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Gold mineralisation in the Dalradian rocks of Knapdale–Kintyre, south-west Highlands, Scotland

Department of Trade and Industry

MRP Report 143

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A G Gunn, M H Shaw, K E Rollin and
M T Styles

BRITISH GEOLOGICAL SURVEY

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SUMMARY

Following reappraisal of regional geochemical and geophysical data for the northern part of the Kintyre Peninsula, a brief survey was conducted by the Mineral Reconnaissance Programme (MRP) to study the distribution of gold in south Knapdale and to assess the prospectivity of known base-metal veins in the area as sources of economic gold mineralisation.

A limited drainage survey, involving the collection of panned concentrates and stream sediments, identified widespread enrichment of gold in several parts of the area underlain by Argyll Subgroup Dalradian metasedimentary rocks. Associated lithogeochemical sampling confirmed the presence of elevated gold concentrations in bedrock and enabled three types of mineralisation to be distinguished.

The highest tenor gold mineralisation was found around Stronchullin in the north-east of the project area. Gold concentrations up to 22 ppm are present in samples of base-metal-bearing quartz veins from spoil material at the derelict Stronchullin mine. This mineralisation is characterised by high levels of arsenic, antimony, copper, lead, zinc, barium and by an elevated gold/silver ratio. Drainage geochemical data indicate the presence of additional bedrock sources of gold in the Stronchullin area and veins carrying high levels of gold have been found elsewhere in the Stronchullin valley, in the Inverneil area in the north, and in the south of the project area near the shore of West Loch Tarbert.

Low to medium tenor gold enrichment has also been identified in association with discordant copper vein mineralisation in the Meall Mor area, in the vicinity of the former mine workings at Abhainn Srathain. This mineralisation is distinguished by high contents of copper, gold and silver. Associated levels of arsenic, antimony, bismuth and gold/silver are low.

Stratiform disseminated pyrite mineralisation, with minor attendant chalcopyrite and sphalerite, of sedimentary exhalative origin is found in a concordant elongate belt extending across the project area for at least 10 km. No gold enrichment has been found in association with this type of mineralisation.

Mineralogical studies carried out on gold-bearing rock samples have provided important additional information on the metallogeny. Gold grains studied in samples from the Meall Mor copper mineralisation are characterised by an unusual chemistry rich in silver and mercury. In contrast, the compositions of alluvial grains studied are typical of gold derived from mesothermal lode type mineralisation. No gold grains were located in the Stronchullin vein samples, but the geochemical and morphological features of the veins indicate a likely mesothermal origin.

The drainage geochemical data reflects these styles of mineralisation clearly and identifies several additional prospective zones. However, the sample coverage attained in this project was not adequate to determine the controls on the gold distribution. A broad association of metal enrichment, locally including gold, with east–west lineations is evident. The importance of north-west trending features and their intersection with east–west structures should be assessed.

In the light of recent discoveries of potentially economic gold mineralisation elsewhere in the Dalradian belt in Scotland and Northern Ireland, further investigations in the south Knapdale area are recommended. Priority should be given to the Stronchullin area and the other known base-metal vein occurrences. Further research, including additional mineralogical studies, is required to investigate possible links between the gold enrichment in the Meall Mor area associated with discordant copper-bearing veins and the post-tectonic quartz veins of the Stronchullin type.

INTRODUCTION

The investigations described in this report were carried out over part of the central Kintyre Peninsula in the Argyll and Bute District, Strathclyde Region, western Scotland (Figure 1). The project area includes part of south Knapdale, north of the village of Tarbert, and also ground between Tarbert and Skipness Point to the south. The survey was conducted as part of the Mineral Reconnaissance Programme (MRP), sponsored by the Department of Trade and Industry (DTI). Full data listings, together with detailed descriptions of samples, are available from the Mineral Reconnaissance Programme Database, BGS, Keyworth, on request.

The project area is underlain by Dalradian metasedimentary and metavolcanic rocks of late-Precambrian age. Several recent discoveries of potentially economic gold mineralisation hosted by Dalradian rocks have been made in Scotland and Northern Ireland. The most important examples in Scotland are found at Cononish near Tyndrum (Pattrick et al., 1991; Parker, 1996) and at Calliachar Burn near Aberfeldy (Mason et al., 1991; Ixer et al., 1996). In Northern Ireland the deposits at Curraghinalt and Cavanacaw in the Sperrin Mountains of County Tyrone also have good economic potential (Cliff and Wolfenden, 1992; Earls et al., 1996; Boland, 1996).

Metalliferous mineralisation has been widely reported in the south Knapdale sector of the project area. Base-metal (mainly Pb) veins have been worked on a small scale at several localities, while stratiform Cu mineralisation was exploited in the Abhainn Srathain area, 1-2 km south of Meall Mor (Figure 1). Few records of production and dates of operation exist, but the high costs and low grades are inferred to have restricted production (Peach et al., 1911). More recently, MRP investigations delineated a broad zone of weak stratiform sulphide mineralisation extending along strike in both directions for several kilometres from the workings at Abhainn Srathain. This belt may be correlated with the pyrite belt of upper Loch Fyne and Central Perthshire which is known to contain significant quantities of base metal and barite mineralisation of sedimentary exhalative origin (Coats et al., 1984).

Gold mineralisation in bedrock has been reported from two former base-metal workings in the district (Peach et al., 1911): (i) at the Stronchullin mine [184 678] and (ii) at the Shirvan (or Castleton) Mine [187 684] at Ballimore, near Lochgilphead. The latter falls outside the present project area.

The BGS regional geochemical data for this area indicates the presence of coincident enrichment in As and Sb over parts of south Knapdale and north-east Kintyre (British Geological Survey, 1993). Similar coincident anomalies of these chalcophile pathfinder elements have been documented in relation to gold mineralisation elsewhere in the Dalradian of the Scottish Highlands (Plant et al., 1989, 1991).

The investigations described in this report were undertaken to provide a modern, systematic assessment of the extent and controls of the gold mineralisation associated with the base-metal veins and to determine the abundance and distribution of gold in south Knapdale and north-east Kintyre more generally. The scope of the surveys was restricted by resource constraints, and investigations were confined to a single, short (three week) period of field investigations with limited associated laboratory studies.

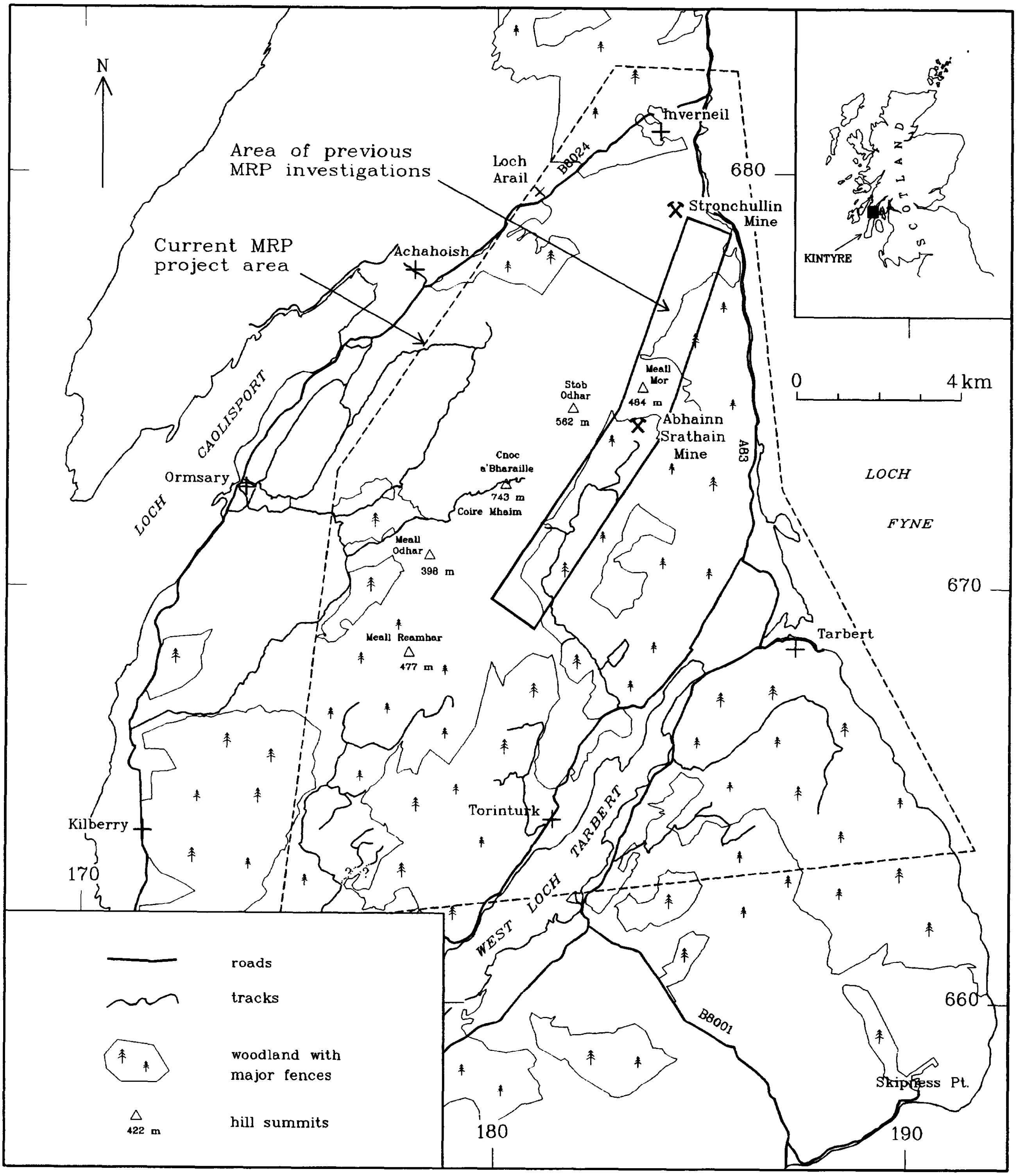

Figure 1 Location map

PLANNING AND DEVELOPMENT FRAMEWORK

The project area is located on the west coast of Scotland in the northern part of the Kintyre Peninsula. The main centre of habitation is the fishing and tourist village of Tarbert situated on the west shore of Loch Fyne at the head of West Loch Tarbert (Figure 1).

The area is mostly upland and is dominated by a prominent north-easterly grain following the main structural trend of the Scottish Caledonian orogen. This gives rise to a series of elongate 'hog's back' ridges, attaining 400-500 m elevation in places, bounded by lithological or structural discontinuities. Much of the lower ground is knobbly in character although on the east coast of the peninsula, adjacent to Loch Fyne, the slopes are over-steepened by ice-scour from Quaternary glaciation.

Traditionally the dominant land use in the area is sheep grazing on the rough open hill-land. Increasingly, due to the favourably high rainfall and low land prices, commercial afforestation has spread and covers more than 50% of the project area. The woodland is densely planted conifer, which restricts physical access to some areas.

Communications to the major city of Glasgow, approximately 80 km to the east, are by the Loch Fyne coastal road via Lochgilphead, Inverary and Loch Lomond. Within the project area tracks for off-road vehicles are numerous and facilitate access into the upland (Figure 1).

Five sites of special scientific interest (SSSI) are located in or close to the survey area. These sites occupy either narrow coastal strips or small wooded valleys close to the coast. None is located close to the principal areas of interest studied in the report. The Mealdarroch national nature reserve is located between Tarbert and Skipness Point in an area smaller than, but partly coincident with, the SSSI which covers about 600 ha of this coastline. The Knapdale national scenic area lies to the north of the prospective area in the vicinity of Loch Caolisport.

GEOLOGY

The project area falls on two 1:63 360 scale geological maps, Jura (sheet 28) and Rothesay (sheet 29). The geological survey was carried out towards the end of the last century and is described in detail in the Memoir published in 1911 (Peach et al., 1911). The geological information shown in Figure 2 is derived from these published maps.

The Knapdale area is underlain by metamorphic rocks of the Dalradian Supergroup, a Late Precambrian to possible Cambrian shelf-sediment and turbidite assemblage. This succession accumulated during the progressive rifting and deepening of extensional basins. The older Appin Group rocks, which do not outcrop in the Kintyre Peninsula, comprise quartzite-shale-limestone sequences laid down in a shallow-water shelf environment. The younger Argyll Group consists of shallow marine deposits with marked lateral facies and thickness variations which were deposited in a series of synsedimentary fault-bounded basins. The overlying Southern Highland Group is composed of mainly turbidite deposits comprising greywacke-siltstone and sandstone sequences. Outcropping a few kilometres to the north of the project area are extensive developments of basic volcanic rocks (the Tayvallich lavas) which mark the onset of continental rifting and initial opening of the Iapetus Ocean at the Argyll Group-Southern Highland Group boundary.

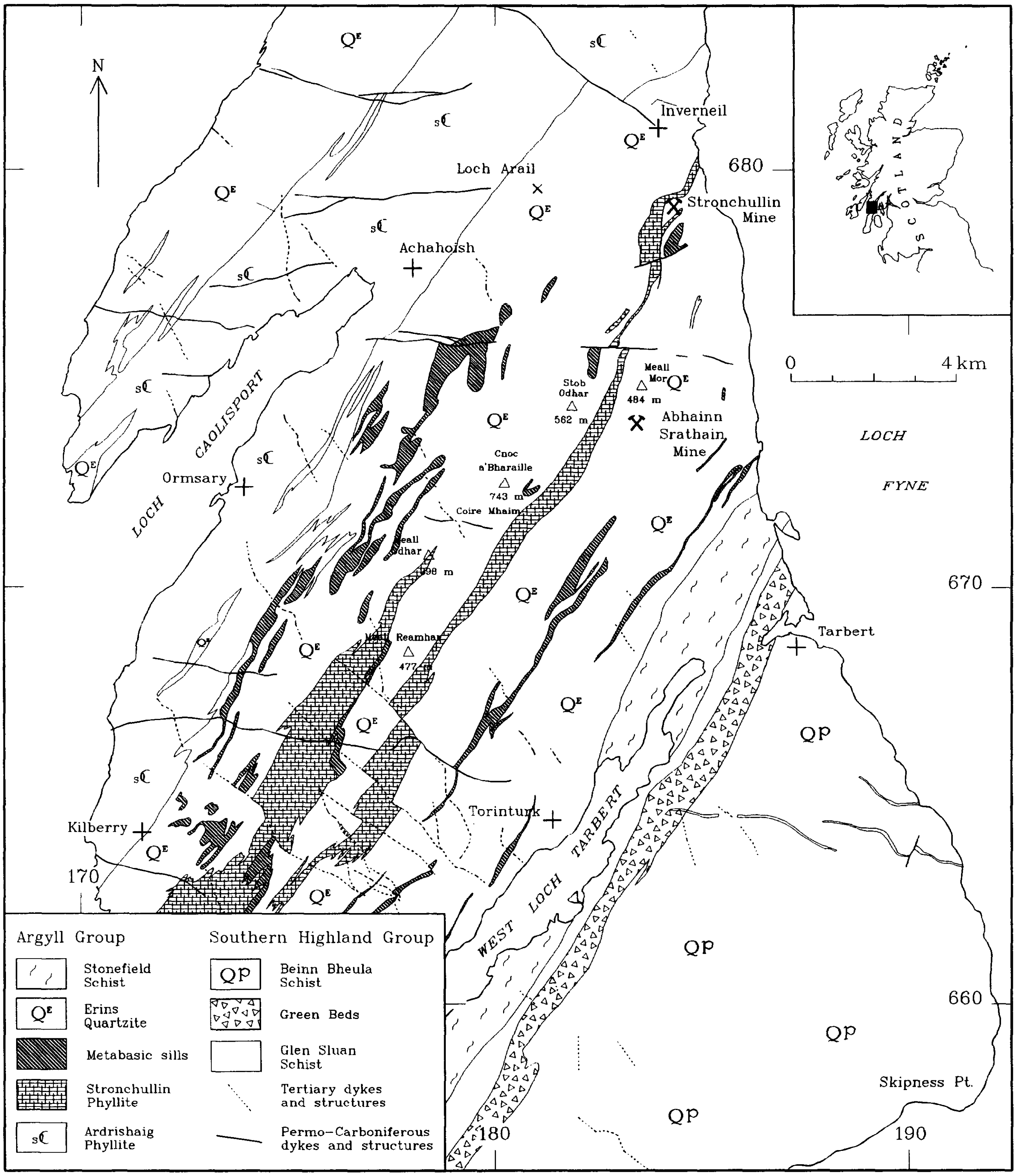

Figure 2 Geological map of the project area and immediate surroundings (from BGS One Inch Series geological map sheets 28 and 29)

All of the Dalradian Supergroup strata have been subjected to polyphase deformation and metamorphism. Age control on these events is provided by the 590±2 Ma age of the inter-tectonic Ben Vuirich Granite which post-dates major nappe-forming tectonism but is earlier than the final episode of crustal thickening and the peak of metamorphism (Rogers et al., 1989). The Tayvallich Lavas have been dated by the U-Pb method on zircons at 590 Ma (Halliday et al., 1989).

Knapdale is located within the south-west Highland block, separated from the remainder of the Grampian terrane by a major north-west trending structure known as the Cruachan Lineament approximately 50 km north-east of the project area. This feature is one of a number of trans-Caledonian structures which traverse the Grampian and Northern Highland terranes (Jacques and Reavy, 1994). They have been interpreted as major long-lived structures which influenced the depositional and tectonothermal histories of the Grampian Highlands. The abundance of igneous rocks varies sharply across the Cruachan Lineament. Extrusive and shallow intrusive bodies of tholeiitic composition are widespread to the south-west of the lineament whereas, to the north-east, the otherwise comparable succession is much impoverished in such rocks.

The lithostratigraphical succession in the project area comprises metasedimentary rocks of the Argyll and Southern Highland Groups (Figure 2). They lie on the inverted lower limb of the Tay Nappe with generally moderate to steep dips to the north and young in a south-easterly direction. They have been metamorphosed to greenschist or epidote-amphibolite facies during the Lower Palaeozoic (Harte, 1988).

Argyll Group

The northern part of the project area, to the north-west of West Loch Tarbert (Figure 2), is underlain by a dominantly clastic metasedimentary succession, with an apparent thickness of about 5000 m, comprising the Lower and Upper Erins Quartzites and the intervening Stronchullin Phyllite (Easdale to Crinan Subgroups). Numerous pre-metamorphic tholeiitic sills are present in this sequence. The Stonefield Schist and Tayvallich Limestone, which are assigned to the Tayvallich Subgroup, overlie these units to the south-east.

Erins Quartzite

This unit is divided into two parts, the Lower and Upper Erins Quartzites, separated by the Stronchullin Phyllite. The Lower Erins Quartzite, which occurs to the north of the Stronchullin Phyllite, forms part of the upper Easdale Subgroup, while the Upper Erins Quartzite is assigned to the Crinan Subgroup. Both successions comprise mainly medium- to coarse-grained immature quartzites, with variable quantities of mica and feldspar. They range from flaggy or schistose types to massive varieties. Localised channel structures and associated along-strike facies changes are indicative of proximal fan-type turbidite sedimentation with subsidence controlled by the development and reactivation of basin-marginal faults (Harris et al., 1978)

Stronchullin Phyllite

The Stronchullin Phyllite is dominated by silvery-grey to medium-grey, locally calcareous, mica schists with subordinate quartz-mica schists and phyllites. The succession is best exposed in the vicinity of the Stronchullin Burn [184 679] and Artilligan Burn [184 676] in the north-east of the project area. A broad (0.5 km wide) graphitic band is developed in the southern part of the outcrop and is best exposed in Gleann da Leirg [184 678].

In the western part of its outcrop the Stronchullin Phyllite is more siliceous than around Stronchullin itself. In this sector the succession is dominated by mica schist and quartzite and there are no black carbonaceous phyllites.

The Stronchullin Phyllite has been correlated with the Easdale Subgroup St Catherine's Graphitic Schist which outcrops to the north-east (Roberts, 1966, 1974).

Metabasic sills

A suite of metabasic sills (formerly termed 'epidiorite') is intercalated within the upper Argyll Group metasedimentary succession in the south Knapdale area. These rocks are predominantly dark, fine grained and massive, although both foliated and coarse-grained varieties are found locally. The sills, which vary in thickness from 0.5 to 250 m, are mostly concordant but are frequently disrupted by later, north-west faulting. In areas of relatively shallow dip they occupy broad, elevated areas with good exposure.

Two distinctive groups of metabasic rocks have been distinguished in the district: (i) the southern type associated with the Erins Quartzite and (ii) the northern type associated with the Ardrishaig Group. The latter are found outside the project area and represent the earliest basic activity in the Dalradian. They occur as thin bands of pyroclastic and detrital volcanic material and are more felsic in composition than the southern type.

The southern type, associated with the Erins Quartzite, is hornblendic, generally fine-grained and massive (e.g. Cnacan Imheir [172 864]). Locally they are coarser and more foliated and may contain hornblende crystals up to 1 cm in length. A belt of this variety extends south-west from Eilean an Dunain [186 673] to Meall Reamhar [183 669] and locally displays spheroidal pillowed textures on a sub-metric scale, indicating a possible extrusive origin.

Stonefield Schist and Tayvallich Limestone

The Stonefield Schist, overlying the Erins Quartzite, is the highest member of the Crinan Subgroup. It comprises essentially garnetiferous mica schists and chlorite-albite schists with beds of quartzose schist and gritty schistose psammite. Subordinate quartzite, calcareous schist and limestone bands are also found within the succession. The latter are possibly infolded beds of the Tayvallich Limestone. The most conspicuous limestone occurs in the Torinturk area, to the south-west of Tarbert [181 664]. In this area the limestone forms a series of en-echelon bands produced by repeated folding. Two minor outcrops of impure limestone are also found on either side of Gleann Fithich [180 665].

Southern Highland Group

Southern Highland Group strata crop out to the south of Loch Tarbert and underlie a large area along the eastern flank of the southern part of the Kintyre Peninsula. The succession is dominated by psammitic turbidites of continental provenance deposited within major submarine fans on a subsiding continental shelf.

Glen Sluan Schist

The Glen Sluan Schist occupies a narrow belt, less than 0.5 km wide, along the southern shore of Loch Tarbert. It is composed of schistose pelitic turbidites comprising dominantly quartz-mica schist with subordinate chlorite-mica schist.

Green Beds

These rocks comprise a range of chloritic and epidotic green schists intercalated with varying proportions of metagreywackes, psammites and quartzites. In the project area they dip steeply and underlie a belt 700-800 m in width to the south-east of the Glen Sluan Schist. The origin of the Green Beds is unclear. A volcanic affinity is suggested by the chemistry and mineralogy, but clear sedimentary features are recorded. A volcaniclastic origin related to the erosion of the Tayvallich Lavas is favoured (Stephenson and Gould, 1995).

Beinn Bheula Schist

The Beinn Bheula Schist underlies the south-eastern part of the project area. It comprises a dominantly coarse-grained turbidite sequence of fine-grained metagreywackes and schistose psammites with subordinate bands of pelite rarely exceeding 100 m in thickness. The grits include pebble conglomerates, with clasts of pale blue-grey quartz and pink oligoclase up to 4 mm diameter.

Post-Caledonian minor intrusions

Lamprophyres

Peach et al (1911) recorded a few lamprophyre sheets in the project area on the coast of Loch Fyne between Artilligan and Stronchullin. These fine-grained rocks of basaltic appearance occur as concordant sills ranging in thickness from a few centimetres up to 3 m. These rocks have not been examined in the present study.

