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MINERAL INVESTIGATIONS IN THE NORTHUMBERLAND TROUGH: PART 5, THE KIRKBEAN AREA, SOUTH-WEST SCOTLAND

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This data package relates to work carried out by the British Geological Survey on behalf of the Department of Trade and Industry

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INTRODUCTION

Exploration for carbonate-hosted base-metal mineralisation on the North Solway coastal belt was undertaken in 1992-93 as part of a broader scale MRP investigation of a 70 km strike length of Lower Carboniferous rocks at the northern margin of the Solway-Northumberland Basin. The project area was selected partly on the basis of its similarities with the tectonosedimentary environment of the Lower Dinantian central Irish basin which hosts several major stratabound lead-zinc deposits, and the presence of geochemical base-metal anomalies coincident with basin margin structures. Two of the most important criteria for the formation of major SEDEX Irish-style deposits, the presence of major syn-depositional basin margin faults and a geothermal system over a zone of high heat flow in the crust (Andrew, 1993), are recognised in the north Solway area. The presence of mafic lavas and possible associated mineralising hydrothermal activity are considered to further increase the economic potential of the area.

Previous research

Detailed investigations carried out by the MRP in the 1970's (Gallagher et al., 1977), involving regional panned concentrate sampling over a 20 km^2 area, overburden geochemistry, geophysics and shallow diamond drilling, led to the discovery of galena and sphalerite in disseminations and dolomitic veins in porous sandstones and cementstones near Westwater (Figure 1). Mineralised breccia zones within the lavas carry chalcopyrite and pyrite. The mineralisation extends over a 4 km strike length of the Lower Carboniferous/Lower Palaeozoic boundary and usually occurs in close proximity to the contact of the basal Carboniferous Birrenswark Lavas and the overlying 'cementstone' facies of the Lower Border Group. Both styles of mineralisation appear to be emplaced along north-easterly trending normal faults and small cross faults.

In the North Solway-Criffel area, reconnaissance geochemical sampling carried out by the MRP in the mid 1970's identified a prominent linear zone of anomalous Cu, Ba, Zn and Pb values in panned concentrates and, to a lesser extent, stream sediments. The results suggest the presence of a possible mineralised structure at the east margin of the Criffel granodiorite affecting Silurian and Lower Carboniferous rocks along a strike distance of some 10-15 km (Leake et al., 1977; Colman et al., 1995). A more systematic geochemical survey based on stream sediments was undertaken in the area between 1981-85 as part of the BGS Geochemical Baseline Survey of the Environment (G-BASE). These data (BGS, 1993) confirm the pattern of base-metal and Ba enrichment approximately coincident with the faulted eastern contact of the Criffel granodiorite.

A multidisciplinary study into the analysis of spatially-related (geochemical, geophysical and geological) datasets and mineral deposit modelling for carbonate-hosted mineral deposits in northern England (Plant and Jones, 1991; Jones et al., 1994) also emphasised the high base-metal prospectivity of the Solway-Northumberland basin. The report suggests that particularly favourable sites for economic mineralisation occur where the northern basin-margin synsedimentary faults cut Courceyan-Chadian rocks at exploitable depths (<0.5 km). Zones of fault intersection can result in areas of dilation and structural disruption which provide potential pathways for mineralising fluids.

Selection of survey area

Based on these concepts, and the presence of coincident base-metal anomalies, a new MRP project aimed at stimulating mineral exploration interest in the northern margin of the Northumberland-

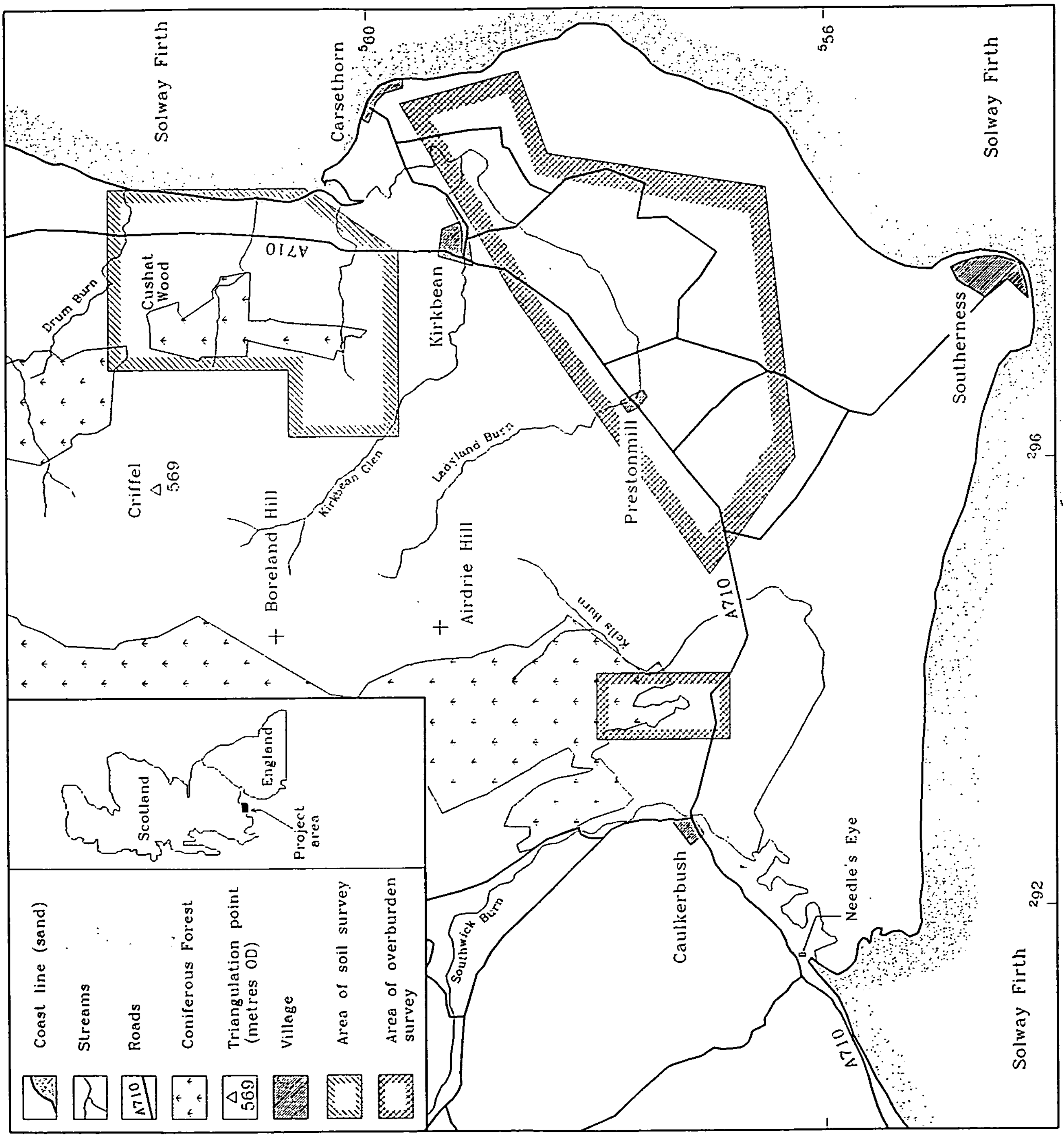

Figure 1 Locational map of the survey area

Solway basin was instigated in 1992. This report describes the results of work carried out over a small area of Lower Carboniferous rocks lying between the north Solway coast and the Criffel-Dalbeattie granodiorite. Selection of the precise target area was guided by the interpretation of structural data compiled from a variety of sources including enhanced Landsat imagery, commercial seismic reflection data, recent BGS geological mapping and ground geophysics. With the aid of this information good resolution of the fault pattern was obtained in the north Solway area where Lower Carboniferous carbonate rocks occur at relatively shallow depth adjacent to the basin margin and in proximity to a major Caledonian intrusive body, a geological setting which invites comparison with some of the major mineral deposits in Ireland.

Physiography

The project area is a relatively narrow coastal strip, 2 to 3 km wide, lying between the north shore of the Solway Firth and the Criffel-Dalbeattie granodiorite (Figure 1). The geology, to a large extent, controls the topography, with low relief (<100 m) characterising the Carboniferous in the south-east, moderate relief over the Silurian (100-200 m) and the highest relief (up to 569 m) over the Criffel intrusion in the north. Drainage direction is principally to the east and south away from Criffel summit, although streams are relatively scarce and, on the low coastal ground, have insufficient energy to cut through the glacial and marine deposits.

Land use over the coastal belt is mainly arable/pastoral farming with cattle and sheep grazing on the marginal hill land and one or two coniferous plantations on the steep east and south facing hill slopes. Apart from a holiday camp at Southerness, which supports a large seasonal influx of tourists, the local population is sparse and concentrated in several small villages including Kirkbean, Prestonmill and Caulkerbush (Figure 1). The principal population centres are the market towns of Castle Douglas, Dalbeattie and Dumfries, all situated about 20 km away.

Planning and development framework

The area of interest occupies a total area of about 35 km^2 centred on the small village of Kirkbean. Good access is provided by means of the main A 710 (Dumfries-Kirkcudbright) coastal road which bisects the area and links, via numerous minor roads and tracks, the low-lying agricultural land along the Solway shore, with the A 75 (Dumfries-Stranraer) trunk road to the north-west, and with the railway at Dumfries.

Part of the area (~ 20%) lies within the Solway Coast and Nith national scenic area. However, the area has a long history of metalliferous mining in the Newton Stewart district to the west, where considerable quantities of Pb and Cu were extracted from vein deposits last century. A large active quarry near Dalbeattie currently produces roadstone and aggregate.

GEOLOGY

The youngest rocks of the area, represented by a sequence of Lower Carboniferous (Dinantian) conglomerates, sandstones and limestones are exposed in several outliers along the northern margin of the Solway Firth. They form part of an almost continuous south-west – north-east trending outcrop at the northern margin of the Solway-Northumberland basin which developed on a folded and weakly metamorphosed basement of Lower Palaeozoic and early Devonian sedimentary rocks. A major granodioritic mass, the Criffel-Dalbeattie complex, intrudes the Lower Palaeozoic greywackes causing extensive granitic veining and recrystallisation within a 1 km-wide hornfels aureole. In the south-west of the area a major east-north-east trending basin margin fault (the North Solway Fault), probably a reactivated Caledonian structure, downthrows the Carboniferous to the south against altered Silurian sedimentary rocks along a strike length of at least 8 km. The fault is responsible for a long straight coastal feature at the base of the cliffs between Portling Bay and Caulkerbush. The geological linework shown in Figure 2 is based on recently completed revision geological mapping by BGS at 1:10 000 scale (OS sheets NX 95 NW, NX 95 NE and NX 96 SE); the stratigraphical succession summarised in Table 1 is a new interpretation based on the same work.

Lower Palaeozoic

Hawick Group

The oldest rocks are represented by Silurian turbidite deposits of Wenlock age (Hawick Group). They are characterised by uniform sequences of medium- to thin-bedded, fine- to medium-grained, greenish-grey calcareous wacke with discrete units of interbedded silty mudstone. Based on facies variations within the overall turbidite depositional regime, the Hawick Group has been subdivided into four formations: the Cairnharrow, Kirkmaiden, Carghidown and Ross, only the last two of which occur in the project area (Table 1). The nature of the junction between the Carghidown Formation and the Ross Formation and the relative ages of the two sequences have been the subjects of debate. However, from the recent detailed biostratigraphical work (White et al., 1992), there is little doubt that the Ross Formation is the younger.

Compositionally, the wackes from each of the formations are very similar. They are mostly fine- to medium-grained, calcareous, poorly-sorted deposits consisting of angular to sub-rounded grains, with up to 40% silt matrix. The grains are predominantly of quartz, with secondary but important amounts of carbonate, feldspar, lithic fragments and mica. Carbonate usually occurs in the matrix as recrystallised grains and the bulk is probably of detrital origin, judging from the fragments which are occasionally still recognisable as bioclastic.

The Hawick Group represents the depositional processes operative in a mid-fan environment and the formations vary only in the relative thickness, frequency and proportion of the various lithologies.

The Criffel-Dalbeattie Pluton

The post-orogenic Criffel-Dalbeattie Pluton is a composite, approximately concentrically zoned granitic body which intrudes Hawick Group (Silurian) rocks of the Carghidown and Ross formations in the northern and western part of the project area. The outer granodioritic phases are succeeded in the centre by a biotite-granite which is locally porphyritic and includes small enclaves of hornblende-biotite-granodiorite. The geometry of the pluton with steeply-dipping contacts has been modelled from Bouguer gravity data by Bott and Masson Smith (1960). The pluton has a typical calc-alkaline chemistry with two geochemically distinct components, which correspond in part with the main petrographical variations (Stephens et al., 1985).

The pluton has been dated isotopically at 397±2 Ma (Rb-Sr whole-rock, Halliday et al., 1980), 406±15 Ma (U-Pb in zircon, Pidgeon and Aftalion, 1978) and 397±8 Ma and 391±8 Ma (K-Ar mineral ages, Brown et al., 1968). The coherent dates indicate emplacement late within the Caledonian orogenic cycle, in the Emsian (Devonian). It was emplaced at quite a high level in the crust, and boulders of granodiorite are found in feldspathic sandstones of Lower Carboniferous age. Thermal metamorphism

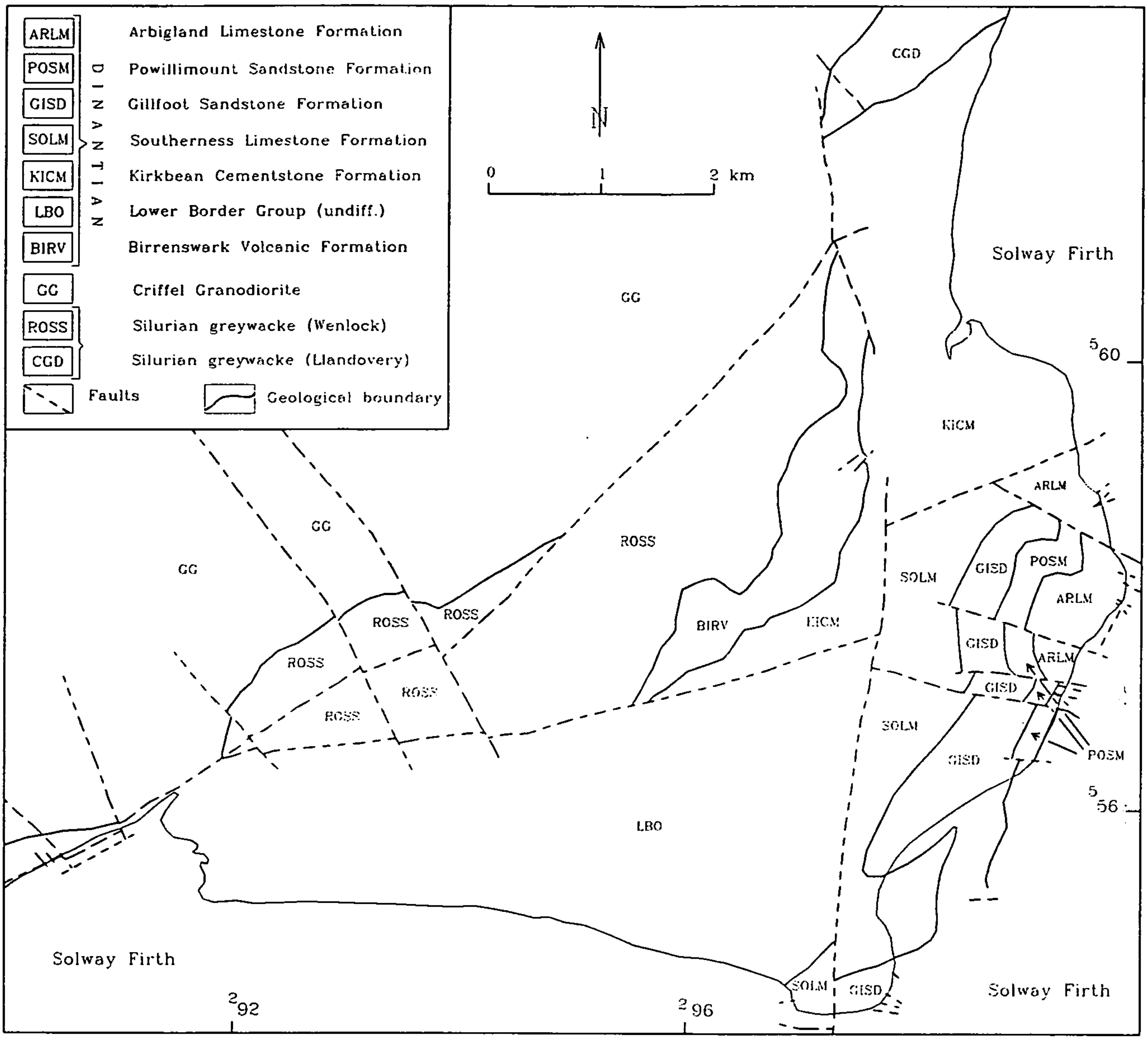

Figure 2 Detailed geological map of the survey area

associated with the intrusion resulted in the development of a 2-3 km wide zone of biotite-hornfels and hornblende-diopside-hornfels (Leeder, 1971).

Upper Old Red Sandstone

A thin sequence of sedimentary rocks assigned to the Upper Old Red Sandstone (Horne et al., 1896; Craig, 1956) is exposed in Kirkbean Glen [29715 55920][*] and Ladyland Burn [29645 55795], north of Prestonmill. The strata rest with marked angular unconformity on steeply inclined turbidites of the Ross Formation and underlie basaltic lavas of the Birrenswark Volcanic Formation (Table 1). The typical lithologies comprise purple-grey, green and red mudstone, red-brown, micaceous siltstone and brownish grey, fine-grained sandstone. The base of the sequence locally comprises a siltstone breccia and conglomerate dominated by greywacke and granite clasts. In Ladyland Burn, the principal lithology comprises soft, red, micaceous mudstone interbedded with sandstone. Both at Kirkbean Glen and Ladyland Burn, numerous carbonate (cornstone) nodules in beds of red mudstone may be the equivalent of palaeosols recognised elsewhere within the Upper Old Red Sandstone sequence of the Scottish Borders (Leeder, 1973; 1976).

