and bedrock samples from pits are presented in Appendix 1. In general the Au concentrations in soils are higher than those in corresponding rock samples.

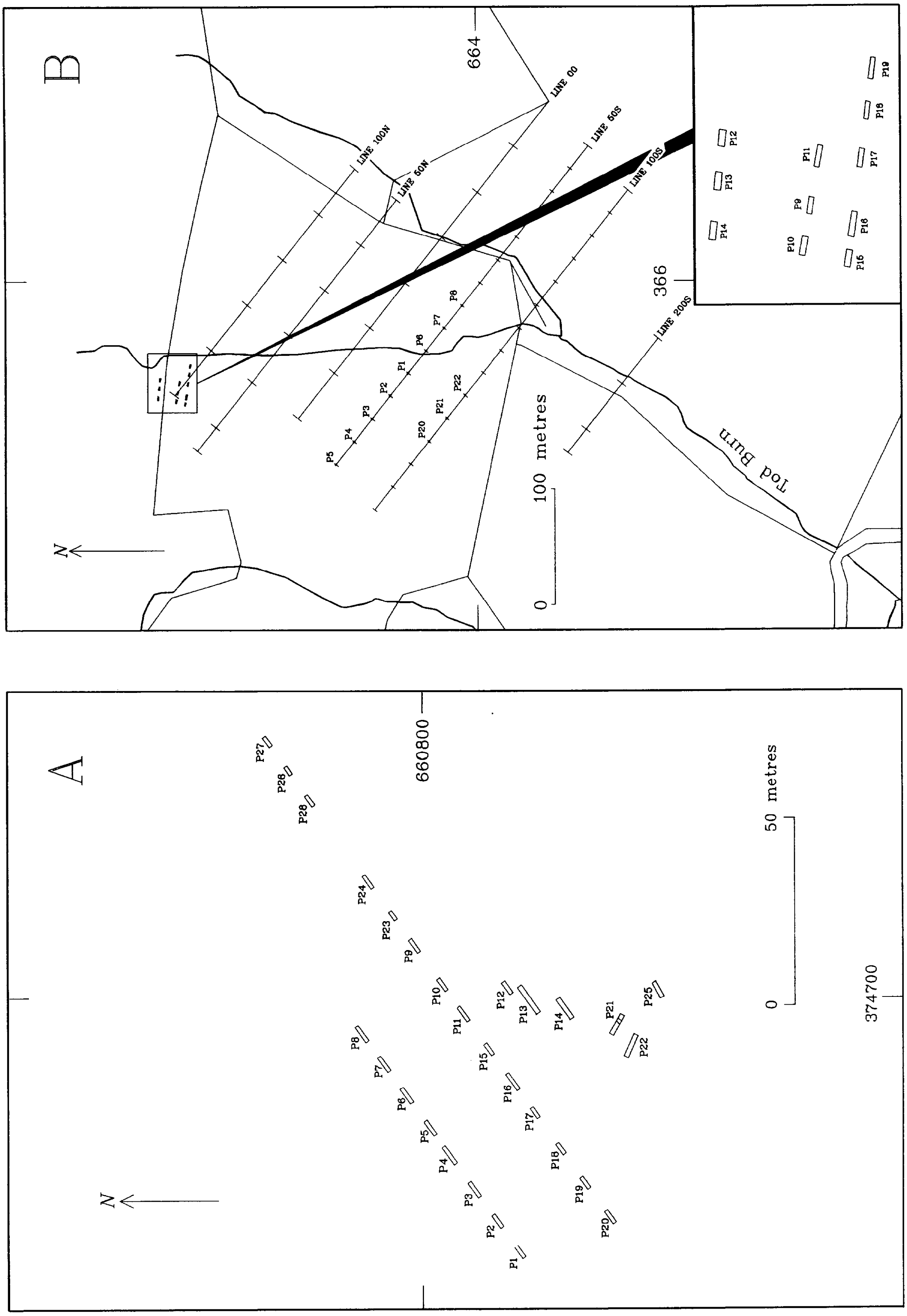

Figure 18 Locations of sample pits at Abbey Hill (a) and Tod Burn (b)

Tod Burn

A total 36 rocks and 33 soils were collected from the 22 holes excavated (Figure 18b). Depth to bedrock ranged from 1 - 2 m in the loamy, well-drained profiles in the western, northern and eastern parts of the sampling area, to more than 5 m in heavy, micaceous clay in the central and southern-central sections. In order to ascertain the potential of the thicker soil profiles for trenching a series of deep overburden profiles were taken using a Cobra percussion drill with samples collected using a through flow sampling tube. Profiles between sites in some central parts of the grid area indicated overburden depths locally in excess of 6 m. This zone was therefore excluded from the trenching programme. Au concentrations in these till samples were highly variable, with the highest value (139 ppb) occurring at 6.3 m depth at site 00N/210W. Consistent low-tenor Au enrichment was present in most profiles, but there was no clear variation with depth.

The dominant lithologies in this area are fine- to medium-grained greywackes, similar to those exposed in the lower section of the Tod Burn [365 663]. Siltstones are rarely encountered, except in the north of the sampling area where they are exposed in the upper part of the Tod Burn west tributary close to the area of detailed pitting.

The majority of greywackes sampled from pits show only minor enrichment in Au, generally in the range 1 - 10 ppb. These samples contain generally lower levels of As than the Au-enriched lithologies. Base-metal values in rocks were not significantly elevated, the maximum Cu value being 68 ppm (Pit 21). Levels of Pb were highest in intrusive lithologies (37 - 43 ppm).

The highest Au levels in the area were encountered in pit 2 [365901 664075], located 45.5 m north-west of the Tod Burn western tributary on a gentle, well-drained slope. The bedrock geology is altered greywacke, with subordinate mudstone, intruded by an altered porphyry intrusion which was only partially exposed. The highest Au concentration [5119 ppb] occurred in purple-brown hydrothermally altered greywacke with spotty white clay alteration of feldspar fragments, and this sample also contained elevated levels of As (107 ppm) and slight enrichment in Sb (6 ppm). In the same hole a sample of hornfelsed mudstone was also enriched in Au (909 ppb) and As (250 ppm). The other two samples from this locality, comprising rotten, hydrothermally-altered fine greywacke and altered porphyrite, contained 32 and 37 ppb Au respectively and were also enriched in As. Zr levels in the three sediment samples ranged from 280 to 390 ppm, compared with the median value for Zr in sedimentary rocks from pits in the area of 200 ppm. Rock samples from adjacent pits P1 and P3 show only minor enrichment in Au, ranging between 4 and 15 ppb. However, in common with Pit 2, they are consistently enriched in As, in the range 104 - 301 ppm.

Detailed trenching of the northern area (Figure 18b) revealed low-tenor Au enrichment confined to Pit 16, with a maximum of 33 ppb. This sample, comprising a heavily Mn-stained hydrothermally altered intermediate intrusive rock, was also enriched in As (103 ppm) and Zr (446 ppm). The overlying C-horizon material was more enriched in Au (190 ppb), similar to the Au content of the original soil sample from this locality. Two samples of similar bedrock from the adjacent pit (No. 9) also contain elevated Zr levels (609 and 559 ppm) but only low levels of Au (14 and 16 ppb respectively).

In all, five samples of porphyritic intrusive rocks were collected from the Tod Burn area. These rocks appear to be more granodioritic in composition, with markedly higher levels of Fe, Ca and Cr, than the Abbey Hill felsic porphyrites. The elevated Zr levels noted above are also distinctive, with a maximum of 609 ppm, suggesting the presence of zircon as an accessory mineral phase.

Discussion

Soil sampling has successfully delineated localised anomalous gold levels in the four detailed sampling areas selected. In two of these areas, namely Abbey Hill and Tod Burn, maximum levels of gold were in excess of 150 ppb.

In the Tod Burn area the majority of sites investigated have low-tenor Au enrichment (< 10 ppb). The site with the highest Au levels occurs at the contact between hydrothermally altered greywacke and a porphyry intrusion. Zr levels in the high-Au greywacke samples are unusually elevated, and comparable to levels in minor intrusions in the area.

In the Abbey Hill area the occurrence of low-tenor enrichment of Au in greywackes, siltstones and porphyry intrusives also points to an association between minor intrusive activity and Au mineralisation. In common with the Tod Burn area, extreme alteration of all lithologies, accompanied by pervasive oxidation of ferruginous minerals, suggests the possible involvement of oxygen-rich meteoric waters in these hydrothermal processes.

LITHOGEOCHEMISTRY

Surface samples

A total of 105 surface samples were collected during the phases of reconnaissance and detailed sampling. The samples, weighing 1-2 kg, were cleaned of their weathered surfaces and then washed to remove entrained soil material. Care was taken to preserve any fine-grained alteration product such as goethite or clay minerals. The samples were prepared and analysed in the same way as for pit samples described above.

Greywacke and siltstone were the most commonly sampled rock types. Attention was focused on areas showing evidence of hydrothermal alteration, brecciation and mineralisation and appropriate outcrops sampled. Because of the variety of lithologies sampled and their various degrees of alteration or mineralisation, summary statistics are not shown.

Minor Au enrichments occur in all lithologies sampled (greywacke, siltstone and porphyrite) throughout the project area. The majority of samples contained only low levels of Au, with 89% of samples below 10 ppb. Values of Au in excess of 100 ppb are contained in Table 7. These include a sample of barite-cemented breccia which yielded 536 ppb Au, the highest value in any surface sample. The breccia is poorly exposed in the embankment adjacent the Whiteadder forest track, 140 m west of the Robber's Cleugh bridge [373 660]. Soil sampling upslope of this occurrence failed to reveal any upslope extension of the mineralisation.

Table 7 Surface rock samples with Au concentrations >100 ppb

No.	Easting	Northing	Au (ppb)	Association	Description
5239	373440	660360	536	Ba	Subcrop - brecciated greywacke
5310	373640	660510	140	Cr	Float - quartz vein
5311	373050	660075	120	Cr	Float - quartz vein with pyrite
5319	374189	661300	130	As	Altered micaceous greywacke
5320	365835	663740	290	As	Siltstone

Disused mines

Two abandoned and partially back-filled copper mines occur in the project area at Hoardweel and Ellemford [NT 76876037 and 72856015]. These workings were purportedly operated in the late 18th century (Wilson and Flett, 1921; Douglas, 1792), although details of production or their viability are not recorded. Copper mineralisation is in the form of malachite and tetrahedrite, largely confined to fracture zones within fine-grained greywackes and siltstones commonly containing clay fault gouge. Surveying and sampling of the mineworkings was carried out in order to establish the presence and nature of structures bearing this type of mineralisation.

Hoardweel Mine

At Hoadweel three galleries are driven into a steeply sloping hillside on the eastern side of the River Whiteadder. A number of surface workings also occur near river level, but the majority of the workings are underground (Figure 19, stippled area). The mine is situated 0.2 km north-east of a microgranite intrusion and 1.3 km north-east of the Cockburn Law intrusion. The three main adits, typically 1.5 m in width, trend in a north-easterly direction and are unsupported. The main adit (B) is connected to the short adit [C] by a previously blocked offshoot adit which was cleared during MRP investigations. Accounts of mining are scant but it seems that the miners followed a number of anastomosing fault zones within which highly fractured fine-grained greywackes and siltstones are mineralised with Cu in the form of malachite. No primary sulphide mineralisation can be seen. Narrow breccia zones and shears containing barite, quartz, malachite and minor probable tetrahedrite occur where chalcopyrite was reputedly recovered in the past (Wilson and Flett 1921). The highest Cu values determined were >10000 ppm (the maximum detection limit) in adit C winze [378680 660360] and in malachite-mineralised veins in adit B offshoot. Au levels in these rocks were in the range 6 - 39 ppb, with one exception (DJR 5271) which, in addition to contaning 340 ppb Au was also enriched in As (963 ppm) and Sb (60 ppm).

Fracture zones containing enhanced levels of Au trend north-east to north-north-east, parallel to the local strike, within which clay alteration or fault gouge is common. Enhanced levels of Au in the range 100 - 1330 ppb) occur in samples 5269, 5271, 5275, 5276, 5279, 5291, 5292 and 5293. All samples are enriched in As (mean 521 ppm) and all but one in Sb (mean 52 ppm), whereas Cu values are of generally low tenor. Five of these Au-enriched samples occur in proximity to a hydrothermally-altered dioritic intrusion in adit B which was not enriched in Au.