Permo-Carboniferous dykes

Permo-Carboniferous dykes, normally oriented east–west, are broad persistent features commonly exceeding 20 m in width. They typically comprise coarse-grained quartz-dolerite of tholeiitic composition.

The most southerly example of this suite occurs near the south-eastern margin of the project area, on the Loch Fyne coast at Rubha Grianain [1914 6633]. This is one of two parallel dykes which transect the island of Bute, 12 km to the east, and extend across the Highland Boundary Fault into the Scottish Midland Valley. The same dyke is exposed to the west of Loch Tarbert, both along the coastline and in the Gleann Fithich catchment [180 665]. From here it extends north-westwards to the south-western shore of Loch Caoirain, where it deviates southwards around the conspicuous crags of Cruach an Locha [178 666], before resuming its westerly trend for a further 7 km to the coast. The width of the dyke varies markedly along its length but averages about 50 m.

Another conspicuous member of this suite is exposed intermittently across the project area between Erines [185 675] and Clachbreck [176 675].

Tertiary dykes

A suite of north-west trending dolerite dykes of early Tertiary age related to the Arran centre is widespread in the project area (Stephenson and Gould, 1995). Dykes of a similar age, related to the Mull dyke swarm, are more common to the north of the project area and on the southern part of the Isle of Jura to the west. These bodies are generally only a few metres wide and have a basaltic rather than doleritic texture. They are olivine-dolerites, locally with minor analcime (termed crinanite in Peach et al., 1911).

Members of this group show clear cross-cutting relations with dykes of the east–west suite (Peach et al., 1911). They commonly occupy faulted tracts, such as the Loch nan Torrain [175 668]–Loch

Caorainn [178 666] fault. Their crooked nature is also noteworthy in some areas where they follow fractures of varying orientations, (e.g. north of Loch Racadal [around 176 666]).

GEOLOGICAL STRUCTURE

Regional deformation

The structural development of the Grampian Caledonides has been explained in terms of three or four major episodes of deformation (Harris et al., 1978; Roberts and Treagus, 1977; Bradbury et al., 1979). An early phase of recumbent nappe folding directed towards the north-west is widely recognised. These structures were subsequently deformed by another episode of folding with a similar orientation and by later upright folds with variable geometry. The concept of fold facing, defined as the direction normal to the fold axis, along the axial plane, and towards the younger beds, provides an important descriptive parameter for many of the folds and an indication of transport direction (Shackleton, 1958).

Early studies indicated that the strata are disposed in large recumbent folds with their lower limbs commonly partly excised by low-angle extensional faults, termed 'slides'. In the south-west Highlands, the major folds are seen to diverge on either side of the early upward-facing, Loch Awe Syncline (LAS). To the south-east of the LAS the Ardrishaig Anticline is interpreted as the core of the large south-east-facing Tay Nappe which covers most of the south and south-east Highlands. Much of the Tay Nappe is flat lying and the present level of erosion is such that most of the exposed strata are in the lower inverted limb. However, in parts of Knapdale, north-west of the Tarbert Monoform, the strata are not regionally inverted. Here the fold axial planes dip steeply to the north-west and the core of the Tay Nappe is exposed as the Ardrishaig Anticline. Near to the Highland Boundary the Tay Nappe lags downwards to form a synformal anticline, the Aberfoyle Anticline, which is downward facing. In Cowal and Bute the Dalradian strata in the Tay Nappe steepen gradually to the south-east, whereas farther north-east the flat belt gives way abruptly to the Highland Border steep belt possibly over a basement structure active in the later phase of deformation.

North-west of the LAS the large north-west upward-facing Islay Anticline exposes quartzites, marbles and schists of the Appin Group on Islay with an envelope of Argyll Group quartzites (Islay Quartzite) possibly over 4000 m thick. The western limb of the Islay Anticline is cut by the Loch Skerrols Thrust and underlain by the deformed Bowmore Sandstone, considered likely to be part of the Dalradian sequence (Fitches and Maltman, 1984). West of the Loch Gruinart fault in Islay, the Colonsay Group comprises over 500 m of strongly deformed metasedimentary rocks with a general north-east strike and younging to the north-west. The stratigraphical affinities of the Colonsay Group remain unclear.

Regional geophysical data

The regional geophysical data is broadly consistent with the main elements of the structural model for the south-west Highlands. However, certain geophysical features provide additional evidence to constrain the sub-surface structure and tectonic development of the region.

The Tayvallich Subgroup of the Argyll Group consists in the type locality of limestones and phyllites overlain by up to 2000 m of submarine spilitic basalts. Further north-east the Tayvallich and Loch Avich Volcanic formations are part of the Southern Highland Group and consist predominantly of a contemporaneous basalt-dolerite-gabbro intrusive sill complex which forms most of the meta-igneous amphibolites seen in the Loch Awe region. These rocks have a relatively low magnetic susceptibility (<0.001 SI) and do not produce significant aeromagnetic anomalies. In contrast the spilitic parts of the formation are significantly magnetic and south-west of Tayvallich are associated with prominent aeromagnetic anomalies of over 400 nT (Figure 3). These anomalies extend offshore to the south-west and

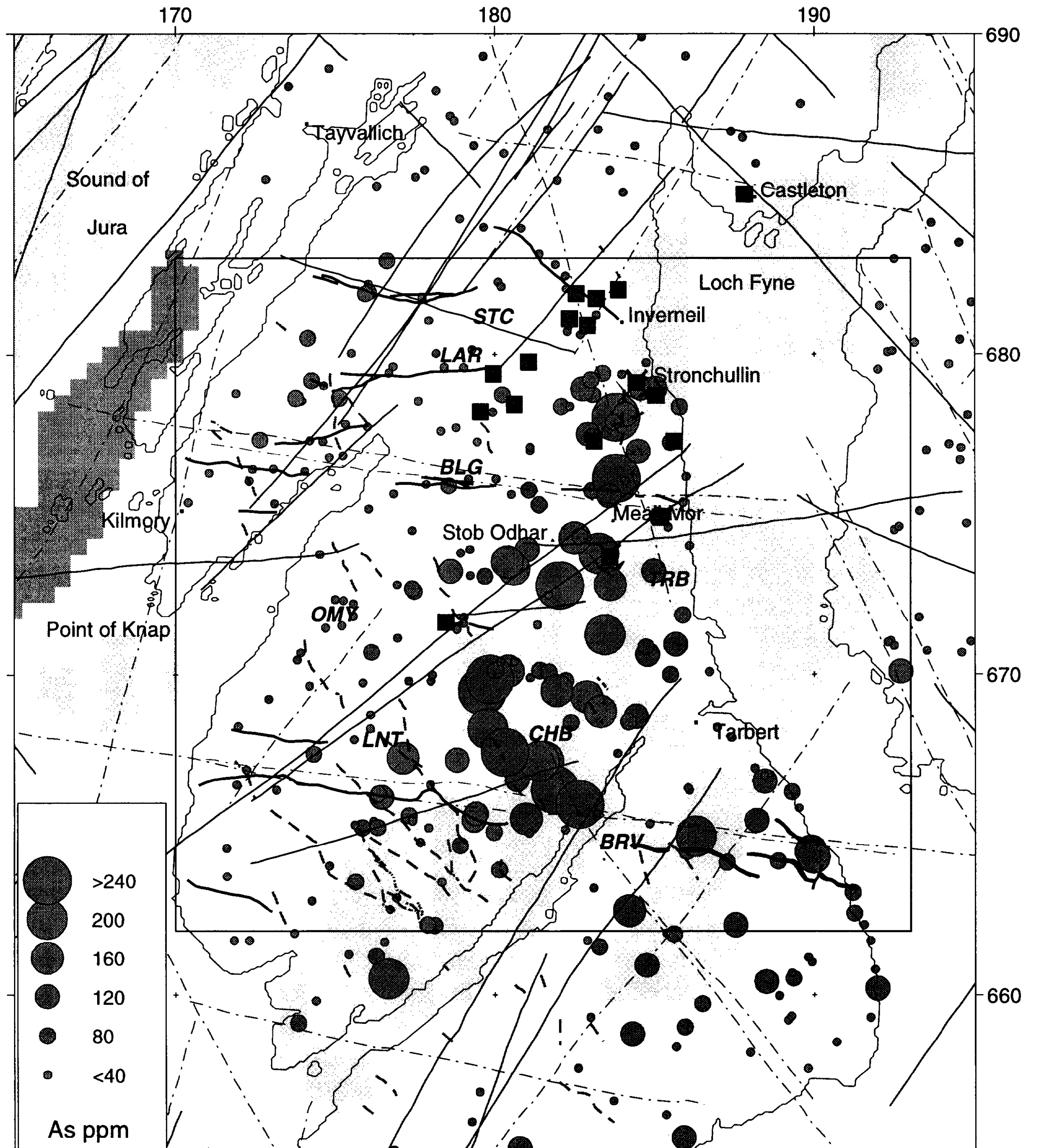

Figure 3 Lineations picked from images of the regional gravity (solid lines) and aeromagnetic data (dash-dot lines). Light shaded region is the zone where the residual gravity anomaly is less than -2 mGal and the darker shaded region the zone where the observed aeromagnetic anomaly is greater than 100 nT. Scaled circles represent the distribution of As in stream sediments derived from the BGS regional geochemical survey of southern Scotland (BGS, 1993). Squares indicate the location of previously recorded occurrences of metalliferous mineralisation. Thick solid lines are quartz-dolerite dykes; thick dashed lines mapped faults and Tertiary dykes. The large rectangle delineates the area of geochemical sampling in this project. Principal lineations discussed in the text: STC - Stronchullin; LAR - Loch Arail; BLG - Baranlongart; OMY - Ormsary; TRB - Tarbert; LNT - Loch nan Torran; CHB - Chaorann Beag; BRV - Bardaravine

have been interpreted as a continuation of the Loch Awe syncline in the Sound of Jura (Westbrook and Borradaile, 1978).

The Islay Subgroup shows a marked thickness variation, from 2 km in the south-west on Islay to over 6 km on Jura in the north-east. The Islay Quartzite has a relatively low density (~2.60 Mgm^{-3}) which is reflected in the Bouguer gravity anomaly map as a broad regional minimum over Jura. A similar, but smaller, local minimum occurs over the main outcrop of the Erins Quartzite in south Knapdale and is seen in the residual gravity anomaly (Figure 3). North-east of Islay the Islay Quartzite is probably in contact with basement gneiss above a tectonic surface including either the Loch Skerrols thrust or the Loch Gruinart Fault. However, Anderton (1988) interpreted the main thickness variations of the Islay Subgroup in terms of accumulation in a half graben bounded to the north-west by a listric fault and at either end by north-west trending transfer faults. The comparable thickness variations seen along strike in the Erins Quartzite might suggest a similar control on deposition of the Crinan Subgroup.

PREVIOUS WORK

Former mining activity

Small-scale exploitation of base-metal vein mineralisation has been carried out in the past at several localities in the Knapdale area (Figure 4). Copper and lead were the principal commodities extracted, but minor production of silver has also been recorded (Peach et al., 1911). The veins, comprising principally quartz, calcite, siderite and baryte, vary from thin stringers up to 4 m in width. Their orientation is commonly north-east, but north-west and east–west trends are also found. Most of the mines were trials on quartz veins, but locally more extensive underground workings were developed from adits and shafts.

The largest scale mining was located on the Inverneil Estate, largely to the south of the Inverneil Burn on the northern flanks of Cruach Mheadonach [182 681]. The mining here was focused on a north-east trending zone of sporadic mineralisation about 2 km in length between Gleann Beag [1823 6810] and a point about 400 m north of Auchbraid [1837 6820]. The mineralisation, comprising breccias and quartz reefs with variable amounts of pyrite and galena, is hosted by a series of quartz schists and phyllites, with minor thin limestones, assigned to the Lower Erins Quartzite. The precious metal contents of these veins is generally not known, but an assay reported in Wilson and Flett (1921) gives an Au content of 0.79 ppm in the lead ore from one of these workings. The quartz vein exploited at this mine was up to 30 cm wide trending 330° and dipping to the south-west.

Other trials on lead-bearing veins were recorded in the original geological survey at Artilligan Burn [185620 677280] and at Allt Na Dunaiche [185190 674900]. Additional metalliferous vein occurrences reported in the memoir (Peach et al., 1911) are also shown in Figure 4.

One of the larger areas of former workings is located at Abhainn Srathain, 1–2 km south of Meall Mor. Here stratiform and discordant vein Cu mineralisation were exploited around the end of the eighteenth century. This deposit was the subject of MRP investigations in 1977-8 and is described in greater detail below.

The Survey memoir also reports the discovery of high gold concentrations in the lead-rich sulphide ores at Stronchullin [184450 679110] and Ballimore [187830 684990]. Although both mines have long-since been abandoned, dumps of spoil material are still present at Stronchullin.

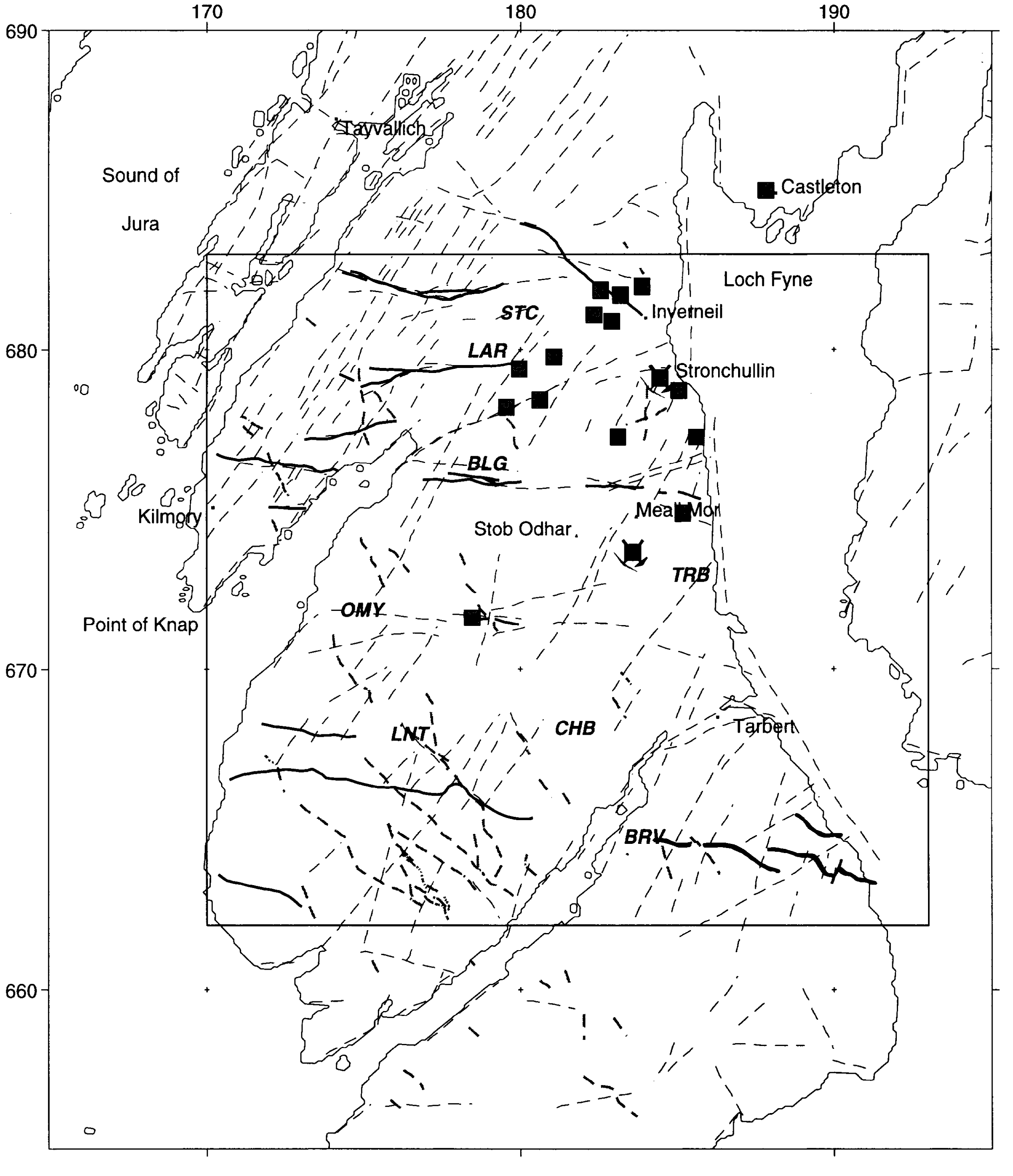

Figure 4 Lineations (thin dashed lines) picked from false colour Landsat satellite images reproduced at 1:250000 scale. Other ornament as Figure 3.

The Stronchullin mine is situated on the gently sloping southern valley-side of the Stronchullin Burn. Extraction of the galena-bearing stockwork, with accompanying chalcopyrite and sphalerite, was largely from a southerly oriented trench approximately 25 m in length. Along this excavation the mineralised quartz reef dips at approximately 70° towards the west. It appears that the galena-rich part of the reef measured about 40 cm in width and that widening of the workings may have been undertaken in an attempt to evaluate adjacent subordinate stockwork mineralisation. Production figures for the mine are not known. However, the available documentation, together with the small scale of the excavation and spoil heaps, suggests that the deposit was of a high grade and low tonnage.

The discovery of gold at Stronchullin was made by the then proprietor at around the turn of the century. The workings may have been widened at around this time in order to remove material for gold assay. Samples of spoil heap material, weighing up to approximately 50 kg, were submitted for assay and yielded Au concentrations in the range 45 to 153 ppm, together with similar levels of Ag. The Cu content of these samples was around 1.5%, while Pb levels exceeded 10%. These high values were confirmed by independent assays from two other companies which also reported high concentrations of As and Sb. Subsequently two shipments of ore, each about 10 tons in weight, were sold to a smelter in south Wales. One of these yielded 37 ppm Au, 75 ppm Ag, 1.2% Cu and 2.1% Pb. The second consignment was found to contain 46 ppm Au, 84 ppm Ag, 1.7% Cu and 3.9% Pb.

The mineral paragenesis of the gold in the Stronchullin ores is unclear. An association of gold with chalcopyrite was tentatively suggested by Hill (in Peach et al., 1911).

The memoir also documents the presence of trace amounts of galena and pyrite associated with elevated levels of Au and Ag, approximately 220 m south-east of Srondoire [184 678]. This site could not be relocated during the current project due to the absence of a more precise location. A small copper lode located about 2.8 km south-west of Stronchullin was also reported to contain about 1.5 ppm Au, 520 ppm Ag and 17% Cu.

Outside the project area at Ballimore, 3 km south-south-east of Lochgilphead, the remains of a former copper mine may be seen as a filled depression in the corner of a small woodland area [187760 684890] and a shallow excavation in the adjacent field. No spoil from the old mine is currently exposed at surface. However, results of the analysis of ore material from the 2 m wide quartz reef yielded approximately 6 ppm Au (Peach et al., 1911). The vein, comprising quartz with pyrite, chalcopyrite and galena, dips to the north-west at 70° and can be traced along strike for a distance of about 1 km.

A metalliferous vein cuts across the watershed at the foot of Coire Mhaim [1793 6716], within the Lower Erins Quartzite. The vein, in excess of 2 m across, is described as comprising a gangue of dolomite, quartz and albite and containing abundant specks of chalcopyrite and sphalerite (Peach et al., 1911).

Regional geochemistry

The BGS regional geochemical stream sediment survey of southern Scotland provides important information on the location of potentially mineralised targets in the Knapdale-Kintyre area (British Geological Survey, 1993). The reader is referred to this publication for presentation and discussion of the complete dataset.

The distribution of As over the project area and immediate surroundings from the regional dataset is illustrated in Figure 3. Arsenic is widely enriched over much of the project area, with approximately 70% of the samples lying above the 95th percentile of the regional dataset (54 ppm). To the north and west of Tarbert a broad area of As enrichment, underlain by the Stronchullin Phyllite and the Upper Erins Quartzite, is accompanied by locally coincident high concentrations of Sb and Bi, up to 7.5 ppm and 3 ppm respectively, at a site about 2 km west-south-west of Meall Mor. Within this area the most conspicuous As anomaly follows the line of the Eas a Chais catchment [180 667] in a north-westerly direction for approximately 2.5 km. Elevated As levels are also present over Southern Highland Group strata to the south of Tarbert. In this area there is also coincident enrichment of Sb, in the range 2–6 ppm, some 6–10 km north of Skipness Point. Elsewhere, samples from the Southern Highland Group strata contain uniformly low Sb levels, below the analytical detection limit.

Antimony concentrations over the Ardrishaig Phyllite, the Stronchullin Phyllite and the majority of the Erins Quartzite are low (<1.7 ppm). However, in the eastern central part of the project area, to the north of Tarbert, Sb contents exceed the 90th percentile (1.7 ppm) for the regional dataset. Included in this area are sites with coincident enrichment in As (mentioned above) together with others draining the pyrite belt about 6 km south-west of Meall Mor.

Over the majority of the project area Bi concentrations fall below the analytical detection limit of 4 ppm. Values of Bi above the 99th percentile (4.2 ppm) occur in three zones in the central part of the project area between Stob Odhar [181 774] and Torinturk [181 664]. At these sites Bi values up to 11 ppm are recorded in association with elevated As contents, up to 175 ppm.

Lead concentrations over the majority of the project area are close to the median value for the regional dataset of 44 ppm. The Pb mineralisation in the Stronchullin area was not detected in this sample medium. The Pb concentration exceeds 150 ppm at only four sites. The highest Pb value (337 ppm) occurs in the vicinity of Erins [185 675] close to two previously recorded mineral veins. Cu and Zn are also highly enriched at this site. A single high Pb value to the east of Cruach Meadonach [183 681] is probably related to the Pb vein mineralisation in that vicinity. In the Eas na Meann catchment [182 668] a single high value occurs, associated with low tenor enrichment in Zn and As. Slight Pb enrichment occurs over the Beinn Bheula Formation (Southern Highland Group) with a single point high value (234 ppm) reported immediately south of Tarbert, associated with elevated Zn contents.

The pattern of Cu distribution in the regional geochemical data shows a weakly defined, stratigraphically controlled enrichment along the line of the pyrite belt. Elevated levels are also present close to Meall Mor mine with attendant enrichment in Zn, Sb and As. Copper enrichment in the regional dataset is also found at several points along the Baranlongart lineation, an east–west trending lineation running from Loch Caolisport, at approximately [176 676], to Erins on the Loch Fyne coast at [186 675]. Pb, Zn, As and Sb are also locally enriched along this structure. A group of three high Cu values (>100 ppm) occurs in the Clachaig area [176 662]. These samples are also enriched in Zn and, in one case, in As. Low tenor Cu enrichment is also found in proximity to the Bardaravine lineation, a major east–west structure occupied by a Permo-Carboniferous dolerite dyke in the south of the area between Gleann Fithich and Cruach Lagain, some 6 km to the west.

Previous MRP investigations

Investigations of stratiform base metal mineralisation in the south Knapdale area were carried out by BGS between 1975 and 1977 (Smith et al., 1978). The objective of this work was to assess the economic potential of the southerly continuation of the Perthshire pyrite belt, an elongate zone of weak stratiform sulphide mineralisation in Argyll Group metasediments, traceable for about 190 km from Glenshee in the north-east to Knapdale in the south-west. The project was centred on the occurrences of polymetallic sulphide mineralisation of probable volcanogenic origin located to the south of Meall Mor [183 673] in the catchment of the Abhainn Srathain. The geological setting, geochemistry, mineralogy and metallogenesis of this mineralisation were studied in detail by Mohammed (1987).