The Kirkbean Glen and Ladyland Burn rocks represent the westernmost outcrop in southern Scotland of the Scottish Borders Upper Old Red Sandstone which is regarded as a wholly fluviatile sequence by Leeder (1973). Palaeocurrent data are consistent with a dominantly south-westerly derivation and compositional characteristics indicate an igneous and sedimentary source-land in Galloway.

Lower Carboniferous

Border Group

The lithostratigraphic formations of the north Solway coast have been placed within a single unit, the Border Group (Table 1) as used by Hughes (1995) for BGS Sheet 6 (Kirkbean) (BGS, 1996), Smith and McMillan (1996) and McMillan in Lintern and Floyd (in press). The tripartite (Lower, Middle and Upper) division of the Border Group defined by Lumsden et al. (1967) and Day (1970) for the Langholm and Bewcastle areas, although reflecting lithological differences, was primarily distinguished on biostratigraphical grounds with unit tops and bases defined by marker horizons. Modern lithostratigraphic practice could, however, consider these tripartite divisions as component formations within the Border Group. The following account describes, where appropriate, biostratigraphical equivalence between the two areas.

Birrenswark Volcanic Formation

At the base of the Lower Carboniferous succession, resting conformably above the Old Red Sandstone strata is a thin sequence of olivine-basalt lava flows, regarded as the westernmost extension of the Birrenswark Lavas of Dumfriesshire (Pallister, 1952) and Langholm (Lumsden et al., 1967). Extrusion of the Birrenswark Lavas and the broadly contemporaneous Kelso Lavas (Francis, 1991) accompanied rift-basin formation and tensional fracturing along the main basin faults (Leeder, 1974), and represent the first magmatic episode in the Scottish Carboniferous volcanic cycle. Their petrography and mineralogy are described in detail by Pallister (1952) and Elliott (1960).

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[*] National Grid Reference

The principal exposure is in Kirkbean Glen where some 15 m of crudely stratified, deeply weathered, dark grey to black, fine-grained, amygdaloidal basalt flows are present. Amygdales, rimmed with chlorite and filled with calcite, up to 1 cm diameter are commonly seen.

Kirkbean Cementstone Formation

Termed the Basal Cementstones by Craig (1956), this formation is thought to represent the oldest Carboniferous strata (Chadian-Courceyan) preserved in the Solway outliers and to be the equivalent of the cementstone facies within the Lower Border Group of the Langholm area (Lumsden et al., 1967). The formation is of the order of 100 m thick and based on limited field evidence the rocks are regarded as resting unconformably on the Birrenswark Volcanic Formation. Locally the sequence oversteps the lavas to lie directly on Wenlock strata and at the north-easternmost extent of outcrop it is downfaulted against granodiorite of the Criffel-Dalbeattie intrusion.

Lithologically the Kirkbean Cementstone Formation resembles the Lower Border Group of Langholm as described by Lumsden et al. (1967), lying either above the Whita Sandstone or directly on the Birrenswark Lavas. At Langholm the top of the Lower Border Group is taken at the base of the Harden Beds, the nearest mappable horizon to the base of the Whitberry Band of the Bewcastle area (Day, 1970). An equivalent horizon containing *Syringothyris cuspidata* (Craig, 1956) is present within the coastal outcrop of the Southerness Limestone Formation of the Kirkbean Outlier (see below).

In Prestonmill Burn [29664 55761] calcareous mudstones rest on an uneven surface of lava. Downstream, dark-grey micaceous mudstones have yielded a sparse fauna including *Modiolus latus* and ostracods. At Kirkbean Glen about 20 m of carbonaceous siltstones and mudstones with thin cementstone stringers are faulted against lavas. North of Kirkbean Glen, strata containing *Modiolus latus* and ostracods are found in sections in the Nimbly Burn [29800 56036], near Brickhouse (Brand, 1996). Exposures near Drum Mains in Cushat Wood [29740 56130] also yielded fossiliferous horizons of Lower Border Group aspect within sequences of thin bedded, cream, hard, cementstones and interbedded mudstones.

The facies of the Kirkbean Cementstone Formation is indicative of deposition of small volumes of fine-grained sediment in shallow, slow-moving water in a predominantly estuarine environment. The impure muddy limestones or cementstones probably formed as a result frequent submergence of mudflats in semi-stagnant saline water.

Southerness Limestone Formation

The type section (Craig, 1956) of the Southerness Limestone Formation occupies a 0.5 km stretch of coast between [2968 5543] and [2973 5541], about 400 m west of the lighthouse at Southerness. The strata are deformed by a gently north-east-plunging anticline at [29703 55416], the eastern limb of which exposes some 135 m of fossiliferous, thin bedded calcareous mudstones, siltstones and limestones. At least four prominent thick beds of sandstone are present. Dips vary from 5-45°. At Southerness [29733 55414], a north-south oriented fault downthrows the succeeding Gillfoot Sandstone Formation against the Southerness Limestone Formation. The contact with the Kirkbean Cementstone Formation is not seen.

Although a number of east-west oriented faults disrupt the shore strata of the Southerness Limestone Formation west of Southerness, a reasonably complete section across the eastern limb of the anticline has been measured and described by Deegan (1970). Limestones range from light grey, massive, crystalline types to dark grey argillaceous and sandy varieties. They contain an abundant, varied marine fauna mainly comprising molluscs and brachiopods. Within this sequence, the Syringothyris Limestone was estimated by Craig (1956) to be 16.7 m thick. The limestone comprises several beds of argillaceous limestone and calcareous mudstone and contains a varied marine fauna of brachiopods including *Syringothyris cuspidata*. The faunal similarities with the Harden Beds of Langholm was noted by Lumsden et al. (1967) and indicates that the Southerness Limestone Formation probably spans the boundary between the Lower and Middle Border Groups of Langholm and ranges in age from Chadian to Arundian (Brand, 1996).

Gillfoot Sandstone Formation

Between 120 and 150 m of strata assigned to the Gillfoot Sandstone Formation are exposed on the shore between the fault at [29733 55414], 400 m west of the lighthouse at Southerness and a position south of Powillimount Farm [29880 55620]. To the east of Southerness [29800 55480], the strata conformably overlie the Southerness Limestone Formation, whereas to the west of the lighthouse they are downthrown against these rocks. The Gillfoot Sandstone Formation is dominated by white and purplish, flaggy, quartzose sandstones, conglomerates with intraformational fragments, red flaggy siltstones and mudstones. Conglomerates which form about 20% of the succession have a calcareous matrix and contain intraformational fragments in addition to pebbles of vein quartz, greywacke and 'porphyrite' (porphyritic microdiorite). The formation is sparsely fossiliferous, but evidence from a derived fauna collected by Craig (1956) from the top of the sandstone on which the lighthouse stands suggests that the strata are of Arundian age and equivalent to part of the Middle Border Group of Langholm (Lumsden et al., 1967).

Powillimount Sandstone Formation

About 160 m of strata exposed on the shore between Powillimount Bay [29880 55610] and Thirlstane [29925 55690] are assigned to the Powillimount Sandstone Formation (Craig, 1956). The top 25 m comprises the Thirlstane Sandstone Member, a prominent ridge of thick-bedded sandstone with spectacular penecontemporaneous deformation structures (Craig, 1956; Deegan, 1970; Ord et al., 1988). Faunal assemblages are similar to those in the Middle Border Group of Langholm.

Lithologies include calcareous and quartzose sandstones, sandy limestones with beds of dark grey fissile mudstones and calcareous mudstones. Locally, thin coals and associated seatearths are present. Sandstone beds are laterally extensive and range in thickness from 0.3 to 3 m. Limestones range from arenaceous to argillaceous types and contain detrital fossil remains, oolites and rolled algal nodules.

Arbigland Limestone Formation

All the coastal strata exposed between Thirlstane and Hogus Point [29970 55890] are assigned to the Arbigland Limestone Formation (Craig, 1956). The sequence is generally more fossiliferous than the Powillimount Sandstone Formation. In particular the section between Arbigland Bay and Borron Point is richly fossiliferous and contains a fine coral fauna. The lithologies in the section between Thirlstane and Arbigland Garden resemble those of the Powillimount Sandstone Formation and include thick-bedded, bioturbated, calcareous sandstones with coalified plant casts, thin sandy limestones, locally with ooliths and algal debris, dark grey carbonaceous mudstones and thin coal partings. Faunal equivalence with the Upper Border Group of Langholm (Lumsden et al., 1967), of Asbian age, is considered most likely (Brand, 1996).

Colvend Outlier

The outlier is found at the south-eastern corner of the project area and comprises scattered outcrops of arkosic conglomerate and sandstone protruding through the modern tidal flats of Southwick Merse [29200 55600]), (Deegan, 1973). On the basis of faunal content of limestones at Orroland [27770

46300], Craig and Nairn (1956) were able to correlate the sequence with the Kirkbean Outlier. The strata generally dip southwards at angles between 20-70° and are downthrown by the north-east trending North Solway Fault against Silurian hornfels and porphyritic microdiorite ('porphyrite'). Near the trace of the North Solway Fault, sheared and brecciated rocks are seen both in cliff sections and in tidal flat outcrops. Brecciated contacts observed in the cores of three boreholes sited near Needle's Eye indicate a sheared contact between Carboniferous and Silurian strata dipping at 50° south-east (Miller and Taylor 1966). No fossils have been found in these rocks.

Superficial deposits

Glaciation during the Pleistocene produced extensive tracts of boulder clay (till) and outwash sands and gravels, though the latter are mainly restricted to the lowest ground south and south-east of Kirkbean. These deposits together with alluvium in the river and stream valleys, and peat, which is thickest and most extensive over the highest ground on the flanks of Criffel, effectively conceal all but a very small proportion (<0.1%) of the underlying rocks.

Over much of the area the deposits are dominated by grey or grey-brown lodgement tills characterised by unsorted, internally structureless material containing abundant clasts of mainly local provenance. Small amounts of shelly marine material, present in tills up to 1 km from the coast suggests marine incursions.

Tills encountered during the overburden survey have very variable thickness (<2 to >10 m), generally showing an increase from the area south of Prestonmill towards Kirkbean, where stream exposures in Kirkbean Glen suggest that 10-15 m of till are not uncommon. Compositionally the finer-grained matrix material comprises between 30 and 40% sand fraction, with clay-grade material and silt making up the balance in the proportion of about 2:1.

Post-glacial intertidal muds and silts cut by tidal channels cover the bedrock around the coast between Southerness and Caulkerbush and over a narrow tract of land between Carsethorn and Drum Burn (Figure 1).

STRUCTURE

Lower Palaeozoic rocks

The Silurian turbidites typically strike east-north-east, ranging from steeply dipping to vertical in attitude. Biostratigraphical evidence defines a sequence of strike-parallel tracts which decrease in age from north to south across the Southern Uplands. However, within each tract the sequence youngs towards the north. This is consistent with the interpretation of the overall structure as being a south-east-vergent imbricate thrust stack. This requires that the thrust front effectively migrated southwards into progressively younger strata contemporaneously with continuing deposition to the south (Stone et al., 1987). The system was rotated into its present, near-vertical orientation through the progressive accretion of new material and, subsequently, collisional processes as Iapetus finally closed.

Movement on the tract-bounding faults was probably associated with the only phase of ductile deformation to have affected many of the rocks in the district and, although recognised regionally by a penetrative cleavage in fine-grained rocks, even this can be locally quite weak.

North-west and north-trending cross-strike faults, usually with an original dextral and sinistral component of movement respectively, are well-displayed in the project area. Their conjugate orientations and movement directions indicate that they formed as a brittle response to north-north-west-compression and/or east-north-east tension. They were probably initiated during the late Silurian because they were utilised by post deformation dyke swarms and are cut by the c. 400 Ma Criffel-Dalbeattie granodiorite. Locally, some faults affect the hornfels aureoles around the granite which may be a result of reactivation during later tectonic episodes.

Upper Palaeozoic rocks

The principal basin-bounding structure in the district is the North Solway Fault, which forms the northern margin to the Solway Basin and controlled the deposition of Dinantian sediments. It is the western continuation of a system of en-echelon syn-sedimentary normal faults which are orientated parallel to the north-east – south-west axial strike of the Solway Basin. Dinantian syn-extensional dislocations oblique to this trend, orientated between north and north-west, are also recognised. Rapid extension-induced subsidence occurred during Courceyan to Chadian times (Chadwick et al., 1995; Chadwick and Holliday, 1991). Syn-depositional fault deformation of hanging-wall strata increases towards the North Solway Fault. Further away from the basin margin, strata of the Kirkbean Outlier show indications of a more stable environment of marginal to shallow marine deposition, although locally there is convincing evidence of syn-depositional seismic activity (Ord et al., 1988) within the coastal outcrop of the Thirlstane Sandstone Member of the Powillimount Sandstone Formation, of Arundian to Holkerian age.

Basin-wide extensional fault activity waned during the Holkerian and Asbian stages. By Namurian times the dominant structural controls on sedimentation were regional thermal relaxation subsidence and the effects of differential compaction. A major phase of basin shortening and inversion effected by the Variscan Orogeny post-dates Westphalian sedimentation and predates the deposition of Permian strata (Leeder, 1988; Chadwick et al., 1995). Evidence of structural inversion is well displayed in the Kirkbean Outlier where the Dinantian strata are folded in a series of north-north-east - south-south-west trending anticlines and synclines. Post-depositional reverse movement, linked to renewed extension during the Permian and the development of Mesozoic basins, occurred on reactivated syn-extensional dislocations oblique to the axial strike of the Solway Basin. These faults, with a general north-south or north-west–south-east trend, cut the folded Dinantian strata and displace the North Solway Fault and Criffel-Dalbeattie granodiorite.

SOIL GEOCHEMISTRY

Soil sampling was undertaken on across-strike traverses located to intersect north-south trending structures associated with a zone of anomalous Cu, Pb, Zn, Ba values discovered in previous MRP surveys to the north of Kirkbean (Figure 1). Assessment of the available BGS gravity and aeromagnetic data also indicated the presence, in this area of a north-south trending fault at the northern margin of the Solway Basin.

Using a hand auger to sample as deeply as possible (average depth 1.1 m) from the base of shallow pits, seventy eight samples were collected at 50 m intervals along three traverses about 1 km apart. Observational information including details of mineralised clasts recorded in the soil pits is given in Table 2A.

Sample preparation and analysis

Soil samples were dried at <80° C, dissaggregated in a hand pestle and mortar and screened at 180 µm (85 mesh BSS). After splitting and subsampling, a 1 g sample was subjected to partial extraction by mixed nitric/perchloric acid attack and analysed by Inductively Coupled Plasma Atomic Emission Spectrometry (ICPAES). The analytical data for Cu, Pb, Ni, Co, Fe, Mn, and Al are given in Table 2B and plots of Cu, Pb, Zn, Ba shown in Figures 3-6.

Distribution of anomalies

The concentration of base-metals in soils is generally low. Peak values of 2-2.5 times background are probably related to mineralisation since the anomalous elements occur at two adjacent sites on the northernmost traverse and, at one site on the southernmost traverse (Figures 3-5 and Table 2B). Ba shows evidence of much stronger enrichment with a well defined group of anomalous values at the western end of the northernmost traverse (Figure 6), coincident with the highest combined Cu, Pb, and Zn values. Clasts of baryte and quartz-baryte vein material were observed in the soil profile at the most anomalous sites (OHS 6504 and 6510; Table 2A) indicating that the source of the Ba anomalies is clearly due to mineralisation. Downhill clastic dispersion has undoubtedly contributed to the 350 m-wide anomalous zone, but from the presence of the sharp uphill cut-off at sample site OHS 6504 [297172 562050], a discrete bedrock source is likely to be situated beneath relatively thin drift close to this site. Gravity data (see below) strongly suggests the presence of a baryte vein dipping steeply to the east. Slightly elevated Ba values (coincident with one or two low order Pb and Zn anomalies) located on the two traverses to the south (Figure 6) define an almost linear north-north-west trending anomalous zone extending down strike for about 2.5 km. This pattern is consistent with dispersion from a vein or veins oriented approximately parallel to the strike and to the faulted western margin of the Kirkbean Cementstone Formation (Figure 2).

MINERAL OCCURRENCES AND ROCK GEOCHEMISTRY

Source of barium anomalies

A search for the source of the baryte clasts seen in the soil pits revealed several small boulders with massive, dense impregnations of baryte and brown to black elongate zones of banded ?iron-oxide 5-10 cm wide, containing dark crystals of ?hematite. The boulders were scattered at surface between sample sites OHS 6502 and 6504, approximately 1 km due west of Drumburn Farm [297900 562100] and 50-100 m uphill of the centre of the Ba anomaly. In addition, at least 30 larger vein-baryte boulders (up to 50 cm x 40 cm x 30 cm) were discovered in a wall intersecting the traverse close to OHS 6507. Most contained only massive baryte, but one or two showed evidence, at the vein margins, either of cementstone or of crystalline quartz and irregular iron-oxide-rich bands. A sample (OHR 6115 at [297218 562039]) collected from one of the massive baryte boulders contained nearly 50% Ba, but only slightly elevated Cu and negligible Zn and Pb. Because of the dense matrix however, XRF data for the base-metals is probably unreliable and the most likely source of the modest Cu, Pb, Zn soil anomalies is small amounts of sulphide associated with vein material.