Ellemford Mine

The single, northerly-trending gallery at Ellemford, near the north bank of the River Whiteadder, occurs close to the eastern edge of the Great Conglomerate within Silurian greywackes. Its entrance, blocked by

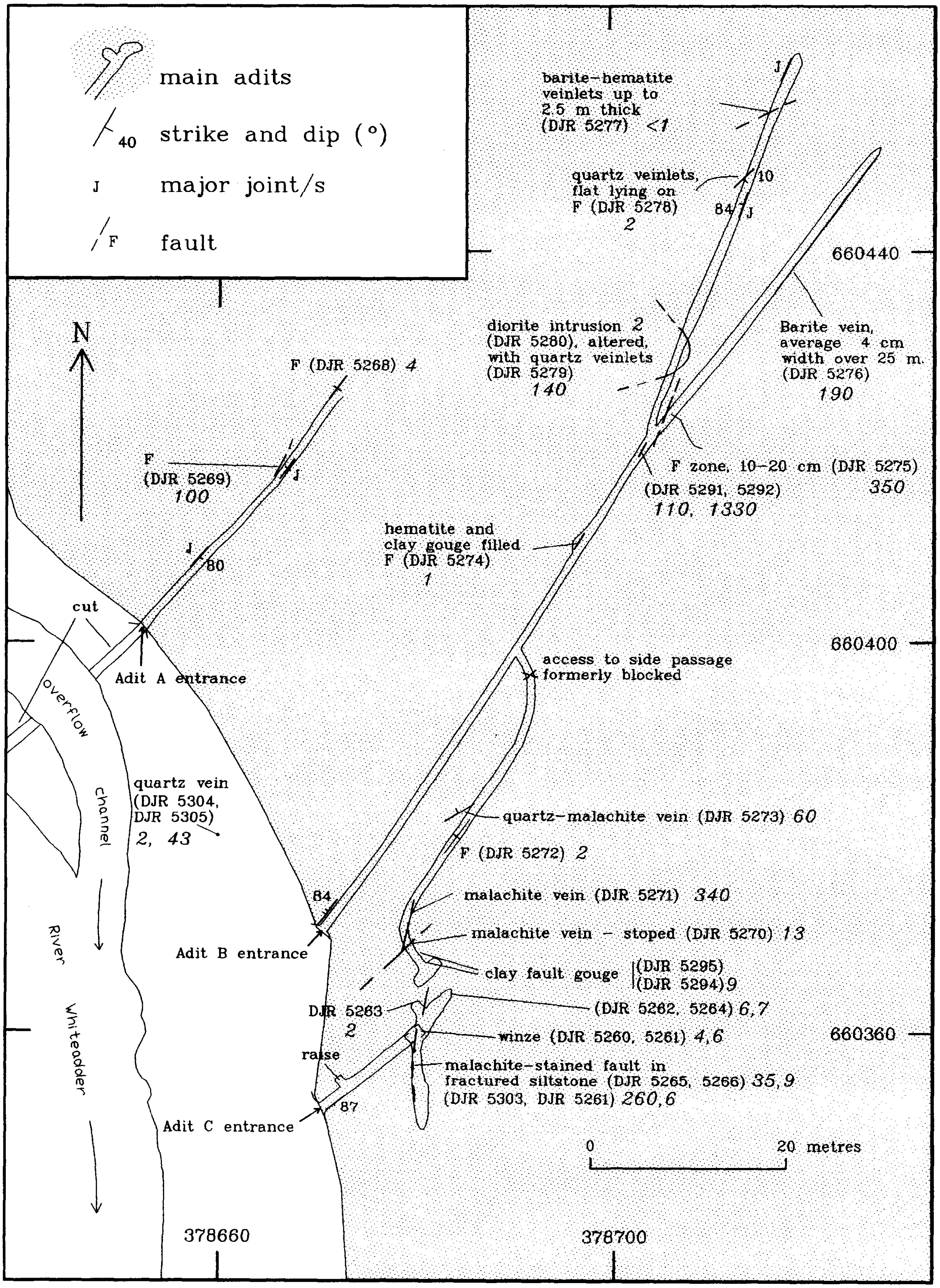

Figure 19 Location of adits and sample sites at Hoardweel Mine (gold values in ppb shown in italics, subsurface stippled)

waste material, was excavated for the purpose of this survey. In common with Hoardweel, the main gallery follows a fault containing Ba mineralisation. Eight samples of bedrock were collected from the workings. Only two of these showed slight enrichment in Au. These were a sample of barite fragments from the adit floor (33 ppb) and red clay fault gouge (13 ppb), from the north-east extremity of the adit. None of the samples collected was enriched in As, Sb or Cu.

Discussion

At Hoardweel gold mineralisation occurs in fracture zones and gouge-filled minor faults, suggesting that these acted as conduits for mineralised fluids. At these sites Au enrichment is accompanied by a markedly high levels of As and Sb. Two small barite veins also showed enrichment in Au, As and Sb. The distribution of Cu mineralisation is largely separate from the Au-enriched samples, and Cu-enriched zones are not significantly enriched in As or Sb. These indicate that the phases of Au and Cu mineralisation occurred separately.

Limited sampling at the Ellemford Mine revealed only minor enrichment in Au. The highest value was associated with barite-rich float and there is minor enrichment in fault gouge. South of Ellemford Mine, on the Whiteadder forest track, Cu mineralisation occurs sporadically as weak malachite staining within ferruginous zones in highly shattered and altered fine greywackes. The Ellemford Mine may have worked mineralisation of a similar type.

GEOPHYSICS

Geophysical surveys were undertaken to determine structural controls related to gold mineralisation in the Duns project area. In particular, the close spatial link between gold enrichment and the Priestlaw and Cockburn Law granitoids was considered worthy of examination by geophysical methods. An orientation study into the use of ground magnetics to define the extent of concealed intrusions was conducted utilising total-field magnetic susceptibility measurements. Results showed little contrast in susceptibility between the greywackes and the minor intrusives, and the detailed traverses did not accurately locate the margins of the intrusives. In consequence, it was decided that a gravity survey might be more useful in clarifying the form of the minor intrusive bodies.

Regional aeromagnetic data

Regional analogue aeromagnetic data for the northern part of the Southern Uplands were collected in 1962 as part of the new magnetic survey of Great Britain (Institute of Geological Sciences, 1972), along east-west flight lines spaced approximately 2 km apart with north-south tie lines about 10 km apart. These data, shown in Figure 20, have been digitised and gridded in relation to the area of detailed investigation (boxed). Significant anomalies are associated with the Priestlaw [363 663] and Cockburn Law [376 658] intrusions, with amplitudes of 80 and 100 nT respectively above background. A third significant anomaly of about 280 nT occurs on the coast just north of Berwick-upon-Tweed and may represent a similar intrusion.

Aeromagnetic anomalies near the north-east corner of the project area are associated with Permo-Carboniferous dykes with arcuate east-north-east trends. The two most prominent dykes are exposed on

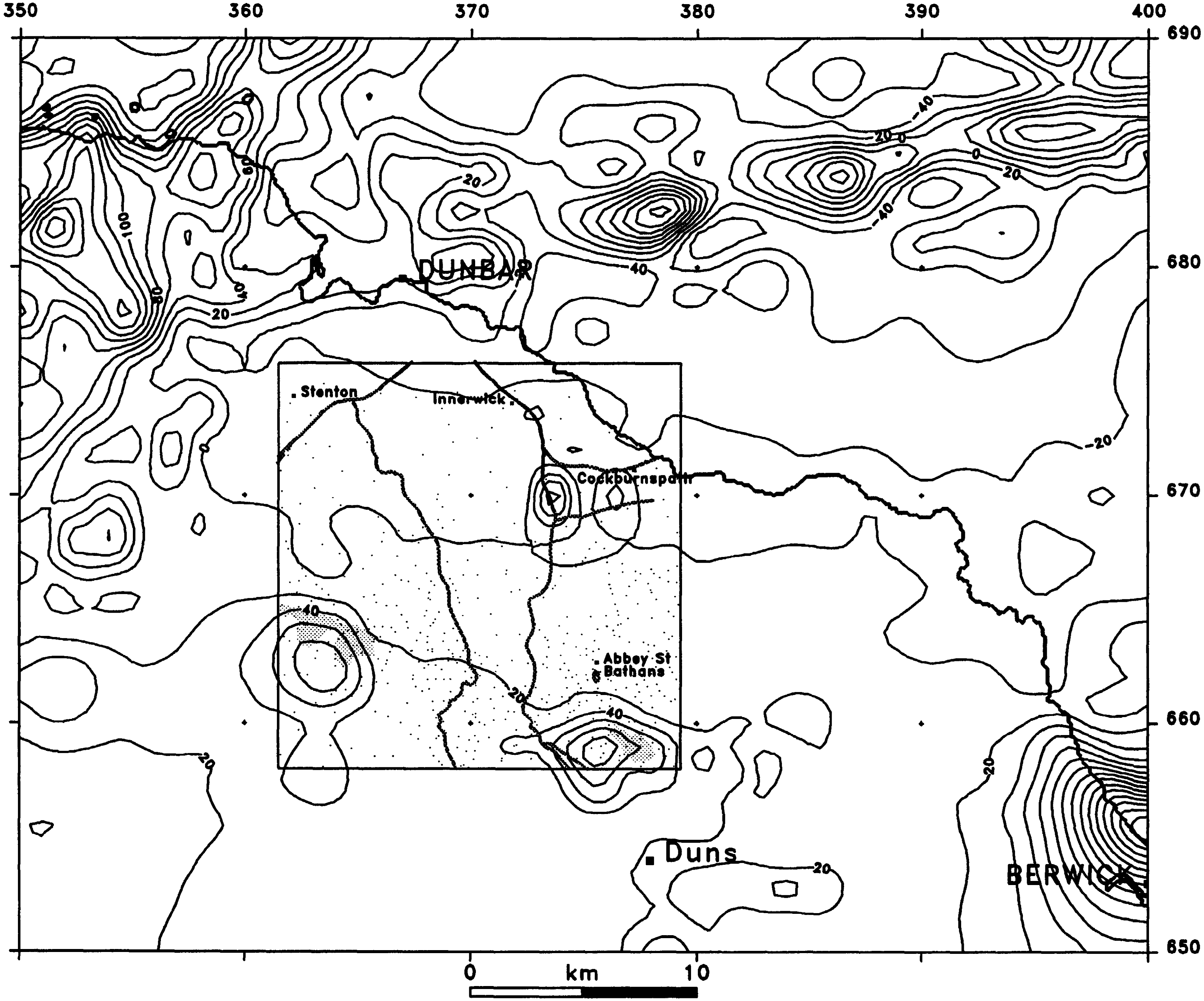

Figure 20 Regional aeromagnetic data

the coast near Dunbar, the more southerly of which is approximately 30 m wide. This dyke has a strong stable NRM, with demagnetised intensities up to 3.5 A m^{-1} and a NRM declination of 196 degrees and inclination 16 degrees (Xu and Tarling, 1987). East-west flight lines are unsuited to rigorous detection of east-west trending structures, so that some of the pole-like anomalies seen on the regional magnetic map might represent parts of an east-west dyke occasionally crossed by the flight line plan.

Regional gravity data

A regional Bouguer gravity anomaly low extends north-north-east across much of the Central Belt of the Southern Uplands. This has a closed minimum close to minor outcrops of felsite and porphyry at Innerleithen [378 672]. A extensive granitic body, the Tweeddale batholith, has been proposed as a possible cause of a regional gravity anomaly across much of the north-eastern part of the Southern Uplands (Lagios and Hipkin, 1979). Across the area of detailed investigations minimum Bouguer gravity anomalies occur over Carboniferous sedimentary rocks on the coast to the east of Innerwick (Figure 21). This anomaly extends north-north-east and east into the North Sea and might be largely due to Carboniferous strata, rather than the proposed Tweeddale batholith. However, the regional gravity low extends south-east of the coastal Carboniferous rocks over Silurian rocks to the east of Abbey St Bathans. South of Innerwick the regional gravity data indicate the relatively low density of the Lower Devonian strata, separating the Carboniferous sequence on the coast from the Silurian of the Lammermiur Hills. The hornblende diorites and quartz diorites of the Priestlaw and Cockburn Law intrusions are not clearly represented in the regional gravity data.

Lineation analysis

Lineations identified in a colour shaded relief image of the regional Bouguer gravity data and the aeromagnetic data are shown in Figure 22. Conspicuous features of this diagram are two sub-parallel gravity lineations (solid lines), trending east-south-east across the project area. The northern lineation lines up approximately with the northern margin of the Priestlaw intrusion. The southern line, at its intersection with the western edge of the figure, coincides with the previously-documented occurrence of vein gold mineralisation at Stobshiel [350 663]. In the east of the figure this gravity feature is replaced by an aeromagnetic lineation (dashed line) trending about 110°, which links the Cockburn Law and postulated Berwick intrusions. It is envisaged that this feature might be reflecting a structure controlling the location of these plutons and their associated minor intrusions.

In the central to south-east sector of the project area three north-west to north-north-west-trending gravity lineations occur. These are considered part of a regional set of lineations, which occur in the northern part of the Southern Uplands and the Scottish Midland Valley to the north of the Southern Upland fault (Figure 1). The arcuate east-north-east trending lineations in the aeromagnetic data suggest that other Permo-Carboniferous dykes similar to those at Dunbar might occur in the target area.

Gravity data collection

Detailed gravity observations were collected within an area defined by Easting 360000-380000 and Northing 657500 - 667500. Priority was given to the main Au-anomalous areas in the vicinity of the Priestlaw and Cockburn Law granodiorites. Due to operational constraints it was not possible to level