In Knapdale the pyrite belt is hosted by orthoquartzite and quartz-mica schist of the Upper Erins Quartzite. This horizon is recognised over a strike length of at least 10 km in south Knapdale. Its cross-strike width varies from 200 to 800 m, but its true thickness is estimated to be less than 200 m. It comprises disseminations and stratiform laminations and blebs of pyrite with sporadic minor chalcopyrite and sphalerite. The disseminations are usually concentrated in centimetric-scale bands, in a ratio with quartz of up to a 1:4. The pyrite occurs as sub-millimetric, euhedral granules, which occasionally produce a weak schistosity. It is generally agreed that this stratiform style of mineralisation has a syngenetic exhalative origin.

In the area between Meall Mor summit and the Abhainn Strathain catchment, 1–2 km to the south, the abundance of sulphide in the pyrite horizon increases, together with the proportion of chalcopyrite. In addition to the widely recognised stratiform style, the mineralisation in this sector also occurs as porphyroblasts, up to 5 cm in size, in quartz and/or calcite veins which display both discordant and concordant relations to the compositional layering in the country rocks. In this area the metasedimentary and epidioritic host rocks are variably epidotised and carbonated. This zone of epigenetic Cu enrichment was the principal target of the former mining activity in the area. About 12 trials were made in the valley and two shafts sunk some 65 m apart. At present the shafts are flooded and the old workings are inaccessible.

The origin of the Cu enrichment in the Meall Mor area has been the subject of much debate. Smith et al. (1978) interpreted the discordant vein mineralisation to result from remobilisation processes during regional metamorphism, while Willan and Coleman (1983) suggested a role for mobilisation associated with sill intrusion. On the other hand, Mohammed (1987) cites textural evidence from field and microscopic studies which indicate that the cross-cutting Cu mineralisation predated both the phase of sill intrusion and metamorphism. Mohammed formulated a genetic model involving pre-metamorphic hydrothermal alteration of the host rocks associated with deposition of discordant veins in a shallow geothermal setting. Introduction of Fe, Mn, Ca, Ti, Si, CO_2, Cu, S, Ag, Au and Co was accomplished by fluid flow focused along fractures to produce the observed mineralisation. The associated alteration of the host rocks led to the formation of epidote, quartz, calcite, chlorite, mica and Mn-rich garnet.

The previous MRP investigations involved detailed drainage surveys, soil sampling, deep overburden sampling and ground geophysical surveys (chargeability, resistivity and magnetics) over the pyrite belt. Sampling was carried out between Srondoire [184 678] and Allt Airigh Stac [181 670] immediately to the east of the Stronchullin Phyllite. Geochemical and geophysical traverses were spaced at 150 m intervals and were generally between 500 and 800 m in length. The geochemical surveys delineated a broad zone of weak stratiform sulphide mineralisation with a strike length of at least 10 km in the Upper Erins Quartzite. Copper enrichment was widespread but variable throughout the zone. The main anomalous area identified was located south of Meall Mor around the Abhainn Srathain mines. Anomalies ascribed both to a broad disseminated Cu source and to narrow Cu-rich veins were recognised. Coincident chargeability anomalies were associated with the disseminated style of sulphide mineralisation.

A short programme of core drilling was carried out in early 1977. Five boreholes, each with an inclined depth of 30–50 m, were drilled to provide sections through the mineralised zones in the Abhainn Srathain area and to investigate coincident geochemical/geophysical anomalies. The maximum Cu tenor reported was 1.06% over a 2.67 m interval. Chalcopyrite, the principal copper-bearing mineral, occurred mostly in a finely disseminated form although sporadically it was also present in small veins. An association between Cu enrichment and epidotised host-rocks, especially epidiorites, was locally apparent. Detailed geological and geochemical logs of the drilling are contained in MRP Report No. 15 (Smith et al., 1978). Core from these boreholes formed the basis for the PhD studies of Mohammed (1987). No Au determinations were made during the course of the MRP investigation at this time or during the course of subsequent research. However Mohammed recorded the presence of a trace of gold as 'a veinlet in a porphyroblast pyrite'.

LINEATION ANALYSIS

The importance of structural control on the location of ore deposits, especially Au-bearing mesothermal veins, is well documented. In order to assess the structural setting of the known mineralisation in the project area and to identify additional targets, an analysis of lineations derived from geophysical, remotely-sensed and topographical data was carried out.

A great deal of structural information is contained within the regional geophysical data. Small variations in the rock physical properties (density and magnetisation) produce changes in anomaly gradient and amplitude which can be used as indications of source distribution. This is best derived from the gradient information of the fields displayed using the shaded-relief technique. Greyscale shaded-relief images from a variety of sun azimuths and inclinations provide the most effective means of achieving this. Similarly, colour shaded-relief images provide both gradient and amplitude information of the field.

In the south-west Highlands much of the amplitude and frequency content of the regional geophysical fields is derived from the deep geology rather than from surface exposures. However, the effects of the near-surface geology can be enhanced by the use of a regional-residual separation. This is accomplished by derivation of regional fields for the aeromagnetic and gravity data by analytical continuation of the observed fields upwards to 2 km and 5 km respectively above observation level. The main features of the residual fields can then be displayed alongside the lineations (Figure 3).

Lineations in the Caledonian terrane may be classified broadly on a hierarchical scale according to their structural significance (Gunn and Plant, 1995). First order geophysical lineations in the gravity and magnetic data are often of the order of hundreds of kilometres in length and are generally related to major structures observed at the surface.

Second order lineations, tens of kilometres in length, are recognised in the aeromagnetic or gravity data but are not directly related to continuous geological structures. These lineations are often associated with a discontinuous lineation in the complementary geophysical field and commonly with exposed or inferred igneous activity.

Third order lineations are observed in gravity and magnetic data as apparently unrelated features less than 10 km in length. These features may be sub-parallel to a geological structure or be an along-strike expression of geology. Terminations of third order lineations might occur at a second order lineation. Long lineations related to unmapped dykes are included in this class.

Fourth order lineations are identified from appraisal of satellite imagery, aerial photographs and topographic maps.

For Knapdale and the surrounding area, lineation analysis has been performed on regional geophysical images plotted at scales of 1:400 000 and larger (Figures 3). The regional images are based on grids of data with a pixel size of 500 m which is the general order of magnitude of the positional accuracy. Lineations derived from Landsat Thematic Mapper (TM) images have also been used to confirm lineations identified from topography and by visual observations in the field, and to complement the geophysical lineation analysis (Figure 4).

Main lineation sets

Structural observations in the Scottish Highlands in general fall into several distinct groupings, each associated with a particular dominant tectonic affinity. These are as follows:

i) NW - Archean shear zones and dykes
ii) NNE - Proterozoic faulting
iii) NE - Caledonian folds, slides, strikes
iv) NNE - late orogenic faulting
v) W - post-orogenic dykes and faults
vi) NW - Tertiary igneous activity

The predominant orientation of Caledonian structures, strikes, and slides is in the north-east quadrant. Within separate terranes there are slight variations in modal orientation but the average trend remains close to 45°.

Azimuthal frequency diagrams for the magnetic and gravity lineations in the 100 km National Grid square NR which covers the project area are illustrated in Figures 5a and 5b. Similar plots illustrate the lineations derived from a TM scene centred over the south-west Highlands (Figure 5c) and the dyke/fault orientations in the project area derived from the published geological maps (Figure 5d).

North-east lineations

These predominate in the Landsat and, to a lesser extent, in the gravity data (Figures 5c and 5a). The strike, lithology and structure of the Dalradian can be related to many of these features. Two gravity lineations, slightly discordant to the regional strike in the project area, trend 050° through Meall Mor and 070° towards Tarbert (Figure 5a). Locally these features appear to truncate the dyke-fault pattern and TM lineations.

North-west lineations

The origin of the north-west structural trend widely observed in the Highlands is the subject of continuing discussion. It has been linked variously to dextral strike-slip in the Late Proterozoic, syn-depositional faulting in the Vendian, late orogenic intrusion and to Tertiary dyke invasion (Speight et al., 1982; Stewart, 1993; Anderton, 1988; Jacques and Reavy, 1994). The existence of this structural trend in exposed foreland regions suggests the likely importance of structural inheritance, whereby old long-lived structures have been reactivated at various times since their inception. Locally the north-west orientation is recognised in mapped major and minor faults showing stratigraphic truncation and dislocation (e.g. Crinan Fault). On a larger

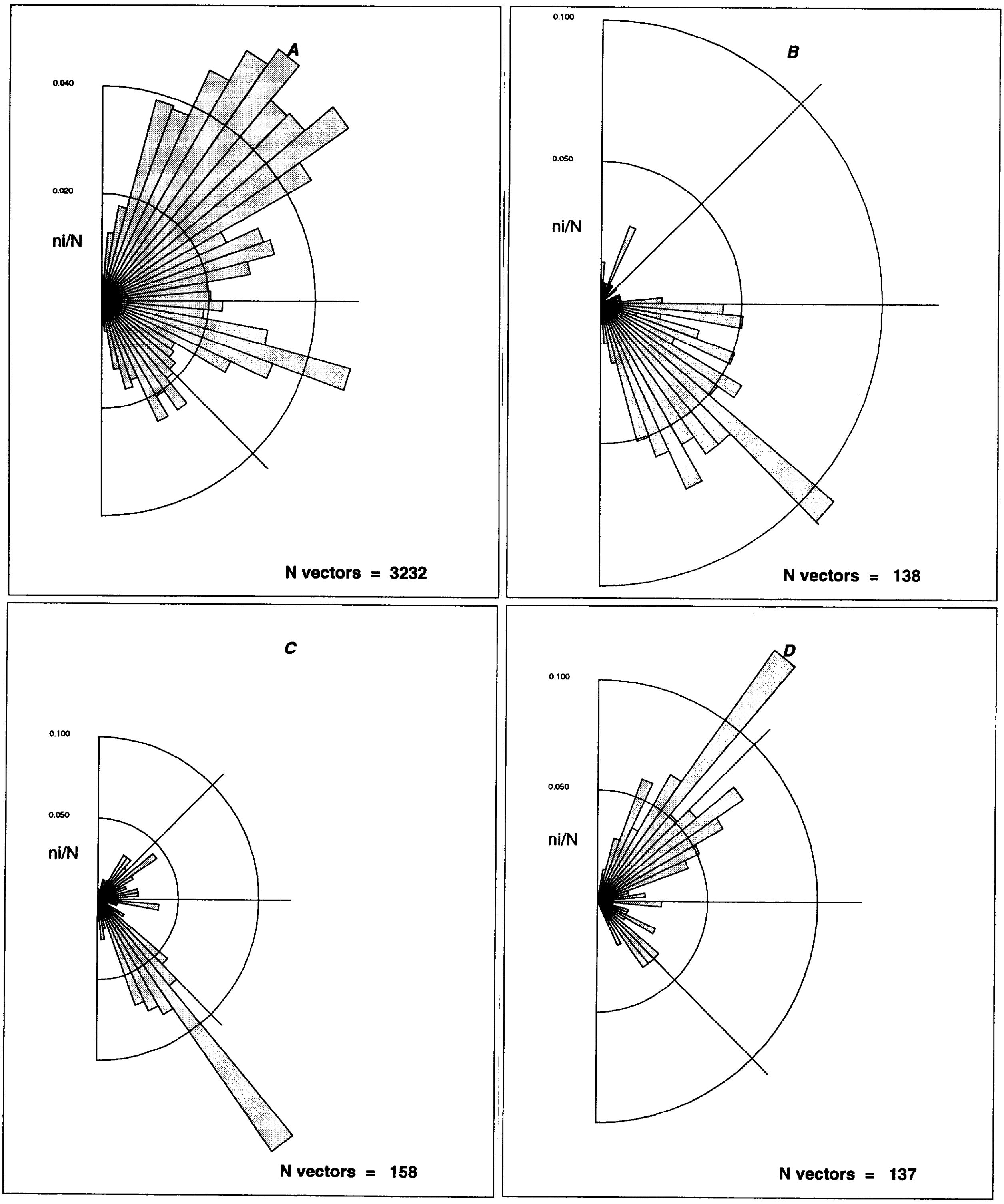

Figure 5 Azimuthal frequency plots of lineations from (a) gravity, (b) aeromagnetic, (c) Landsat and (d) dykes and faults. Regional gravity and magnetic lineations from British National Grid square NR; Landsat lineations derived from an image over the south-west Highlands; dykes and faults derived from 1:50 000 geological maps of the project area

scale, images of the regional gravity data suggest a more important set of features affecting the development of the Tertiary centre on Mull and possibly extending south-eastwards into the target area.

Fourth order topographic lineations with a north-west trend are generally associated with well-defined, relatively short topographic features, seldom exceeding 2 km in length. A north-west set is observed in the satellite data over much of the project area. The aeromagnetic data also identifies a prominent set of north-west lineations directly associated with Tertiary dykes.

East–west lineations

The existence of an east–west lineation set within the Grampian and Moine terranes to the north of the Cruachan Lineament was recognised by Watson (1984) who considered them to be conjugate to north-east trending late orogenic sinistral strike slip faults. The post-orogenic east–west trend is associated with a regional Permo-Carboniferous dyke swarm related to volcanic activity in the Central North Sea and the Oslo Graben (Smythe et al., 1995). Several quartz-dolerite dykes across Knapdale can be traced into the Midland Valley and eastwards over 200 km to the Central Graben. These lineations have clear magnetic, and commonly topographic, expression in the project area. They are not associated with significant displacement of the Dalradian strata.

Target lineations

Several fourth-order lineations identified from topographic maps, stream patterns and field appraisal are directly related to lineations observed in the geophysical data and together these have been used to identify potentially prospective zones in the project area (Figures 3 and 4). The principal targets are as follows [azimuth in degrees]:

1. Stronchullin lineation (STC) [110°] - runs from Cnoc Dubh [174 682] along the Eas Daltot valley and passes over the Meall Ruadh ridge without significant topographic expression. This lineation has associated strong gravity features as far as about 2 km west-north-west of the Stronchullin mine. TM lineations are present along its western half.

2. Loch Arail lineation (LAR) [090°] - runs from about 1 km west of A Mhaol Odhar [176 679] along the line of an Breac-laraich through Loch Arail. Eastwards beyond this point its course is indistinct but it may follow the eastern section of the Stronchullin Burn. It has mapped faults and TM lineations along its western section, but has no geophysical signature.

3. Baranlongart lineation (BLG) [100°] - runs from Clachbreck on the west Knapdale coast along the line of the Baranlongart Burn, passes along the Eas Dubh, the upper reaches of the Artilligan Burn and the Allt an Erins. Mapped faults and a quartz-dolerite dyke are associated with magnetic and Landsat lineations but no gravity lineation.

4. Ormsary lineation (OMY) [095°] - stretches along the Ormsary Water in the west, along the line of the Eas Nan Cat and is then displaced a few hundred metres northwards into the upper reaches of the Allt Creag nan Gobhar. The lineation passes to the north of Cnoc a' Bharaile summit [180 672], but after that becomes indistinct. It probably follows the east–west section of the Abhainn Strathainn and then continues through the plateau col at Allt na Beisde col [1853 6730]. A Landsat lineation in the west and central part of the target area with a 080° gravity lineation in the central part but no magnetic lineation.

5. Bardaravine lineation (BRV) [100°] - mapped faults west of West Loch Tarbert and mapped quartz-dolerite east of the loch are associated with a continuous magnetic lineation which appears to be related to the northern dyke exposed on the shore of Loch Fyne south of Tarbert. No clear gravity or Landsat lineation.

6. Chaorann Beag lineation (CHB) [150°] - with prominent magnetic expression south of West Loch Tarbert, minor mapped Tertiary dykes south-west of Stob Odhar and discontinuous Landsat lineations.

7. Tarbert lineation (TRB) [160°] - a prominent magnetic lineation extends from north of the project area to just south of Meall Mor. Little other evidence of structure although minor Tertiary dyke outcrops south of Tarbert might be related.

8. Loch nan Torran lineation (LNT) [130°] - this north-west topographic feature passes through Gleann Fithich - Loch a Chaorainn - Loch nan Torran, associated with mapped faults and Landsat features.

DRAINAGE GEOCHEMISTRY

Drainage geochemical samples were collected during May-June 1995 from 117 sites over an area of approximately 130 km^2 (Figure 6). The main targets for the sampling programme were: known metalliferous veins; areas with elevated As and Sb contents defined by the regional geochemical survey; and the structural lineations identified as favourable loci for the occurrence of gold mineralisation. In accordance with these priorities, the majority of samples were derived from catchments in the Erins Quartzite, the Stronchullin Phyllite and the Beinn Bheula Grits.

Sample collection, preparation and analysis

Sampling was undertaken according to the techniques developed for precious-metal exploration by Gunn (1989). To minimise loss of gold while digging, sampling was carried out using a concave-bladed shovel with a raised back edge plate. Panned concentrate samples were collected in the field by wet screening through 2 mm 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 a final volume of 150 ml. Stream sediment samples were obtained by wet screening to -150μm. The sediment was allowed to settle prior to pouring off excess water and decanting into a Kraft bag.

In the laboratory, panned concentrates were dried at low temperature and divided into two equal parts with a riffle splitter. One half was milled, while the other was retained for reference or for further studies. Stream sediment samples were dried, disaggregated and milled prior to sub-sampling for analysis. Both sample types were analysed for a range of elements by X-ray fluorescence spectroscopy (XRF) at BGS, Keyworth. Analysis of Au was carried out by lead fire assay of 30 g sub-samples, followed by ICP or AAS techniques, at Acme Analytical Laboratories of Vancouver, Canada.

Stream sediments

The Au concentrations in stream sediment samples are generally low, with the median value for the complete dataset of 2 ppb and only 6 samples (5%) exceeding 19 ppb (Table 1). Concentrations in samples from catchments underlain by Southern Highland Group strata are uniformly low with a maximum value of 11 ppb Au (Figure 7).

The chalcophile gold pathfinder elements, As, Sb and Bi, have complex distribution patterns with sporadic local enrichments (Figures 8 and 9). The median concentration of As in the overall dataset is 60 ppm, which is significantly greater than normal crustal levels and the clarke value for shales

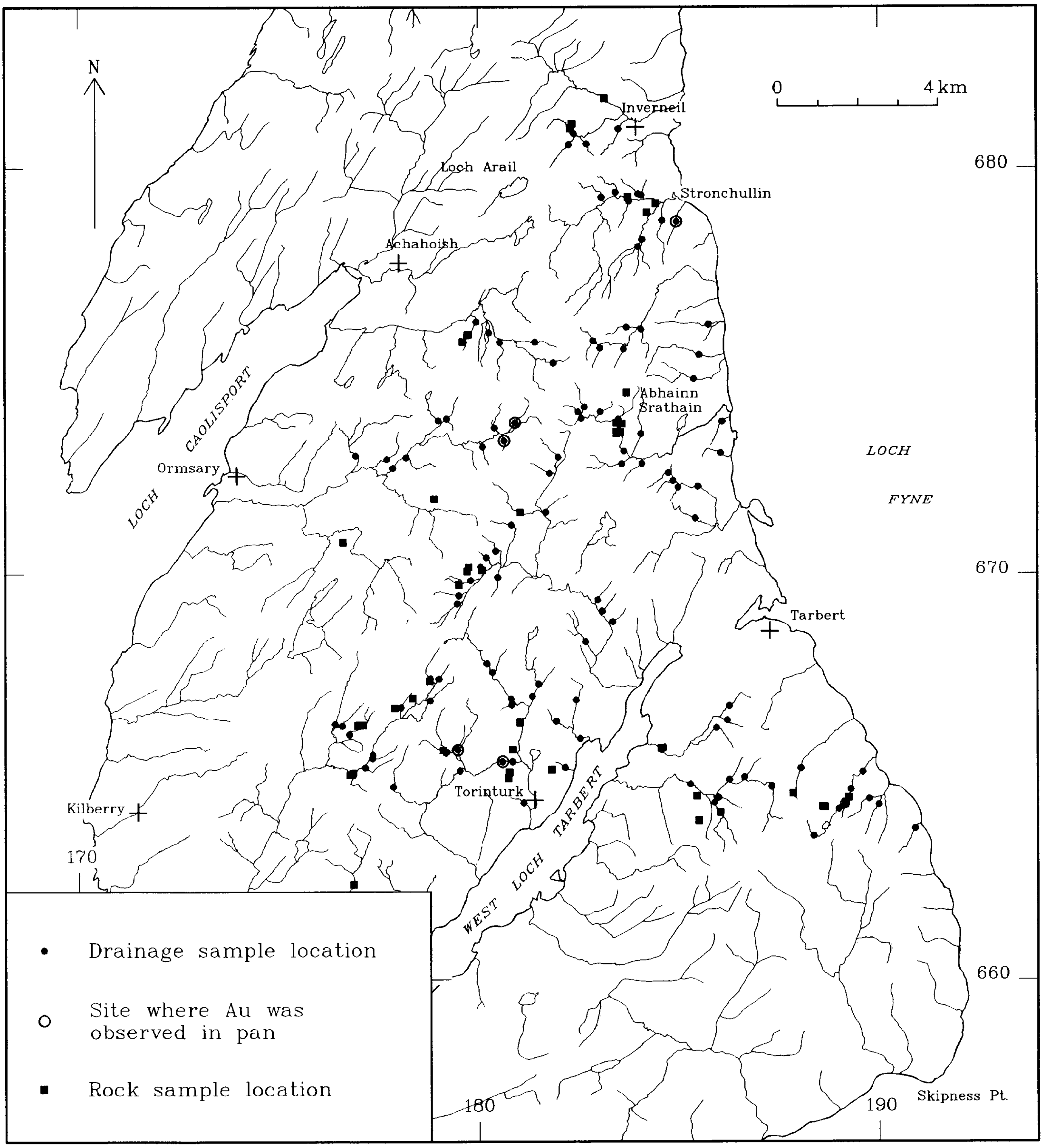

Figure 6 Locations of drainage and rock sample sites in the project area

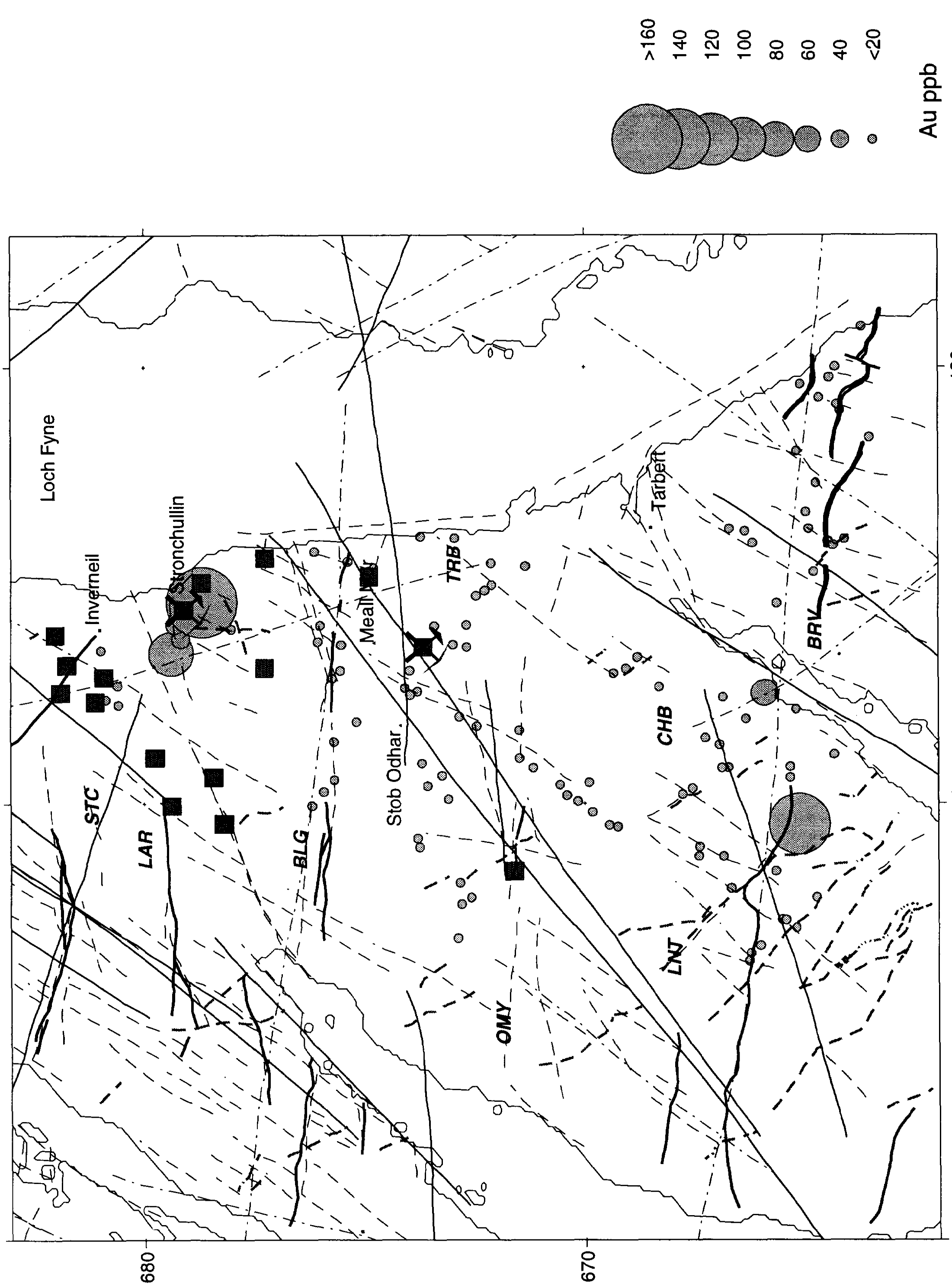

Figure 7 Distribution of gold (Au) in stream sediment samples plotted with detail of lineation analysis in the Tarbert area. Named lineations and other ornament as Figure 3