An *in-situ* occurrence of vein baryte has been reported from a stream section in Cushat Wood [297300 561900] just 100 m south of the northernmost soil traverse (Leeder, 1971). The vein is described as thick and steeply dipping and emplaced along the faulted contact between the granodiorite and micritic limestones and shales of the Kirkbean Cementstone Formation. However, the mapped position of the main north-south trending fault at the east margin of the Criffel intrusion (Figure 2) is

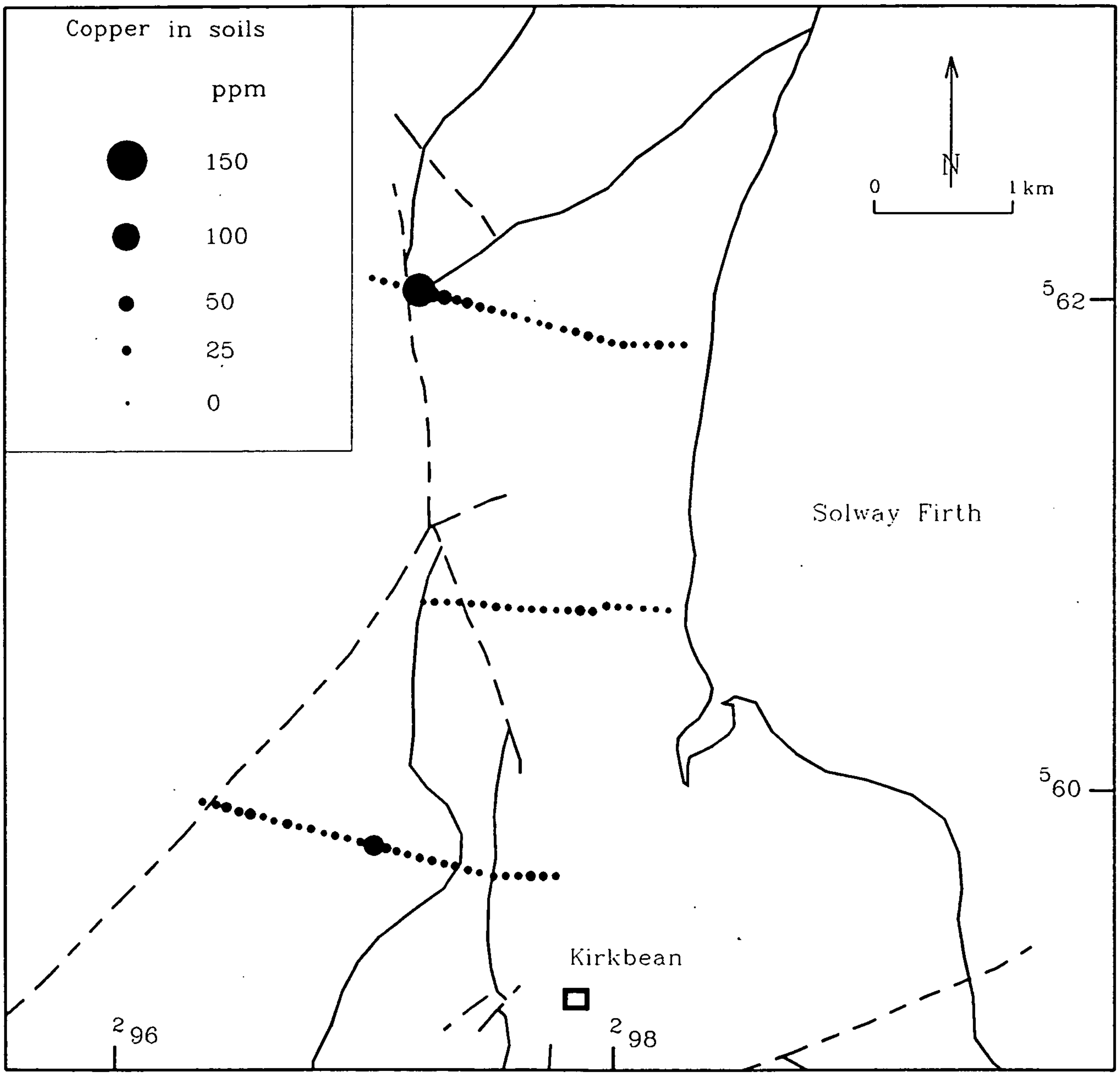

Figure 3 Copper in soils

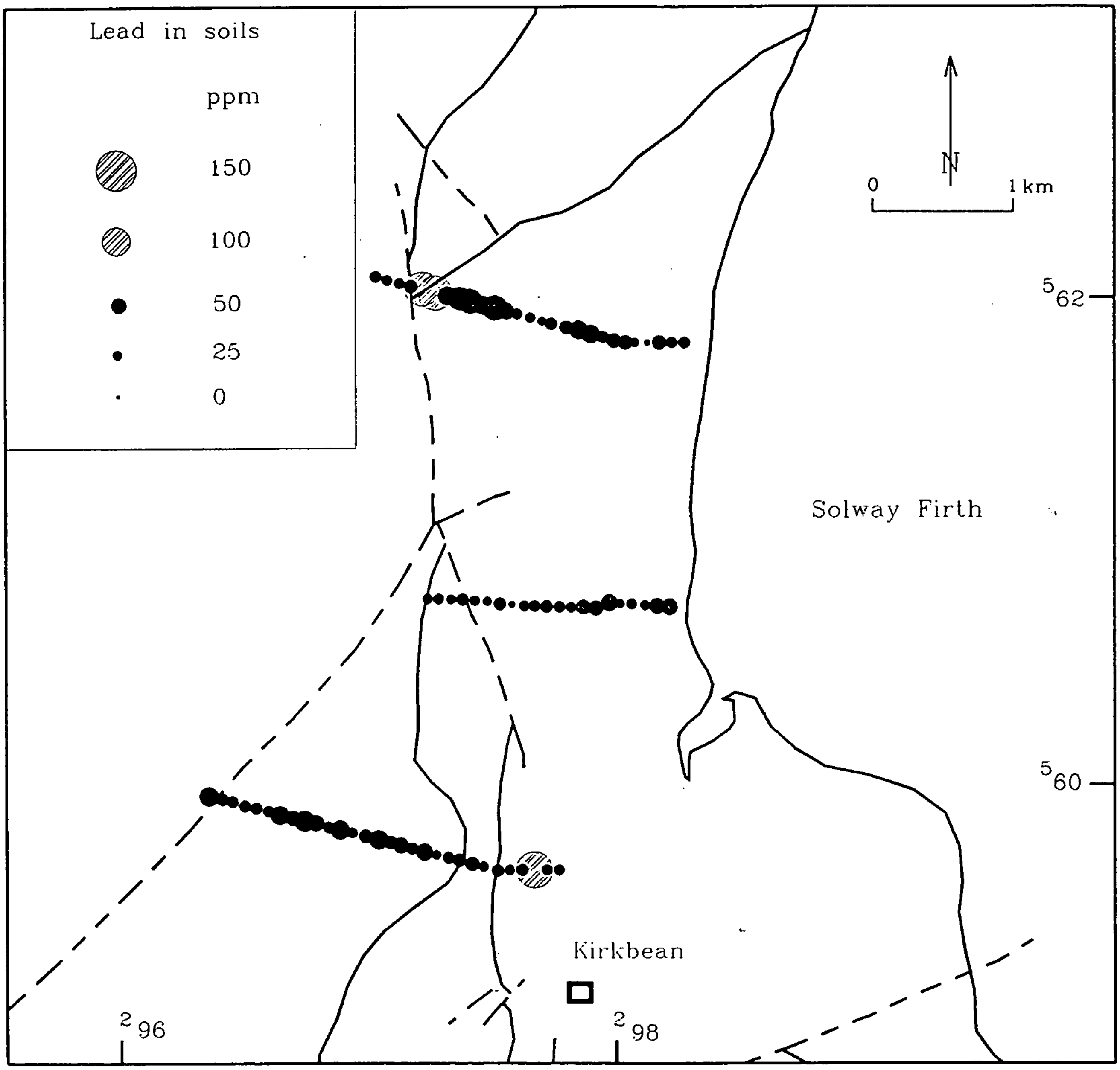

Figure 4 Lead in soils

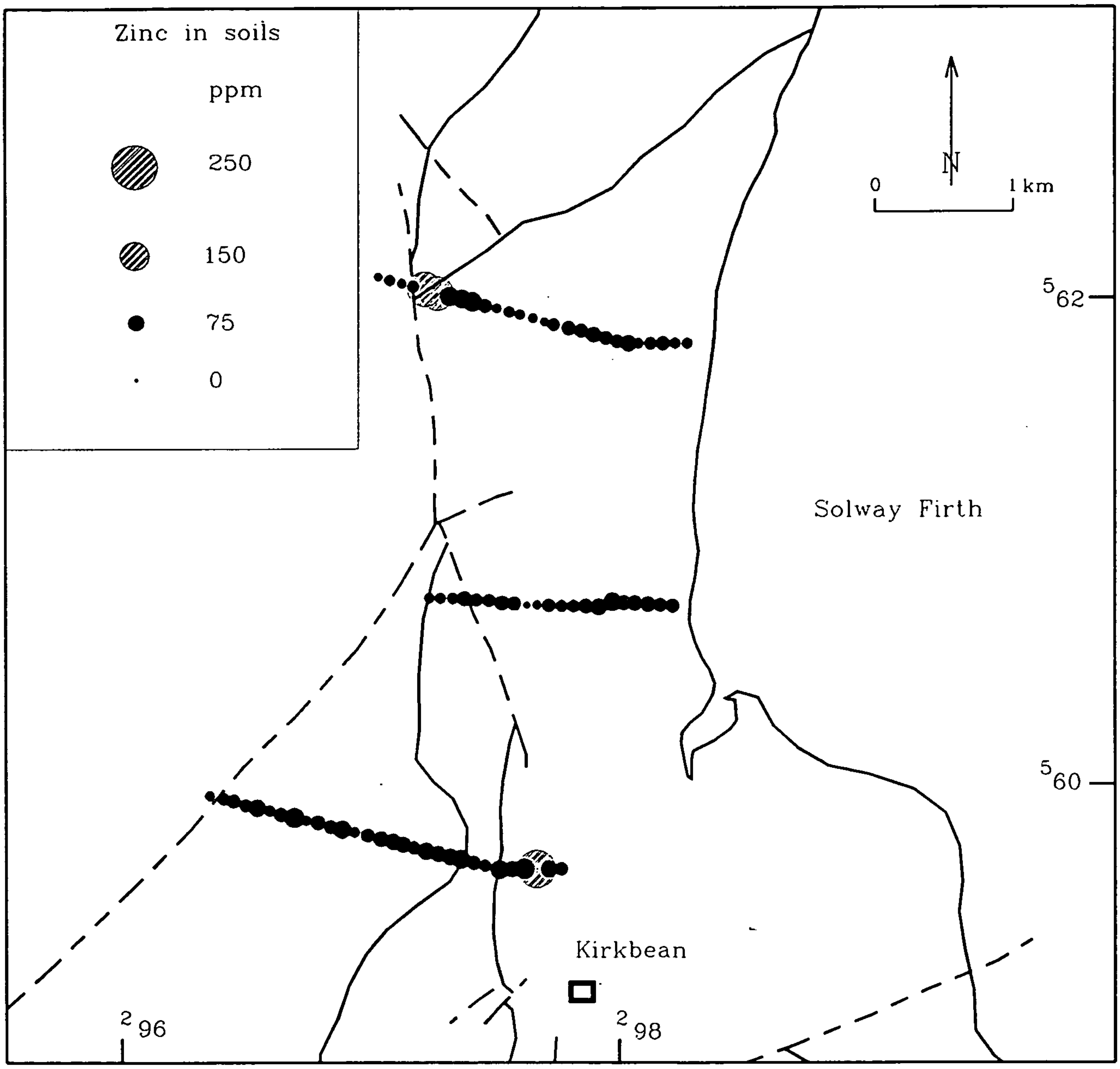

Figure 5 Zinc in soils

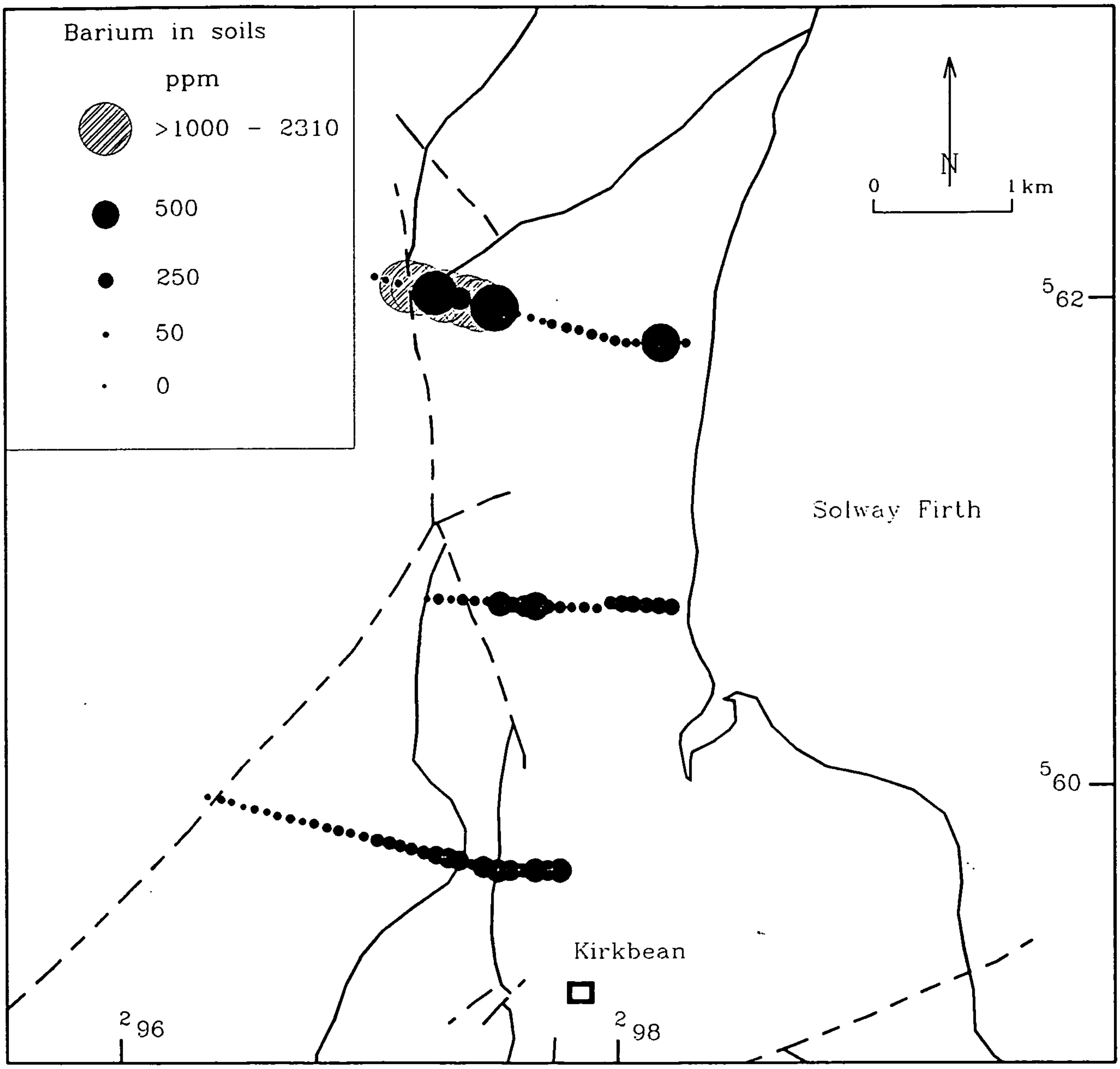

Figure 6 Barium in soils

parallel, but offset about 150 m to the west of the vein. The locality was visited and sampled (OHR 6118) during the course of the investigation. Several large massive float blocks of baryte were seen in the stream section 50-80 m downstream of the source outcrop which comprises a massive baryte-quartz vein with iron-oxide banding similar to that seen on the soil traverse. The vein exposure, in the north bank of the stream, has a strike length of about 5 m, is up to 3 m wide and trends about 340 °. Linear projection of the vein to the north does not explain the observed distribution of quartz-baryte clasts in the soil profiles on traverse 1 (Table 2A), which occurs further uphill close to the surface trace of the main north-south fault. However, north-west trending cross faults and small splay faults have been identified as a result of revision mapping in the vicinity of Cushat Wood and upper Drum Burn (Figure 2), and it is therefore possible that more than one vein exists within a zone of complex faulting close to the granodiorite contact.

Other mineral occurrences

During the soil survey available rock outcrops were examined for evidence of mineralisation and/or alteration and a small number of samples (2-3 kg) collected for chemical analysis (Table 3A).

Base-metals (Kirkbean Glen; Drum Burn)

In Kirkbean Glen, Craig (1956) makes reference to small crystals of galena in greenish-grey carbonaceous siltstones with irregular cementstone stringers. Detailed inspection of the extensive outcrop about 180 m upstream of the A 710 road revealed a 20-30 m-long section of intensely carbonate-veined siltstones with several interbedded buff-coloured micritic limestones up to about 0.5 m thick. Within one such limestone a network of irregular carbonate veins, up to 2 cm wide, contained occasional crystals of fresh galena, but the mineralisation could not be traced laterally and appeared to be confined to the margins of the vein. The analytical data for a representative sample of the limestone (OHR 6106, Table 3B) indicates in addition to Pb, minor enrichment of Zn and Cu, however apart from the galena no other sulphides were seen in this outcrop. About 70 m upstream of the galena locality small amounts of pyrite accompanied by chalcopyrite and secondary copper staining (?malachite) were discovered in a net veined, fine-grained limestone in faulted contact with the Birrenswark lavas (OHR 6105). Minor amounts of chalcopyrite were also discovered in carbonate-veined limestone (OHR 6108) 20 m downstream of the galena locality, but copper contents are low at both localities and of no economic significance (Table 3B). Other samples of carbonate-veined, faulted and hematised lava from Kirkbean Glen (OHR 6101 and 6104) or from Drum Burn (OHR 6110) to the north showed no evidence of metal enrichment. Thermally metamorphosed samples of shattered ?greywacke from Drum Burn (OHR 6111-6113) similarly contained only background base-metal concentrations.