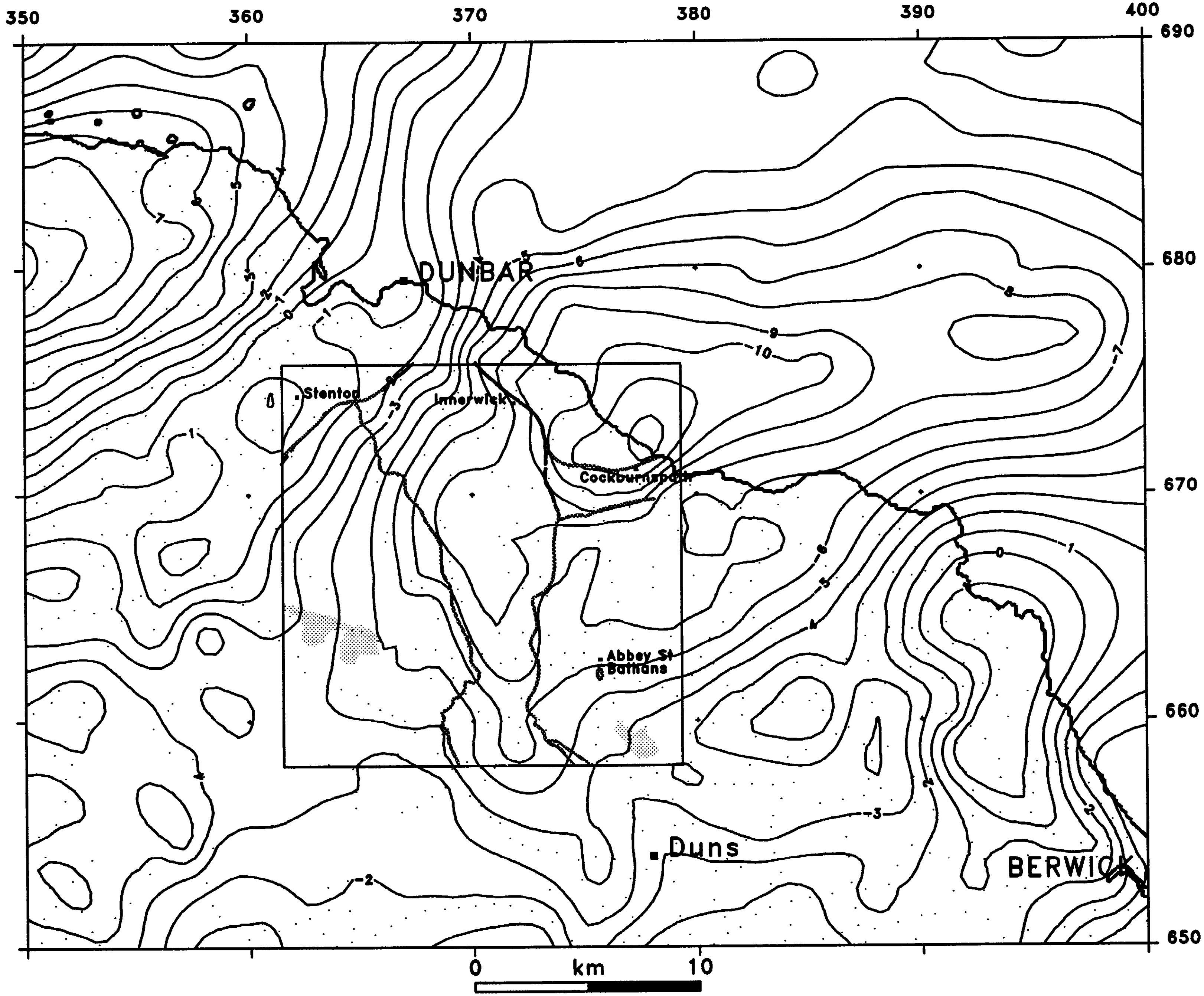

Figure 21 Regional gravity data

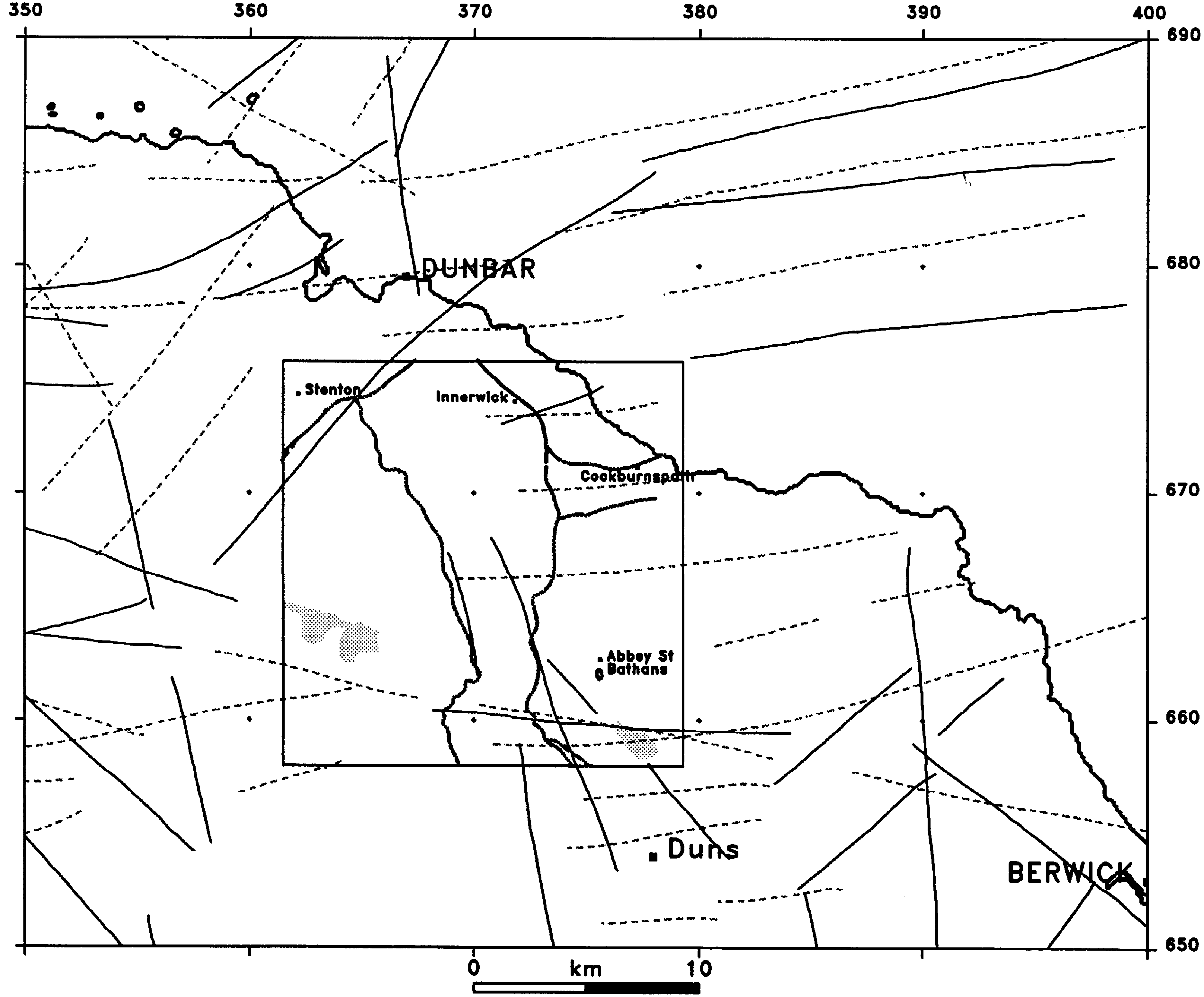

Figure 22 Lineations from regional aeromagnetic and gravity data

stations. Instead, measurements were taken at bench marks, spot heights and at contour cuts taken from the Ordnance Survey 1:10000 topographic maps.

Detailed gravity data

The detailed gravity observations made in the project area complement the new regional gravity data collected over the Lammermuir Hills. All the gravity data were terrain corrected, using a digital terrain model with a pixel size of 50 m, based on digital contour vectors from the Ordnance Survey 1:50000 Landranger map series. Within the project area a total of 571 stations were collected. Terrain corrections within 3 km of the station are generally less than 1 mGal but locally above 2 mGal. Bouguer gravity anomalies at a reduction density of 2.75 Mgm^{-3}, gridded at 0.25 km, contoured at 0.5 mGal, are shown for the area of geochemical investigation in Figure 23. A residual gravity anomaly for the same area is shown in Figure 24, based on a regional anomaly produced by upward continuation of the observed Bouguer gravity anomaly to 2 km above observation surface. A strong positive residual anomaly of about 0.5 mGal is associated with the northern and south-eastern sides of the Cockburn Law anomaly, although residual anomalies cross the Priestlaw intrusion.

Prominent gradient features are associated with the Great Conglomerate and the southern margin of the Carboniferous immediately south of Cockburnspath. A local positive anomaly on the west side of the Devonian rocks suggests some continuity with a structure parallel to the Carboniferous-Silurian boundary, on the east side of the Devonian conglomerate.

A subset of the data within the exploration area was examined using a second method of regional residual separation. Data for the region south of grid line 670 km N were reduced to OD at a density of 2.67 Mgm^{-3} and gridded at 0.2 km. The Bouguer anomaly map is shown in Figure 25. A residual anomaly across this region was calculated by subtraction of a second-order polynomial surface, representing the regional Bouguer gravity anomaly. The residual map is shown in Figure 26. The residual map appears to show a positive feature to the north-east of the Priestlaw body, trending east-south-east from about [365000 665000]. This is consistent with regional structures seen in images of the gravity data (Figure 22).

Conclusions

1. Regional aeromagnetic data indicate regional east-west-trending Permo-Carboniferous quartz dolerite dykes cross the region. The main late-Caledonian intrusions of Priestlaw and Cockburnlaw are associated with regional magnetic anomalies of about 100 nT and occur on an east-south-east lineation, which extends to an anomaly of 300 nT on the coast at Berwick-upon-Tweed. This anomaly is presumed to be caused by an unexposed granitoid intrusion.

2. Residual Bouguer anomalies in the Priestlaw - Cockburn Law area, derived from upward continuation of the observed data, appear to show a local positive anomaly north of Cockburn Law and suggest that east-north-east structures seen near the coast might extend west of the Great Conglomerate.

3. Detailed residual gravity anomalies derived from simple polynomial regional data indicate the presence of a local positive anomaly to the north of the exposed part of the Priestlaw granodiorite and a similar east-south-east positive feature north-east of the Cockburn Law body. The detailed gold sampling area of Tod Burn lies at the southern margin of this anomaly. Linear anomalies trending east-south-east and

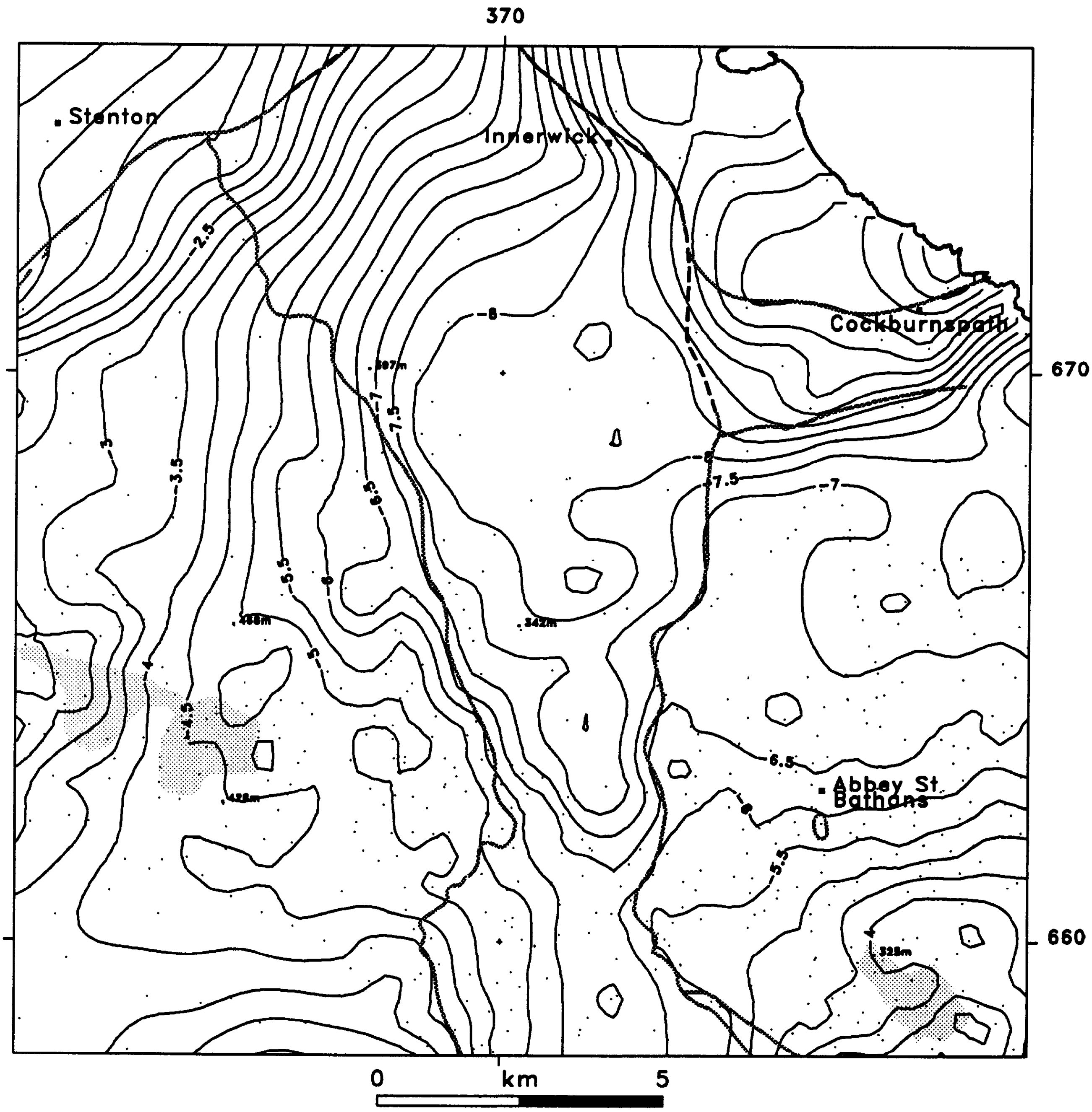

Figure 23 Bouguer gravity data for project area gridded at 0.25 km. Intrusions stippled.