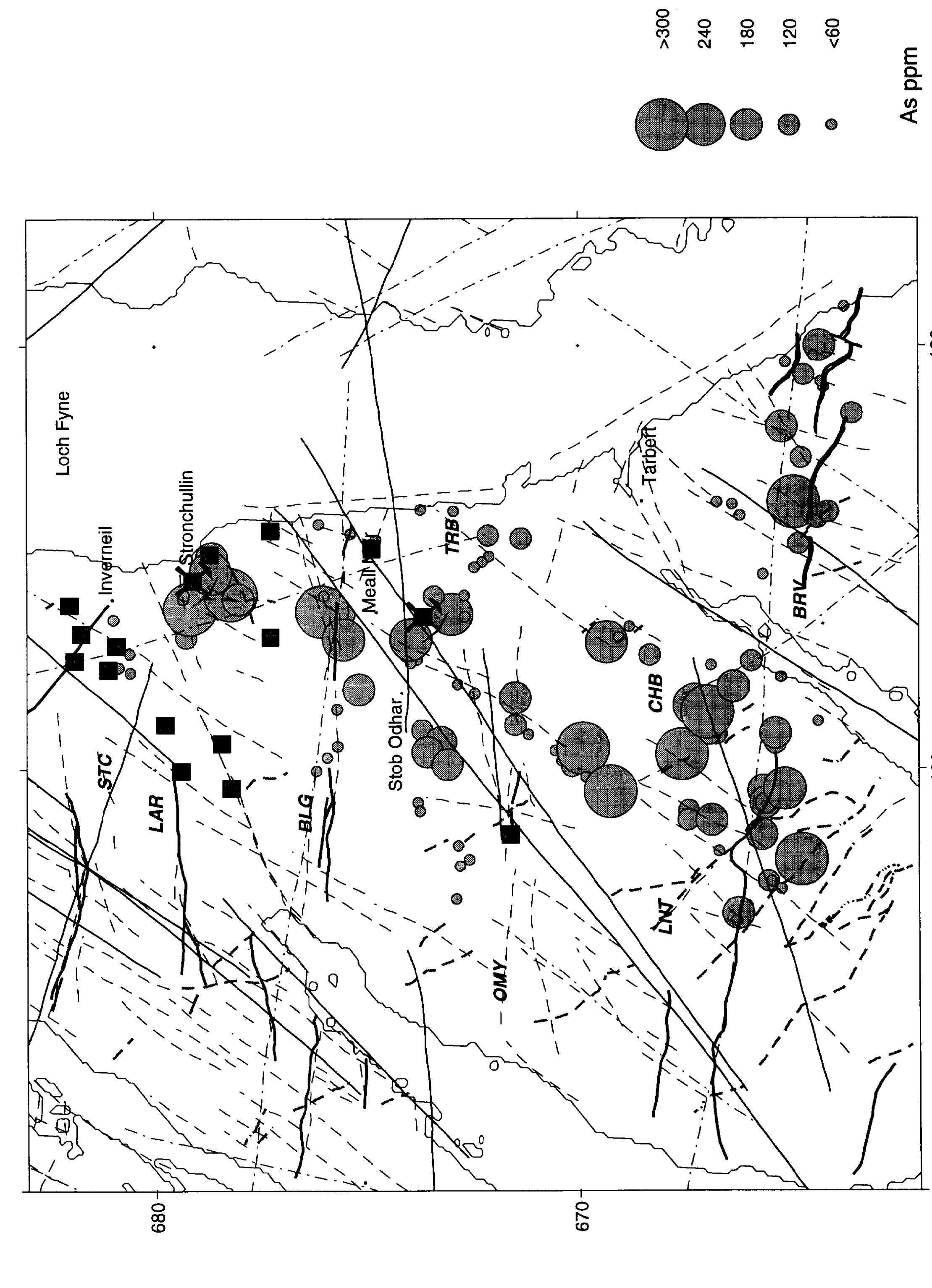

Figure 8 Distribution of arsenic (As) in stream sediment samples plotted with detail of lineation analysis in the Tarbert area. Named lineations and other ornament as Figure 3

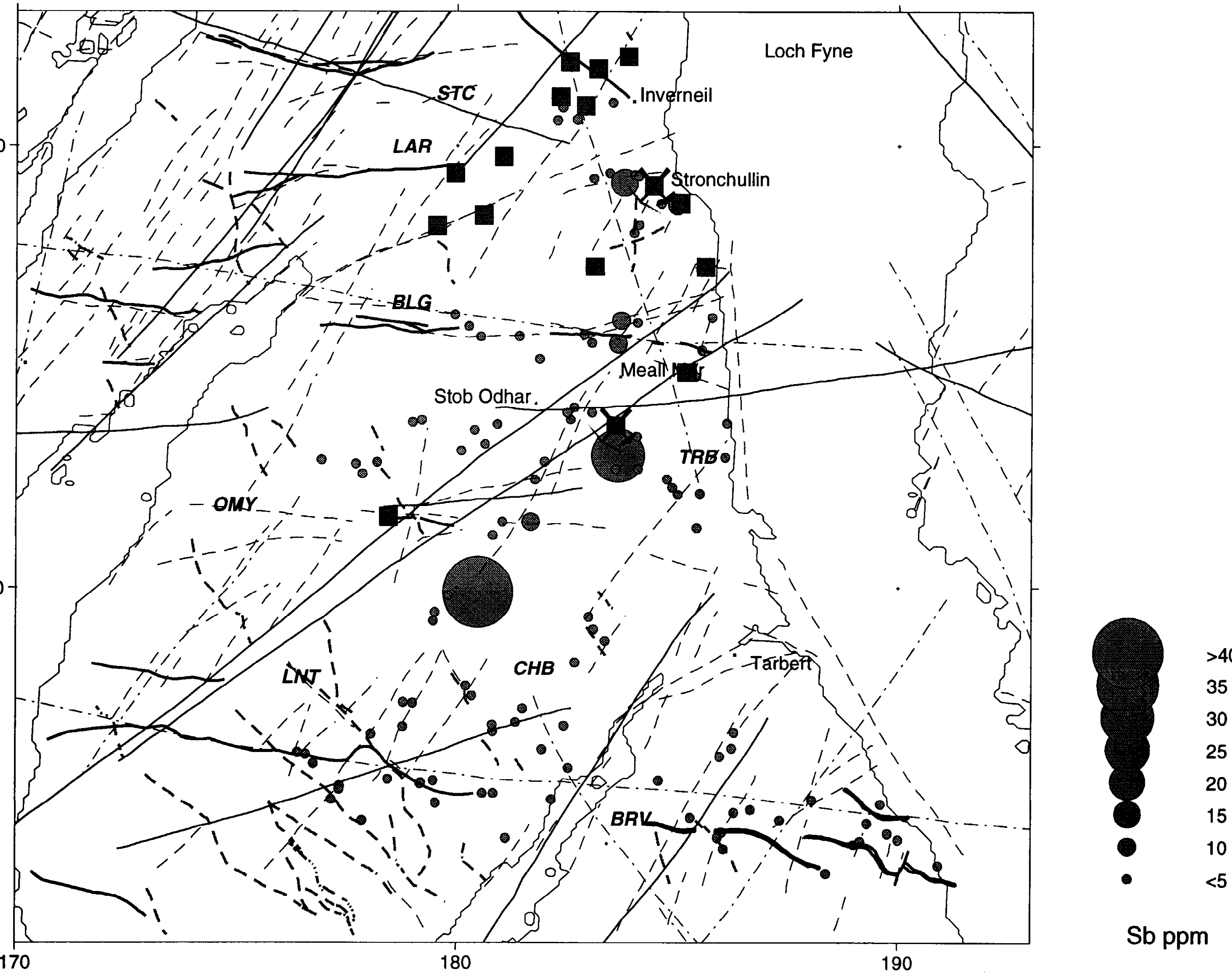

Figure 9 Distribution of antimony (Sb) in stream sediment samples plotted with detail of lineation analysis in the Tarbert area. Named lineations and other ornament as Figure 3

(1.8 ppm and 15 ppm respectively). The median As concentration in the 20 sites underlain by Southern Highland Group catchments is 59 ppm, not significantly different from the complete dataset.

Table 1 Summary geochemical data for stream sediment samples
(n=117; all values in ppm, except Au ppb)

Element	Minimum	Median	75%	90%	95%	Maximum	Mean
Au	2	2	4	8	19	178	7
Ag	5	5	5	5	5	5	5
As	6	60	135	226	284	437	95
Ba	208	1237	1512	2045	2381	22000	1573
Bi	3	3	3	4	4	7	3
Ca	1429	5432	9148	16066	19082	48957	7660
Co	15	47	57	82	104	126	49
Cu	8	26	39	63	79	188	34
Mn	573	7404	12160	21886	26482	40832	9693
Mo	13	16	17	18	19	23	16
Pb	18	47	67	85	111	233	56
Sb	3	3	3	3	5	39	4
W	5	5	5	6	7	10	5
Zn	63	181	278	414	493	841	228

Bismuth and Sb concentrations show only minor enrichments above the analytical detection limits of 3 ppm and 5 ppm respectively. The highest Sb content reported (39 ppm), located about 5 km south-west of the Abhainn Srathain mines, is associated with elevated As (275 ppm) but has a low Au content (Figure 9). Similarly, high As and Sb values are reported from a site on the Abhainn Strathainn below the old workings with no attendant Au enrichment.

The maximum reported value of Bi is 7 ppm, with only six sites greater than or equal to 5 ppm. The highest concentrations are found in proximity to the Bardaravine lineation, the east–west structure traversing the southern part of the area close to northing 665000. The other elevated levels lie on an east–west trend passing just north of the Meall Mor mine, which is associated with a discontinuous lineation in the gravity field trending 080°.

No values of Ag above the analytical detection limit of 5 ppm were reported in the stream sediments.

Elevated Au concentrations are found in two principal zones. In the Stronchullin area four values fall within the range 29 to 178 ppb Au, the highest value reported in the stream sediment dataset. Samples from tributaries of the Stronchullin Burn draining in northerly and southerly directions have elevated Au contents. These catchments lie within the outcrop of the Erins Quartzite and, to a minor extent, the Stronchullin Phyllite. The samples collected from the Stronchullin Burn catchment are locally enriched in Sb, As, Ba and Zn (Figure 10). Cu and Pb concentrations are generally close to median values, 26 ppm and 47 ppm respectively. Bi levels do not exceed the analytical detection limit (3 ppm) in this area.

The second highest Au value (127 ppb) was derived from a north-east-flowing tributary of the Gleann Fithich, located on Erins Quartzite, close to the intersection of the Bardaravine and Loch nan Torran lineations associated respectively with major east–west and north-west trending dykes. This sample is also significantly enriched in As (220 ppm) and Zn (402 ppm). Another sample with a high Au content was collected from a site approximately 3 km farther to the east-north-east also situated close

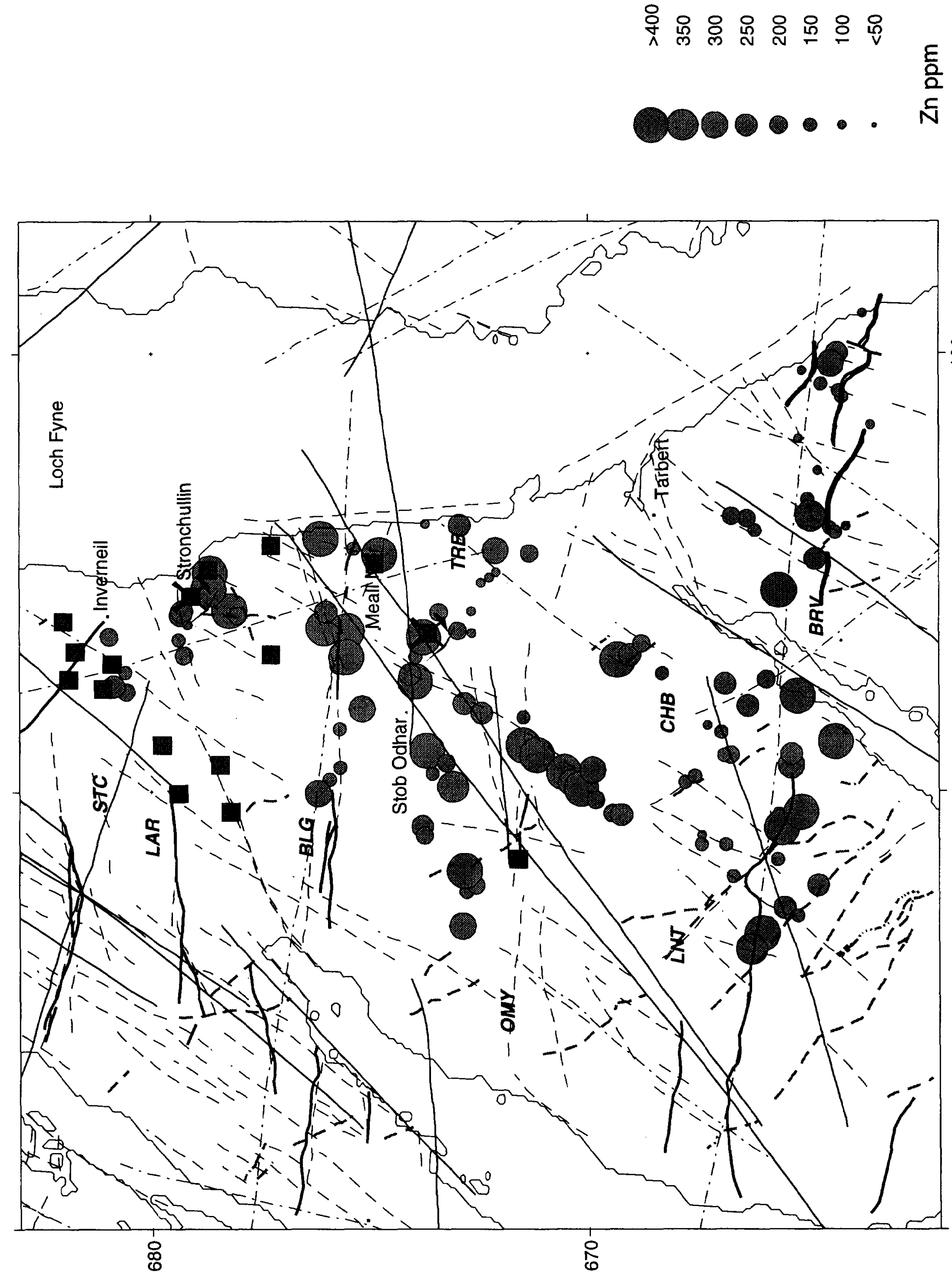

Figure 10 Distribution of zinc (Zn) in stream sediment samples plotted with detail of lineation analysis in the Tarbert area. Named lineations and other ornament as Figure 3

to the Bardaravine lineation. This sample is also enriched in As (77 ppm) and Bi (6 ppm), with attendant low base-metal contents.

In the north of the project area around Inverneil, where Pb vein mineralisation is widely developed, the available data do not indicate any significant enrichment in Au in the stream sediments.

The southern sector of the Erins Quartzite has generally high levels of As, with the majority of values exceeding 60 ppm. The high amplitude As anomaly following the line of the Eas a Chlais catchment (Chaorann Beag lineation) in a north-westerly direction identified in the regional geochemical survey was confirmed in the present work. A value of 293 ppm As reported from a site draining the north-eastern flank of Meall Buidhe along this lineation lies very close to the maximum As value (520 ppm) reported in the regional survey in this area. Additional anomalous As values reported in the present survey from this sector are associated with distinct north-westerly trending lineations which are fault zones locally occupied by Tertiary dolerite dykes. These sites include the one noted above in the upper section of Gleann Fithich [177850 664745] and another in a tributary of the Abhainn na Cuile about 700 m south-west of the summit of Meall Reamhar. Low to moderate tenor Au enrichment is present at a number of sites in this zone, both in stream sediments and pan concentrates, although there is no correlation in detail with the widespread high tenor As enrichment.

Moderate As enrichment also occurs at sites in the Beinn Bheula Grits (Southern Highland Group). Almost 50% of the samples from Southern Highland Group catchments exceed the median value of 60 ppm As for the whole dataset. These sites have a close spatial association with the Bardaravine geophysical lineation coincident with the east–west Permo-Carboniferous dykes extending across the project area. High levels of Pb and Ba, sporadically with attendant enrichment in Bi and Zn, are also found in proximity to this lineation (Figure 11).

In the central part of the area sampled, around Meall Mor, Au concentrations in stream sediments are generally low, attaining a maximum of 12 ppb. However, local As enrichment is found in this area. To the north of Meall Mor four values in excess of the median lie close to the trace of the Baranlongart lineation. To the south, around the old mine workings, elevated As concentrations are found in association with high Cu levels related to the mineralisation in this sector.

The main zones of Pb enrichment are in the south of the project area (Figure 11). In proximity to the Bardaravine lineation, especially at sites underlain by Southern Highland Group strata, the Pb values are high. Sporadic high Pb concentrations are also found along the Chaorann Beag lineation. The highest Pb value (233 ppm) in the dataset is found in the Allt na Beisde [186 672] about 2.5 km east-south-east of the Abhainn Srathain mines along the possible eastern extension of the Ormsary lineation. The high Pb content at this site is associated with weak enrichment in Au (10 ppb) and Zn and Ba. Neither the Pb veins in the Inverneil area or at Stronchullin are reflected in the Pb distribution in stream sediments This may be due to the low density of sample coverage in these areas.

The distribution of Cu in stream sediments shows an area of particular enrichment centred on Meall Mor (Figure 12). Sites around the old mines at Abhainn Srathain contain high Cu levels associated with elevated Sb and As. The maximum Cu concentration reported (188 ppm) is derived from a site at the eastern end of the Baranlongart lineation about 2.5 km north of the old mines and is accompanied by a high As concentration. Elsewhere the pattern of Cu enrichment in the area reflects the generally high levels found in association with the disseminated stratiform mineralisation of the pyrite belt.