Uranium-copper mineralisation (Brandy Cove)

Epigenetic uranium-copper-bismuth mineralisation in north-west trending fissure veins cutting the hornfelsed aureole of the Criffel granodiorite is well exposed in cliff sections at Brandy Cove [288560 554160], 1-2 km south-west of the project area, and Needle's Eye [291530 556220]. The mineralisation forms the eastern limit of an 11 km-long zone of similar mineralised structures along the north shore of the Solway Firth between Balcary Point [282900 549300] and Caulkerbush (Miller and Taylor, 1966; Basham et al., 1989). All the vein occurrences show distinct structural similarities in occupying zones of tectonic disturbance caused by shearing and extensive brecciation of the Silurian rocks in a 20-30 m wide zone parallel to, but offset to the north of the North Solway Fault. A detailed economic assessment of the uranium content of the most promising veins at Needle's Eye was undertaken utilising radiometric and radon-concentration surveys, trenching and diamond drilling (Miller and Taylor, 1966). Although total uranium concentrations of about 1% were reported, it was concluded that the width of this and neighbouring structures, was not sufficient to support mining operations.

Recent sedimentological and mineralogical studies by Parnell (1988, 1995) indicate that the uranium was deposited as a result of the interaction between migrating hydrocarbons from the Solway Basin with uranium-enriched groundwater derived from fractures within the Criffel intrusion. A similar process has been suggested to account for the presence of thoriferous bitumen nodules discovered in Lower Carboniferous sandstones a few kilometres to the south-west of the project area (Veale and Parnell, 1996).

Samples OHR 6114 and 6119 (Tables 3A and 3B) were collected from two of the most prominent vein exposures (varying from 5 to 25 cm wide) at the margin of a small porphyry intrusion at Brandy Cove. Secondary copper and intense iron-oxide staining is strongly developed in the country rock for several tens of centimetres adjacent to the veins. In one of the veins, small amounts of baryte and hematitic chert are present in a dolomitic gangue together with black amorphous material thought to be hydrocarbon. The analytical data (Table 3B) confirmed the presence of Cu-mineralisation, but failed to detect high levels of uranium despite the presence of high radioactivity.

OVERBURDEN GEOCHEMISTRY

Sampling and analysis

Because of the poor geochemical contrast displayed by soils, especially over the heavily drift-covered lower ground underlain by Lower Carboniferous rocks, a reconnaissance-scale deep overburden sampling programme was undertaken. Evaluation of geophysical data together with recent geological mapping indicated an intersection, just to the south of Kirkbean, of a major east-north-east trending fault, possibly synthetic to the North Solway Fault, with a north-south trending structure (Figure 2). This was considered to represent a favourable lithological and structural target for base-metal mineralisation and eighty power auger holes were drilled on ten traverses at approximately 500 m line spacings and 100-200 m hole separation between Kirkbean and Caulkerbush (Figure 1). The objective of the five holes drilled on the westernmost traverse to the east of Caulkerbush, which also coincides with a fault intersection, was to investigate possible along-strike extensions of the epigenetic uranium-copper-bismuth mineralisation exposed in the cliffs near Needle's Eye [291520 556220].

At each site about 8 litres of till, collected from the basal 1-2 m of the hole, was wet screened to remove clay and fine silt, and the remaining -2 mm fraction (normally 0.5-1.5 litres) reduced by panning to yield a concentrate of 30-40 ml. Additionally, a sample of till from the maximum attainable depth was collected and after drying and dissaggregation, sieved at 180 μm to produce a fine-fraction for chemical analysis. The lithology and morphology of clasts recovered during the wet screening operation was recorded to provide an indication of provenance, and transport distance. The panned till samples were analysed by XRF for Cu, Pb, Zn, Ba, Ni, Fe and Mn (Table 4) and the sieved till samples analysed by ICPAES for the same range of elements (Table 5).

The average penetration depth of the power auger was 4.3 m (range from <1 to 11.2 m), but exposures of till seen in the lower part of Kirkbean Glen and of sand and gravel on the low-lying ground south-east of Kirkbean exceed 12 m. Bedrock was encountered, and basal till sampled, in approximately 30% of holes, the remainder terminating either in ablation material or sorted deposits of sand and gravel. Compositionally the lower parts of the till profiles are represented by a very compact, grey or grey-brown, silty clay containing numerous large boulders and pebbles of mainly local origin.

Most of the till concentrates are characterised by dark silt or fine sand compositions containing an estimated 2-20 vol. % total heavy mineral component in which magnetite, hematite, rutile and pyrite are the principal phases in decreasing order of abundance. Concentrate samples collected over the Birrenswark Volcanic Formation are characteristically dark brown in appearance and contain a significantly higher proportion of iron ores and ferromagnesian minerals relative to other Carboniferous or Silurian lithologies.

Geochemical data for till samples

The geochemical data for panned and sieved tills are presented in Tables 4 and 5 respectively. The spatial distribution for Cu, Pb, Zn and Ba in the panned till samples is shown in Figures 7-10 and for sieved till in Figures 11-14. For conciseness in the text, results for the two sample types are differentiated by the subscripts u and t respectively after the symbol of the element concerned, for example Zn in panned till is abbreviated to Zn_u. Comparison of the interquartile concentrations for the base-metals and barium in the two sample media (Table 6) indicates generally improved geochemical contrast in the panned fraction and thus, easier recognition of anomalous samples.

Copper

The data for the two till fractions show a small increase in average Cu levels over the Birrenswark Volcanic Formation probably reflecting underlying bedrock composition. Elsewhere there is little evidence of either covariation or a systematic relationship with lithology or structure (Figures 7 and 11). The highest Cu_u values of the data set (470 ppm at [298160 557380] and 94 ppm at [298165 557660]) (Table 6) occur over rocks of the Southerness Limestone Formation, both samples corresponding with the observation of abundant pyrite in the panned concentrate (Table 4). Small amounts of chalcopyrite and galena in the first sample and of more abundant sphalerite in the second are supported by the chemical data (Table 4), although the magnitude of the anomalies and the absence of a coherent pattern does not indicate a mineralised source of any economic significance close to surface. Samples collected over the Silurian hornfels near Caulkerbush contained only low levels of Cu and it is deduced therefore that the epigenetic Cu-U-Bi mineralisation at Needle's Eye is unlikely to extend very far along strike. Evidence from the residual gravity anomaly (Figure 24) indicates that the mineralisation may terminate against, or be displaced by, cross faults oblique to the main North Solway Fault.

Lead

Values of Pb_u and Pb_t are mostly low and in the range 20-50 ppm (Figures 8 and 12). There are no coherent patterns although Pb_t shows a small increase around the southern margin of the Birrenswark Volcanic Formation. The highest value in both sample types occurs over the lavas at sample site OH 7008 (563 ppm Pb_u and 264 ppm Pb_t) (Table 6) about 300 m south west of Prestonmill. Although sulphides were not recognised in the panned concentrate at this site, their presence is inferred from anomalous levels of Zn in the same sample (430 ppm Zn_u and 382 ppm Zn_t). Similar anomalous associations have been reported from tills overlying the Birrenswark Lavas in the Westwater district, along strike to the north-east (Gallagher et al., 1977). Shallow drilling over these anomalies revealed small amounts of sulphide in dolomitic veins and breccias, although much of the Pb and Zn in faulted lavas was found to be associated with the iron-oxide component. One or two low-order Pb_u values, associated in one instance with high Cu (see section above), are recorded over the Southerness