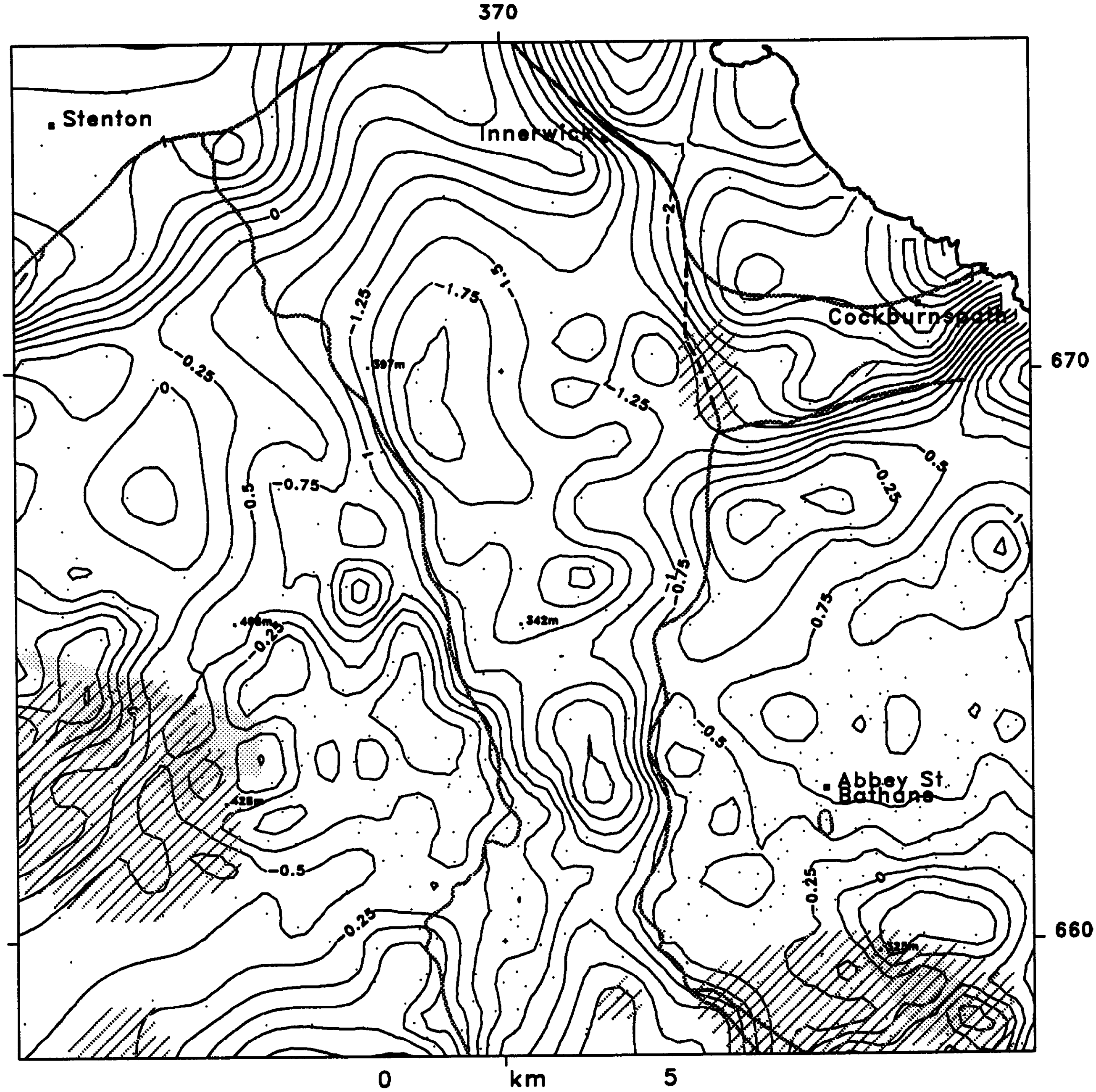

Figure 24 Residual gravity data for project area.
Intrusions stippled. Diagonally shaded where anomaly >50 nT.

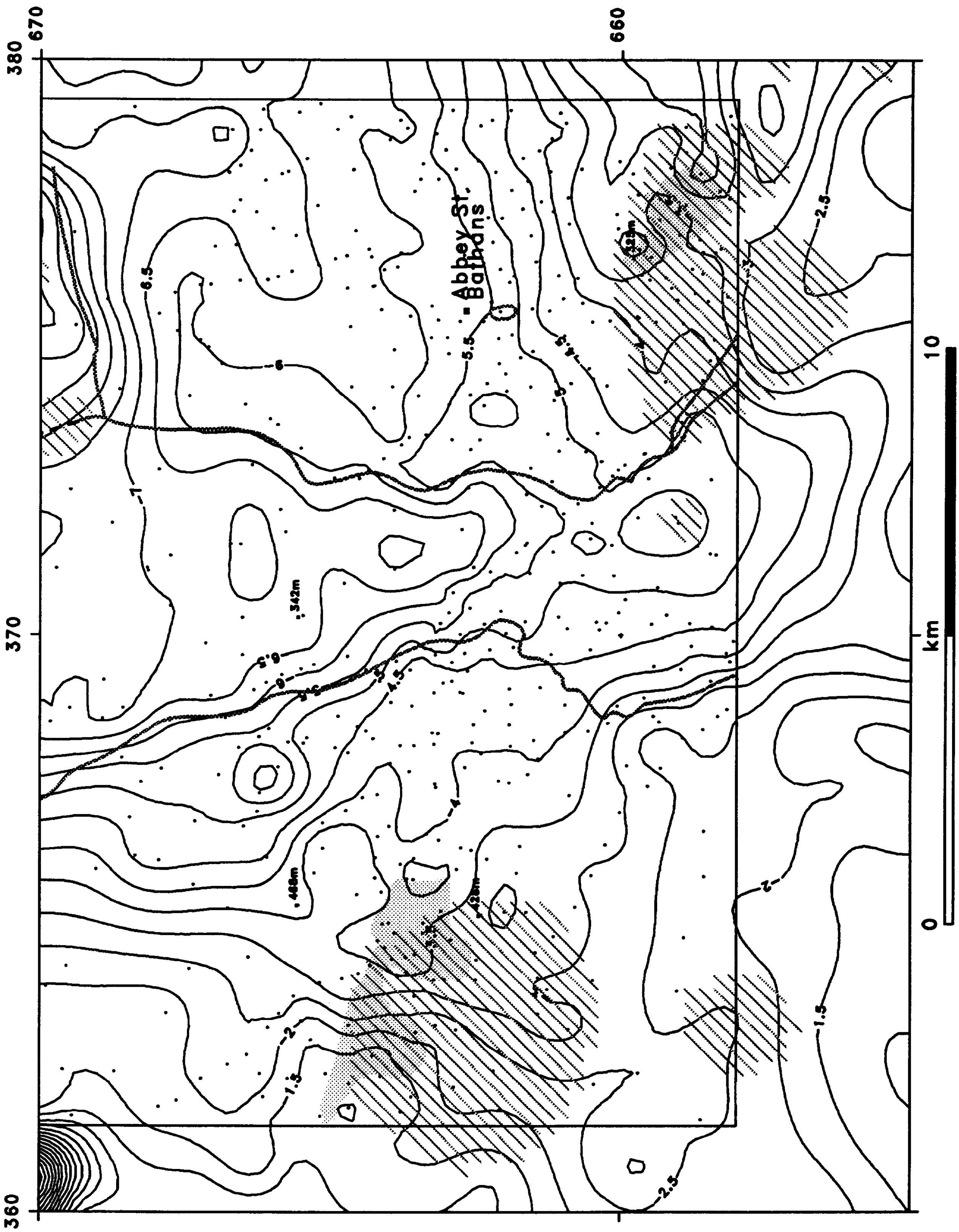

Figure 25 Bouguer gravity data using regional residual separation.
Intrusions stippled. Diagonally shaded where anomaly >50 nT.

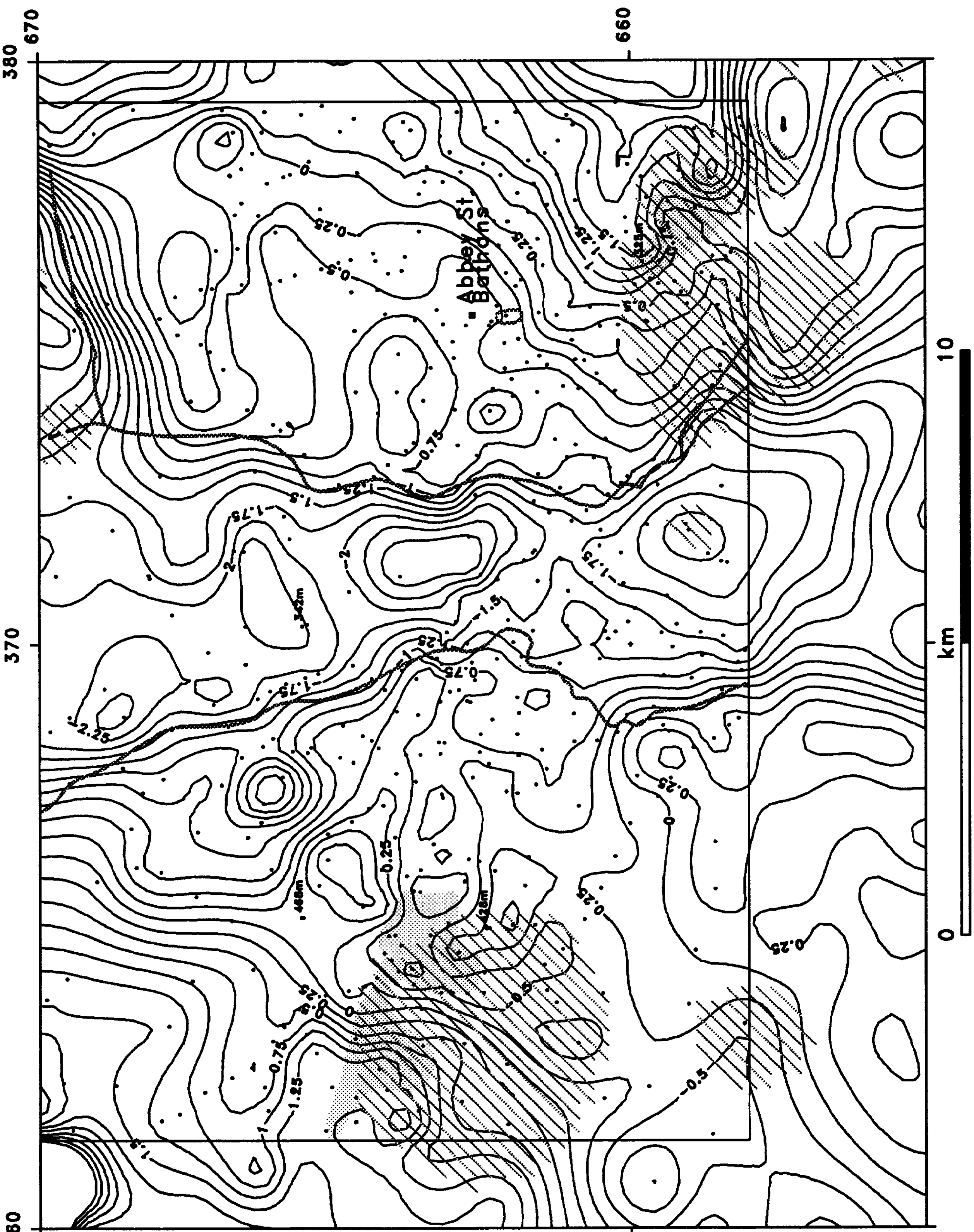

Figure 26 Bouguer gravity data - second polynomial subtracted.
Intrusions stippled. Diagonally shaded where anomaly >50 nT.

west-north-west from this zone are interpreted as being part of a possible major structure through the Lower Palaeozoic succession.

MINERALOGY AND PETROGRAPHY

A total of 32 rock samples were selected for mineralogical and petrographic examination. The majority were selected because they contained enhanced Au, although some unmineralised and altered and some unmineralised and unaltered variants were also submitted. It should be noted that, due to the intensity of alteration in the most Au-enriched samples, it was not possible to submit these for thin-section preparation. The majority of those samples prepared are also strongly altered, with development of coatings and penetrations of very fine-grained iron minerals, probably Fe-oxyhydroxide ('goethite') or poorly crystalline hematite. Au may be highly irregular in its distribution because of the nugget effect, or it may be invisible because it occurs as a trace element in otherwise normal minerals in the rocks.

Techniques

Polished thin sections, approximately 30 μm in thickness, were prepared by the Thin Section Laboratory at BGS, Keyworth. Each sample was vacuum-impregnated with blue dyed resin in order to preserve the friable structure and indicate porosity present in the rocks when received, as distinct from holes in the sections resulting from plucking during section preparation. This procedure was notably successful, allowing detailed examination of the structure and mineralogy of the loosely bound, altered and weathered samples. The degree of dye penetration suggests porosities above 30% in some samples. The thin sections were examined under a Zeiss Universal petrological microscope in both transmitted and reflected light modes, using a standard quartz-halogen light source with daylight blue filter. A series of photomicrographs were taken to illustrate textural features, using the 35 mm camera built into this microscope. Thin sections of the two most Au-rich samples were examined by scanning-electron-microscope and electron microprobe in an attempt to locate minute Au particles which might be present. Detailed descriptions of these rocks are given in Appendix 2.

Overview

The samples represent bedrock exposed in stream sections and shallow excavations at sites related spatially to geochemical anomalies. Bulk rock concentrations reported for gold and other elements are shown, indicating that the original samples contained values up to about 5000 ppb Au, together with minor enrichment in arsenic and copper. However, the rocks are strongly altered, with development of goethitic and limonitic coatings and penetrative alteration. Such primary metalliferous minerals as might have been present are no longer to be seen, and the alteration masks much of the initial character of the rocks. The purpose of the study was to elucidate the pre-alteration rock types, attempt to identify the location of Au in the Au-enriched samples and provide information on the style of attendant mineralisation.

The sedimentary rocks, especially the fine-grained pelitic varieties, display evidence of low-grade contact metamorphism. Hydrothermal alteration and mineralisation is indicated by pseudomorphs after pyrite, and possible other sulphides, which occur both disseminated and in fracture veinlets. It is therefore possible that Au was initially enriched during hydrothermal alteration, and this may have been related to volcanic activity indicated by the igneous samples.

The measured bulk Au values are all well below 1 ppm except for samples DJR7056 and DJR7057. These are strongly altered greywacke and hornfelsed mudstone respectively. DJR7056 shows clear evidence of having undergone sulphide mineralisation, but such evidence is lacking for DJR7057. Optical examination of polished thin sections in reflected light failed to indicate the presence of visible gold. Follow-up examination of the thin sections by scanning electron microscope in backscattered-electron (BSEM) and energy-dispersive (EDA) analysis modes similarly failed to locate gold particles. Systematic grid searches by electron-microprobe ("Turboscan") were equally unsuccessful. It is possible that the gold occurs dispersed as a minor constituent of the secondary iron minerals in the rocks, or occurs in the loose ferruginous coatings of the rock clasts which are hardly represented in the thin sections.