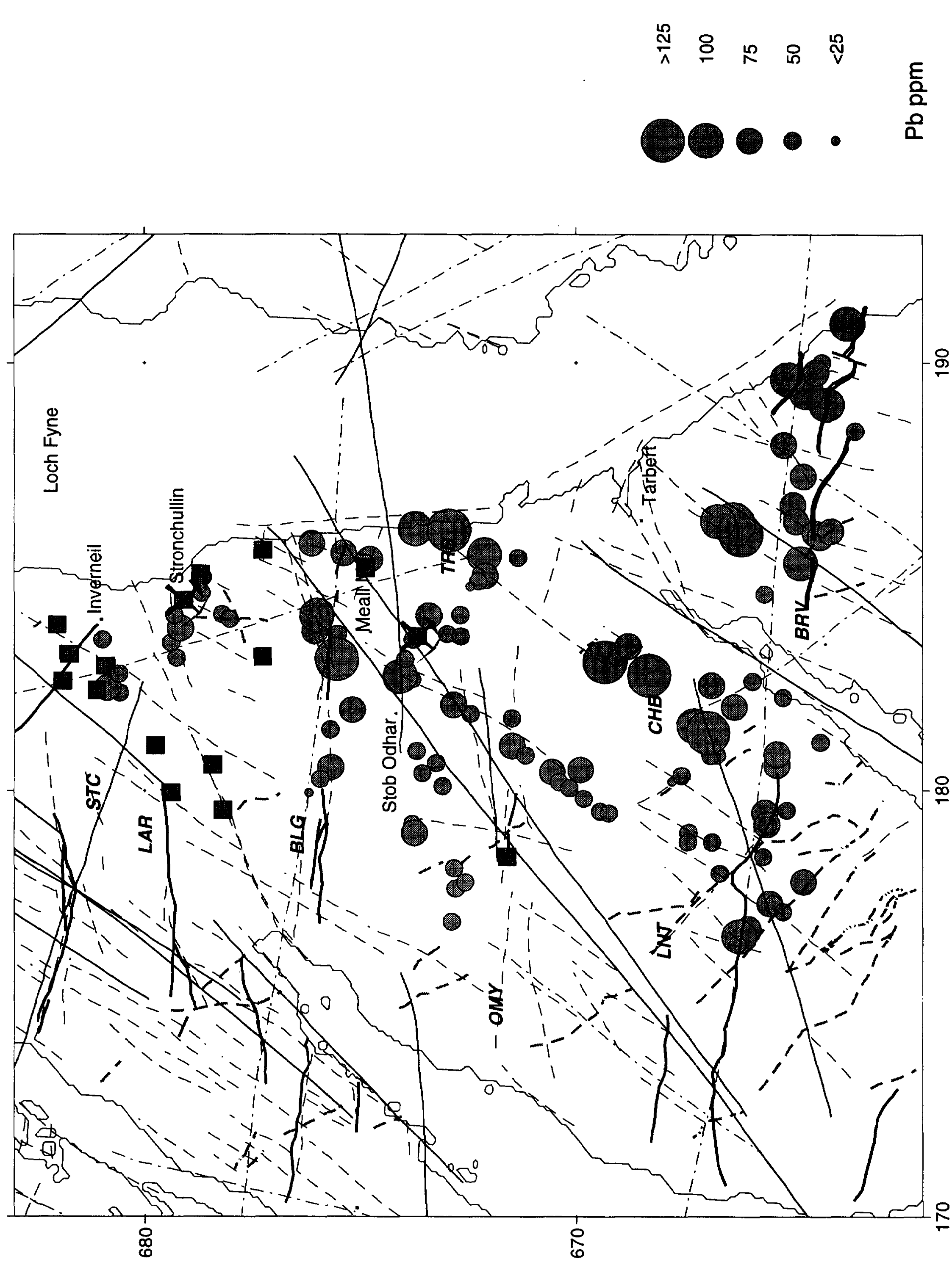

Figure 11 Distribution of lead (Pb) in stream sediment samples plotted with detail of lineation analysis in the Tarbert area. Named lineations and other ornament as Figure 3

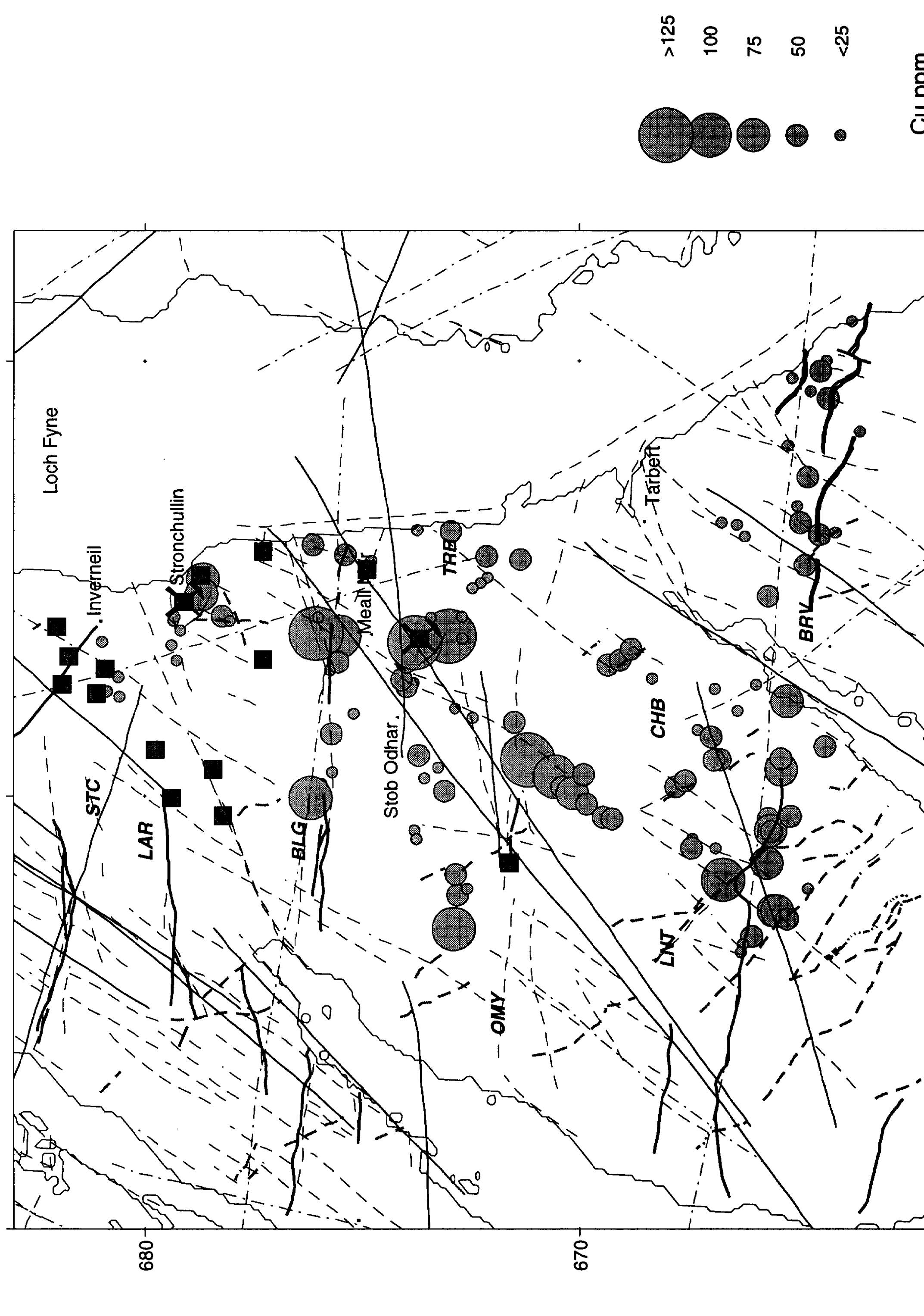

Figure 12 Distribution of copper (Cu) in stream sediment samples plotted with detail of lineation analysis in the Tarbert area. Named lineations and other ornament as Figure 3

Panned concentrates

The distribution of Au determined in panned concentrates is shown in Figure 13. The median content of Au in these samples is 4 ppb (Table 2). More than 10% of the samples (ie 12 sites) contain in excess of 250 ppb Au. Discrete grains of native gold were observed in concentrates in the field at five localities.

Table 2 Summary of geochemical data for panned concentrate samples (n=117; all values in ppm, except Au ppb)

Element	Minimum	Median	75%	90%	95%	Maximum	Mean
Au	2	4	13	267	616	5559	151
Ag	5	5	5	5	7	21	5
As	2	22	43	82	103	305	34
Ba	5	337	628	2189	5312	204700	3808
Bi	3	3	3	3	6	18	3
Cu	3	24	45	105	233	1110	63
Mo	7	15	16	17	18	21	15
Pb	3	16	25	41	64	194	22
Sb	3	3	3	5	13	411	8
W	5	5	5	6	8	19	5
Zn	13	71	120	177	221	655	98

The Stronchullin area is picked out by the distribution of Au in concentrates, as it is in stream sediments (Figure 13). In the Stronchullin catchment all Au values exceed the median, with reported Au concentrations from three sites exceeding 100 ppb. The majority of samples from this area are also significantly enriched in As but there is no close correlation between the Au and As contents (Figure 14). Similarly, Sb values are locally enhanced with two localities reporting 12 ppm and 23 ppm respectively (Figure 15). Bi is enriched at only a single site near Stronchullin.The reported value of 18 ppm is the highest in the dataset and is coincident with the maximum Au value from the Stronchullin catchment (Figure 16).

In the Inverneil area elevated Au levels are present in a single concentrate only (1465 ppb). There are no attendant high values of base-metals or chalcophile pathfinder elements at this site, but Pb and Zn show sporadic low tenor enrichment in the Inverneil area.

Elevated Au concentrations are also present in two tributaries of the Artilligan Burn close to the eastern end of the Baranlongart Lineation. The Au enrichment is accompanied at both sites by enhanced levels of As, Cu, Pb, Ba, Bi, Sb and Zn (see Figures 17, 18, 19 and 20).

A cluster of high Au values in pans is found to the west and south-west of Meall Mor, in streams draining the ridge between Cnoc a Bharaille [180 672] and Stob Odhar [181 674]. Sporadic enrichment in As, Cu, Pb and Zn is present in this zone, although the distribution patterns do not correlate in detail with that of Au. Sites in proximity to the Abhainn Srathain workings are especially enriched in Cu and at two of these locations the highest Sb concentrations in the dataset, 128 ppm and 411 ppm, are present.

A distinct zone of Au enrichment in pan concentrates is also present in the south of the project area to the west of West Loch Tarbert, principally in the Glean Fithich catchment. In this zone Au contents in the range 336 to 5559 ppb are accompanied by weak enrichments in As, Cu and Zn at several sites,

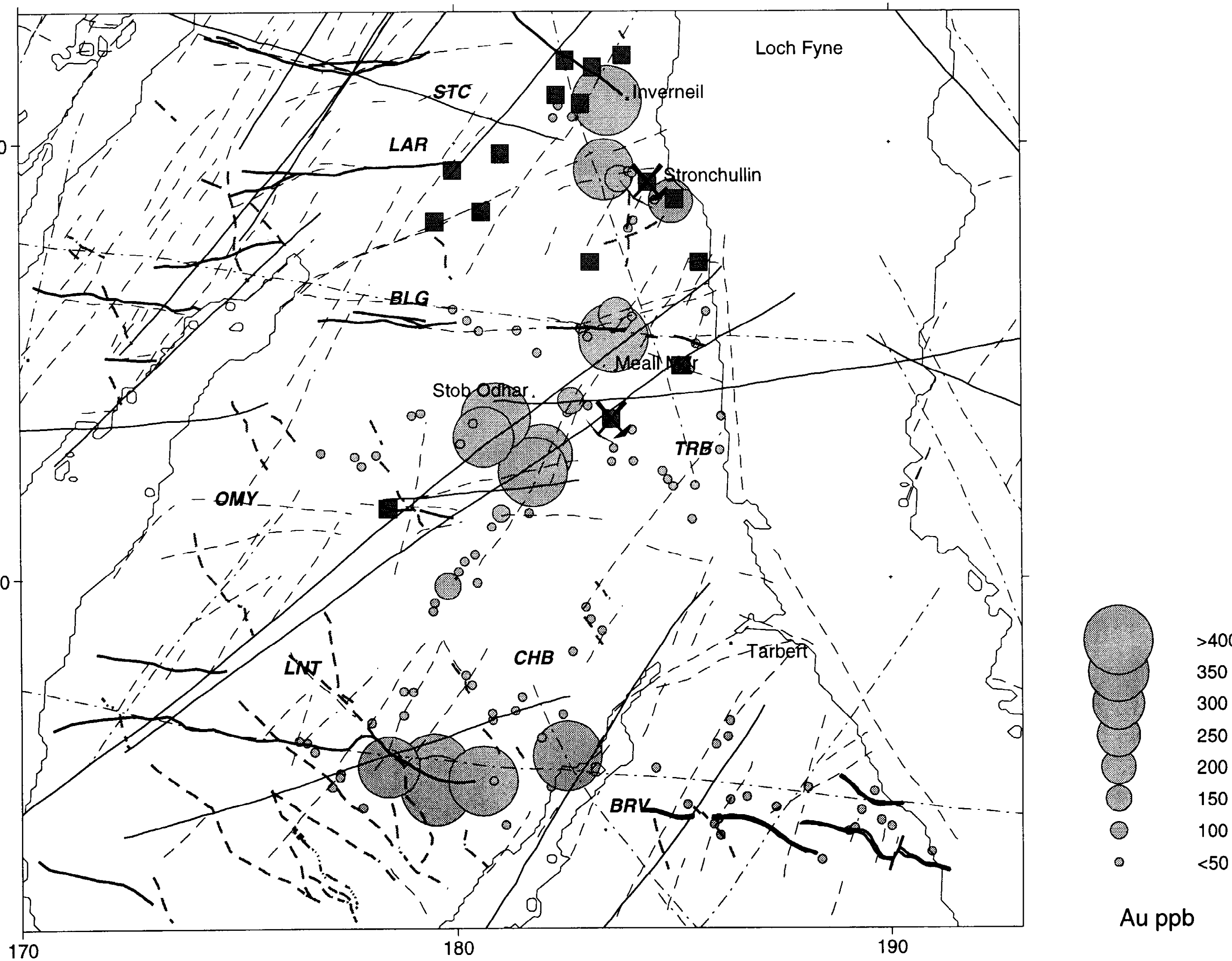

Figure 13 Distribution of gold (Au) in panned concentrate samples plotted with detail of lineation analysis in the Tarbert area. Named lineations and other ornament as Figure 3

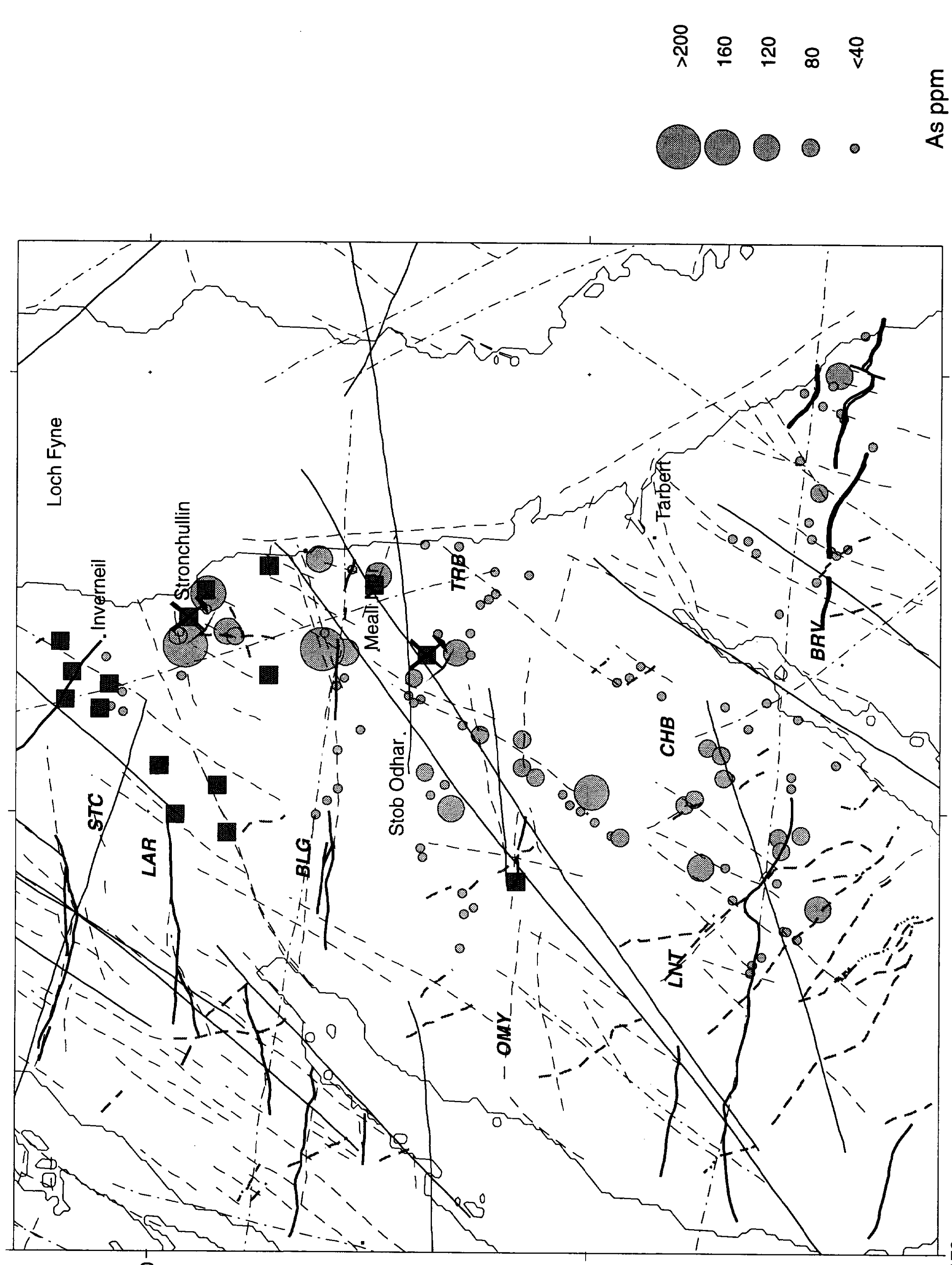

Figure 14 Distribution of arsenic (As) in panned concentrate samples plotted with detail of lineation analysis in the Tarbert area. Named lineations and other ornament as Figure 3

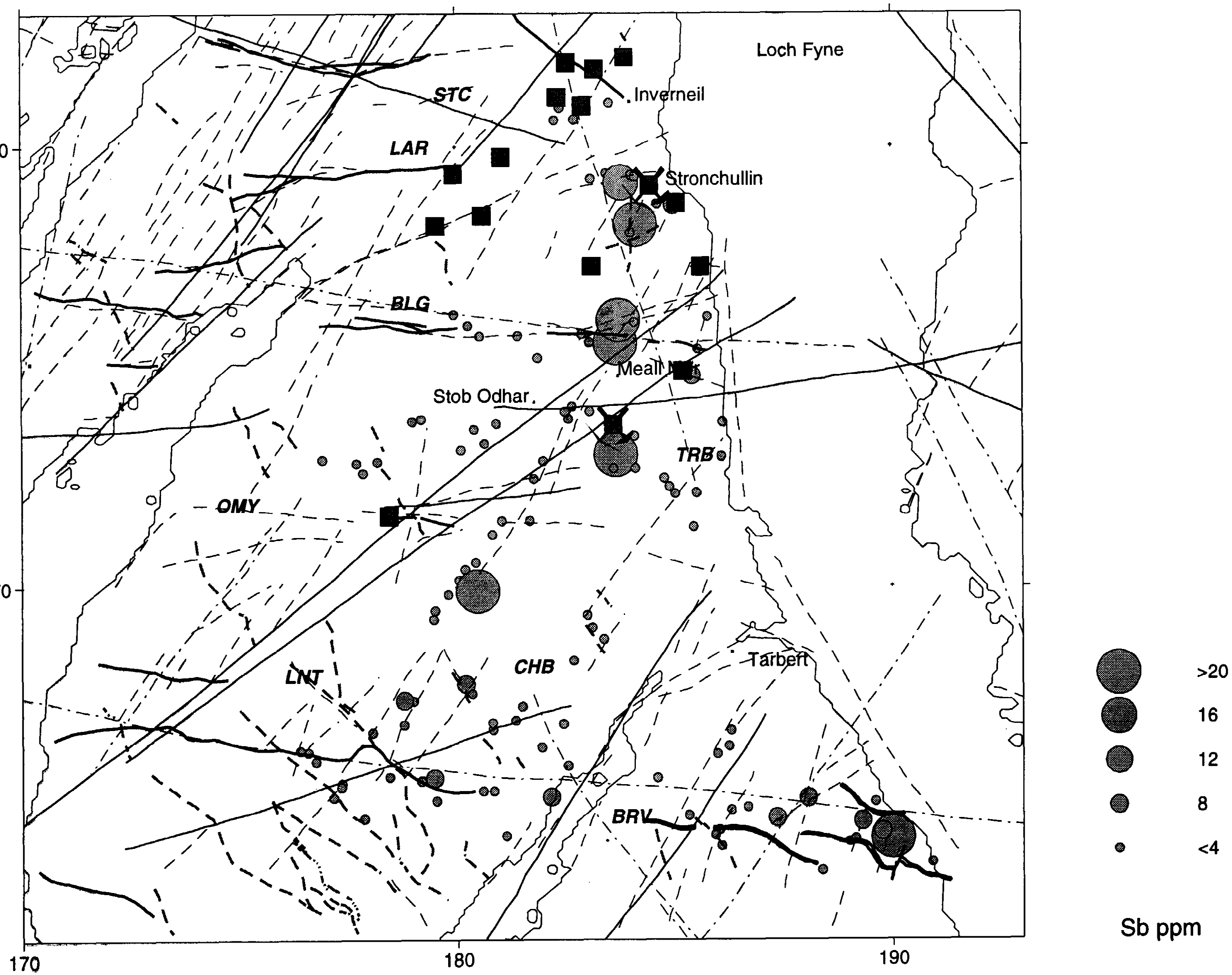

Figure 15 Distribution of antimony (Sb) in panned concentrate samples plotted with detail of lineation analysis in the Tarbert area. Named lineations and other ornament as Figure 3

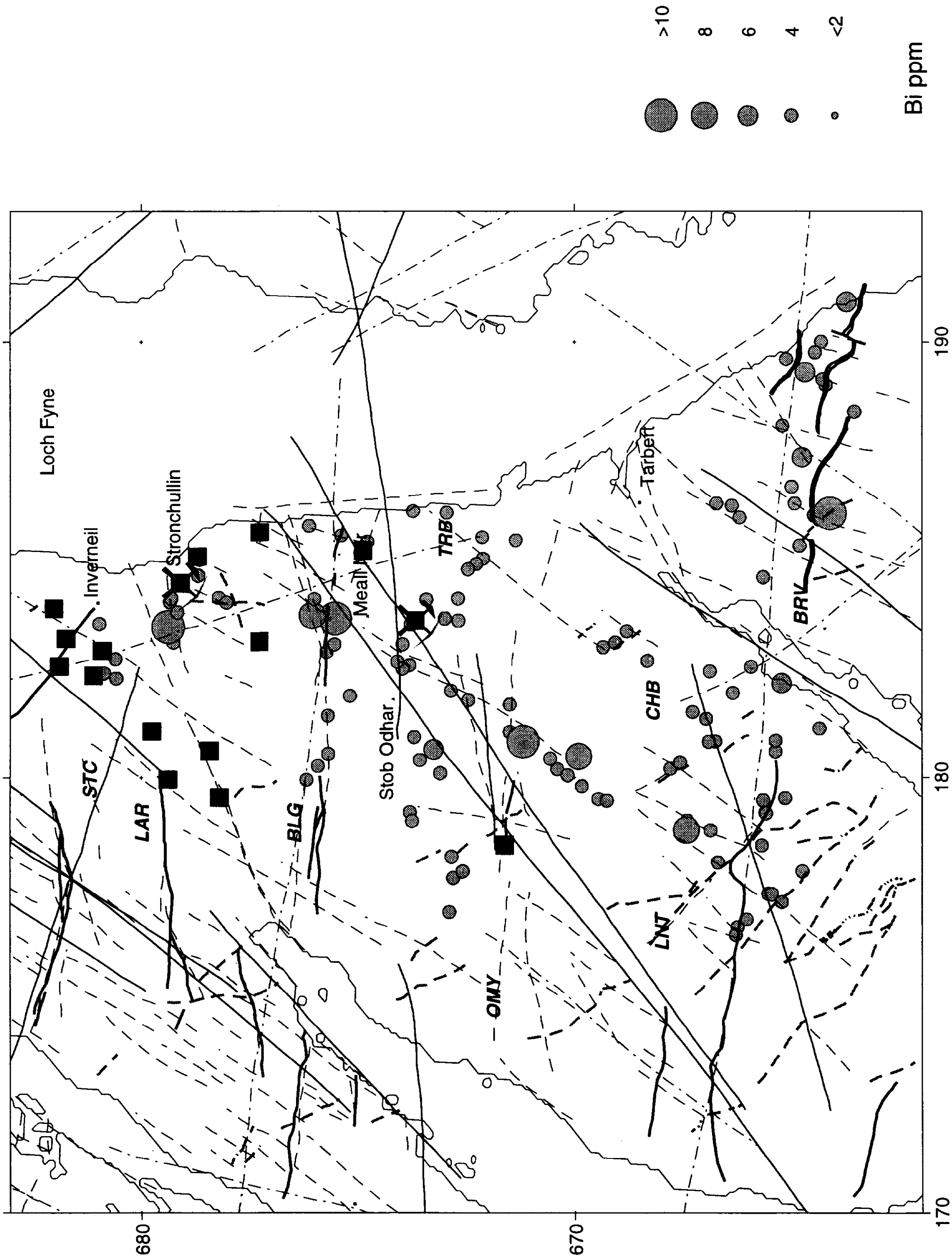

Figure 16 Distribution of bismuth (Bi) in panned concentrate samples plotted with detail of lineation analysis in the Tarbert area. Named lineations and other ornament as Figure 3