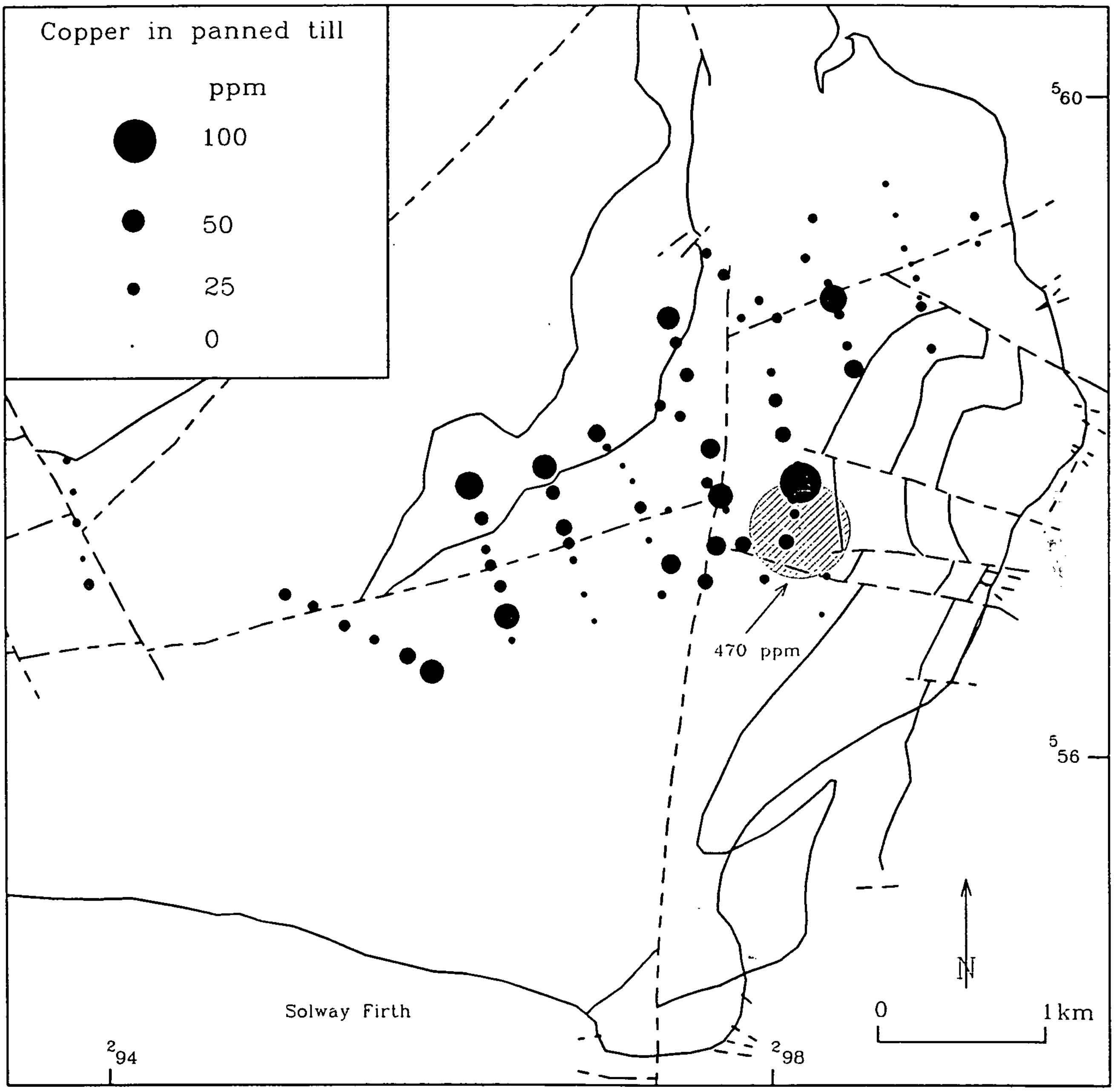

Figure 7 Copper in panned tills

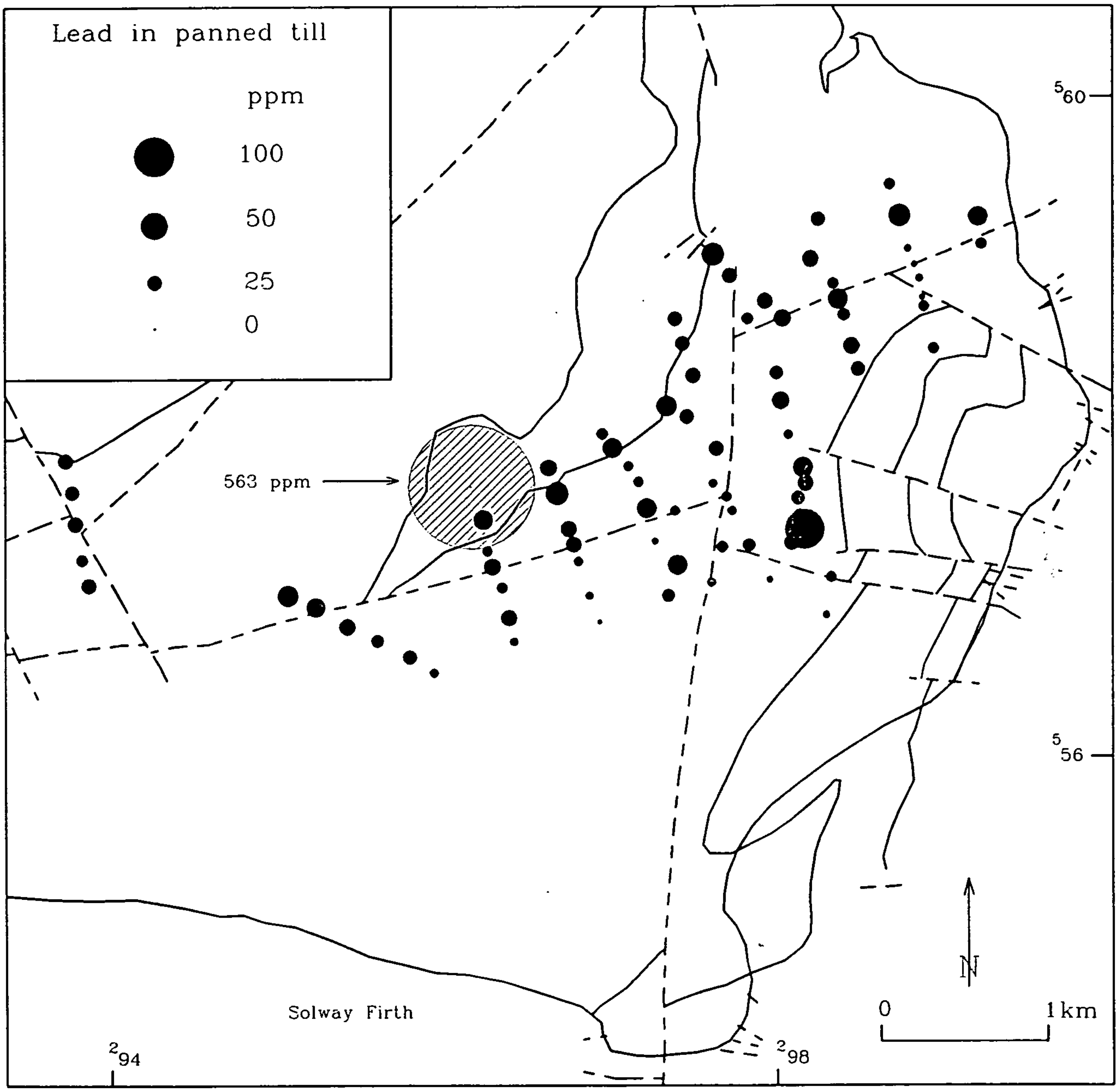

Figure 8 Lead in panned tills

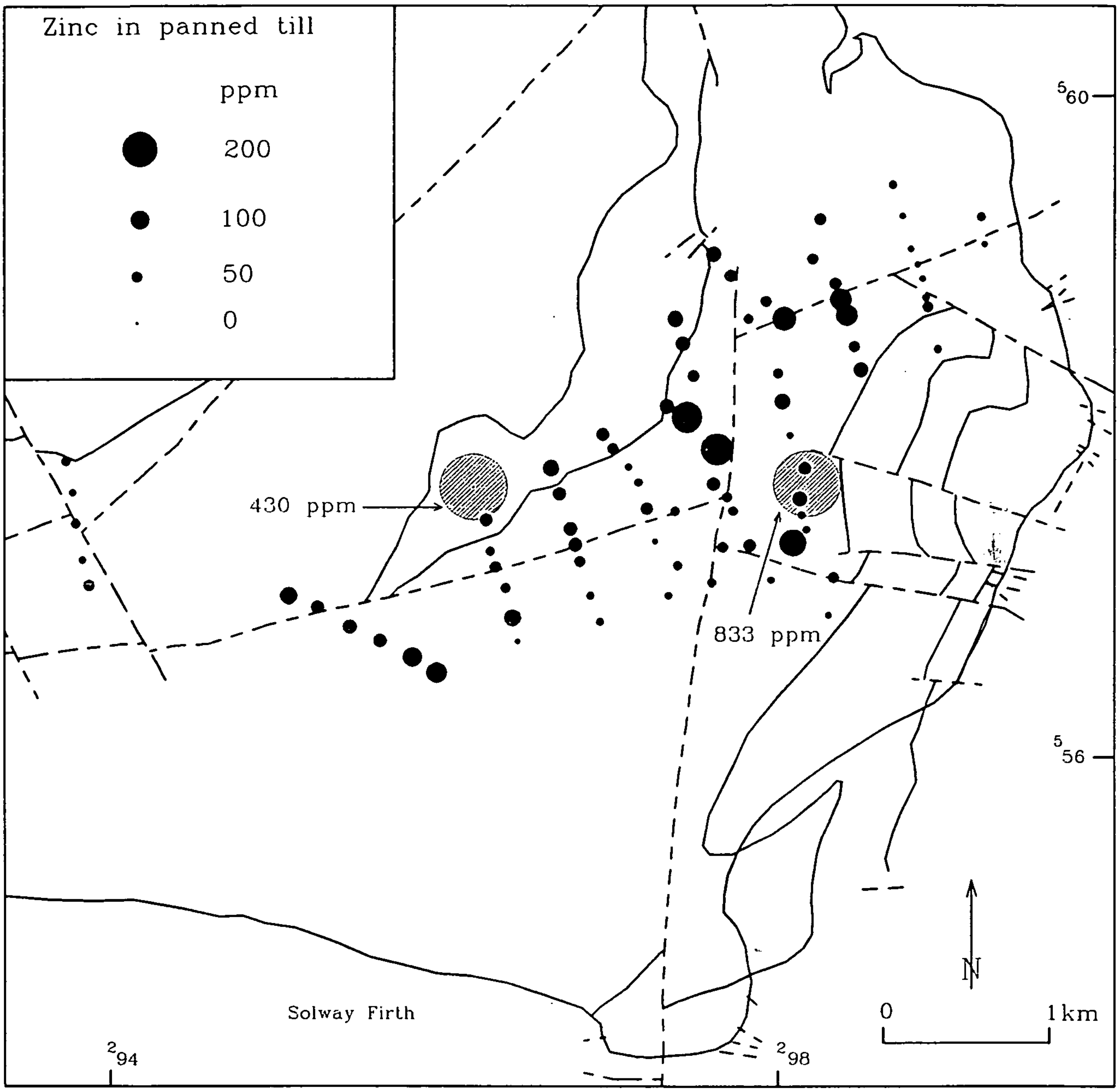

Figure 9 Zinc in panned tills

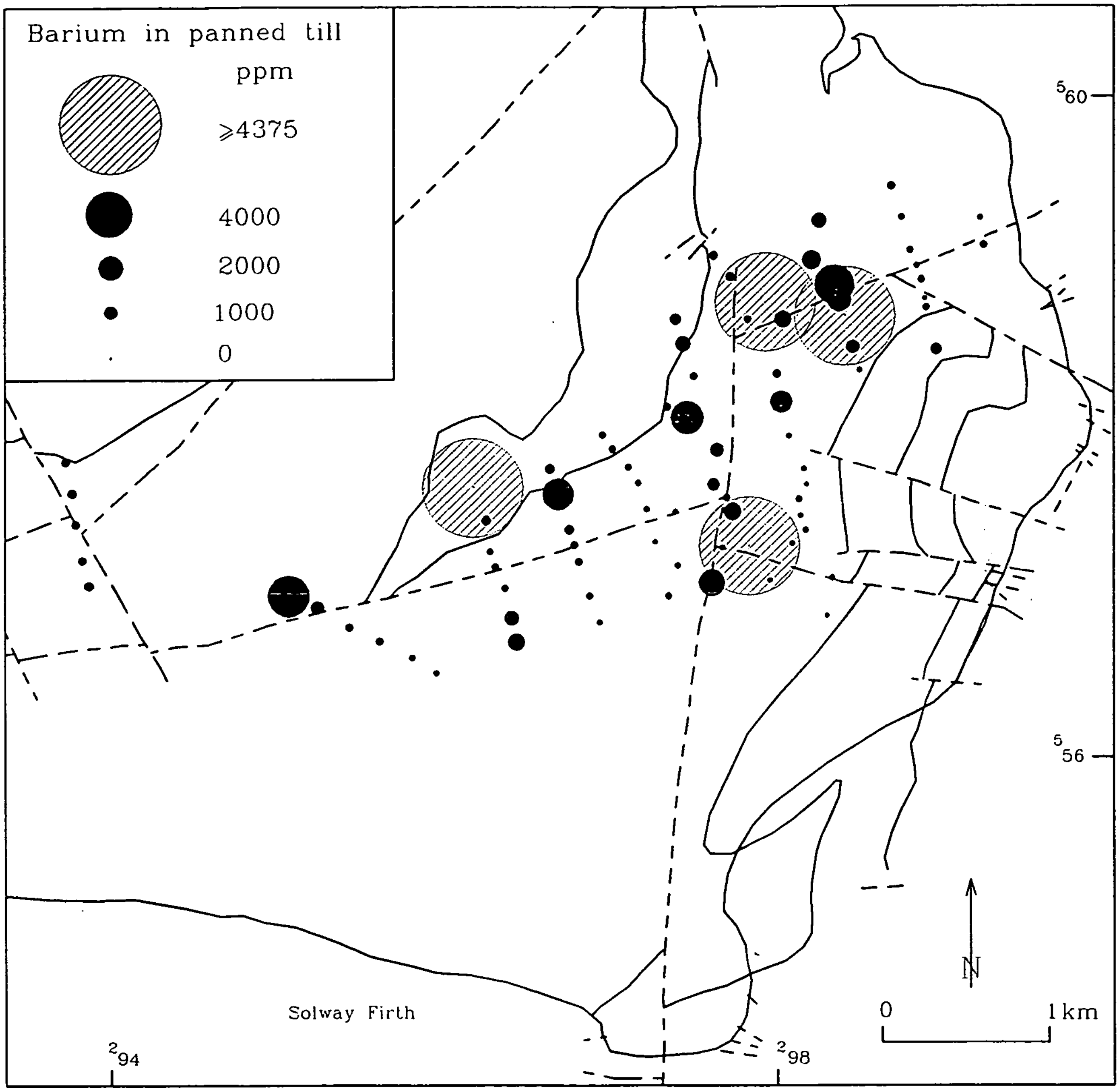

Figure 10 Barium in panned tills

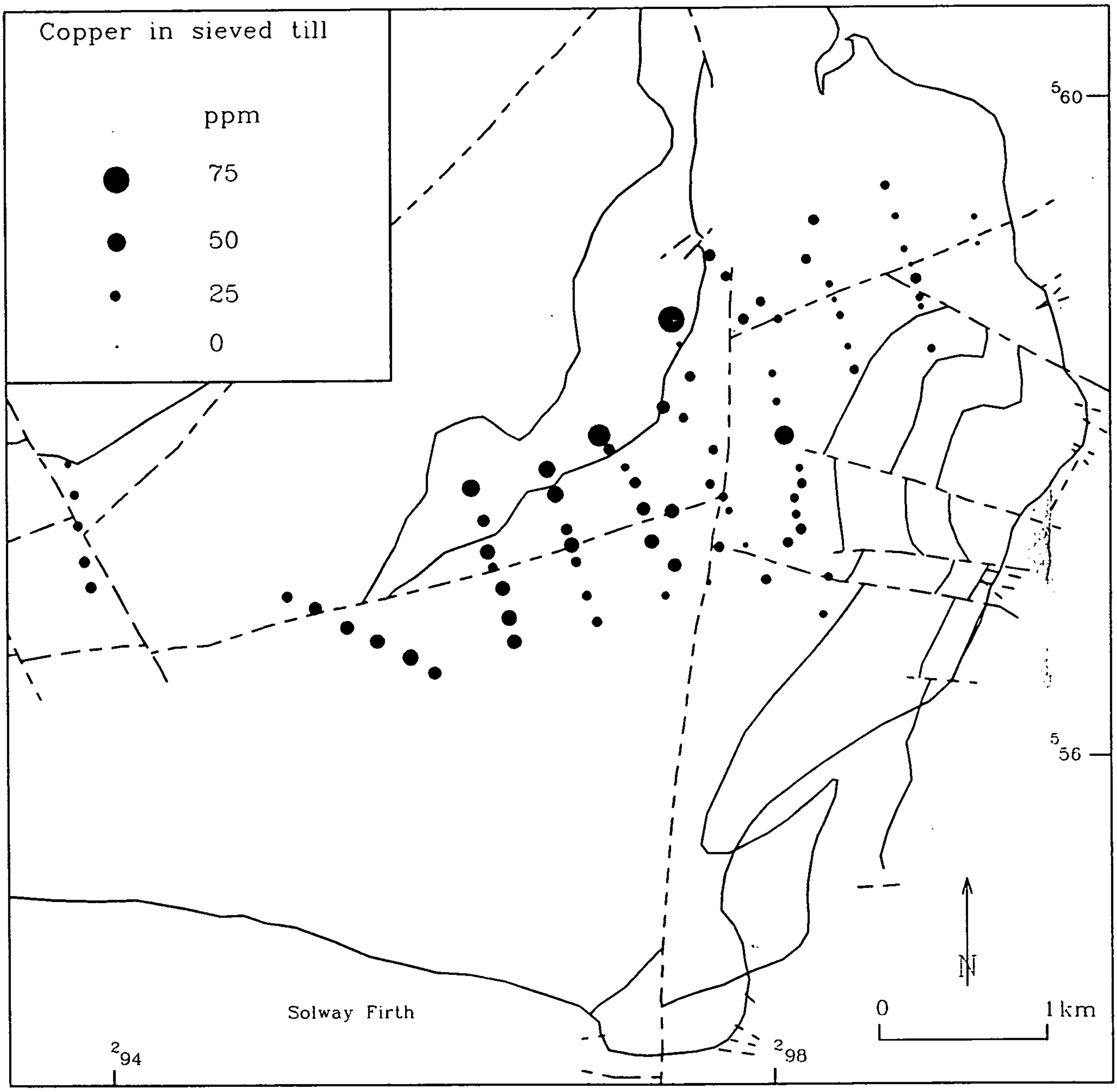

Figure 11 Copper in sieved tills

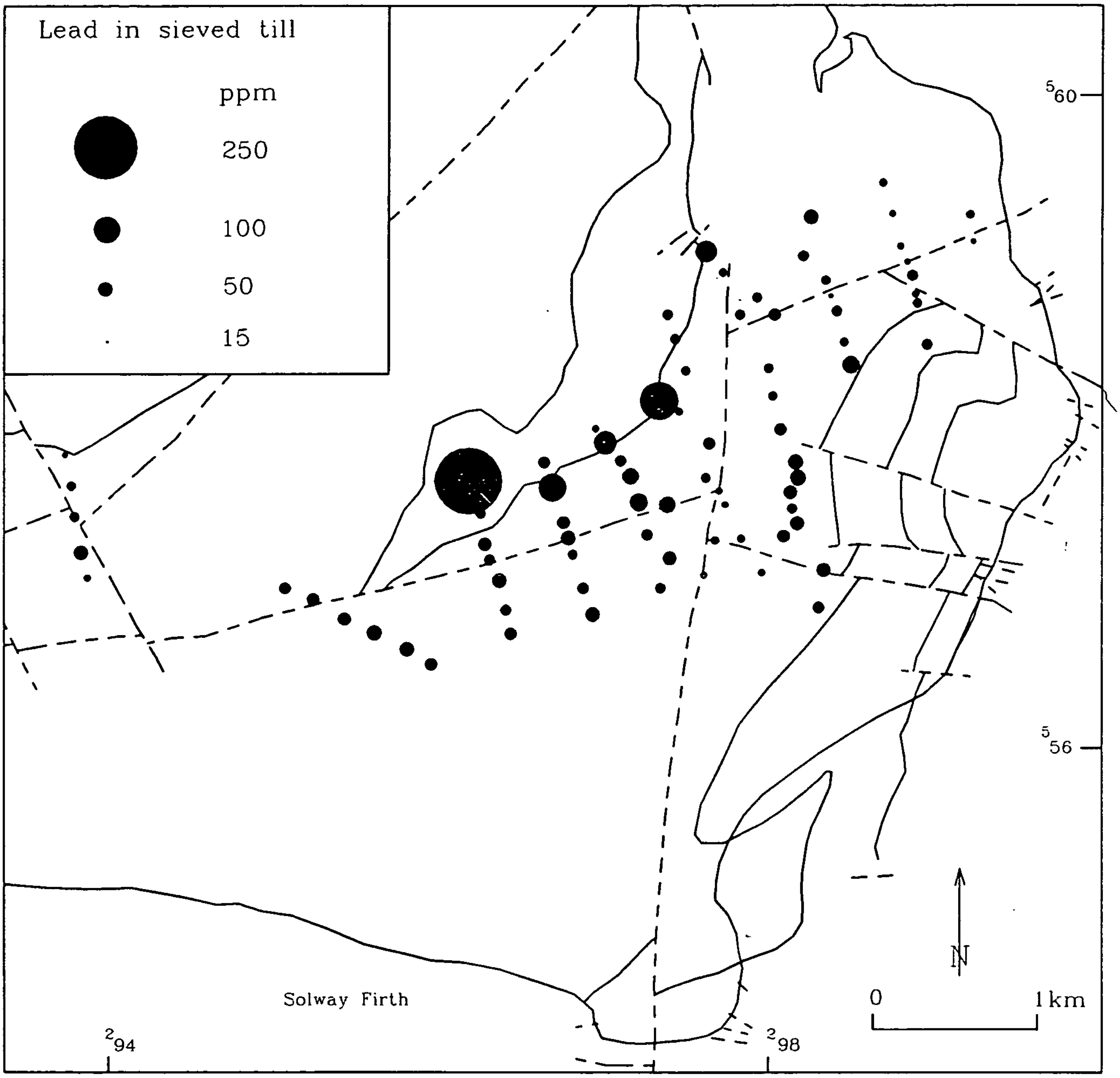

Figure 12 Lead in sieved tills

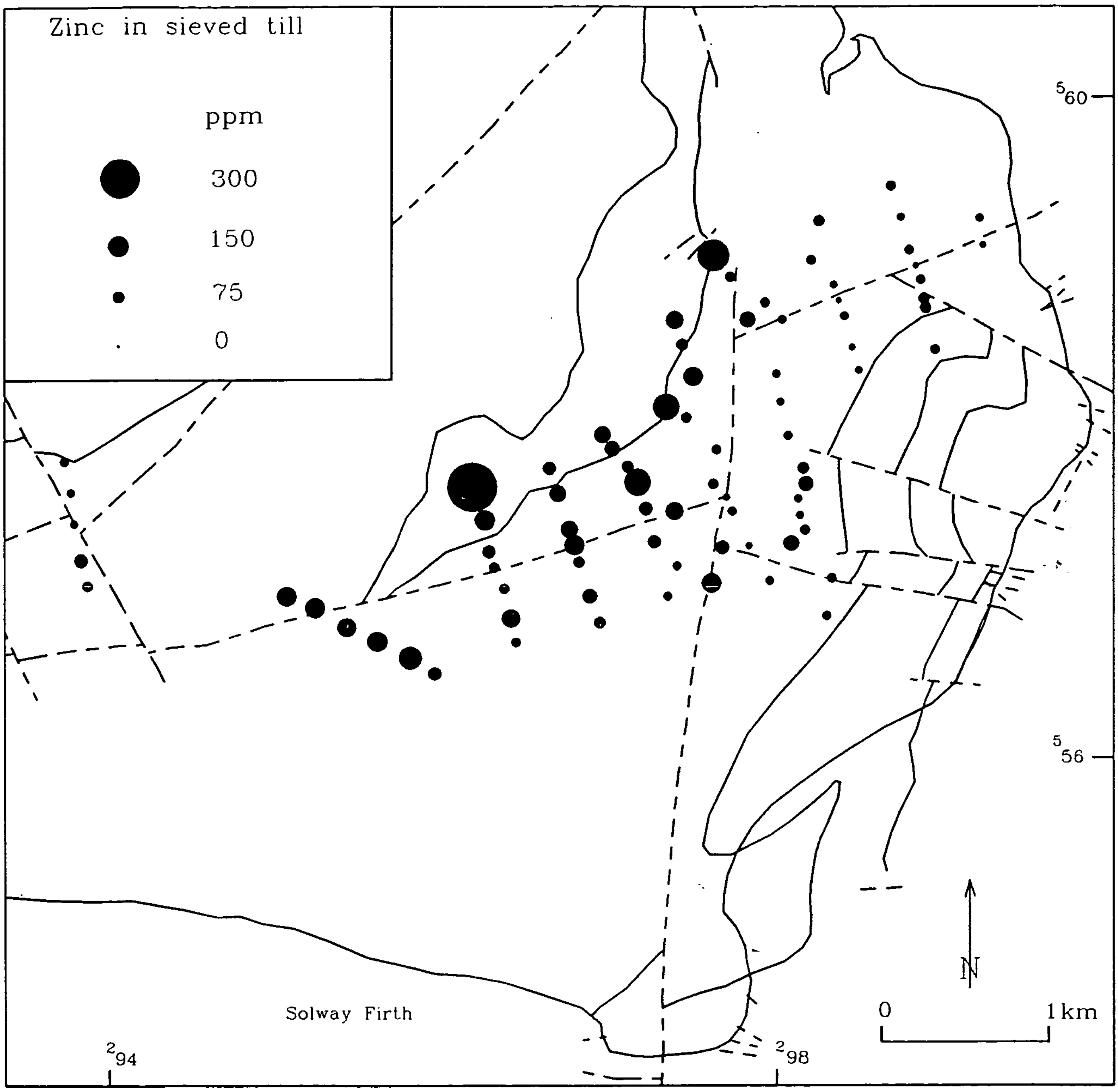

Figure 13 Zinc in sieved tills

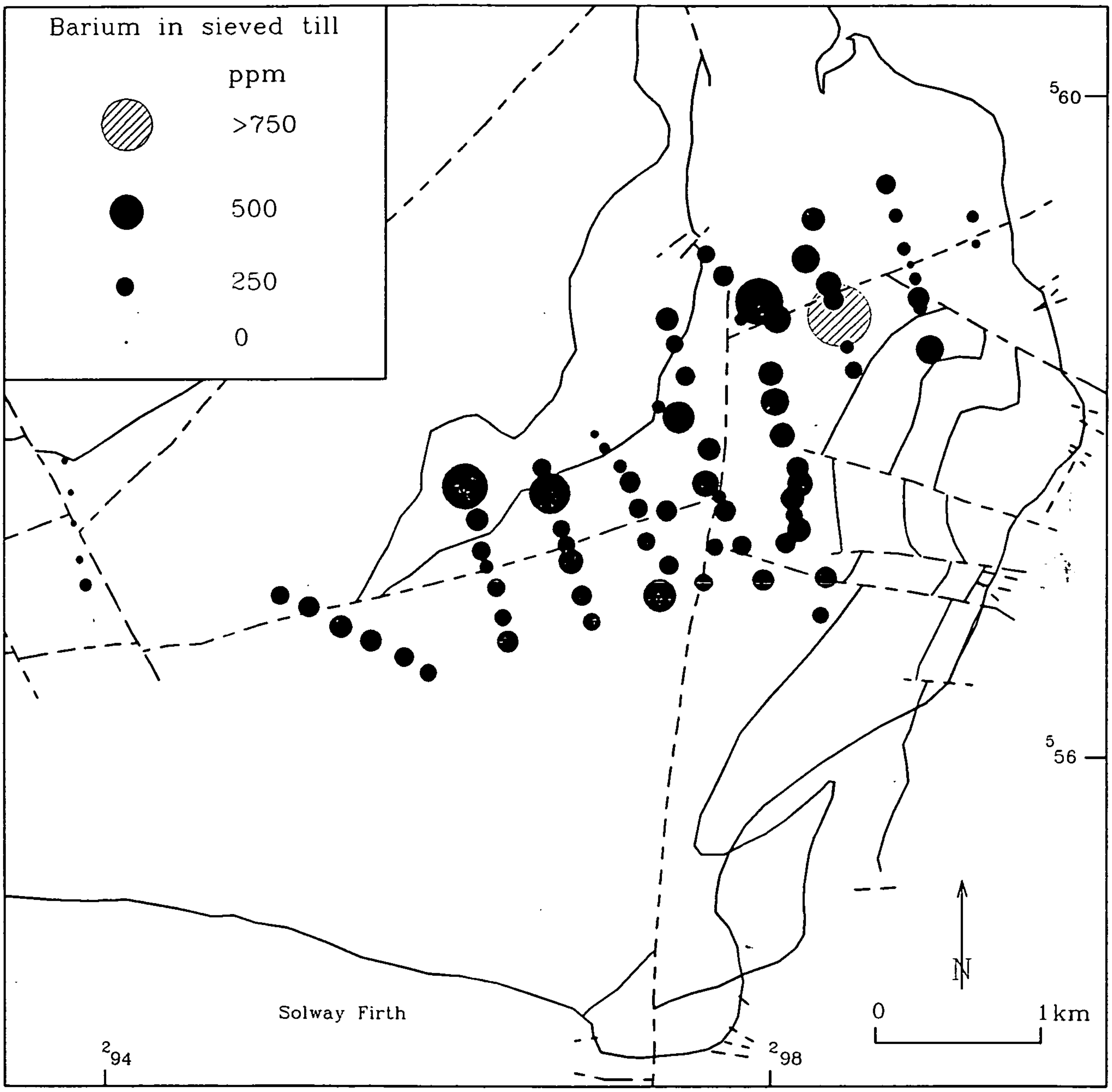

Figure 14 Barium in sieved tills

Limestone Formation, but the absence of a corresponding Pb (or Zn) enrichment in the fine fraction suggests that they are the result of only minor mineralisation.

Zinc

The main Zn-anomalous sites are situated over the Birrenswark Volcanic Formation 300 m west of Prestonmill (430 ppm Zn_u, 382 ppm Zn_t), described under *Lead* above, and over the Southerness Limestone Formation (833 ppm Zn_u, 106 ppm Zn_t), described under *Copper* above (Figure 9 and 13). Two other slightly elevated values (175 ppm Zn_u at [297450 558065], and 179 ppm Zn_u at [297630 557870]) located over the Kirkbean Cementstone Formation may reflect minor mineralisation since they occur at adjacent sites, the former accompanied by high Ba_u (2785 ppm) and the observation of a few grains of coarse-grained sphalerite in the pan. Generally however, the Zn data for both media are considerably lower than over areas of mineralised Lower Carboniferous rocks along strike to the north-east (Gallagher et al., 1977; Smith and McMillan, 1996). In the Westwater area for example, in a comparable tectonostratigraphic setting, Zn_p concentrations of several thousand ppm, frequently associated with high amplitude Pb_p, Cu_p and Ba_p anomalies, are commonly developed over minor sulphide mineralisation in carbonate veined cementstones and lavas.

Barium

Barium is more strongly concentrated in overburden samples than the base-metals (Figures 10 and 14). The highest values (>4000 ppm) are scattered over the area showing little relationship with lithology, but most occur either close to the lava-sediment contact or within 100-200 m of major mapped faults. In the four samples containing the highest Ba values (>4375 ppm) and in several other samples containing >2000 ppm Ba, abundant coarse white baryte fragments were recorded in the panned concentrates indicating proximity to possible fracture-controlled mineralisation in underlying bedrock. Only one of these samples, located about 300 m to the west of Prestonmill (OH 7008 at [296170 557640]), contains sufficiently high values of Pb, Zn, (and slightly enhanced Cu) to indicate an association of Ba with base-metal mineralisation. Clasts observed at this site were dominantly mudstone-sandstone-siltstone suggesting that the lavas which, on the basis of the geological map should underlie this site, may have been locally faulted out.

Ba levels in the fine fraction of the till are generally low in comparison with the panned samples, but values in the two media are quite closely correlated and the highest Ba_u value of the dataset (3.02% at [298395 558680]) also contains the highest Ba_t value (890 ppm). The anomalies here, and at the adjacent sample site to the west (OH 7049 at [297920 558765]), and 1.5 km to the south (OH 7027 at [297825 557285]), lie close to the projected down-strike extension of the baryte vein recorded in Cushat Wood [297300 561900], suggesting that the vein may be continuous over a strike length of nearly 5 km.

GEOPHYSICS

Introduction

Detailed geophysical surveys (total magnetic field, electromagnetic and gravity) were carried out during a two week period to delineate target areas for deep overburden sampling, to indicate possible extensions of baryte mineralisation discovered by soil sampling in the area north of Kirkbean, and to check geological boundaries. A limited amount of regional gravity survey work was also undertaken in the Kirkbean area in order to increase the density of observations.

The study area for the geophysical investigations is outlined in Figure 15 with the principal geological boundaries and the 1:10,000 scale geological map-sheet numbers indicated for reference. The rock units shown are described under the Geology section above.