Alteration

Collectively, the samples indicate two stages of alteration which have affected both greywackes and Caledonian intrusives. The earlier alteration is intense, pervasive sericitisation and pyrite dissemination seen both sedimentary and igneous samples. This was accompanied by fractures sealed by quartz veining which carried sulphide grains, probably pyrite and in places, arsenopyrite and/or chalcopyrite. The alteration thus has hydrothermal, mesothermal character. The later alteration is fracturing accompanied by deposition of Fe-oxyhydroxide minerals and hematite. The alteration penetrated rocks affected by the earlier phase, and entailed almost complete oxidation of the early sulphide minerals. Primary Cu sulphide is altered to secondary sulphide ("djerleite") and malachite. The alteration also entailed a considerable degree of renewed fracturing and brecciation, affecting rocks probably not affected by the earlier phase. It differs considerably from the early phase, and is suggestive of invasion of fault-induced fracturing by high-Eh, possibly iron-bearing formation waters derived from Devonian (or younger) ferruginous sediments which are known to overlie unconformably the Lower Palaeozoic rocks in the area.

It is therefore possible to propose that the presence of Au in these rocks arose by a two-stage process involving initial incorporation as a trace constituent of early stage sulphide minerals, followed by re-incorporation into Fe-oxyhydroxide during the later alteration. Au in associated stream sediments might be derived by weathering and erosion of these source rocks.

STRUCTURAL INTERPRETATION

Within the project area the most conspicuous structural indicators are the orientations of the two principal suites of minor intrusive rocks (Figure 27). The Silurian turbidites are intruded by porphyritic, intermediate to acid dykes of late-Caledonian age, the majority of which trend generally NE. In contrast, basaltic intrusions of Carboniferous age are confined to the Great Conglomerate, and are oriented in a NW - SE direction.

It has been suggested that the NW - SE oriented dykes within the Great Conglomerate were emplaced within en echelon tension-fractures developed at about 45° to the regional shear couple (Elliott, R W, in Davies et al., 1986). The orientation of this shear couple corresponds closely to the NNW trend of the mapped regional gravity lineaments (Figure 27). Coincident linear features may also be traced on monochrome aerial photographs. It is suggested that these lineaments define the orientation of a sinistral shear zone which controlled basin development and subsequent dyke emplacement. The lineaments

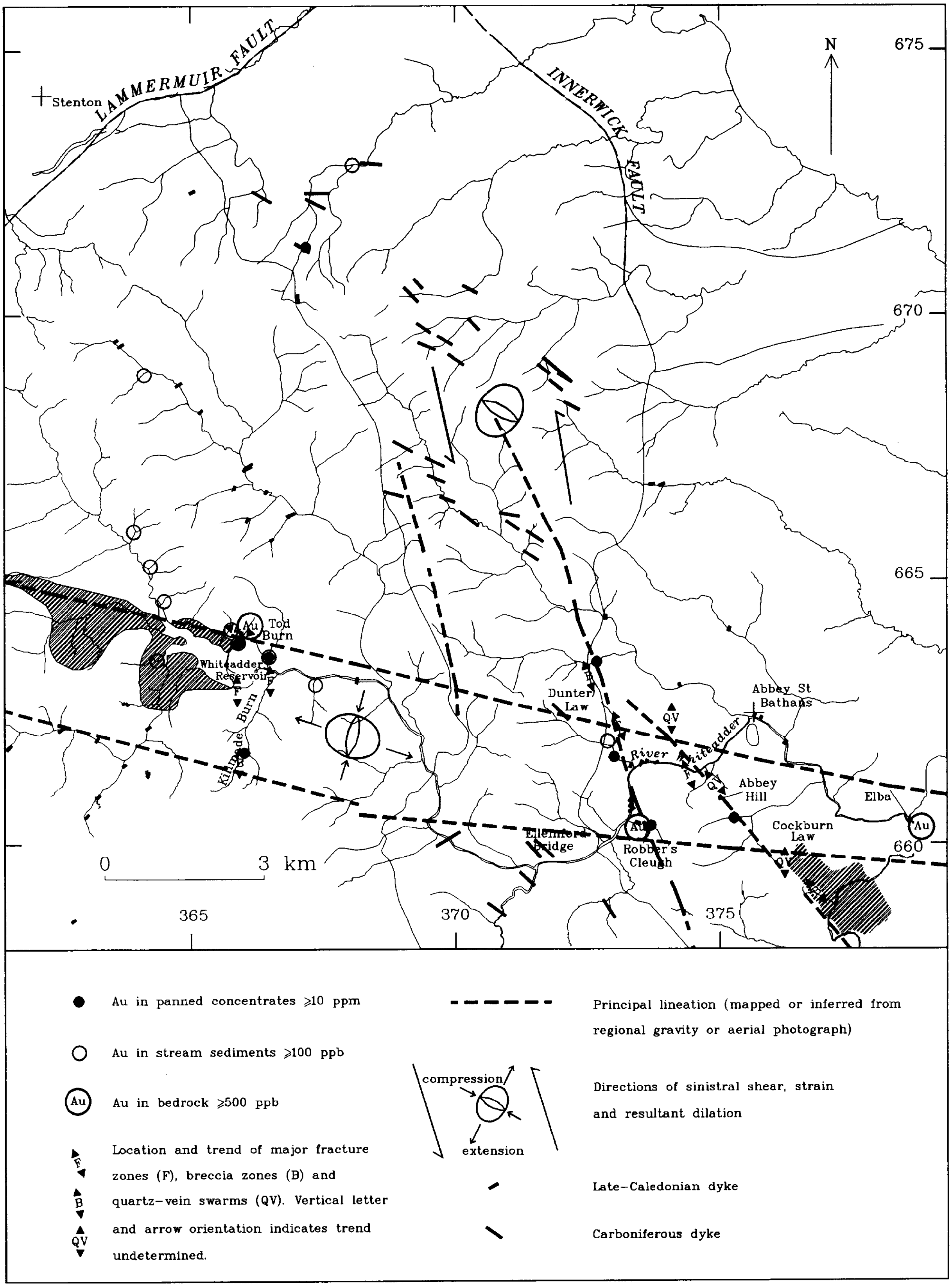

Figure 27 Structural interpretation of project area

extend south-east into Silurian rocks, along which are zones of intense fragmentation, brecciation and quartz-veining. Along these features also occur a number of gold occurrences in both drainage samples and bedrock. The detailed project areas of Abbey Hill and Cockburn Law lie on or close to the NW-trending feature and the Dunter Law area lies on a NNW-trending lineament.

Regional gravity data and a regional arsenic in stream sediments data define a pronounced WNW - ESE lineament which transects the project area on the same trend as the River Whiteadder (Figure 27) and appears to extend into the Scottish Midland Valley. This trend is comparable with a suite of late-Caledonian lineaments in the Scottish Highlands (Watson, 1984), which are believed to have developed as a conjugate set to the major NE-SW sinistral strike-slip faults within the Caledonian terrane. Brittle fracture and dilation within this zone permitted the emplacement of the plutons of Priestlaw, Cockburn Law, the auriferous Stobshiel body to the west-north-west of the project area and Lamberton Moor on the east coast. The injection of a profusion of minor intrusives in proximity to this zone may have also been expedited by fracture formation.

In addition to localised magma emplacement, rupturing of the country rock and changes in fluid pressure permitted the migration of mineralised fluids into zones of dilation. In this way already emplaced minor intrusives as well as country rock were hydrothermally altered. The importance of dilation zones in shear-related gold mineralisation is recognised in both mesothermal and epithermal gold systems (Sibson, 1987; Jahoda et al., 1989).

With the data available it is not possible to precisely correlate gold mineralisation with discrete tectonic regimes. However, the distinctive association between gold mineralisation and barite veining and barite-cemented breccia at a number of localities in the south-east part of the project area, together with the existence of minor barite veining within the Great Conglomerate in the Dunter Law area [3721 6631] suggests that mineralising events occurred in or continued into the early Devonian.

CONCLUSIONS AND RECOMMENDATIONS

1. Drainage sampling in the Duns area indicates that gold mineralisation occurs within Silurian clastic rocks of the Gala Group in proximity to late-Caledonian granitoid plutons. Sporadic enrichment of gold and associated pathfinders (As, Ag, Hg) over a broader area suggests that traces of gold mineralisation might also be present locally in the Lower Devonian Great Conglomerate. Reconnaissance drainage data also show a tightly-constrained zonation of As and Ag close to the main intrusions.

2. Detailed follow-up of the main reconnaissance drainage anomalies by soil sampling revealed localised low to medium tenor gold enrichment at the four localities investigated. In three of these there is a close association between gold enrichment and broader zones of elevated arsenic. Although direct spatial asssociations between gold and the base metals and antimony are not evident, minor occurrences of elevated antimony and copper may also be products of the same hydrothermal event.

3. Gold enrichment occurs in a variety of lithologies which are invariably oxidised and hydrothermally-altered. This enrichment appears to be fracture-controlled and hosted in veins or breccia zones. There is a frequent association with late-Caledonian porphyritic intrusives which are themselves locally gold-

mineralised. The quartz-vein zone on Abbey Hill area is coincident with a broad zone of markedly enhanced arsenic in soils. It is considered that this occurrence warrants further investigation.

4. Geophysical data indicates that the main focus of gold mineralisation was constrained within a major east-south-east-trending regional structure, the proposed 'Whiteadder Lineament'. The association between the Priestlaw and Cockburn Law intrusions and this zone indicates a structural control on magma emplacement. Gravity data indicate that at least one concealed intrusion also lies along the same trend. Subordinate north-west to north-north-west-trending lineaments in the south-east of the project area also coincide with elevated gold in drainage and bedrock samples.

5. The widespread, pervasive oxidation in greywackes and siltstones near the main granitoid plutons is consistent with ingression of meteoric fluids at a high structural level. The position of the present erosion surface in close proximity to the Devonian unconformity aids this interpretation. It is possible that low-temperature upgrading of gold within these areas, as the result of supergene processes, may have occurred during the early Devonian.

6. The establishment of major structural controls on gold mineralisation in the Duns area provides a number of potential exploration targets. The Tod Burn and adjacent catchment areas, lying within a newly-revealed gravity anomaly, provide a target for intrusion-hosted gold. The south-east quadrant of the project area may alternatively provide targets for fracture-hosted quartz-lode deposits. It is probable that further gold discoveries will be made within the Whiteadder Lineament.

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APPENDIX 1 Comparisons of Au levels in soil and bedrock samples from Abbey Hill area pits.

All values in ppb.
Rock codes: G=greywacke, S=siltstone, P=porphyritic intrusive.
NS=not sampled, - = below bedrock level.

Hole No./rock code	Bedrock	0 - 0.5 m	0.5 - 1 m	1 - 1.5 m	>1.5 m
Pit 1 - G	NS	NS	NS	6	8
Pit 5 - G	NS	NS	NS	27	3
Pit 5 - P	NS	NS	NS	39	96
Pit 6 - G	NS	32	-	-	9, 37, 3
Pit 7 - S	NS	NS	90	-	96
Pit 8 - G	NS	190	-	-	13
Pit 9 - G	NS	11	-	-	1
Pit 10 - G	7	9	-	-	1, 48, 4
Pit 11 - G	NS	NS	36	-	1, 8
Pit 12 - G	NS	7	-	-	14
Pit 13 - S	NS	17	12, 13	-	3, 28, 5
Pit 14 - G	NS	NS	NS	18,27	1
Pit 15 - G	NS	NS	55	-	1
Pit 16 - S/G	NS	24	NS	NS	7
Pit 17 - G	NS	NS	20	-	3
Pit 18 - G	NS	16	NS	-	2
Pit 19 - G	NS	7	NS	-	2
Pit 20 - S/G	NS	NS	6	-	7
Pit 21 - G	NS	20, 11	NS	-	6, 9, 6
Pit 22 - S	NS	NS	31	-	3
Pit 23 - G	NS	6	NS	NS	2
Pit 24 - G	NS	190	NS	-	22
Pit 25 - G	NS	33	NS	-	8
Pit 27 - G	NS	6	NS	-	1
Pit 28 - S/P	88	NS	12	-	6, 6

APPENDIX 2 Detailed petrographic rock descriptions

Field descriptions, locations and Au or other relevant analytical values are shown in italic.

1. DJR 5271 - QUARTZOSE GREYWACKE

Location: Hoardweel Mine [378680 660372]. 340 ppb Au.

Hand specimen - The sample consists of three rough pieces of rock respectively 3, 3 and 2 cm wide. One piece is a friable breccia, composed of a weakly cemented aggregate of 1-4 mm angular to rounded fragments, apparently of quartz and greywacke. The fragments are coated with soft earthy grey-brown limonitic material accompanied by traces of malachitic material and pale green to creamy material which may be malachite, finely intermixed with white clay or baryte. A second piece is very like the first, but the third appears to be of pale pink, altered granodioritic rock partly coated with earthy dark greyish brown limonitic material in which 1-5 mm fragments of quartz and/or granodiorite are embedded. The coatings also contain patches of yellow limonite/jarosite and traces of earthy pale green malachitic material. No visible gold was located by hand lens.

Thin section - Quartzose greywacke in which poorly rounded, poorly sorted 0.1 to 0.6 mm size quartz grains form about 50%, within a sericitised groundmass which includes intensely altered clasts, probably of feldspar or feldspathic rock. Weak pervasive hematitic alteration is present around fractures, but is negligible in intervening wallrock.

The rock is strongly fractured on a sub-millimetric scale, giving a loosely cemented fabric made up of badly fitting, angular clasts of greywacke held together by quartz-hematite fracture fill. In the fracture fill, quartz occurs as euhedral crystals and areas of interlocking anhedral mosaic and also as unusually elongated spindle-like crystals of uncertain origin. The quartz appears to have been crushed slightly. It occurs embedded in a micro-porous hematite matrix. In places, the hematite takes the form of a low density trellis-like structure of interconnecting septa, with about 60% interstitial pore space, which probably formed on the cleavage of a mineral (possibly dolomite) which has since been dissolved away.