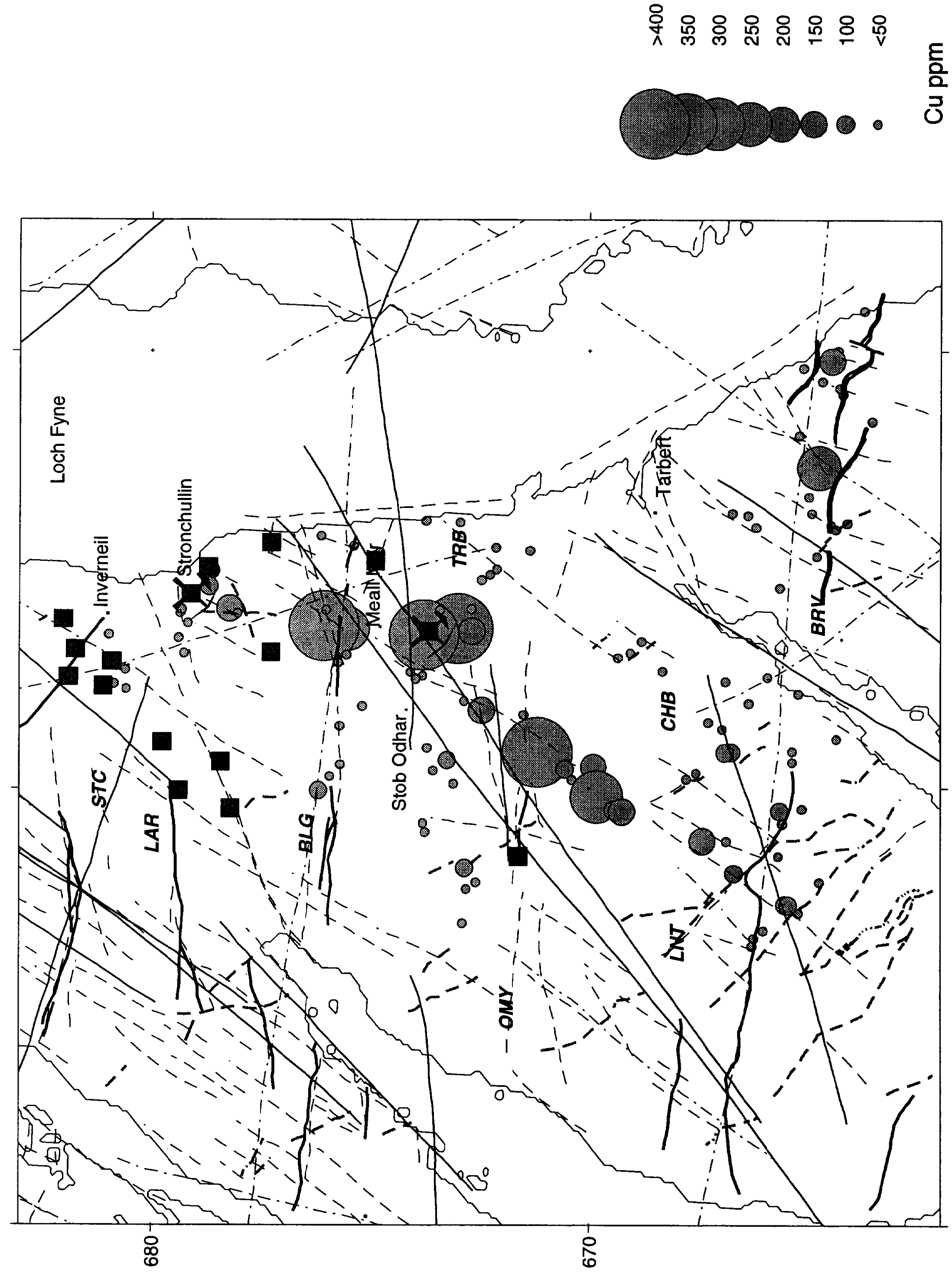

Figure 17 Distribution of copper (Cu) in panned concentrate samples plotted with detail of lineation analysis in the Tarbert area. Named lineations and other ornament as Figure 3

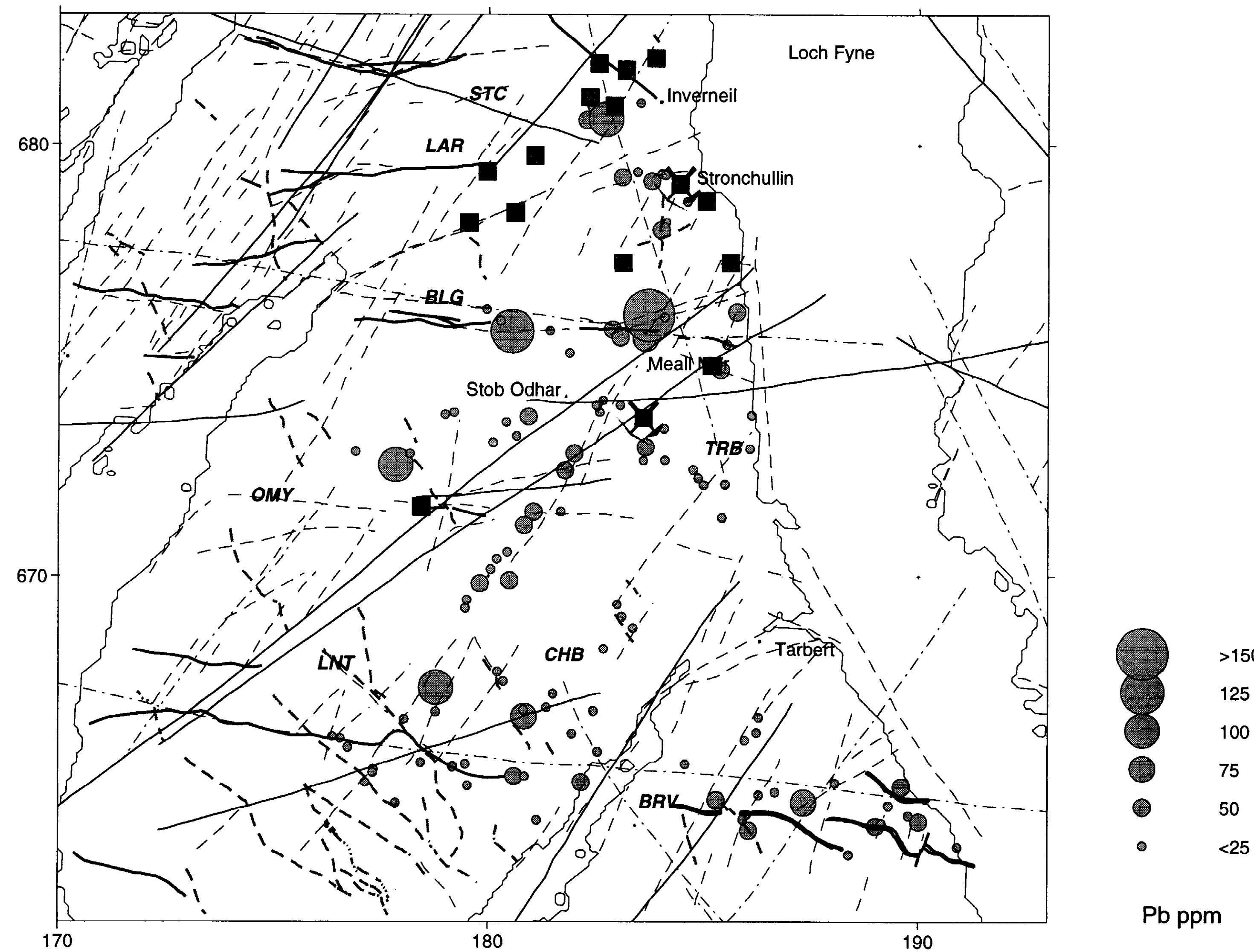

Figure 18 Distribution of lead (Pb) in panned concentrate samples plotted with detail of lineation analysis in the Tarbert area. Named lineations and other ornament as Figure 3

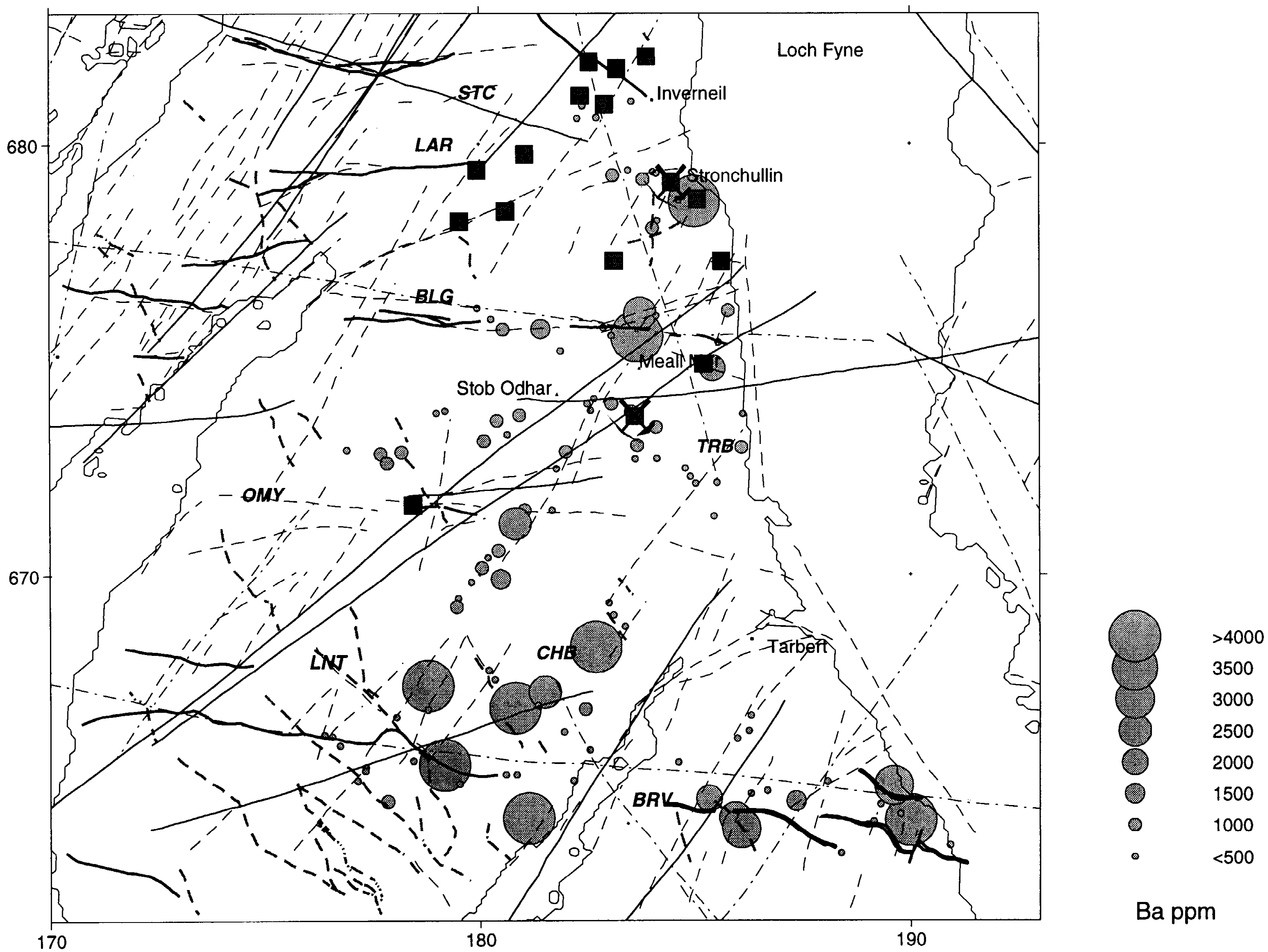

Figure 19 Distribution of barium (Ba) in panned concentrate samples plotted with detail of lineation analysis in the Tarbert area. Named lineations and other ornament as Figure 3

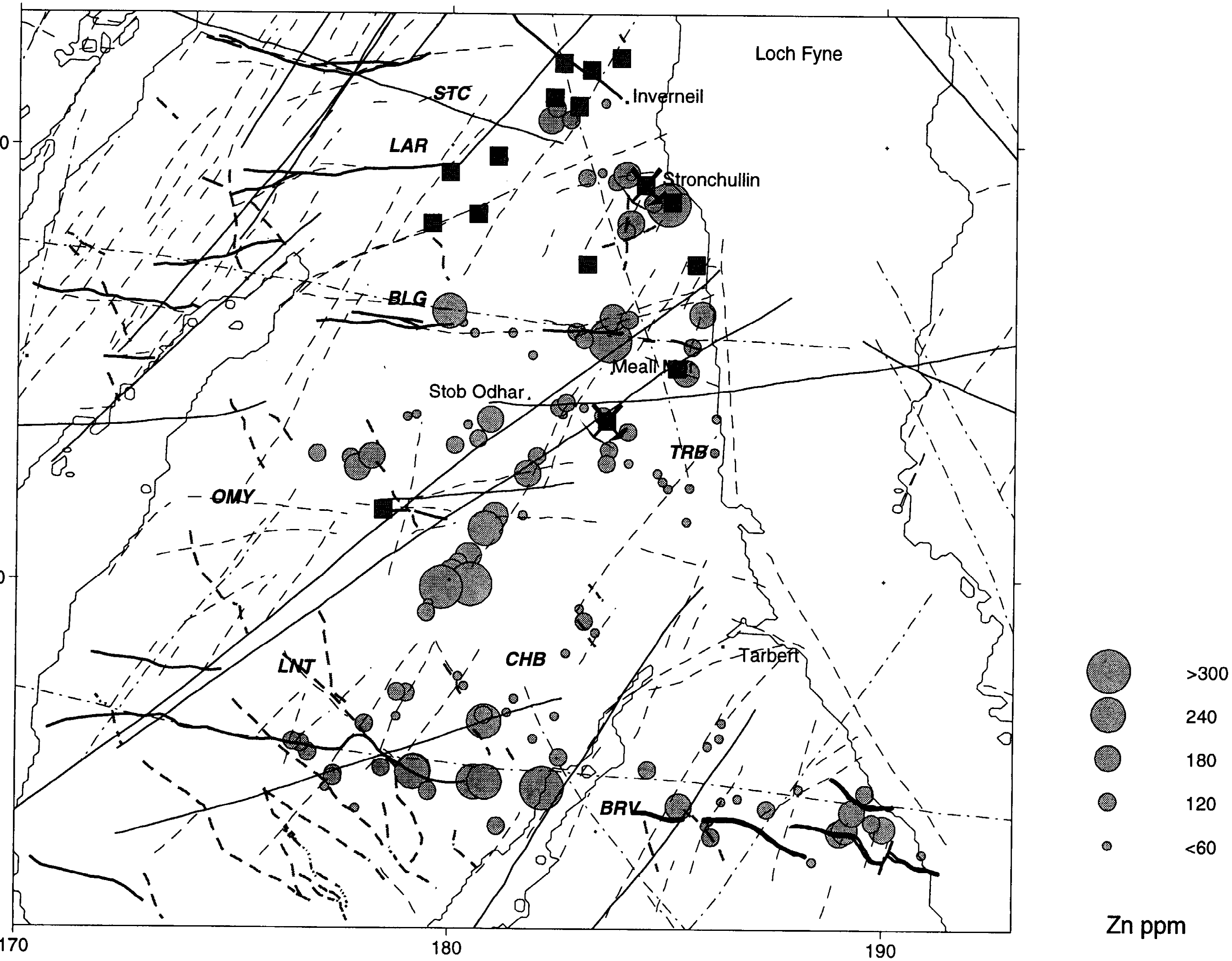

Figure 20 Distribution of zinc (Zn) in panned concentrate samples plotted with detail of lineation analysis in the Tarbert area. Named lineations and other ornament as Figure 3

while Sb and Ba are sporadically present at high levels. This belt of metal enrichment has a close spatial association with the Bardaravine lineation, the major east–west structure in this sector. Over the eastern section of this lineation, at sites underlain by Southern Highland Group strata, there is conspicuous enrichment in Pb and Zn, together with locally elevated concentrations of As, Sb, Ag, Bi, Cu and Ba. Gold contents, however, over this sector are uniformly low.

In addition to the local enrichment in Ag noted in proximity to the eastern end of the Bardaravine lineation, the highest Ag levels in concentrates (maximum 21 ppm) are from sites in the south of the project area to the west of West Loch Tarbert associated with the Chaorann Beag lineation. The two highest concentrations are associated with the highest Ba levels in the dataset (>10 % Ba). A relationship with baryte vein mineralisation, which is found sporadically in the project area, is suggested by this association of Ba and Ag. Analyses of rock samples from two barite veins in the southern sector of the project area supports this explanation.

Discussion

The drainage geochemistry defines three principal areas of Au enrichment in the project area. In the Stronchullin area elevated Au contents in both stream sediments and panned concentrates are found in several small discrete catchment areas on both sides of the Stronchullin valley. The elevated Au contents are associated principally with enrichments in As and Sb, although locally Ba, Zn and Bi are also present in high concentrations. The influence of structural control on the distribution of metals in the Stronchullin area is not clear from the available data. Distinct gravity and magnetic lineations of considerable extent intersect in the upper Stronchullin valley. The extension of the east–west oriented Loch Arail lineation, defined by faulting and local dyke intrusion, may also pass along the Stronchullin valley.

In the south of the project area, to the west of West Loch Tarbert, Au enrichment is also present in both sample types. The principal inter-element association is with As, although Sb, Zn, Bi, Cu, Zn, and Ba are also locally enriched. These sites are clearly disposed along the western end of the Bardaravine lineation, but the possible significance of intersecting north-west trending lineations must also be considered. The eastern end of the Bardaravine lineation, where it transects Southern Highland Group strata, is also associated with enrichment in a suite of metals, Pb, As, Zn, Ba and locally Ag, Sb, Bi and Cu, but not including Au.

In the central part of the project area around Meall Mor elevated Au values are reported in panned concentrates only. At the eastern end of the Baranlongart lineation high Au levels are associated with elevated As, Ba, Cu, Pb, Zn, Bi and Sb. High As values are also present in stream sediments at these sites. To the south-west of the old workings at Abhainn Srathain, to the south of Stob Odhar, four sites contain high Au values in concentrates. These are accompanied by low tenor enrichments in As, Cu, Pb and Zn.

The vein mineralisation in the north of the project area around Inverneil and Loch Arail is not identified in the drainage geochemical data. This is probably due largely to inadequate areal coverage and sampling density in this sector.

LITHOGEOCHEMISTRY

A suite of 82 rock samples was collected during the field survey. The samples, each 2–3 kg in weight, were either composite chip samples derived from several points on exposed surfaces or were channel samples across veins or alteration zones. Particular emphasis was placed on the collection of mineralised and altered rocks, either from old mine workings or in proximity to lineations and lineation intersections. Sixty-two samples were selected for geochemical analysis. Reference specimens were retained for mineralogical studies. The remainder of each sample was crushed and milled in a chrome-steel Tema mill. Representative splits were analysed for a range of trace and major elements in pressed powder pellets by XRF. Gold was determined by lead fire assay on 30 g samples followed by ICP.

Summary statistics for the lithogeochemical data are presented in Table 3 and and a complete listing of the data given in Appendix 1. The spatial distribution of Au in rock samples is shown in Figure 21.

Table 3 Summary of geochemical data for rock samples
(all values in ppm, except Au in ppb, CaO and TiO_2 in %)

Element	Minimum	Median	75%	90%	95%	Maximum	Mean	No. Samples
Au	2	5	41	208	1341	22060	780	60
Ag	5	5	8	21	33	59	9	60
As	5	7	16	51	206	646	37	59
Ba	5	481	985	1977	5371	480400	13226	60
Bi	3	3	3	4	4	5	3	56
CaO	0.05	0.09	2.12	11.58	18.66	46.24	3.68	60
Cu	3	51	201	6240	6500	6500	1040	60
Mo	1	17	19	23	34	112	18	59
Pb	3	11	31	164	2405	10000	442	60
Sb	3	3	5	16	107	955	36	60
TiO_2	0.02	0.55	0.81	1.86	2.32	3.88	0.72	60
W	5	5	6	15	18	50	8	51

Vein mineralisation

The highest Au concentrations are found in quartz vein material collected from the old dumps at the former Stronchullin mine. Three large composite samples (1064, 65 and 66), each approximately 5 kg in weight, were analysed and Au contents in the range 8–22 ppm reported. In hand specimen the veins comprise massive buck quartz with local patches of coarse grained prismatic crystals infilling small cavities or forming discontinuous bands up to a few decimetres in length. Sporadic rare clasts of wall rock, micaceous psammite and pelite, are enclosed within the veins which also contain local micaceous or chloritic partings. There is no evidence in hand specimen of multiple phases of veining or significant recrystallisation. Metallic sulphides are widespread but highly variable in abundance. Overall, the veins contain about 2–3 % sulphides. However, locally they vary from being barren to containing in excess of 10 % sulphides. The most common sulphides are sphalerite and galena which are found mainly in monomineralic aggregates or coarse clusters a few centimetres in size, up to a maximum of about 10 cm. Pyrite is a less abundant component of the veins and occurs sporadically, sometimes with minor chalcopyrite, as streaky patches and stringers aligned near parallel to vein margins. Pyrite and chalcopyrite are also found intergrown with galena in sporadic small patches of massive sulphide. No visible gold was observed in these veins either in the field or under binocular microscope in the laboratory.