Figure 16 shows the geological outline of the geophysical survey area with the three soil sample traverses (SL-1, SL-2 and SL-3) and six geophysical traverse lines (GP-A, GP-1, GP-B, GP-C, GP-2, and GP-3). These were located to coincide as closely as possible with the soil traverses and also with the position of the Bench Marks used for elevation control. On the northernmost soil line (SL-1) a marked zone of Ba and weaker base-metal anomalies in the vicinity of the faulted contact between the Criffel granodiorite and the Kirkbean Cementstone Formation (Figures 3-6) provided the principal target for detailed geophysical follow-up. A further objective was to delineate the sub-outcrop of the Birrenswark Volcanic Formation. UK aeromagnetic survey data (Smith and Royles, 1989) do not indicate a clear magnetic signature over this formation in the Kirkbean area, but results from surveys further to the east (Gallagher et al., 1977) suggested that it should be detectable by ground magnetic survey. Also of importance was the recognition and characterisation of geological faults affecting the Carboniferous rocks including information on their location, geometry and spatial relationships.

Geophysical measurements

The geophysical traverses were oriented approximately east-west (perpendicular to the principal structure under investigation). Several of the traverses followed fence lines, but were offset laterally by 10-20 m to reduce any disturbance to the magnetic and electromagnetic measurements. Survey stations were marked by canes at 50 m intervals using the position of the main north-south A 710 road as a reference base line (station no. 0) for each traverse. Surveys performed along each line were as follows:

Total field magnetic, VLF-EM: all lines.

Magnetic total field and Very Low Frequency electromagnetic (VLF-EM) measurements were recorded at 10m intervals along all the survey lines using a Scintrex IGS-2 field system. Diurnal corrections to the total magnetic field were made by means of a continuously recording base station magnetometer sited at the field base. The Rugby transmitting station signal (16.0 kHz) was employed for the VLF-EM observations.

Gravity observations: GP-1, GP-2, GP-3 and limited regional infill.

Gravity measurements were made at 50 m intervals along GP-1 and GP-2, but on GP-3 additional measurements were taken at 10m intervals in the vicinity of the inferred extension of the baryte vein.

Observations were made using a LaCoste-Romberg Model G land gravity meter. Elevations were determined by tacheometric levelling using a Wild RDS theodolite and staff. Levelling ties connected the three profiles and Bench Marks provided the means of checking and reducing the levelling observations. Survey loop closure errors did not exceed 0.2 m.

Regional infill gravity observations were made at 89 stations, sited at Bench Marks (elevations accurate to within 0.01 m) and spot heights (accurate to within 0.5 m) identified from the Ordnance Survey 1:10,000 scale topographic maps. All gravity observations were tied to a local base station established at Barend Holiday Lodges, Sandyhills, Kirkudbrightshire, observed gravity = 981497.24 mGal. The local base was in turn tied to the FBM at Buittle (NGRN 1973), observed gravity = 981488.16 mGal. Tide corrections were applied to the observed data and all gravity readings were corrected for instrument drift. Latitude corrections were applied in accordance with the Geodetic

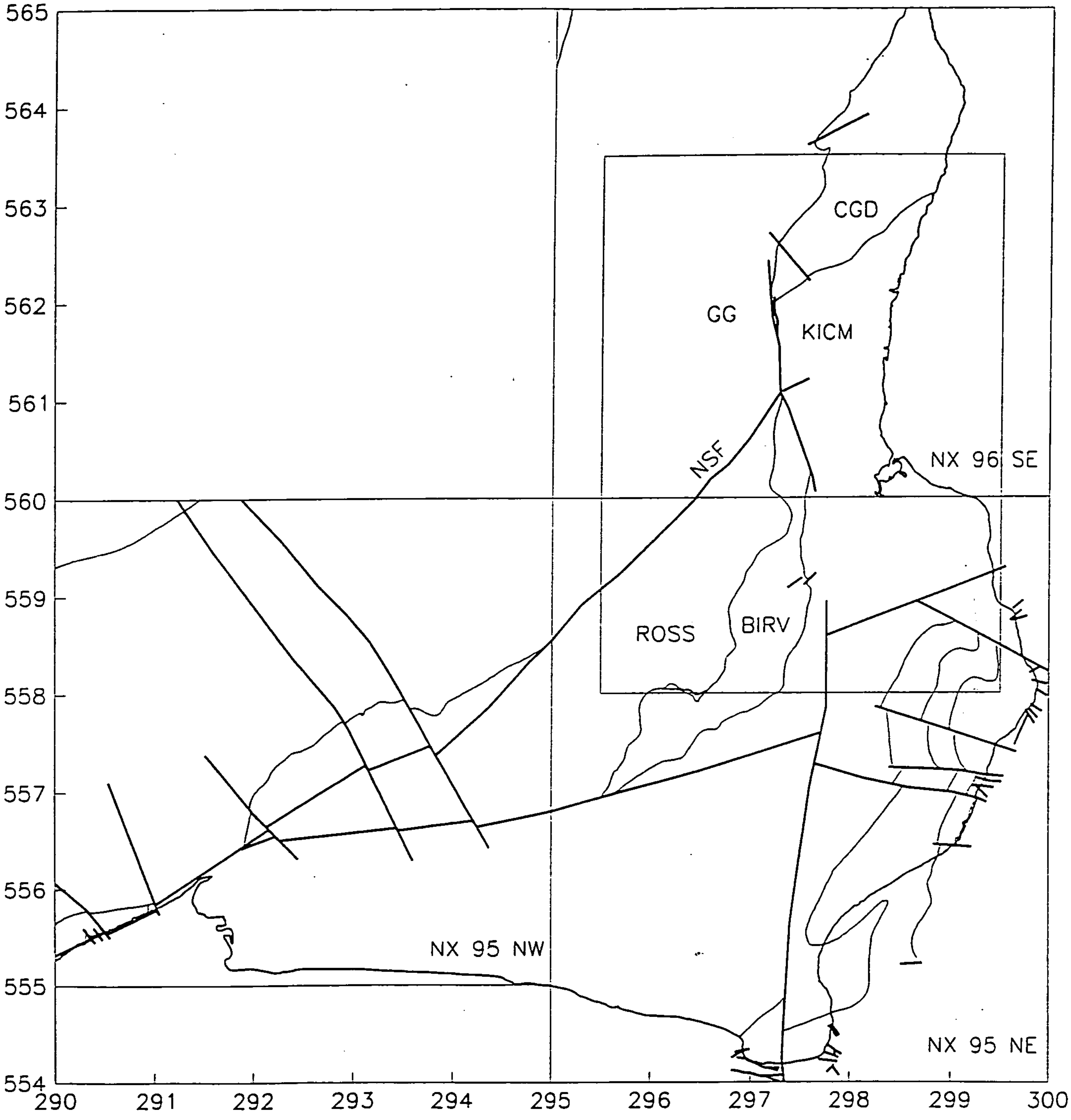

Figure 15 Simplified geological map of the Kirkbean district (geophysical survey area outlined)

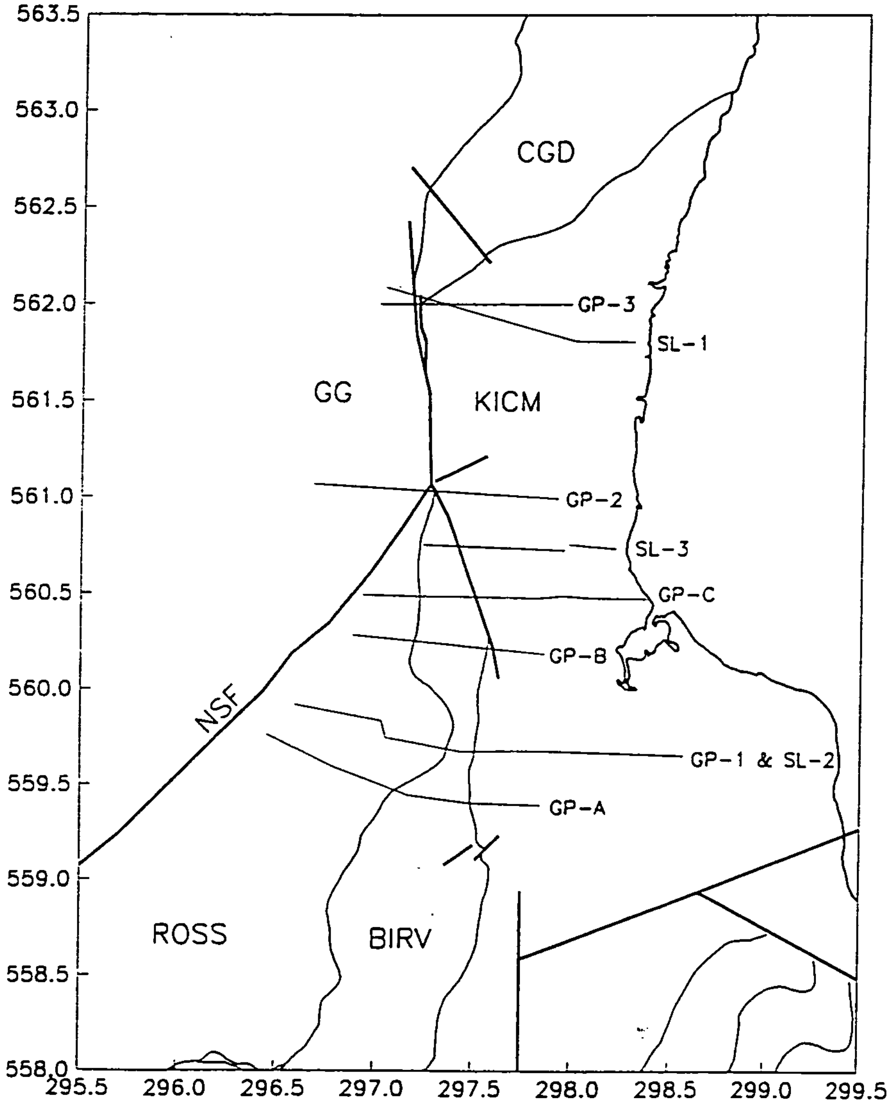

Figure 16 Geophysical (GP) and soil traverse (SL) locations

Reference System (1967) and Bouguer gravity anomalies were calculated assuming a reduction density of 2.67 Mg/m^3. Terrain corrections were calculated out to a distance of 45.8 km (Hammer Zone M) from each gravity station. A digital terrain model with a grid size of 50 m (derived from a combination of Ordnance Survey digital terrain data and measured gravity station elevations) was used to correct for terrain within a 7 x 7 km square containing the gravity station. The effect of more distant terrain was calculated using an existing matrix of estimated mean elevations in 1 x 1 km squares.

Results

VLF-EM and total field magnetic data

Figure 17 shows the VLF-EM in-phase and quadrature component responses along each of the six traverses. Figure 18 shows the VLF-EM horizontal field, while Figure 19 shows the magnetic total field data (nT). The position of mapped geological boundaries is indicated in each figure and the numbers at the base of each figure show station distance in metres west (negative) and east of the roadside base-line. Points of observation marked '+' on Figures 18 and 19 indicate sites of cultural interference (fences etc.) crossed by the survey line. Such structures often cause 'spikes' in observed magnetic and electromagnetic profiles. The electromagnetic data indicated that a power-line at the eastern end of GP-1 was not live.

Gravity data

Figure 20 shows Bouguer gravity anomaly profiles for traverses GP-1, GP-2 and GP-3. For display of the gravity data in contour-map form, values of Bouguer gravity anomaly were first interpolated onto a regular grid using a minimum-tension technique and a grid cell dimension of 0.1 km. The areal limits selected for the grid were 290-300 kmE and 554-565 kmN (National Grid coordinates).