One edge of the thin section captures one side of a banded fracture veinlet <1 mm wide, consisting of a discontinuous outer zone of pale green clay, flanked by a more continuous zone of deep red translucent goethite, internally micro-banded and micro-colloform. At the extreme edge of the section are traces of earthy microgranular goethite, probably representing the original centre of the vein. The vein is loosely cemented, with micro-porosity and hairline fissure porosity. The thin section shows almost no reflectivity, except for the micro-banded vein at its edge, in which occur (a) a few c. 0.1 mm hematite grains floating in the goethite and preserving within them traces of original pyritic sulphide, and (b) infrequent flakes (5-20 mm) of highly reflective material, not identified optically.

2 DJR 5275 - GRANODIORITE

Location: Hoardweel Mine [378706 660423]. 350 ppb Au.

Hand specimen - The sample is a single rough piece of rock c.6 cm wide. An angular piece of pale pinkish grey argillised and fractured granodiorite bounded by joint surfaces covered with tenuous limonitic coatings. Internal fractures host 1-2 mm thick porous veinlets of white and grey coated quartz. No visible gold was located by hand lens.

Thin section - A medium-grained greywacke in which poorly sorted, angular, <0.1 to c. 0.3 mm quartz grains (c. 50%) and abundant sericitised feldspar grains occur in a pervasively sericitised groundmass. Hematite occurs as very fine granules, sparsely disseminated through the rock and as coatings of accessory heavy mineral grains. The thin section is crossed by a sub-parallel set of fracture veinlets and associated oblique hairline fractures. The principle fractures are spaced 0.1 to 1.0 cm apart, and contain veinlets up to 1 mm thick. These veinlets consist of quartz and hematite. Interlocking anhedral quartz forms c. 50% of the thicker veinlets and nearer 90% of thinner ones. In the former, it is accompanied by fine-grained, micro-porous hematite pseudomorphs formed after originally abundant minerals. Tapering pseudomorphs may represent replacement of arsenopyrite, while more equant and irregular areas may represent replacement of pyrite. Fine dissolution porosity within the hematite forms about 20% of the total vein volume. Subsidiary hairline fracture may be sealed by quartz or by porous hematite. These apart, no porosity is apparent within the wallrock.

Within the oxide material in the fracture veins are minute ragged, straggling areas of probable hematite and a minor amount of discrete, compact grains of hematite. In the wallrock occur accessory hematite and probable secondary Ti-oxide, formed by replacement of sulphide grains and primary detritial grains respectively. Rare traces of probably pyrite are seen as <20 mm specks typically armoured in detrital quartz grains.

3. DJR 5276 - MASSIVE BARYTE

Location: Hoardweel Mine. Adit B [378723 660443]. Bedrock, 4 cm wide barite vein. 190 ppb Au.

Hand specimen - The sample consists of two rough pieces respectively 5 and 4 cm wide. The larger piece is a dense sample of creamy, coarse-grained massive baryte partially coated with earthy, very fine-grained hematite. The other piece consists of weakly cemented breccia composed of subrounded, sub-cm clasts of pale grey probable argillic altered siltstone, forming c. 70% and embedded in a matrix of porous, earthy, red hematite containing traces of possibly pale baryte. No visible gold was located by hand lens.

Thin section - Massive barite, made up of interlocking radiating bunches of slender blades with weak iron-staining. Plate-like dissolution pores are common, developed along hairline fractures and as more isolated slot-like pores. There are also infrequent opaque cuboid psuedomorphs and fine-scale dissolution pores. The total porosity is about 2-4 % overall. Traces of hematite occur as skeletal pseudomorphs c.0.1 mm in size, sited on micro-fissures in the host barite.

4. DJR 5320 - MICROGRANITE

Location: Tod Burn, 100 m upstream from road [365830 663780]. Bedrock. Reddened quartzose greywacke. Not analysed.

Hand specimen - The sample consists of a single rough, 5x6 cm sized piece of grey, weakly reddened quartzose greywacke with at least one prominent muscovite band. The rock is crossed by a set of parallel fractures spaced 5 to 25 mm apart, which carry porous quartz veins c. 3 mm thick. No visible gold was located by hand lens.

Thin section - Altered massive, aphyric, felsitic microgranite, consisting essentially of quartz (c. 40%), sericite (c. 25%), muscovite (c. 5%) and hematite (c. 30%). The original igneous texture is preserved, but feldspar has been replaced by sericite, altered to secondary muscovite and hematite, and secondary quartz formed in the groundmass. Hematitic granules are present throughout.

At one side of the thin section, the rock passes into an area of intensely sericitised rock with little hematite. At the opposite side, the rock is crossed by two sub-parallel fracture veins respectively 1.0 and 1.5 mm wide, which contain a vuggy fill of anhedral interlocking quartz mosaic accompanied by minor K-feldspar, muscovite and chlorite. The chlorite is an almost colourless variety present as patches of radiating plates. Vugs up to 4 mm long by 1 mm wide, forming c.30% of the veins, are contained by quartz with euhedral crystal faces. They are coated with opaque 'hematite', and are accompanied by fissure porosity created by a few unsealed hairline cracks parallel to the veins in the immediate wallrock. Fine-grained dissolution porosity is extensively developed in hematite grains in wallrock within 2 mm of the veins. Porosity is negligible further from the fractures, but is present again in the above-mentioned highly sericitic zone where up to 10% of fine dissolution porosity is present.

Significant reflectance is shown only by accessory minute hematite pseudomorphs, some of which show cuboid forms indicating replacement of c. 0.1 mm wide pyrite crystals. These apart, the secondary ferruginous material is apparently crypto-crystalline, possibly goethite or other Fe-oxyhydroxide mineral phases.

5. DJR 5337 - RHYOLITIC TUFF

Location: Cockburn Law [376288 659660]. Bedrock. 5 ppb Au.

Hand specimen - The sample consists of a single cm sized piece of pale pinkish grey altered agglomerate with perhaps 10% porosity as widely distributed spheroidal cavities up to 2 mm wide, mode <1 mm, which may be vesicles in which dissolution of a soluble mineral such as carbonate has taken place. The clasts are poorly sorted, rounded, c. 15 mm size, of altered andesite or dacite.

Thin section - Welded rhyolitic tuff possibly formed by welding together of an emulsion of quasi-liquid magma globules. The rock has a glassy groundmass which contains irregular quartz grains up to 0.4 mm in size, which appear to be the result of shattering of phenocrysts or xenocrysts rather than being whole phenocrysts. The ground mass also contains biotite flakes which vary from minute to phenocrysts up to 0.5 mm wide. It also contains numerous xenolithic clasts of biotite-granite and granodiorite, with variable sericite/muscovite replacement of feldspar and biotite. Moderate hematitic alteration is concentrated into certain areas, with a distribution which appears to be distinct from that of porosity, varying from generally absent to zones of high porosity related to fissuring at the margin of the sample. Associated with the porosity is a small amount of late-stage hematite, forming discontinuous, localised rims to the pores. Fresh biotite is notably preserved within the porous zone. Hematite grains up to 0.1 mm in size occur sparsely, and rare micron-sized metallic or sulphidic blebs are present.

6. DJR 5340 - QUARTZOSE HYDROTHERMAL VEINSTONE

Location: Cockburn Law [374095 662300]. Bedrock. Not analysed.

Hand specimen - The sample consists of a single 10x8x6 cm sized piece of hydrothermal veinstone mostly consisting of grey to white coarse-grained quartz with a greasy lustre. The texture varies from massive, interlocking, impervious, to areas of high porosity accompanied by pockets and coatings of limonitic material, suggesting areas of crushing of the vein and penetration by iron-rich water. In the part of the sample originally furthest from the vein margin the sample becomes a porous, limonitic aggregate of euhedral quartz crystals. The opposite face of the sample is approximately planar, representing the edge of the vein, with a skin of dark green-grey chloritic altered wallrock; slivers of chloritic wallrock also occur within the vein margin. No visible gold was located by hand lens.

Thin section - Hydrothermal quartz veinstone. The thin section shows a passage from turbid, early-stage quartz with an interlocking, sutured (mortar texture), anhedral fabric, into rock dominated by a porous aggregate of 1-4 mm, subhedral to euhedral unstrained quartz crystals. The euhedral aggregate encloses detached areas of turbid, early-stage quartz and contains minute lensoid pockets of very fine-grained, possibly cataclased quartz at boundaries with areas of the early-stage quartz. Moreover, the open, cavernous fabric of the euhedral quartz is curious in that it hosts intergranular pockets of lithic clasts (sericitic phyllite) and areas of medium-grained third stage quartz. The remaining pore space is lined, and partially occluded, by coatings of goethitic material. Some examples show partial linings of brown, translucent, micro-colloform goethitic material around an open mesh or trellis of plates of microgranular geothite which suggests a relict of the cleavage of an earlier mineral which has been dissolved out (carbonate or sulphide mineral/s?). The total remaining porosity is estimated as 5%.

Tiny (<10 mm) hematite granules occur sparsely in some geothitic areas, and very rare metallic blebs of similar size were noted in goethitic material. Isolated c. 10 mm pyrite blebs were observed within a patch of very fine-grained hematite. Substantial goethitic/hematitic patches suggest replacement of sulphide originally deposited with the quartz.

7. DJR 5347 - RHYODACTIC PORPHYRY

Location: Abbey Hill [374460 660480]. Quartz-feldspar-porphyry. 3 ppb Au.

Hand specimen - The sample consists of a single 5x5x3 cm sized, angular piece of pervasively limonite impregnated, massive probable microgranodiorite or andesite, although the primary texture is obscured by the ferruginous material.

Thin section - Porphyritic biotite-plagioclase rhyodacite which has undergone strong sericitic alteration. Plagioclase occurs as phenocrysts up to 1.5 mm in size, and as clots about 4 mm wide. Muscovite and muscovite-chlorite pseudomorphs occur after mafic crystals, but biotite flakes up to 1 mm wide survive. The very fine-grained sericitic groundmass contains accessory minute quartz grains which could be primary of have been formed during alteration.

The rock contains approximately 15% of disseminated hematitic/goethitic material, present as minute ragged clots and replacement of minute mafic grains in the groundmass. Very fine dissolution porosity is present throughout the hematitic material. Most of the opaque material shows very little reflectivity, and only a sparse amount of 20 mm hematite granules is present.

8. DJR 5348 - RHYODACITIC PORPHYRY

Location: Abbey Hill. Local Grid: 375W 00 [374088 660379]. 0 ppb Au.

Hand specimen - The sample consists of a single 12x9x2.5 cm sized piece of rock, and a number of smaller fragments. The largest piece is earth-coated on one side, but the other face is a broken surface showing a 1.5 mm zone of penetrative iron staining, within which is a core of pale grey rock with white mottling, interpreted as altered microdiorite or microgranite. Mafic minerals are obscured by the alteration, but examples of quartz and muscovite grains >1 mm wide were noted.

Thin section - Porphyritic rhyodacite in which 40% of plagioclase phenocrysts up to 2 mm in size are strongly sericitised. Mafic phenocrysts up to 1 mm in size have been replaced by muscovite with hematitic micro-granules deposited along the cleavage. The very fine-grained quartzo-feldspathic groundmass contains only a minor amount of minute sericitic clots, but disseminated hematitic patches and granules are abundant.

Fine dissolution porosity of around 1-2% occurs within hematitic patches, accompanied by very minor hairline fissure pores with minute hematitic granules hosted within them. Some hematitic patches are sites at the centre of muscovite clusters, suggesting that the hematite may have formed by replacement of sulphide formed during the sericitic alteration stage. Micron-scale hematite granules are common, but are not volumetrically significant. These apart, the opaque component consists of probable geothite.

9. DJR 5364 - RHYOLITIC AGGLOMERATE

Location: Cockburn Law [376920 659190]. Float from boulder pile. 1 ppb Au.

Hand specimen - The sample is a single 6x6x3 cm sized piece of dark 'ruby' red, pervasively ferruginous-altered agglomerate. Clasts are poorly sorted, some >3 cm in size, and collectively form c.30% or more of the rock. Some have a conspicuous appearance in which red areas are set in a groundmass of chalky white material. Others are carious and highly porous. The reddened groundmass is siliceous. Porosity varies greatly, reaching about 40% in carious clasts, but being perhaps near to 10% overall.

Thin section - Flow foliated glassy rhyolite hosting xenoliths of biotite-microgranite. The rhyolite itself is little altered, save for fine disseminated hematitic granules and isolated 'hematite'-rimmed c. 1 mm size dissolution cavities, but the xenoliths are strongly altered in three stages: (1) development of c.1 mm wide bands of very fine cataclastic granulation, which do not extend into the enclosing glassy rhyodacite and hence pre-date its formation; (2) muscovitic alteration accompanied by minor chlorite; (3) strong development of dissolution porosity throughout feldspar crystals, accompanied by micron to mm scale dissolution cavities often part filled by hematitic material deposited in them. As a result, the xenoliths, which range from 2 to 15 mm wide in the thin section, contain about 20% of visible porosity as well as about 20% of hematitic material. Micron-scale hematite granules occur in areas rich in oxide coating on dissolution cavities. A few <20 mm hematite grains appear to represent replacement of primary mafic granules.

10. DJR 5367 - GREYWACKE

Location: Philip Burn fault zone [372860 663513]. 2 ppb Au.

Hand specimen - The sample is a small bag of coarse gravely clasts up to 2 cm in size; a bag of unconsolidated, ill-sorted, friable, rough-surfaced, ferruginous rock clasts possibly derived from an poorly cemented, iron-impregnated fault crush breccia. The nature of the background lithology is not clear.