In addition to high concentrations of Pb, Zn and Cu, elevated contents of As, Sb, Ba and Ag are present in the gold-bearing veins at Stronchullin. Au/Ag values are high, falling in the range 0.4 to

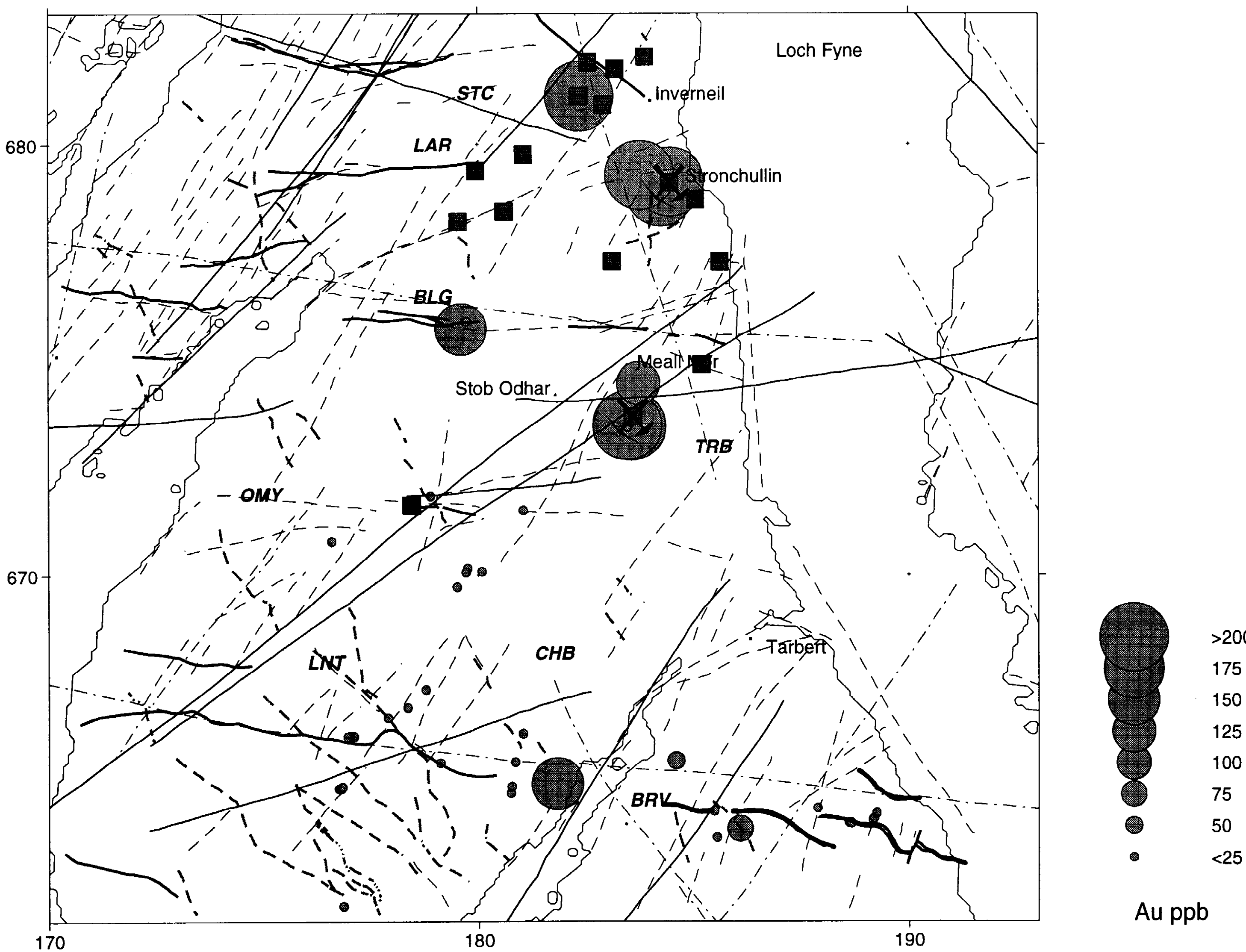

Figure 21 Distribution of Au in rock samples plotted with detail of lineation analysis in the Tarbert area. Named lineations and other ornament as Figure 3

1.7. Concentrations of Bi and W were not reported in these samples due to spectral interference effects in the XRF determination of these elements.

A sample of quartz vein material (1063) collected from an in-situ exposure approximately 250 m to the south-west of the Stronchullin mine contains 299 ppb Au. This vein, 15 to 20 cm wide, is exposed over a length of approximately 5 m trending 034° and dipping steeply towards the south-east. The vein has textural similarities to those found at the mine, although in this case there is a higher proportion of open-space filling textures. In contrast to the veins at the mine, pyrite is the only sulphide phase observed in hand specimen at this locality. Pyrite comprises up to 5 % of the vein and occurs as cm-scale aggregates of crystals 2–4 mm in size. Sporadic euhedral cubes, up to 1 cm, are also present. This vein is enriched in As (194 ppm), Mo (112 ppm) and W (15 ppm), but contains low concentrations of Cu, Pb, Zn, Ag, Bi and Sb.

Another quartz vein sample from the Stronchullin area (1082), collected about 700 m west-north-west of the old mine, also contains high Au levels (985 ppb). This vein, up to 15 cm wide, can be traced for about 5 m along strike in a north-easterly direction in general concordance with the main foliation of the enclosing micaceous gritty psammite and quartzite. It is highly fractured and weathered with locally intense limonite staining. Sporadic remnants of pyrite are preserved and an overall original pyrite content of about 3 % is inferred. In addition to the high Au contents, this sample is enriched in Sb (44 ppm), and weakly in Cu (99 ppm) and Mo (19 ppm).

Another auriferous vein (1062) was sampled in a loose block found in a small quarry in the forest to the south-east of Lochan Liath, approximately 5.5 km south-west of Tarbert [181820 665160]. This sample was derived from a 10 cm wide vein with a texture similar to those in the Stronchullin area, but with a higher proportion of coarse, drusy prismatic quartz. In hand specimen pyrite and chalcopyrite occur as sporadic cm-scale blebs comprising about 5% of the vein. The Au enrichment (138 ppb) is accompanied by high Cu and low tenor enrichment in Pb. The provenance of the block from which this sample was derived is uncertain. No similar veins are exposed in the quarry face.

Location of the sites of previous mining on veins in the north of the area is difficult due to the recent afforestation. Evidence of former working was found in the forest at the site of the Gleann Beag mine [182360 681100]. At this location the exposed mineralisation comprises a set of parallel quartz veinlets, each 0.5 to 1.5 cm wide, trending approximately 070° and dipping southwards at about 60°. Sparse pyrite and galena were observed in these veins and in the immediate quartzite wallrock. The maximum Au value reported from this locality (198 ppb) is in a sample of spoil material containing broader quartz veinlets, up to 5 cm wide, with about 2% pyrite in euhedral cubes up to 3 mm in size and subordinate streaks of galena (1069). The elevated Au concentration is accompanied by high contents of Pb, Ba, Sb and moderate As.

Stratiform mineralisation

Samples representative of pyrite belt metasediments were collected from a few localities. These typically comprise quartzite and micaceous quartzite with 1–2% disseminated pyrite. They generally have low Au contents and sporadic local enrichment in Cu, Zn and Ba. The chalcophile pathfinder elements, As, Sb and Bi, are present at very low levels, commonly below the analytical detection limits. Lead contents seldom exceed 10 ppm. A notable contrast in geochemistry is found in a zone of gouge and quartz veining close to a conspicuous north-west trending linear topographic feature, approximately 1.4 km south-east of the summit of Meall Reamhar. This sample (1033) contains only 6 ppb Au, but As and Sb contents are high (350 ppm and 26 ppm respectively). Moderately high levels of Pb, Cu, Zn and Ba are also present. Apart from the low Au content, this trace element assemblage is similar to that found in the Stronchullin veins.

Eight samples were collected and analysed from the area on the south side of Meall Mor. Four of these were from exposure or spoil at the old mine workings and trials at Abhainn Srathain. These samples, comprising epidiorite and quartzite with irregular quartz veining, are mineralised with sporadic blebs and discontinuous stringers of chalcopyrite and pyrite. The Au contents of these samples lie in the range 30–355 ppb and are accompanied by elevated Cu levels in excess of 3000 ppm. They are moderately enriched in Ba and Zn, up to a few hundred ppm, and Ag, up to a maximum of 21 ppm. Arsenic, Sb, Bi and Pb are present in low concentrations. Similar veined and altered epidiorites and metasediments collected from track-cut exposures on the flanks of the valley about 200 m to the south-west of the site of former mining are also enriched in Au up to a maximum of 195 ppb. These samples have very high Cu contents and are moderately enriched in Ag, Zn and Ba.

A single sample (1079) collected from a site about 800 m to the north of the Abhainn Srathain mines in a cutting on the track to the summit of Meall Mor shows a similar pattern of trace element enrichment i.e. elevated Au, Cu, Ag, Zn, Ba. In addition, this sample is also enriched in Pb (165 ppm). The sample was derived from a 5 m wide section of veined and mineralised quartzite and schistose semipelite. Chalcopyrite and pyrite occur as discordant stringers and clots and locally as cm-scale aggregates within coarsely crystalline fracture-filling quartz veins. Gold grains identified in this sample by optical microscopy have been further studied using the electron microprobe.

Au/Ag values in samples from the pyrite belt and around Meall Mor are generally very low (<0.02). This relative enrichment in Ag contrasts markedly with the silver-poor auriferous veins at Stronchullin.

Lineation targets

Three samples were collected in the Baranlongart Burn area in proximity to the east–west Baranlongart lineation. Two samples (1077 and 1078) from a red clay alteration zone, 27 m wide, within epidiorite are enriched in Cu, up to 528 ppm, but Au levels attain a maximum of only 12 ppb. A third sample from this vicinity (1076), comprising a heterogeneous brecciated, veined and silicified zone in metasediments immediately adjacent to a dolerite dyke, has an Au concentration of 141 ppb. This alteration extends about 30 cm away from the dyke and is accompanied by sporadic coarse pyrite and subordinate galena mineralisation. The elevated Au content is associated with moderate enhancements in Ag, Ba, Cu, Pb, Mo and Zn. Fine gold grains, tentatively identified in this sample by reflected light microscopy, were confirmed by electron microprobe studies.

A series of samples was also collected from Southern Highland Group strata to the south of Tarbert. In general the gritty psammite and schistose pelites contain uniformly low levels of Au, with local minor enrichments in Ba and base-metals. However, several fault or fracture controlled alteration zones in the metasedimentary sequence show considerable variations in trace element abundances. These zones of intense reddening, up to several tens of metres wide, are locally enriched in Au. At one site an Au value of 55 ppb is accompanied by elevated As and Pb together with low tenor enrichment of Cu and Zn. This locality is situated close to a mapped north-west trending fault, locally occupied by a dolerite dyke, and its intersection with the east–west Bardaravine lineation. The other sample carrying an elevated Au concentration is derived from the immediate wallrock of another north-west trending dolerite dyke. This pervasively reddened quartz-mica schist has no associated enrichments in other trace elements.

Two further samples of similarly reddened rocks collected from the same track section less than 100 m away have no enrichment in Au or other trace elements.

Three samples of quartz-dolerite from this sector contain uniformly low levels of Au and have trace element abundances comparable with clarke values for rocks of this composition.

Discussion

The gold-bearing quartz veins in the Stronchullin area are characterised by high contents of Au accompanied by elevated Pb, Zn, Cu, As, Sb, Ba, Ag and relatively high Au/Ag values. Molybdenum and W are also locally enriched in these veins. Limited sampling of the vein mineralisation in the Inverneil area yielded similar trace element abundance patterns characterised by Pb, Ba, As and Sb accompanying the Au enrichment.

Metasedimentary rocks containing disseminated stratiform pyrite mineralisation from the pyrite belt are sporadically enriched in Cu, Zn and Ba but contain low levels of Au. However, a single sample associated with one of several linear north-west topographic features yielded a geochemical signature comparable to the Stronchullin veins i.e. high As, Sb, Cu, Pb, Zn and Ba. The Au content of this sample is low, but further investigation of these structures in this area is justified on account of the trace element enrichments reported.

Rock samples from the Meall Mor area illustrate the distinctive geochemical signature of the Cu mineralisation in this sector. Low to moderate tenor Au enrichment is widespread and is accompanied by elevated Cu, Ba, Zn and Ag. The concentrations of As, Sb, Bi and Pb in rocks from this area are generally low. A similar trace element assemblage, together with elevated Pb and Mo, is reported in a single auriferous sample of veined and brecciated wallrocks of a dolerite dyke close to the Baranlongart lineation. This may indicate the role of structure in the development of this style of auriferous mineralisation.

Several linear zones of hypogene alteration evident in locally intensely reddened and rotten rocks were sampled in the southern part of the project area. In two places Au enrichment was recorded in these zones, both in proximity to north-west trending dykes and faults. Enrichment in As and Pb, together with subordinate Cu and Zn, accompany the high Au at one site indicative of a similar trace element assemblage to that found at Stronchullin.

The associations between Au and selected elements in rock samples from the project area are illustrated in the scatter plots shown in Figure 22. The geochemistry of the auriferous quartz veins of Stronchullin type contrasts clearly with the copper mineralisation around Meall Mor (samples principally of metabasite).

MINERALOGICAL STUDIES

A suite of rock specimens was selected for mineralogical study on the basis of field observations and the lithogeochemical data. The samples studied and their locations are given in Table 4. The purpose of the mineralogical investigations was to describe the samples, to provide a broad classification of the the type of mineralisation present and to locate gold grains. Selected samples were studied using electron microprobe techniques to search for gold grains either where the reported Au concentrations are high and/or where fine discrete grains of possible gold were observed under reflected light. In this way it was hoped to derive a preliminary mineral paragenesis for the gold-bearing mineralisation.

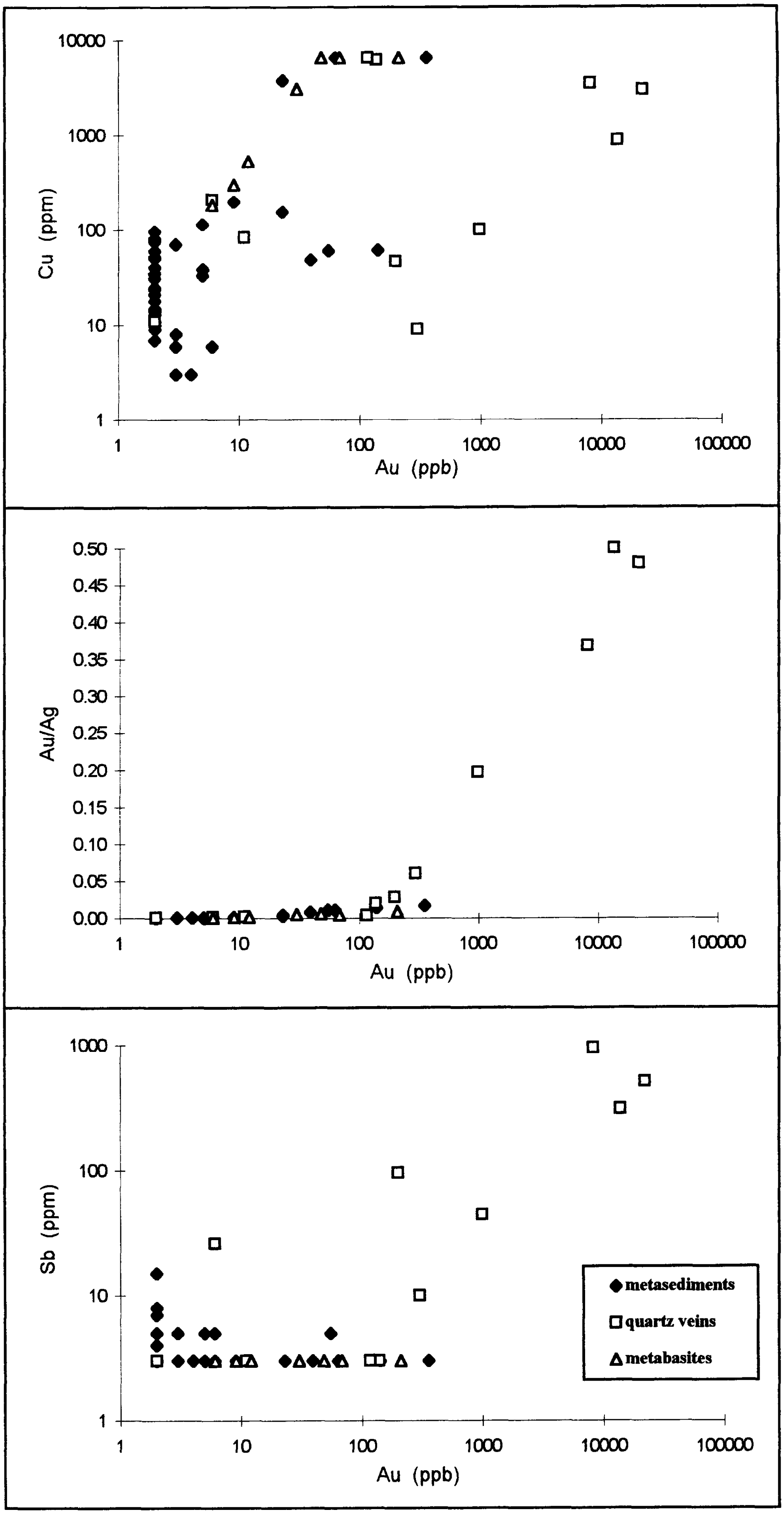

Figure 22 Relationships between Au and Cu, Au/Ag, Sb in rock samples

Table 4 Rock samples selected for mineralogical study

Site	Easting	Northing	Description	Au (ppb)
1062	181820	665160	quartz vein	138
1063	184240	678900	quartz vein	299
1064	184460	679125	quartz vein	8105
1065	184460	679125	quartz vein	13728
1066	184460	679125	quartz vein	22060
1069	182360	681100	quartz vein	198
1082	183760	679282	quartz vein	985
1053	183600	673680	metabasite	68
1054	183560	673470	quartz-mica-schist	355
1071	183460	673480	metabasite	195
1079	183720	674460	quartzite	116
1076	179600	675720	silicified breccia	141

Petrography

Twelve polished thin sections were studied by transmitted and reflected light optical microscopy: seven of the base metal vein type, four of the stratiform type and a single sample of silicified breccia. The gold content in each sample is given in parentheses after the sample number.

Vein mineralisation

PKR 1062 (138 ppb): a coarse-grained quartz vein with most grains showing strain and some microshears with fine recrystallised quartz. A little interstitial carbonate is present. Coarse opaque minerals, up to 6 mm in size, are pyrite and chalcopyrite with slight alteration along fractures. No grains suspected to be gold were observed.

PKR 1063 (299 ppb): a coarse-grained quartz vein, with strained quartz and coarse opaque minerals up to 3 mm in size. The opaque minerals are pyrite with finer pyrite also present. No grains suspected to be gold were observed.

PKR 1064 (8105 ppb): a fine-grained quartz-mica schist cut by a coarse quartz vein which contains micaceous layers and coarse sphalerite and opaque minerals up to 5 mm. The coarse opaque minerals are complexly altered and now consist largely of hematite and magnetite with remnants of chalcopyrite and pyrite. Some sulphosalt is also present. It is possible that they were originally largely chalcopyrite. Baryte is present as late infillings within the quartz and as late cross cutting veins. No obvious gold was seen.

PKR 1065 (13000 ppb): a coarse-grained quartz vein with finer quartz carbonate veins, with the carbonate showing iron staining. There is a little interstitial baryte, together with coarse sphalerite and galena; the sphalerite shows exsolution of chalcopyrite and small inclusions of pyrite. No obvious gold was observed.

PKR 1066 (22060 ppb): a coarse-grained quartz vein with a screen of mica schist and coarse sphalerite and opaque minerals. Baryte and fine carbonate appear to be interstitial to quartz and may be later. The opaque minerals are largely galena with a minor amount of a grey ?Cu-Pb sulphosalt and a little covellite. No obvious gold grains were observed.

PKR 1069 (198 ppb): a fine-grained schistose metaquartzite cut by a coarse quartz vein. There are a few scattered pyrite grains that show peripheral alteration to magnetite and some interstitial secondary goethite. No grains suspected to be gold were observed.

PKR 1082 (985 ppb): a coarse-grained quartz vein with included quartz schist fragments. No sulphides were seen but ferruginous pseudomorphs after sulphides and possibly Fe carbonates are present. Micas are altered to clay.

Stratiform mineralisation

PKR 1053 (68 ppb): a fine-grained schistose amphibolite consisting of green hornblende with interstitial quartz, carbonate and scattered garnet. The amphibolite contains layers with abundant garnet, carbonate and minor opaque minerals, that are possibly early veins though they could be deformed primary compositional variation. There are also distinct later veins of coarse quartz, carbonate and opaque minerals. There is chloritic alteration connected with the later vein. The opaque mineral in the early 'vein' is pyrite with peripheral alteration to hematite. The opaque minerals in the late vein are coarse pyrite with peripheral marcasite, chalcopyrite and sphalerite. The marcasite is partly altered to hematite and the chalcopyrite to ?Fe-sulphate. There are scattered grains of fine chalcopyrite and possibly fine gold away from the vein.

PKR 1054 (355 ppb): a fine-grained quartz-muscovite schist with clay pseudomorphs after feldspar. The schist is cut by quartz veins with coarse mica, sulphides and some chlorite. The sulphides are coarse chalcopyrite and lesser pyrite. The chalcopyrite has a distinctive alteration around the margins with ?bornite, digenite and Fe-oxide. No grains suspected to be gold were observed.

PKR 1071 (195 ppb): a fine-grained schistose amphibolite composed of green hornblende and quartz with localised carbonate and some layers with abundant garnet and epidote which may be extensively altered but could be primary variation. Sulphide veins are subparallel to the foliation. The sulphides are dominantly chalcopyrite with lesser pyrite and a little sphalerite. Some of the pyrite grains are altered to magnetite. There is scattered fine brassy mineral that is probably chalcopyrite.

PKR 1079 (116 ppb) a fine-grained micaceous metaquartzite, with thin sulphide veins and disseminated fine sulphides. The sulphides are mostly chalcopyrite with lesser pyrite, minor sphalerite and a little copper sulphosalt. Some parts are extensively altered to goethite. The sulphide veins have coarse mica, chlorite and rutile associated with them. Further checks using the electron microprobe identified fine gold in this sample.

Silicified Breccia

PKR 1076 (141 ppb): complex coarse quartz veins cutting finer quartz-carbonate-sericite vein material. Sulphides present comprise coarse-grained pyrite and chalcopyrite with fine chalcopyrite. Further checks using the electron microprobe confirmed the presence of fine gold in this sample.

Summary

The samples studied are largely vein material which show evidence of several phases of mineralisation. Those of the vein type are largely coarse-grained quartz veins with minor carbonate and are dominated either by pyrite and chalcopyrite or by sphalerite and galena with minor sulphosalts.

The stratiform type shows an early phase with 'veins' dominated by pyrite subparallel to the metamorphic fabric. The pyrite itself is deformed in some samples. This phase could be associated with a calcic, 'rodingite' type of hydrothermal alteration of the rocks, with the formation of abundant garnet, epidote etc., but could also result from primary compositional variation in calcic metasediments. The possible compositional banding in the amphibolite, with calcic layers, along with the abundance of quartz and low feldspar content suggests the amphibolites are metasediments rather than metabasalts. The later phase of sulphide mineralisation formed in coarse cross-cutting veins with chalcopyrite dominant with lesser pyrite, galena, sphalerite and sulphosalts.

All types of samples show evidence of low temperature alteration, with feldspars altered to micas and clays, hornblende to chlorite and the late sulphides to oxides and hydroxides.

Use of electron microprobe to search for gold grains

The Cameca SX50 electron microprobe was used to make automated searches for gold grains on the polished thin sections cut from the samples with the highest gold assays and those where possible fine gold was seen during optical examination. The TurboScan searching program measures the backscattered electron signal at points on a 1 micron grid over the sample. Where the signal is strong, indicating a high mean atomic number (equivalent to density *sensu lato*), an X-ray measurement is made to identify its source. If the X-ray counts indicate the presence of gold the location of the point is stored for later recall and detailed examination.

No gold was found in the samples from the Stronchullin mine with high chemical assays for gold (1064, 1065, 1066). This shows that there must be a considerable 'nugget effect'. The thin sections prepared are a very small sample compared to the bulk assay sample and can easily miss the gold if it is inhomogeneously distributed.

In searches of five samples where optical examination suggested that gold might be present (1053, 1069, 1071, 1076 and 1079) the automated searches revealed small gold grains in 1076 and 1079.

Gold grains were found in five areas of the section in sample PKR 1076. In each area the mode of occurrence was the same. Coarse pyrite grains are traversed by thin stringers of fine galena. The gold occurs as clusters of tiny grains, mostly around 2 μm in size, along with the galena in these stringers. The reason for the formation of these stringers is not clear, but could be related to a deformation event that post-dates pyrite formation. Microshears, in some places carrying carbonate, cut the quartz vein and carbonate is present along fractures in the pyrite. These might be related to the gold mineralisation event.

Gold was found in only one area of the section of sample 1079. It occurs at the edge of a chalcopyrite vein as a cluster of small grains around the margins of, and in cracks through, chalcopyrite and is intergrown with sphalerite. The gold is intimately associated with mica, rutile, chlorite, quartz and carbonate along the side of the sulphide vein. To identify the complex relationships of these very fine grains and the spatial chemical variation, microchemical maps were made of this part of the slide.