Figure 21 shows a contour map of the Bouguer gravity anomaly data for the Kirkbean district (contours are at 1 mGal intervals) together with the distribution of gravity observations. Previously acquired data are marked as open circles (o); new data for the present study by asterisks (*). Figure 22 shows the contoured data combined with the geology.

In order to highlight local variations in the Bouguer anomaly, a third order regional polynomial surface was fitted to the observed data and then removed to produce Figure 23; a third order residual gravity map (with contours at intervals of 0.2 mGal) with sites of observation marked. Figure 24 shows the same contours overlain on geology.

Rock densities

Only very limited direct information is available on the density of the Lower Carboniferous sedimentary rocks from the Kirkbean area. Determinations on six specimens gave a mean saturated bulk density of 2.72 Mg/m^3 (Entwisle, 1993), which is a high figure for these units and may not be representative (for example, a limestone specimen from the Powillimount Beds had a measured density of 2.83 Mg/m^3, which is anomalously high for this lithology). A variety of published sources indicate that the Lower Palaeozoic turbidites of the Southern Uplands have an average density of approximately 2.72 Mg/m^3. The density of the Criffel-Dalbeattie pluton decreases from about 2.71 Mg/m^3 in its outer (relatively basic) phases to about 2.63 Mg/m^3 in its central (relatively acid) core (Bott and Masson Smith, 1960). No measurements are available on the average density of the drift deposits at this locality, although figures in the range 2.0-2.1 Mg/m^3 are typical elsewhere in the UK.

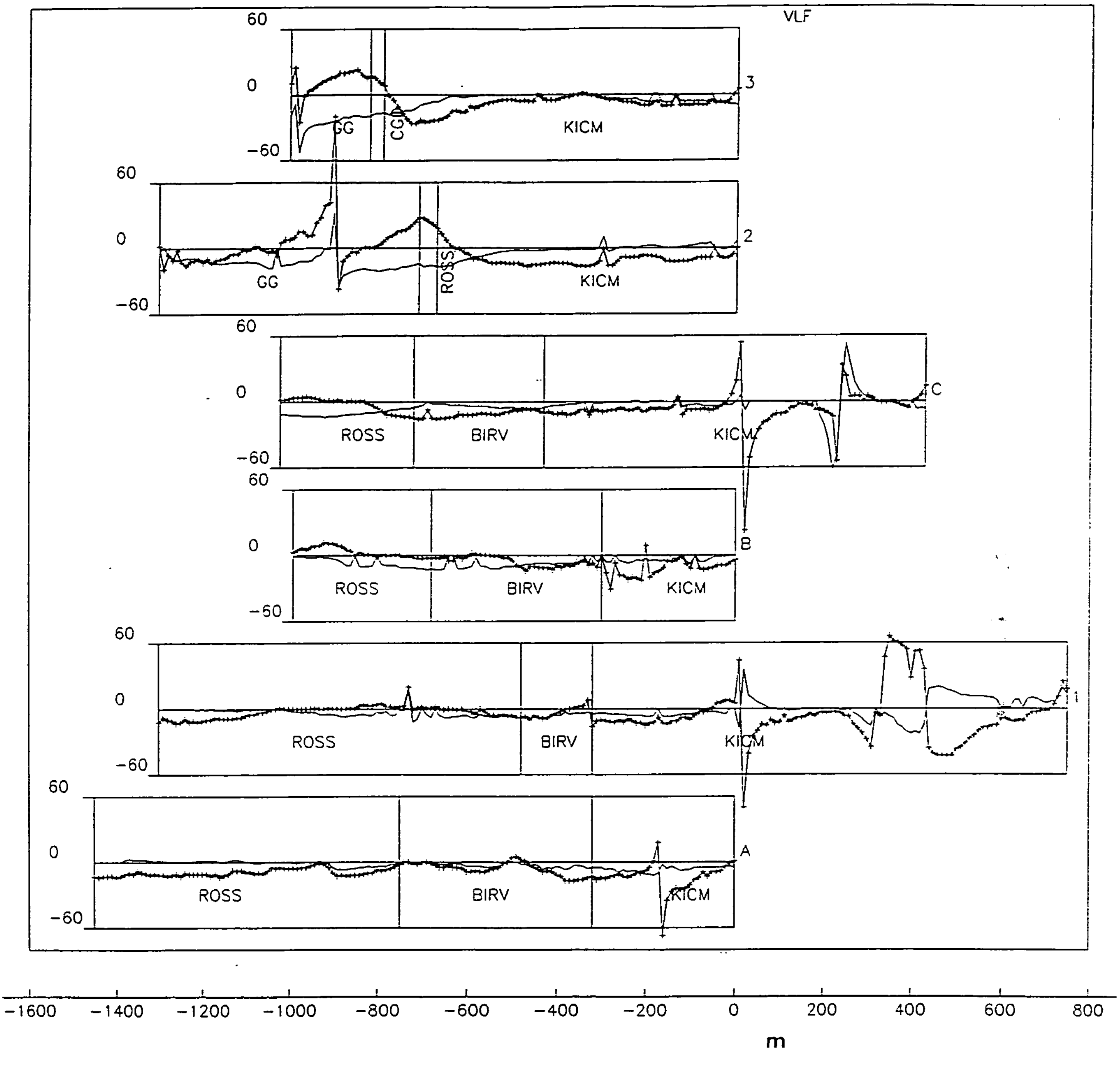

Figure 17 VLF-EM in-phase (crosses) and quadrature profiles. Units=%. Distances are referred to a 'base line' along the A 710 road

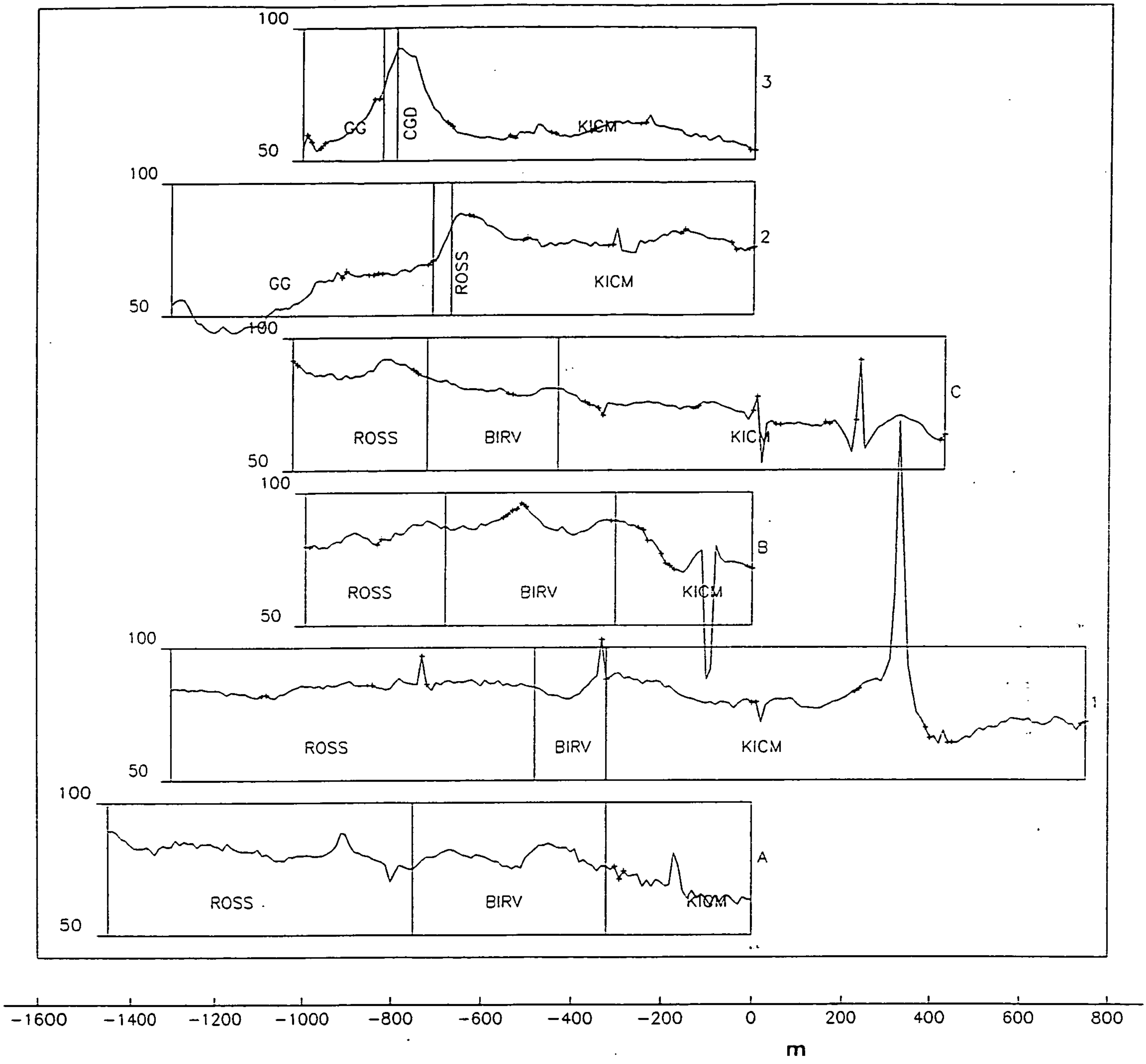

Figure 18 VLF horizontal field profiles. Arbitrary units. Crosses indicate locations of cultural interference

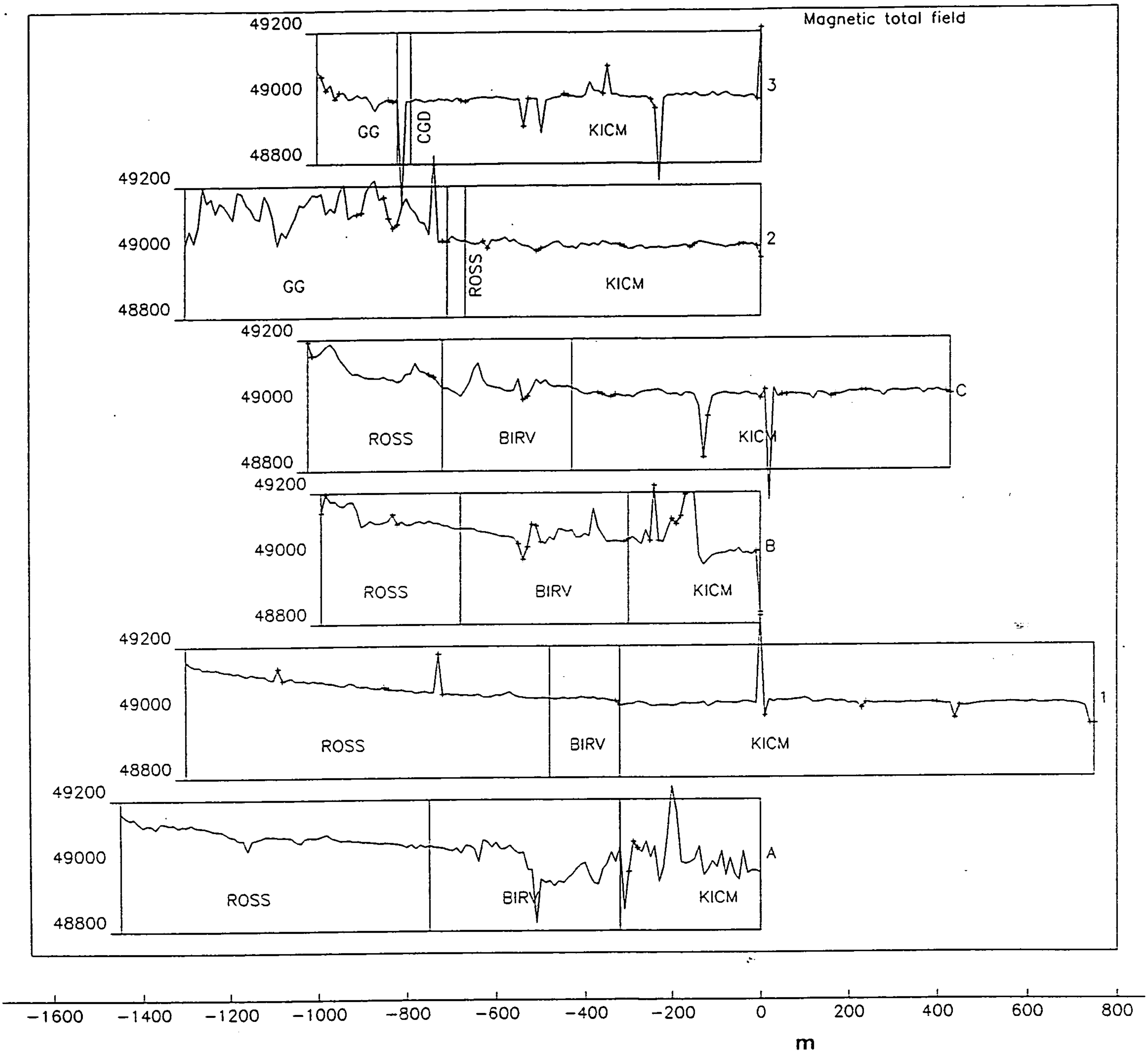

Figure 19 Magnetic total field profiles. Units=nT. Crosses indicate locations of cultural interference

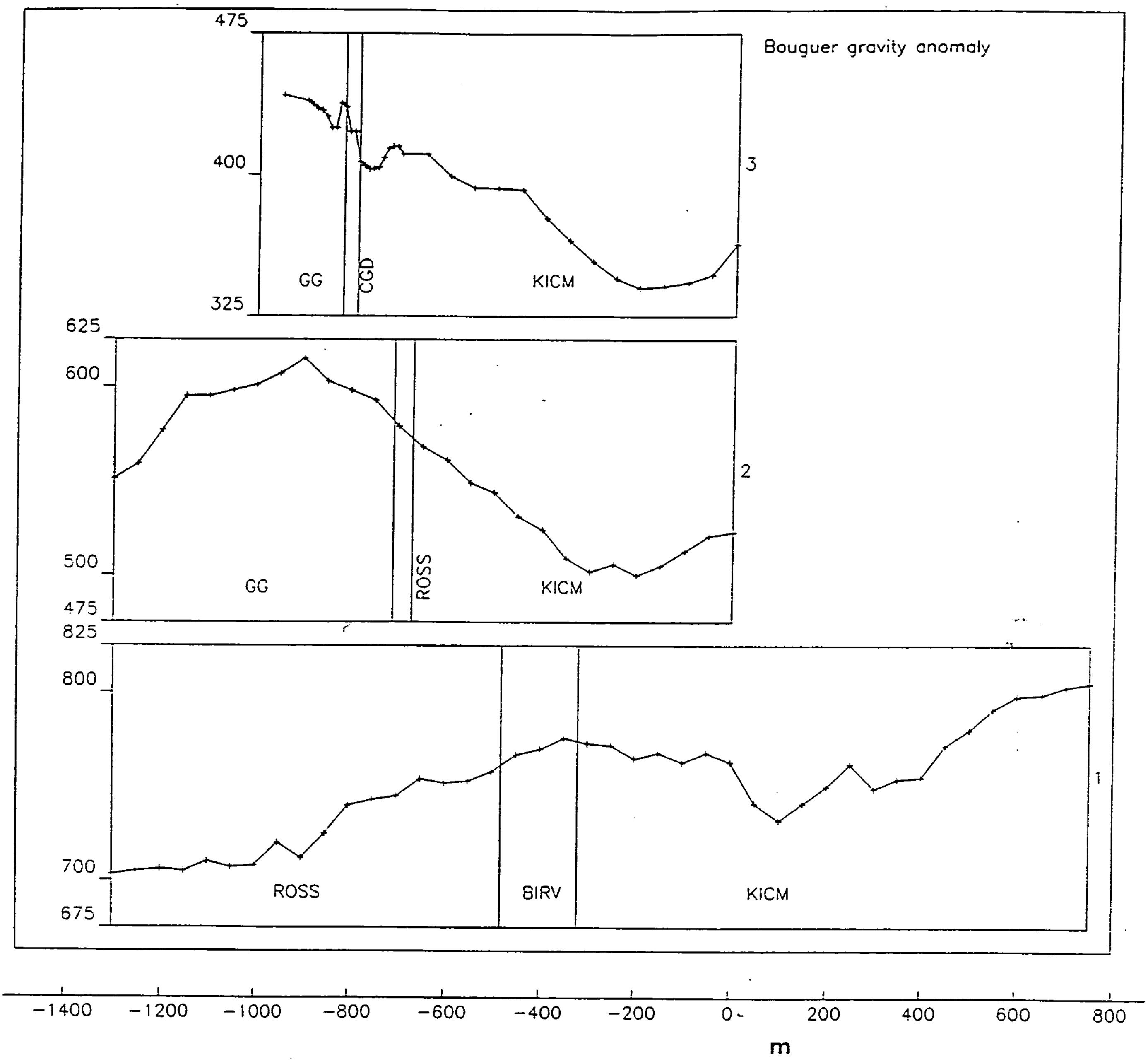

Figure 20 Bouguer gravity anomaly profiles. Units=hundreths of mGal. Crosses indicate locations of gravity stations