Thin section - The thin section shows sections through three separate rough-surfaced, elongated rock clasts, chosen to represent the bulk sample. One is a gouge-breccia of ground up quartzose greywacke, heavily impregnated with c.50% of hematitic material. The other two are of pale, quartz-rich greywacke sandstone, showing pervasive sericitic alteration of the groundmass accompanied by muscovite flakes which are, at least in part, secondary. Disseminated cuboid opaque grains up to 0.4 mm in size, forming c. 4% of the rock, appear to be hematitic material formed by replacement of disseminated pyrite. These two clasts also have tenuous external coatings of hematitic material. The gouge contains a semi-massive aggregate of very fine-grained hematite. The greywacke pieces contain common hematite replacements of pyrite crystals, and also rare preservation of pyrite as a c.50 mm wide platy grain seen armoured in quartz.

11. DJR 5372 - QUARTZ-WACKE

Location: Tod Burn, beneath small waterfall [365960 663950]. 18 ppb Au.

Hand specimen - Two rough pieces of rock, respectively 5x4 and c.3 cm in size, of vivid brick red, hematite-coated, porous rock. Both appear to be of a fine-grained grey felsite, which has been intensely fractured and impregnated with earthy hematite. Broken surfaces of the original rock however display white chalky argillaceous alteration. Yellow limonite/jarosite occurs as rare 1-2 mm patches in the hematite coatings. No visible gold was located by hand lens.

Thin section - Quartz-wacke in which very poorly sorted quartz grains ranging in size between <0.1 mm and 0.35 mm form about 50%, set in a groundmass of silt grade detritus. The grains are angular, of poor sphericity, and the modal grain size varies in an patchy fashion across the thin section.

The rock is strongly fractured, resulting in a close-spaced network of interconnecting fractures, with minimal overall displacement. The fractures are lined and partially sealed by opaque, probably hematitic or geothitic material, accompanied by about 50% of fissure porosity. In detail, many of the thinner fractures are discontinuous, indicating either partial annealing or, more probably, fracture formation by dissolution on parts of otherwise cryptic or incipient proto-fractures. The absence of any thin section evidence of a break in the fabric of wallrock between separate sections of what appear to be single discontinuous fractures is remarkable. In contrast, the many of the more prominent fractures develop into zones of micro-brecciation of wallrock, set in an opaque-micropore matrix. Fracture widths are typically 0.1-0.3 mm, and the widest observed in the thin section is 1.1 mm thick. Fractures form about 20% of the rock, and the total porosity is estimated to be about 10% of the rock.

Poorly to non-reflecting oxidic material is seen throughout the thin section. A trace constituent of minute (<5 mm) blebs of strongly reflecting metallic or sulphidic material is seen armoured within quartz grains and embedded in secondary oxide.

12. DJR 5373 - SILICIFIED PORPHYRITE

Location: Trackside, 130 m W Robber's Cleugh [373400 660360]. 3 ppb Au.

Hand specimen - A single rough piece, 5x6 cm in size, of pale pinkish grey altered agglomerate with perhaps 10% porosity as widely distributed spheroidal cavities up to 2 mm wide, mode <1 mm, which may be vesicles in which dissolution of a soluble mineral such as carbonate has taken place. The clasts are poorly sorted, rounded, c. 15 mm, of altered andesite or dacite.

Thin section - The thin section shows intense brecciation accompanied by deposition of porous hematitic cement. The host rock appears to be a cherty rhyolite or quartz-rock of hydrothermal character, with areas (clasts or possible phenocrysts) of sericitised material and areas of medium-grained quartz mosaic. An estimate of overall proportions is 'hematitic' cement 30%, porosity 20%, host rock 50%.

The distribution and fabric of the 'hematitic' alteration is highly variable, and is post-dated by the development of porosity which consists of irregular, semi-connected fissures, hairline fractures and localised dissolution cavities. Porosity is also seen as vuggy centres to post-'hematite' quartz veinlets. Examples include areas of massive oxide enclosing minute detached wallrock fragments; other areas contain irregular oxide patches which appear to have been brecciated and recemented by later-formed quartz; areas of semi-massive oxide shot through with a mesh of bladed quartz pseudomorphs possibly indicating replacement of barite. Minute oxide grains and granules occur disseminated through the fine-grained quartz-mosaic wallrock.

It is suggested that the oxide formed by replacement of sulphide mineralisation, and that the paragenesis was as follows:

(1) Silicification and sericitisation of the original rock, accompanied by sulphide-barite mineralisation.
(2) Fracturing, brecciation and hematitic alteration of sulphide minerals.
(3) Further stages of fracturing and recementation by quartz.

Grey, low reflectance goethite or hematite form a high proportion of the otherwise poorly crystalline Fe-'oxide' component of the thin section, occurring as extensive irregular minute patches, pseudomorphs after sulphide grains, micro-colloform fracture coatings and by local wallrock replacement.

13. DJR 5621 - DOLERITE

Location: Abbey Hill local soil grid (pit) [374734 660850]. 96 ppb Au.

Hand specimen - A single rough, crudely rounded piece, 5x3 cm in size, of soft, grey-coated rock which on broken surfaces is seen to be pale pink, porous, argillic altered felsite or micro-granodiorite. No visible gold was located by hand lens.

Thin section - The thin section has a pervasive pale blue colour, indicating blue-dye resin penetration of porosity present throughout the sample. The rock is a strongly altered dolerite. It contains about 40% of tabular plagioclase phenocrysts up to 3 mm wide, in a fine-grained groundmass with minor pervasive hematite alteration. Many of the phenocrysts are hematitised, while a few others show pale clayey alteration. Disseminated opaque pseudomorphs (probably hematite) and moldic dissolution pores form about 2%. They often have an euhedral cuboid form, suggesting replacement of pyrite. The original sample margin is marked by a 2-3 mm wide zone of hematitic alteration. Porosity is also created by c.1% of unsealed hairline fractures which are discontinuous where propagated as sets of en echelon shears. There is also an uncertain amount of cryptic micro-porosity throughout the groundmass of the rock. Skeletal hematite patches up to 0.2 mm wide represent replacement of original opaque grains, and micron-scale hematite flecks occur in altered feldspar crystals.

14. DJR 6239 - GREYWACKE

Location: Abbey Hill soil anomaly site [374048 660474]. 100 ppb Au.

Hand specimen - A single rough, angular piece, 5x4 cm in size, of friable, grey earth-coated, pale-yellow, argillised, muscovitic greywacke. This rock contains lensoid bedding-parallel cavities <12 mm long, which are lined by grey coated quartz; an additional 1-2 mm thick lens of the same quartz lies 3 mm from the edge of the cavities. No visible gold was located by hand lens.

Thin section - Feldspathic quartz-greywacke, a massive, poorly sorted, gritty rock with grains in the size range 0.1 to 1 mm. It has a well-compacted fabric, with little intergranular matrix. Feldspar grains and opaque grains are common, both often showing fine dissolution porosity. Other detrital constituents include conspicuous muscovite flakes and lithic grains of muscovitic phyllite and brown-stained mudstone.

The rock is crossed by fracture veinlets made up of anhedral, interlocking quartz, which enclose lensoid patches of fine-grained vermiform chlorite. Local vugs, typically 2 mm long, are lined by hematite-rimmed subhedral quartz, and there are traces of fine-grained gouge and localised micro-porous hematite pockets pseudomorphous after probable sulphide. These veinlets are older than a sparse set of incipient, discontinuous, hairline fractures, locally hematite-lined, which crosscut the quartz veinlets. The hairline fractures are associated with the dissolution porosity in the wallrock (see above). Very fine dissolution porosity is seen to pervade mudstone clasts and a conspicuous 1.5 mm clast of apparent basalt. The overall porosity is estimated as 2-4%. including vugs in the quartz veins. Hematite occurs as granules <50 mm in size, common in the matrix of the rock, and as psuedomorphs after original mafic detritial grains.

15. DJR7002 - HORNFELSED SILTSTONE

Location: Abbey Hill Pit 2 [374639 660779]. Depth 1.5 m. Grey siltstone with purple bands. 39 ppb Au.

Hand specimen - The sample consists of three pieces, the largest 8 x 4 x 1 cm, of grey mudstone in which pervasive reddening is accentuated in certain mm-scale bands. The fragments have tenuous geothitic surface coatings covered in soft earthy limonitic material.

Thin section - Iron stained thinly banded siltstone in which alignment of fine-grained white mica flakes creates a bedding parallel lepidoblastic fabric suggesting low grade contact metamorphism. Sparse detritial magnetite grains up to 0.03 mm in size are present, showing incipient hematitic alteration. The thin section also reveals swarms of granules, c. 0.01 mm in diameter, of possible hematite or goethite. They form up to 50% of some bands, and may have been formed by replacement of carbonate grains or fine-grained diagenetic pyrite. The rock is cut by a network of hairline fractures which have in part closed up without development of a mineral vein, and in part remain as fissures occupied by discontinuous goethitic fills and semi-continuous fracture pores. External geothitic surface coatings are preserved in the edges of the thin section.

16. DJR7005 - PORPHYRITIC DACITE

Location: Abbey Hill Pit 3, [374640 660781]. Red-brown rotten feldspar porphyry with 98 ppb Au.

Hand specimen - The sample consists of loose "gravel" made up of pieces, up to 3 cm in size, of salmon-pink, highly friable and soft, altered volcanic rock in which white clayey pseudomorphs after feldspar phenocrysts are conspicuous.

Thin section - Strongly altered volcanic rock, possibly dacitic, in which the blue-dyed mounting resin picks out an intense network of unsealed sub-mm scale fissures developed throughout the rock. The rock also displays a high degree of pervasive microporosity, giving an overall porosity of perhaps 40%. Common pseudomorphs after tabular feldspar (probably plagioclase) crystals up to 3 mm long probably originally formed about 40% of the rock, but are now made over to microporous clay-mica material. Mafic phenocrysts, originally biotite and/or hornblende up to 2 mm long, formed about 10% of the rock. These now consist of microporous mixtures of clay-mica and opaque microgranules. In reflected light, the granules are seen to be of probable rutile or anatase together with probable geothite/hematite. Goethitic pseudomorphs after cuboid crystals of probable pyrite form about 5%. The remaining groundmass is microporous clay-mica material with c. 20% disseminated opaque granules, possibly goethite.

The evidence for the former presence of pyrite indicates that the rock underwent pervasive hydrothermal alteration before the dominant clay-rich alteration took place.

17. DJR7011 - PORPHYRITIC DACITE

Location: Abbey Hill, Pit 5 [374664 660798]. Depth 1.8 m. Bedrock. Rotten feldspar porphyry, with 96 ppb Au.

Hand specimen - The sample consists of several pieces up to 5 cm wide of highly altered porphyritic volcanic rock now seen as soft, friable, pink-red, highly porous rock with sparsely distributed white clay-altered feldspar phenocrysts up to 2 mm in size.

Thin section - Strongly altered volcanic rock, possibly dacitic, in which the blue-dyed mounting resin picks out an intense network of unsealed sub-mm scale fissures present throughout the rock. The rock itself also displays a high degree of pervasive microporosity together with dissolution cavities formed after cuboid crystals (probably pyrite), giving an overall porosity probably greater than 30%. Feldspar phenocrysts up to 1.5 mm in size, originally about 10% of the rock, are now pseudomorphed by microporous clay-mica material. Mafic phenocrysts are now represented by spongy areas with minute granules of possible anatase and goethite. It is also possible that sparse muscovite flakes may have formed by replacement of biotite. In the groundmass, pervasive microporosity and geothitic granules accompany fine-grained white mica and quartz, and the forms of original groundmass feldspar plates are clearly visible. Disseminated pyrite, now part dissolved and the remainder altered to goethtitic material, originally formed perhaps 5%.

This evidence indicates that the rock underwent a stage of hydrothermal alteration and pyrite deposition prior to later intense leaching and oxidation possibly during weathering and soil formation.

18. DJR7015 - HORNFELSED MUDSTONE

Location: Abbey Hill, Pit 7 [374680 660809]. Depth 1.3 m. Bedrock. Light grey mudstone, with 96 ppb Au and 165 ppm As.

Hand specimen - The sample consists of four pieces, the largest about 6 cm wide, of pale grey mudstone with soft, mid-brown surface coatings of limonitic material and patches of white clay. Sub-mm grains of grey metallic-looking mineral, probably sulphide or hematitic pseudomorphs after sulphide, are present in an annealed fracture seen cutting bedding at about 80° in the sawn face cut in one of the pieces.

Thin section - Thinly banded mudstone which has undergone contact metamorphism to a very fine-grained lepidoblastic muscovite-rich pelitic hornfels, part red-stained due to minute goethitic granules concentrated into certain areas. This iron discoloration has a patchy distribution giving the appearance of having been displaced on a series of sub-parallel fractures which lie at an acute angle to the bedding. The fill of the fractures varies from opaque grains and clayey material, to opaque grains accompanied by open fissure-pore space. The fractures are up to 0.2 mm wide and form less than 5% of the rock in the thin section. The opaque grains in the fractures form about 2% of the thin section, and are hematitic psuedomorphs after sulphide crystals (pyrite and, possibly, arsenopyrite). The host rock contains abundant minute granules probably of rutile as well as more felsic areas hosting skeletal geothitic pseudomorphs after sparsely disseminated crystals, probable of pyrite, up to 0.05 mm in size, but has little or no bulk porosity.

It is clear that this rock underwent a stage of fracturing and hydrothermal sulphide mineralisation. Since this mineralisation evidently pre-dated the pervasive goethitic oxidation, it is suggested that the apparent displacement of the latter on the fractures is probably deceptive.

19. DJR7019 - FAULT BRECCIA

Location: Abbey Hill, Pit 10 [374705 660796]. Depth 1.2 m. Bedrock. Red-brown clay from joints in highly fractured greywacke, with 48 ppb Au.

Hand specimen - The sample consists of a 'gravel' made up of a large number of pieces up to 2 cm in size of soft, friable, brown, heavily limonite-impregnated, porous rock. It is possible that this may have resulted in some degree from breaking up of the sample during handling.