Microchemical maps of gold grains

Microchemical maps are constructed by making analyses on a grid of points (usually 256x256). For small areas, such as those studied here, the electron beam is moved over the specimen with a grid spacing as small as 0.1 μm. The data collected are X-ray counts with no correction for matrix effects. However, as the matrix is essentially the same within each grain this will produce little error. The data are presented as multicolour maps, each showing the concentration of a particular element according to a rainbow scale where red indicates the highest concentration. The scale is a relative scale for each element and a particular colour does not indicate a particular absolute concentration.

Microchemical maps of sample PKR 1079 are presented in Styles (1996). The distribution of Au and Ag are similar but there is some distinct micron-scale variation in Au and Ag contents. This variation has relatively sharp boundaries and is interpreted as of low temperature origin as no homogenisation has taken place.

The map for Hg indicates the presence of Hg within the gold. Examination under high magnification reveals that the higher Hg levels correspond to areas of high Ag. There are also spots distinctly enriched in Hg which do not exactly correspond with the gold grains and show that there is a mercury mineral present at the edges of some of the gold grains. It was not possible to determine the exact nature of this high-Hg phase but it could be an Hg-Ag sulphide.

The maps for Zn and S show the distribution of sulphides. They show that sphalerite occurs both around the margin of the chalcopyrite, the main sulphide, and as separate grains along with gold within the silicates. Sphalerite is a component of the gold mineralisation event.

The maps for Si show three silicate minerals, mica, chlorite and quartz. There is an area close to the gold grains that is neither silicate nor sulphide and is Ti oxide, probably rutile.

Quantitative electron microprobe analysis of gold grains

Gold in rocks

All the gold grains found in the rock samples are small, and quantitative analysis is difficult. Most analyses showed some components from surrounding sulphides, such as S, Cu and Fe, but these elements have been removed from the analyses shown in Table 5. The analyses have been normalised to make those analyses with larger amounts of these components easier to compare with the others.

PKR 1076: The gold from this sample, which occurs with galena inside pyrite grains, is actually electrum containing 20–30 wt% Ag. There are possibly two distinct compositions with 33 and 45% atomic Ag respectively. The Hg contents are moderate, 0.1–0.9 wt%; many gold grains from other areas have Hg below detection (ca 0.05 wt%).

PKR 1079: The microchemical maps show clearly that the gold in this sample is highly variable in composition. Attempts were made to analyse the extreme compositions, the areas that are bright red on the Au and Ag maps respectively. The gold-rich composition is best shown by g1 (Table 5) which has 39 wt% Ag (45% atomic) and is electrum. The most silver-rich g1/2 (Table 5) contains 66 wt% Ag (79% atomic) and is auriferous silver. There is also a correlation with Hg content: the Ag-rich parts have the highest Hg, around 9 wt%. This is very high for natural gold and even the lower values around 1% are much higher than found in most gold.

Mercury-rich electrum occurring in grains of very variable composition is unusual and rather distinctive and has been found in other BGS studies in Scotland, particularly at Calliachar Burn in Perthshire. Some analyses from Calliachar Burn are given for comparison.

Table 5 Electron microprobe analyses of gold grains from south Knapdale compared with some examples from Calliachar Burn

Sample/grain number	Wt % element				Wt % element normalised				Atomic proportions		
	Au	**Ag**	**Hg**	**Total**	**Au**	**Ag**	**Hg**	**Total**	**Au**	**Ag**	**Hg**
PKR 1079											
g1	60.99	39.56	0.79	101.34	60.18	39.04	0.78	100.00	45.51	53.91	0.58
g1/2	20.15	56.23	7.72	84.10	23.96	66.86	9.18	100.00	15.45	78.74	5.81
g2	47.04	43.04	1.10	91.18	51.59	47.20	1.21	100.00	37.12	62.02	0.85
g2/2	21.68	46.26	4.97	72.91	29.74	63.45	6.82	100.00	19.53	76.08	4.40
g3	48.01	43.01	1.26	92.28	52.03	46.61	1.37	100.00	37.57	61.46	0.97
PKR 1076											
g1	75.71	20.28	0.26	96.25	78.66	21.07	0.27	100.00	67.00	32.77	0.23
g2	68.33	31.03	0.15	99.51	68.67	31.18	0.15	100.00	54.60	45.28	0.12
g3	70.16	30.02	0.10	100.28	69.96	29.94	0.10	100.00	56.09	43.83	0.08
g4	77.90	21.48	0.97	100.35	77.63	21.41	0.97	100.00	65.98	33.22	0.81
Alluvial gold											
PKP 54/g1	81.86	14.08	0.96	96.89	84.48	14.53	0.99	100.00	75.44	23.69	0.87
PKP 54/g2	82.87	14.37	0.00	97.23	85.23	14.77	0.00	100.00	75.96	24.04	0.00
PKP 91	83.67	14.98	0.00	98.65	84.82	15.18	0.00	100.00	75.37	24.63	0.00
PKP 92/g1	96.50	4.00	0.00	100.57	95.95	3.98	0.00	99.93	92.96	7.04	0.00
PKP 92/g2	82.80	16.60	0.00	99.45	83.26	16.69	0.00	99.95	73.20	26.80	0.00
Calliachar Burn											
	62.4	32.9	5.2	100.50	62.09	32.74	5.17	100.00	48.91	47.09	4.00
	73.9	21.6	4.8	100.30	73.68	21.54	4.79	100.00	62.60	33.41	3.99
	54.6	43.2	2.2	100.00	54.60	43.20	2.20	100.00	40.25	58.15	1.59

Gold in panned concentrates

Five grains of alluvial gold collected from streams in the project area were also analysed. The results are shown in Table 5. Unfortunately there are insufficient grains available to be confident that they are wholly representative of the local mineralisation. However, the results show that alluvial gold has a completely different composition from that found in the rock samples, with 14–16% Ag in most grains. This silver content is typical of shear zone-hosted mesothermal mineralisation. This suggests that there are two types of gold mineralisation in the Knapdale area. No micro-inclusions of other minerals were found in the gold.

Discussion

Studies of the vein type mineralisation show a sequence of quartz veins with carbonate and either pyrite and chalcopyrite or galena and sphalerite as the dominant minerals, both pairings associated with minor sulphosalts. Several of these samples had high assays for gold, up to 22,000 ppb, but visual examination and microprobe searching failed to locate gold. This is no doubt the result of the 'nugget effect'. Study of additional sections is clearly needed to locate the gold in these samples and thus to interpret the mineralisation history.

The stratiform-type mineralisation shows early pyrite that is in 'veins' subparallel to the metamorphic foliation and is deformed in some samples. Later cross-cutting veins are dominated by chalcopyrite with pyrite, galena and sphalerite. Late stage alteration is present in all samples studied. This group of samples has lower assay values 100–200 ppb, but microprobe searching located 'gold' in two of the five samples examined. The 'gold' in both cases was silver-rich, either electrum or auriferous silver. In one sample it occurred in late microshears, probably with carbonate, and in the other in late veins with sphalerite, mica, chlorite and rutile.

The alluvial gold has a different composition to the silver-rich type found in the rock specimens. Its composition is typical of mesothermal vein mineralisation and may be responsible for the high gold contents of the Stronchullin veins.

The high-silver type of gold mineralisation is possibly only of minor significance but is a distinctive type and is similar to Calliachar Burn in Perthshire. It appears to be a late, low-temperature overprint, possibly associated with sphalerite, baryte and phyllosilicates.

DISCUSSION AND CONCLUSIONS

Geochemical surveys have identified widespread gold enrichment in drainage and rock samples in the south Knapdale sector of the project area. Three distinct styles of metalliferous mineralisation have been recognised. These may be distinguished on the basis of their morphology, mineral parageneses and geochemical abundance patterns.

The most widely distributed type of mineralisation is of syngenetic sedimentary exhalative origin. It comprises stratiform disseminated pyrite with minor chalcopyrite and sphalerite mineralisation in the upper part of the Argyll Group metasedimentary sequence. It occupies a tract of ground 200–800 m wide and can be traced over a strike length of about 10 km. This mineralisation can be correlated with the Perthshire pyrite horizon which extends north-eastwards from Knapdale for at least 190 km to Glenshee and possibly beyond. Available geochemical data indicate that there is no Au enrichment associated with this stratiform mineralisation in the south Knapdale area. In the drainage geochemical data it is characterised by sporadic enrichment in Cu, Zn and Ba with attendant low levels of Au, As, Pb, Bi and Sb.

Close to Meall Mor, in the area centred on the former mines at Abhainn Srathain, a discordant style of copper mineralisation is developed. This comprises coarse blebby chalcopyrite in quartz-carbonate veins and stringers, together with minor pyrite and sulphosalts. It is associated with a varied silicate assemblage including garnet, epidote, chlorite, biotite, hornblende and sphene. On the basis of recrystallisation, deformation and mobilisation textures observed in the ore minerals and their host rocks, Mohammed (1987) developed a genetic model for this mineralisation involving pre-metamorphic hydrothermal processes in a shallow geothermal setting. The observed trace element distributions and associated alteration assemblage were produced by fluid-rock interaction focused along fractures and other structural discontinuities. Observations made in the present study are not inconsistent with this hypothesis. However, recrystallisation and redistribution of ore and gangue minerals during regional metamorphism and deformation events must also be considered. In particular the identity, form, proportions and abundance of original mineral phases are likely to have been modified by the later tectonic events making formulation of a genetic model for this style of mineralisation more problematic.

The geochemical signature of the discordant copper mineralisation is clearly displayed in the drainage and rock geochemical datasets. It is distinguished by relatively high levels of Cu, Au and Ag, with local enrichments in Zn and Ba. Au/Ag values are characteristically low. Arsenic, Sb and Bi levels are present in low concentrations in rock samples, but sporadic enrichment in Sb, and to a lesser extent in As, is noted in the drainage samples. The presence of sulphosalt species reported in the mineralogical studies may explain the locally elevated Sb and As.

The third type of metalliferous mineralisation recognised in the area comprises post-tectonic base-metal-bearing quartz veins. This style is typified by the veins at the former Stronchullin mine, but it is also found in the north of the area around Inverneil and Loch Arail and, to the south of Stronchullin, in the Artilligan Burn and Erins areas. A similar vein was also located in float in the south of the area near Lochan Liath, about 5.5 km south-west of Tarbert. These veins display textural, morphological and geochemical features comparable with other auriferous mesothermal veins found in Scotland and elsewhere. They have a distinct geochemical signature characterised by elevated levels of Au, As, Pb, Sb, Ba and Au/Ag. In addition, elevated levels of Cu, Zn, Ag, Mo and W are locally present.

The limited mineralogical studies carried out in this investigation support the identification of the three styles of mineralisation derived from the geochemical data. In addition, they have provided important additional information on the nature and chemistry of the gold-bearing systems.

The gold grains studied in samples of the discordant copper mineralisation from the Meall Mor area have variable compositions but are generally Ag-rich. Some of the grains also contain detectable levels of Hg, up to a maximum of 9 wt%. These high Hg contents are a particularly unusual feature, much higher than those normally found in mesothermal lode gold deposits. High Hg levels in Au grains have been reported in the vein deposits hosted by Dalradian rocks at Cavanacaw in Northern Ireland (Cliff and Wolfenden, 1992) and at Calliachar Burn in the Scotttish Highlands (Mason et al., 1991; Ixer et al., 1996). High Hg concentrations in gold grains have also been documented in volcanogenic massive sulphide (VMS) deposits in north-east Queensland, Tasmania and Manitoba (Huston et al., 1992; Healy and Petruk, 1990). These observations may have implications for the setting in which the mineralisation in Knapdale was emplaced. Copper, Au and associated elements may have been derived from sub-volcanic basic intrusions now represented by the metabasic sills within the upper part of the Argyll Group succession.

Unfortunately no gold grains were located in the Stronchullin-type base-metal quartz vein samples studied in this project. However, the morphology, texture and geochemistry of the veins are similar to those found in mesothermal shear-zone hosted gold deposits. The small population of alluvial grains recovered during the drainage survey are quite different from those found in the rocks from Meall Mor. The compositions of the alluvial grains are characterised by low Ag and Hg concentrations comparable with gold found in typical mesothermal lode gold deposits. This suggests that the source mineralisation for the alluvial grains found in Knapdale may be of this type. Further work is required to confirm this suggestion and to characterise the chemistry of the gold at Stronchullin. In addition possible links between the early, pre-tectonic gold enrichment in the Meall Mor area and the post-tectonic auriferous veins of the Stronchullin type should also be investigated.

The importance of structural control in localising vein-type gold deposits has been recognised worldwide in mesothermal ore districts (Hodgson, 1993). The mineralisation is developed in zones of high strain related to major regional strike-slip faults. The location of the ores is commonly controlled by complex anastamosing shear-zone systems or by the intersections of multiple shear-zones. The timing of ore emplacement generally post-dates regional metamorphism and deformation. The link between discordant structures and gold mineralisation has also been documented in the orthotectonic and the paratectonic Caledonides of Scotland (Coats et al., 1993, Shaw et al., 1995, Gunn and Plant, 1995). Consequently, analysis of the structural lineations can play an important role in identifying potential sites for gold mineralisation.

Various lineation sets have been identified in the Knapdale-Kintyre area by analysis of geophysical, geological, satellite and topographical datasets. The dominant orientations are: north-east–south-west; east–west; north-west–south-east. The low density of sampling in some sectors of the project area in conjunction with regional nature of the magnetic and gravity datasets combine to make it difficult to identify particular lineation sets or lineation intersections which have controlled the emplacement of mineralisation.

The east–west lineation sets have clear spatial associations with enrichments in various trace elements, locally including Au. For example, the eastern end of the Bardaravine lineation is associated with elevated levels of Pb, Zn and Ba in drainage samples. In addition, enrichment in Au and As have been demonstrated over the western section of this lineation. The importance of north-west–south-east lineations and their intersections with east–west features on controlling trace element distribution patterns may also be significant. Further studies in the south of the area, to the west of West Loch Tarbert, are required to investigate the role of these structures which are particularly conspicuous in this section of the project area. Minor enrichments of Au in Southern Highland Group strata associated with north-west trending lineations to the south of Tarbert also warrant further study.

The controls on the location of the gold-bearing quartz veins in the Stronchullin area have not been identified in the present investigations. Lineations trending 110° and 090° may intersect in proximity to the mine. Local lithological controls may also be important, especially the juxtaposition of pelitic and psammitic rock types which contrast markedly in their physical competence. Further detailed geological and structural surveys are required to clarify the local setting of the base-metal veins at Stronchullin and elsewhere in the northern sector of the project area.

Gold mineralisation has been reported widely throughout the Dalradian terrane, both in Scotland and in Northern Ireland. The principal examples of potential economic significance in the Scottish Highlands are located at Cononish, near Tyndrum and at Calliachar Burn, near Aberfeldy. In Northern Ireland, the most important deposits are found at Curraghinalt 15 km north-east of Omagh in County Tyrone and at Cavanacaw in the Lack inlier to the south-west of Omagh. These are typical high grade, low tonnage (<1 million tonnes) mesothermal lode gold deposits. They occur in post-tectonic, structurally controlled quartz veins comprising either single veins with considerable vertical and along-strike continuity or suites of en-echelon veins of more limited extent. They record a complex history of repeated movement along the ore-controlling structures which resulted in multiple phases of brecciation, recrystallisation and veining. They exhibit considerable variation in grade along strike and in depth leading to the development of discontinuous high grade ore shoots. They are hosted by metasedimentary sequences which include units of contrasting physical competence, such as psammites and pelites, which are favourable for vein development. Associated wall-rock alteration is limited both in intensity and areal extent. The base-metal veins present at Stronchullin and elsewhere in the project area may be compared with the gold-bearing veins found elsewhere in the Dalradian. They share similar geological and structural settings and exhibit comparable geochemical and mineralogical features. The widespread gold enrichment in the drainage and lithogeochemical datasets demonstrated in this limited survey suggest that there is good potential for the discovery of additional economic gold mineralisation of this type in the south Knapdale area.

RECOMMENDATIONS

Further investigations to elucidate the nature and economic potential of gold mineralisation in the south Knapdale area are strongly recommended. These should include:

i) Geochemical sampling to determine the detailed distribution of gold in the area. Attention should be focused on the known occurrences of base-metal mineralisation and on sites with anomalous multi-element geochemical signatures identified in this survey.

ii) Additional mineralogical studies of the base-metal veins, especially in the Stronchullin area, in order to constrain the ore mineral paragenesis and the processes responsible for mineralisation.

iii) Detailed geological mapping and structural analyses to determine the controls on the distribution of the auriferous veins in the Stronchullin area. Close-spaced overburden geochemical and ground geophysical surveys should also be conducted in this area to provide additional structural information and to define the extent of the mineralisation.

iv) Evaluation of other prospective targets identified in this survey by further detailed geochemical sampling, mapping and structural analysis.

v) Study of the discordant copper mineralisation in the Meall Mor area to clarify the nature and genesis of the associated gold enrichment and investigate its relationship with the auriferous base-metal veins.

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Appendix 1 Geochemical data for rock samples
(all values in ppm, except Au in ppb, CaO and TiO_2 in %)

Site	Easting	Northing	Au	Ag	As	Ba	Bi	CaO	Cu	Mo	Pb	Sb	TiO_2	W	Zn
1004	188600	664260	2	9	5	129	4	7.61	75	13	3	3	2.29	5	93
1005	188630	664260	3	5	5	860	3	0.05	6	15	5	3	0.73	5	19
1006	188650	664250	2	5	18	488	3	3.75	31	15	3	8	0.82	13	57
1007	189150	664320	2	5	5	1027	3	0.16	21	18	8	3	0.99	5	45
1008	189180	664360	3	5	5	507	3	1.12	8	17	4	3	0.68	5	39
1009	189240	664480	2	5	7	353	3	1.58	50	15	7	3	0.58	5	38
1011	180740	664950	2	7	5	114	3	7.38	60	14	3	3	2.31	5	104
1014	187860	664590	5	59	5	480400	5	0.05	113	4	6	3	1.84	5	30
1016	184605	665705	<2	<5	9	996	<3	<0.05	52	6	15	<5	0.75	15	59
1017	184600	665700	2	5	11	981	3	0.18	24	17	12	3	0.93	5	42
1018	186060	664120	55	<5	80	708	<3	<0.05	60	5	164	<5	0.643	16	129
1019	185520	663920	2	5	10	665	3	0.05	25	14	14	3	1.35	5	63
1020	185460	664520	3	7	13	308	<3	5.27	70	3	17	<5	2.47	19	118
1021	185460	664520	5	33	<5	260800	<3	<0.05	38		10	<5	1.47	50	29
1022	184570	665690	39	5	6	860	3	0.12	48	20	6	3	0.74	5	72
1028	180080	670080	2	5	8	740	3	0.09	15	17	11	3	0.78	5	89
1029	179750	670160	3	5	5	286	3	0.05	3	18	3	3	0.18	5	7
1030	179710	670060	2	5	5	1380	3	0.05	81	15	10	3	0.57	5	396
1031	179500	669715	4	5	5	58	3	0.05	3	20	5	3	0.15	6	37
1033	178760	667340	6	5	350	339	3	0.05	208	19	40	26	0.42	5	358
1036	177890	666680	6	<5	<5	1024	<3	<0.05	6	1	7	<5	0.61	14	39
1038	177100	666260	2	5	23	329	3	0.11	40	18	12	3	0.42	5	47
1039	177000	666260	2	5	11	675	3	0.10	79	34	31	3	0.85	6	438
1040	177000	666260	2	10	17	1059	5	0.07	95	36	14	3	0.65	5	544
1041	176960	666250	2	5	5	109	3	0.05	10	24	5	3	0.25	5	4
1044	176760	665050	<2	<5	8	1760	<3	<0.05	9	5	41	<5	0.848	19	185
1045	176810	665050	2	5	7	10	3	0.05	7	23	7	3	0.29	5	13
1046	176840	665090	2	5	6	15	4	0.08	11	23	86	3	0.26	6	18
1049	176860	662340	<2	<5	<5	1261	<3	<0.05	9	5	15	<5	0.811	17	31
1050	183470	673705	63	6	5	474	4	0.26	>6500	17	3	3	0.43		131
1051	183600	673680	30	6	5	19	3	18.62	3031	12	3	3	0.08	5	111
1052	180740	664950	3	<5	12	54	3	<0.05	<3	4	6	<5	0.637	14	12
1053	183600	673680	68	15	5	26	3	17.70	>6500	12	12	3	0.10		490
1054	183560	673470	355	21	5	314	3	0.37	>6500	17	4	3	0.16		143
1055	181040	671500	9	5	5	1868	3	0.05	198	18	9	3	0.72	5	96
1057	180760	665100	2	5	9	14600	3	0.05	18	19	17	3	0.45	5	13
1059	181020	666320	2	5	316	755	3	0.05	35	17	20	15	0.63	5	69
1060	180840	665660	2	14	9	93	3	46.24	13	14	15	7	0.07	5	11
1061	179100	665640	2	5	31	349	3	0.05	14	19	3	3	0.34	5	3
1062	181820	665160	138	7	5	82	3	0.14	6211	17	269	3	0.02	5	13
1063	184240	678900	299	<5	194	51	<3	<0.05	9	112	10	10	0.027	15	4
1064	184460	679125	8105	22	646	2960		0.14	3463	34	>10000	955	0.12		6700
1065	184460	679125	13728	8	90	4885		<0.05	874	3	2400	313	0.089		>10000
1066	184460	679125	22060	46		1074		0.06	2978	19	>10000	516	0.04		10000
1067	182320	680980	6	5	15	249	3	26.71	6	13	24	3	0.18	5	32
1068	182360	681100	2	5	7	558	3	0.05	11	20	35	3	0.16	5	13
1069	182360	681100	198	7	32	660		0.09	46	18	2500	96	0.22	7	30
1070	183460	673480	48	8	5	26	3	19.46	>6500	15	10	3	0.16	5	396

Appendix 1 (continued) Geochemical data for rock samples
(all values in ppm, except Au in ppb, CaO and TiO_2 in %)

Site	Easting	Northing	Au	Ag	As	Ba	Bi	CaO	Cu	Mo	Pb	Sb	TiO_2	W	Zn
1071	183460	673480	195	25	5	71	3	11.30	>6500	13	8	3	0.18		725
1072	183460	673440	23	9	5	21	4	7.35	3739	17	10	3	0.14		1501
1073	178340	666920	5	5	5	644	3	1.13	33	19	26	3	0.70	5	118
1074	178880	671830	23	5	6	722	3	0.06	154	38	10	3	0.53	5	106
1075	176600	670780	6	7	5	165	3	8.58	182	13	9	3	2.05	5	105
1076	179600	675720	141	10	13	174	3	14.14	61	19	164	3	0.23	5	668
1077	179740	675900	9	6	5	19	3	0.32	299	13	9	3	3.88	5	160
1078	179720	675890	12	8	9	158	3	0.66	528	17	41	3	3.74	5	123
1079	183720	674460	116	34	19	676	3	0.08	>6500	21	165	3	0.24		657
1080	183180	681720	2	5	44	5	3	11.23	25	15	31	4	1.08	5	36
1081	183180	681720	11	5	17	3411	3	7.41	83	19	125	3	0.05	5	67
1082	183760	679282	985	5	27	132	3	0.05	99	19	8	44	0.04	5	8