Thin section - The thin section reveals that the rock is a breccia made up of angular, cm-scale clasts of a pale rock, weakly cemented by gritty brown sediment, the latter forming about 30% of the thin section. The clasts are of rock made up of an interwoven mesh of fine-grained phyllosilicates, probable white mica and chlorite now altered to clay and possibly corrensite. It is crossed by infrequent quartz-sealed fractures which do not continue into the breccia matrix. The origin of the clasts is uncertain. They may be a strongly altered igneous rock, possibly a tuff, although there are no relict diagnostic textures to confirm this. The matrix consists of badly sorted, coarse sand of angular iron-stained grains, in which mm-scale clasts of the pale rock and also of vein quartz, together with sub-mm hematitic granules, are conspicuous. A significant degree of porosity is present as interstitial pores within the sand and sub-mm width fissures at the sand-clast interfaces.

It is suggested that the rock originated as a near-surface fault-breccia before its eventual incorporation into weathered soil-like material.

20. DJR7049 - GREYWACKE

Location: Abbey Hill area forest track, trackside quarry [374400 661285]. Float from quarry face. Medium-grained, highly altered greywacke with sericite/chlorite and pseudomorphs after pyrite, with 21 ppb Au, 75 ppm Cu and 63 ppm As.

Hand specimen - The sample consists of a single angular, 6 cm wide fragment of massive mid-grey greywacke. Orange-brown goethitic coatings cover external surfaces, and such material also forms patchy impregnations of the interior of the sample. Mm-scale muscovite flakes on one bedding-controlled surface have a mirror-like quality. A trace amount of white, metallic, possible pyrite grains were noted at one point of the sawn fresh surface of the sample.

Thin section - The thin section reveals a quartz rich greywacke, with significant plagioclase, muscovite and chlorite (after probable biotite), together with accessory tourmaline and rutile, in a muscovitic groundmass with common minute patches of chlorite. The rock is poorly sorted, with angular grains; grain size generally less than 0.3mm. The largest quartz and muscovite grains tend to be elongated, up to 1 mm long, and to display a crude alignment which is also mimicked by a 1 mm thick lensoid quartz-filled gash. No evidence of mineralisation was recorded. Interstitial dissolution pores form 5 to 10% in some areas, while others contain about 10% of hematitic granules related to infrequent hematite-sealed hairline fractures.

21. DJR7050 - HYDROTHERMAL BRECCIA

Location: Abbey Hill area, forest track., trackside quarry [374400 661065]. Float from east end of quarry. Medium-grained greywacke with goethite coated open quartz veins, with 23 ppb Au.

Hand specimen - The sample consists of three saw cut pieces 6-8 cm long by 2 cm thick, of pale grey, fine-grained, massive rock which has been strongly fractures (brecciated), dilated and cemented by white hydrothermal quartz which forms about 30% of the sample piece used to make a thin section. The quartz is carious, with earthy goethitic coatings covering highly irregular surfaces and coating dissolution voids up to 6 mm wide.

Thin section - The host rock is weakly iron-stained greywacke rich in quartz grains up to 0.4 mm in size and muscovite flakes up to 0.2 mm in size. It displays moderate sorting and sphericity of angular grains set in a micaceous matrix with minor chlorite and c.2% of dissolution pores. In the thin section, angular clasts 2 to 15 mm in size of this rock, often elongated or cuspate, form 40%, enclosed by an interlocking mosaic of weakly strained, prismatic to anhedral quartz crystals from 0.2 to 3.0 mm in size. Within this quartz are cavities up to 8 mm in width, lined or 50% filled by spongy goethitic opaque material. Some of the cavities are bounded by euhedral faces of the surrounding quartz, while others appear to mimic tabular or prismatic forms which impinged into the quartz. The cavities are clearly of dissolution origin, and probably represent pockets of coarse hydrothermal sulphides which were originally present in the rock. The spongy fill contains a small number of minute (<50mm) flakes of white highly reflective metallic material.

In contrast to the poorly consolidated fault-breccia (DJR7019), this sample represents brecciation cemented by hydrothermal quartz probably at a deeper structural level, and hence probably at an earlier stage. The quartz was probably appreciably mineralised.

22. DJR7054 - SANDSTONE

Location: Tod Burn, Pit 2 [365901 664075]. Depth 2.8 m. Bedrock. Rotten purple-brown fine greywacke, with 320 ppb Au and 104 ppm As.

Hand specimen - The sample consists of several angular pieces up to 5 cm wide of soft, strongly altered sandstone. The pieces have earthy limonitic external surface coatings, and interiors in which minute white grains, possibly altered feldspar, are set in a fine grained purple groundmass. No mineralisation was recorded under the hand lens.

Thin section - Strongly altered, massive sandstone, in which subangular quartz grains up to 0.2 mm in size, moderately sorted and of variable sphericity, form about 40%. The groundmass displays some 30% microporosity. Within the groundmass, original grains are seen to have been altered to tenuous relicts of clay, rutile and hematite, and some 15% of disseminated geothitic granules is also present. Local clusters of pyrite grains have been made over to goethitic pseudomorphs. The rock is crossed by an intersecting network of close-spaced fractures now partially sealed by goethitic material.

The pyrite pseudomorphs and the fractures provide the only indications of possible mineralisation, and the location of any gold and arsenic which may be present in the hand specimen remains undetermined.

23. DJR7055 - PORPHYRY OR BASALT

Location: Tod Burn Pit 2 [365901 664075], adjacent DJR 7054. Depth 2.8 m. Bedrock. Buff porphyry with millimetre-scale, purple-stained fracture veinlets, with 37 ppb Au and 250 ppm As.

Hand specimen - The sample consists of several pieces up to 3.5 cm in size of soft, pale yellow-brown, earthy rock, highly altered and with a secondary high porosity. As a result, the rock has a noticeably light feel, indicating a low specific gravity.

Thin section - The thin section shows a strongly altered rock, probably originally a feldspar-phyric dacite or basalt. What remains consists of clayey pseudomorphs, with up to 50% microporosity, formed by replacement of phenocrysts, set in a groundmass of quartz, clay, iron-stained degraded chlorite, and opaque granules, with about 30% microporosity. Opaque possible hematite granules c.0.01 mm in size form c.15% of the rock throughout the thin section. Quartz forms pockets and fracture veinlets, now disrupted and part dissolved.

The petrographic sample gives little indication of hydrothermal alteration.

24. DJR7056 - GREYWACKE

Locality: Tod Burn Pit 2 [365901 664075]. Depth 2.4 m. Purple fine-grained greywacke, grey-white spotted, with what may be a thin horizontal siltstone band. Also sparse clay-filled microfissures, with 5119 ppb Au and 107 ppm As.

Hand specimen - The sample consists of four pieces up to 2.5 cm in size of greywacke strongly altered to a soft clay-limonite coated rock. The interior of the pieces shows minute white clay-altered grains, possibly of feldspar, set in a purple groundmass.

Thin section - Strongly altered quartz-rich greywacke with moderate sorting, roundness and sphericity, and grains up to 0.4 mm in size. Quartz grains form about 60%, accompanied by grains altered to microporous clay and opaque granules, the latter forming about 15%. Detrital magnetite appears to have survived as common accessory grains of magnetite and hematitic replacement of magnetite. In addition, preserved cuboid and rectangular grain outlines up to 0.5 mm wide indicate that approximately 2% of disseminated pyrite and/or arsenopyrite was originally present. The rock also contains about 5% of pores less than 0.1 mm in size, disseminated and sited along fractures less than 0.2 mm wide which also contain goethitic material. Similar goethitic material is also seen as coatings preserved in the edge of the thin section.

Despite the high reported bulk Au concentration of this sample, no gold was located under the optical microscope. However, unlike DJR7055, there is clear evidence of hydrothermal sulphide having been present both disseminated and possibly in the cross-cutting fractures.

25. DJR7057 - HORNFELSED MUDSTONE

Location: Tod Burn Pit 2 [365901 664075]. Depth 2.4 m. Possible bedrock. Orange-purple clay with centimetre-scale angular siltstone fragments altered to buff-orange clay, with 909 ppb Au and 280 ppm As.

Hand specimen - The sample consists of several pieces up to 5 cm wide of a very friable, heavily altered, porous, grey-yellow limonitic rock in part mottled with brown goethitic areas. The bag also contains a considerable amount of earthy yellow material which has rubbed off the rock fragments during handling. The interior of the pieces reveals a massive, pale grey siltstone or mudstone. One piece has broken to reveal an interior fracture coating of red-brown colloform goethitic material. No hydrothermal mineralisation was observed by hand lens.

Thin section - The rock is a mudstone which has undergone contact metamorphism to produce a spotted pelitic hornfels. The rock has a pervasive fabric made up of c.60% pale, white mica rich, 0.1 mm ovoid spots which coalesce to make a semi-continuous framework through which occurs c.40% of a dark green, chloritic, interstitial component. Through this rock runs a network of hairline fractures which are seen variously as quartz and possible feldspar veinlets and as slender fissures partially sealed by poorly-crystalline goethitic oxide. The hornfels displays diffuse mm-scale banding, and varies from pale pink areas with subdued expression of spotting, to darker areas where spotting is sharply defined due to oxidation, and pervasive microporosity is present. The edge of the section preserves goethitic coatings, and on one edge of the section disoriented hornfels fragments are seen attached to the main fragment by clay-goethite cement.

26. DJR7063 - GREYWACKE

Location: Tod Burn Pit 5 [365842 664123]. Depth 1.25 m. Dark grey very fine-grained greywacke, with joint surface oxidation to pink-brown clay, with 234 ppb Au.

Hand specimen - The sample consists of a single piece of massive, mid-grey greywacke about 6 cm in size. Tenuous brown ferruginous surface coatings cover 0.5 cm thick margins in which the rock is altered to a pale, minutely mottled appearance of white clayey specks in brown-grey groundmass.

Thin section - Poorly sorted greywacke, with a weak grain-alignment fabric. Abundant grains of strained quartz are accompanied by minor albite, orthoclase and chert, together with amounts of heavy mineral grains (tourmaline, monazite), mudstone clasts and c.1% of opaque grains. The grains display variable sphericity (e.g. elongated mudstone clasts) and angularity. About 10% of muddy interstitial matrix is present, and includes fine-grained biotite of possible contact metamorphic origin. Porosity is negligible except in one margin of the thin section, where feldspar dissolution has taken place to create a zone with about 10% porosity together with fine-grained secondary clay. Some of the 0.1-0.2 mm opaque grains are detritial, probably magnetite, but others are pseudomorphs after probable pyrite.

The presence of probable pyrite grown in the fabric of the rock suggests that it underwent a stage of hydrothermal mineralisation.

27. DJR7075 - PORPHYRITIC BASALT

Location: Tod Burn Pit 16 [365899 664252]. Depth 2.8 m. Bedrock. Pink brown altered porphyry, heavily Mn stained and fractured, with white-grey clay pseudomorphs after phenocrysts, with 33 ppb Au and 103 ppb As.

Hand specimen - One 7 cm piece of rock. Brown-black Fe-Mn rich oxidic coatings cover the surfaces of the irregular-shaped ('lumpy') sample of grey-brown rock in which c.10% of white, clay-altered feldspar laths suggest altered basalt. The groundmass is minutely spotted: sub-mm brown spots in a paler orange-brown groundmass. Black oxidic material seals hairline fractures which criss-cross the sample.

Thin section - Porphyritic basalt which has undergone strong alteration to produce a rock in which the original phenocrystic texture is preserved despite being made over to what appears to be a fine-grained clay-quartz chalcedony rock with opaque granules and appreciable microporosity. Where brown goethitic alteration is intense, porosity is almost absent. Goethitic halos surround apparent chalcedonic pseudomorphs after 2mm wide olivine phenocrysts, and a goethitic coating is captured along one edge of the thin section.

The petrographic examination has not produced evidence of hydrothermal mineralisation other than strong oxidation.

28. DJR7082 - GREYWACKE SILTSTONE

Location: Tod Burn Pit 18 [365918 664250]. Depth 2.6 m. Bedrock. Light grey-brown greywacke-siltstone, reddened, with Mn and hematitic stained fracture surfaces, with 32 ppb Au and 148 ppm As.

Hand specimen - The sample consists of three angular pieces up to 4 cm in size of strongly fractured grey rock with loose earthy yellow-brown limonitic coatings. The interior of the pieces shows a massive grey fine-grained greywacke with elongated clusters of sub-mm white sulphide grains, possibly arsenopyrite, developed along bedding planes, and forming about 1 % of the rock.

Thin section - Massive greywacke siltstone, poorly sorted, with angular to subrounded quartz grains mostly <0.1 mm wide, although some are up to 0.2 mm wide. The quartz is accompanied by altered (oxidised) biotite flakes, flakes of muscovite and rare minute mudstone clasts. Pale (bleached) biotite is a major constituent of the 20% matrix fraction. Opaque grains (goethite-hematite) up to 0.1 mm form about 5%. Goethitic films seal infrequent hairline fractures lying oblique to the bedding in so much as the latter is indicated by crude weak banding and weak alignment of the muscovite grains.

The sulphide grains reported from the hand specimen were not located in the thin section.

29. DJR7084 - SANDSTONE

Location: Tod Burn Pit 19 [365927 664248]. Depth 1.8 m. Mn-hydroxide pan within rotten greywacke siltstone, with 26 ppb Au.

Hand specimen - The sample consists of three pieces, each about 4 cm in size, of massive, pale-grey, medium-grained greywacke with infrequent dark grey mudstone clasts. Rough external surfaces are covered with patchy, pale yellow-brown and dark brown, ferruginous oxide coatings which have impregnated up to 3 mm into the underlying rock and also form a 3mm thick fracture veinlet.

Thin section - Greywacke sandstone in which quartz forms about 50% as poorly sorted, angular grains, bitten into (pitted) by corrosion possibly during diagenesis. The rock also contains pale brown flakes of altered biotite forming about 5%, and an abundant matrix of white mica and darkened (oxidised) chlorite and/or biotite. Some 2% of opaque grains up to 0.1 mm in size is present. Goethitic staining is intense within 1 mm of a 0.1 mm wide fracture veinlet of goethitic material and clay. Porosity is very low despite the alteration and corrosion of quartz grains.

No evidence of hydrothermal alteration was recorded.