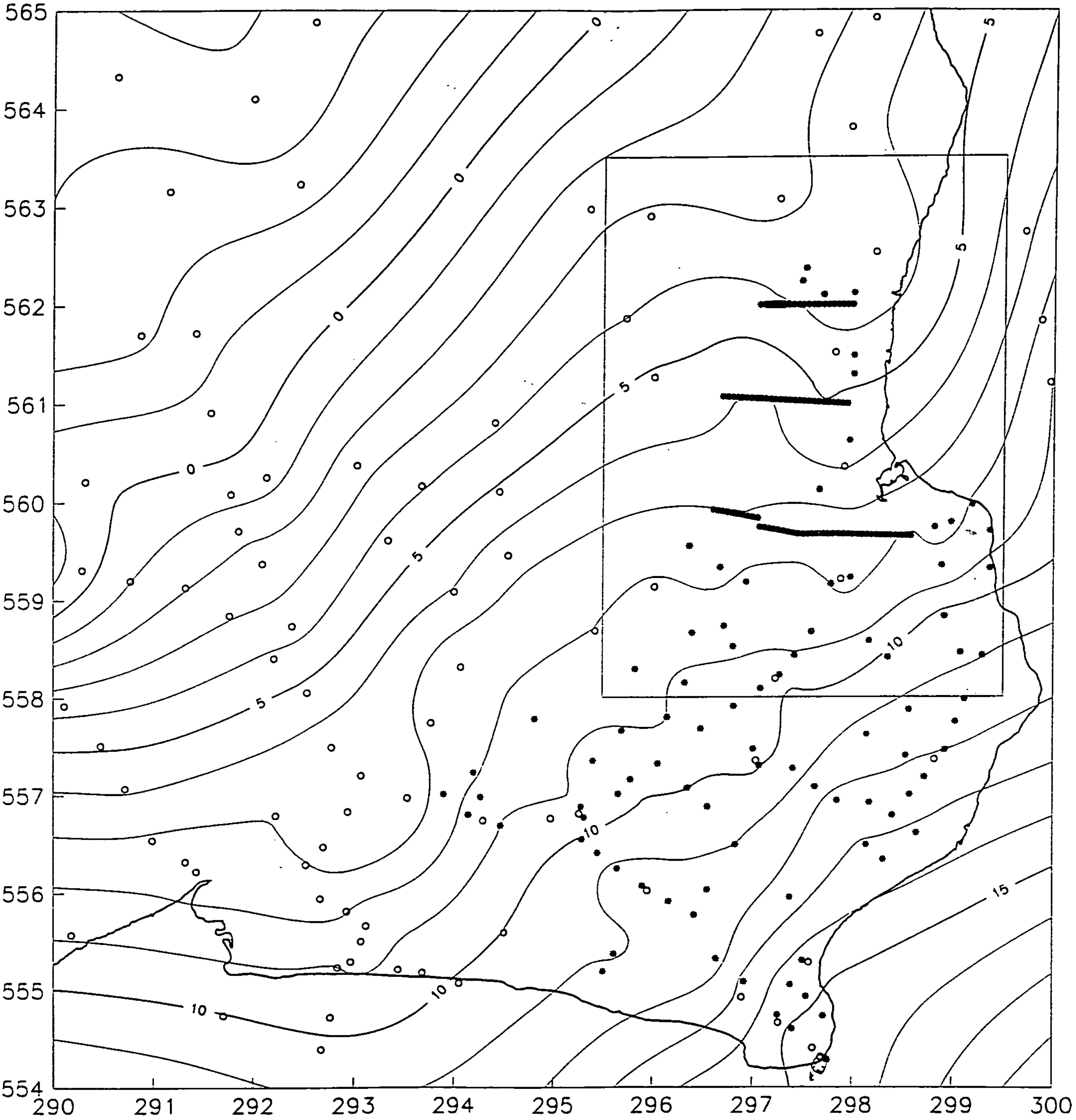

Figure 21 Bouguer gravity anomaly data for the Kirkbean district contoured at 1 mGal intervals and showing sites of gravity observation (geophysical study area outlined). Circles=existing stations; asterisks=new stations

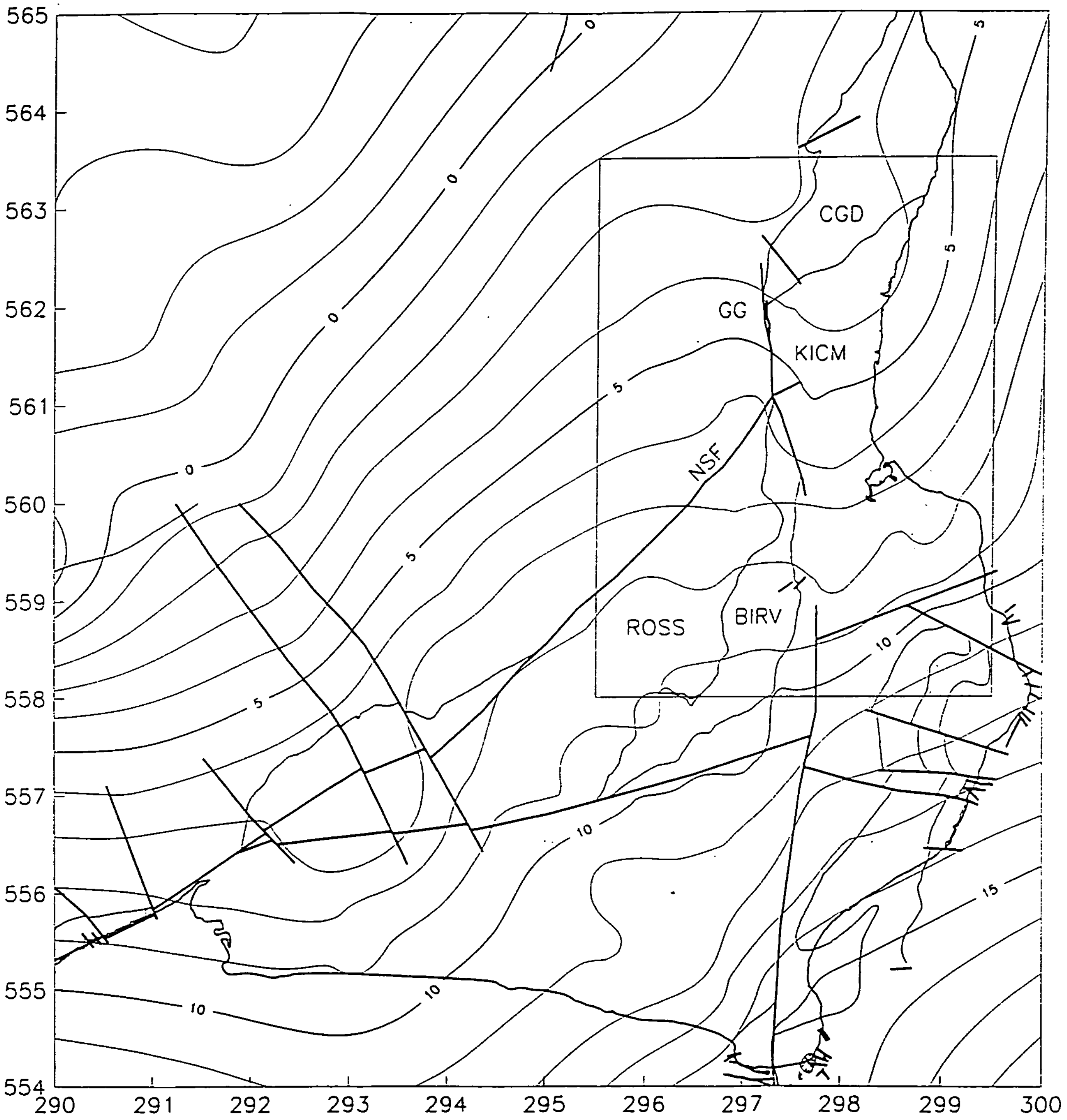

Figure 22 Bouguer gravity anomaly data for the Kirkbean district contoured at 1 mGal intervals and combined with the geological map data (geophysical study area outlined)

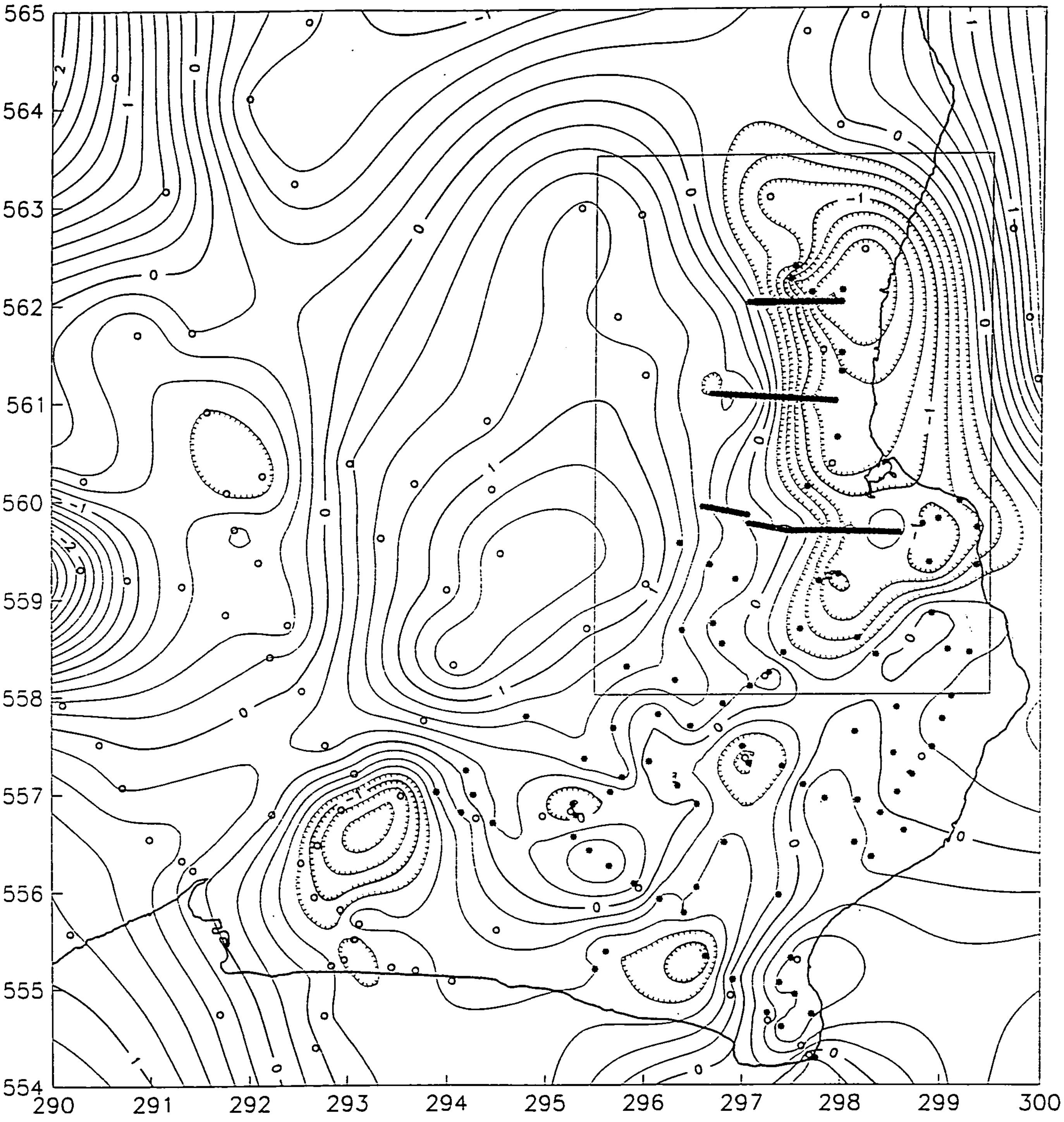

Figure 23 Bouguer gravity anomaly 3rd order residual data for the Kirkbean district contoured at 0.2 mGal intervals and showing sites of gravity observation (geophysical study area outlined)

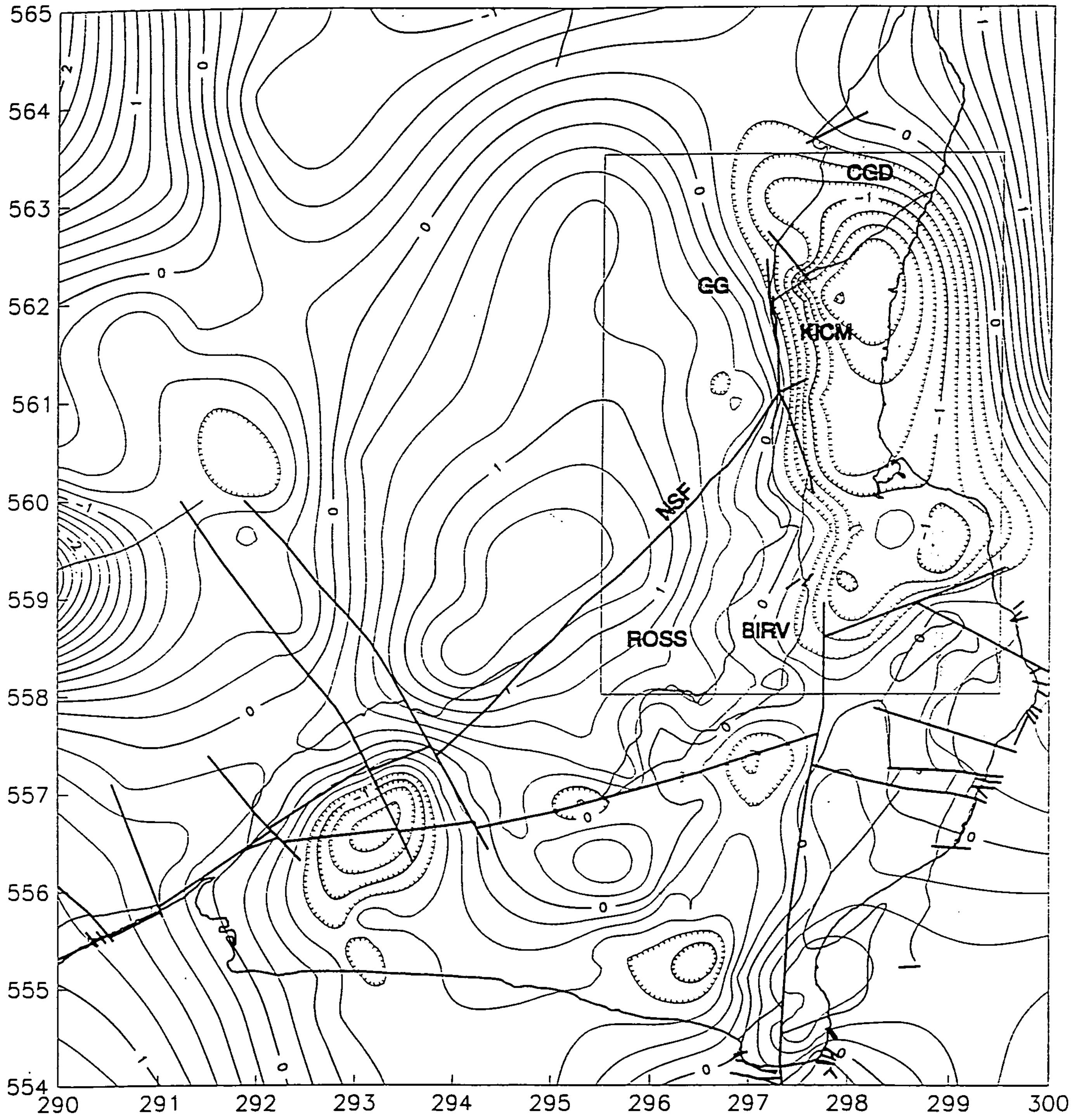

Figure 24 Bouguer gravity anomaly 3rd order residual data for the Kirkbean district contoured at 0.2 mGal intervals and combined with the geological map data (geophysical study area outlined)

Interpretation

The pattern of residual gravity anomalies

The Bouguer gravity anomaly data shown in Figure 22 indicate that the area is dominated by a regional gravity field which decreases from south-east to north-west. This is primarily due the relatively low density granitic core of the Criffel-Dalbeattie pluton. Local disturbances are superimposed on this regional gradient and are highlighted by the residual maps (Figures 23 and 24). Perhaps surprisingly, in view of the small density contrasts indicated by physical property determinations, there is a close correlation between residual gravity features and mapped bedrock structures. A distinct residual gravity gradient zone (eastward decrease in anomaly values) aligns with the north-trending fault on the east side of the Criffel-Dalbeattie pluton, which has an eastward downthrow; this gradient zone can be traced southwards to the northern end of a further north-trending fault (Figure 24). The latter is exposed on Southerness Point [297300 554100] where it also has an eastward downthrow; its southern part appears to align with a further residual gravity gradient zone which, however, defines a westward decrease in gravity values. A further residual gravity gradient zone appears to correlate with a mapped east-north-east - trending fault which intersects the coastline about 100 m south of South Carse [299350 559300]; again the sense of the gravity gradient (northward decrease) is opposite to that of the fault (southward downthrow). The explanation for these observations requires a combination of bedrock structure and variations in the thickness of the low density overburden.

The detailed gravity profile along line GP-2 (Figure 20) illustrates how the gravity gradient to the east of the Criffel-Dalbeattie pluton contains both 'bedrock' and 'superficial' effects. An eastward decrease in Bouguer anomaly values of about 1 mGal is observed along this profile, but the true amplitude of the effect is very probably greater than this because of the underlying westward increase in the regional field. Assuming an anomaly amplitude of 1.5 mGal and a density contrast of -0.7 Mg/m^3, a thickness change of about 50 m in the drift deposits would be required to explain the observed effect. However, bedrock is exposed a short distance to the north of GP-2 at about -300, where local topography suggests that there is unlikely to be more than 10-15 m of drift immediately beneath the profile. Such a thickness could explain local variations (e.g. the increase in gravity gradient between -400 and -300) but cannot explain the entire gradient zone which therefore appears likely to include a contribution due to the eastward thickening of relatively low density Carboniferous (and Upper Devonian?) sedimentary rocks. The geometry of this thickening is poorly constrained because of the uncertainty in rock densities and lack of geological control. It is theoretically possible that a relatively dense outer component to the Criffel-Dalbeattie pluton could contribute to the observed gradient, but the available density data do not suggest the presence of such a component.

A similar partitioning into bedrock and superficial components can be tentatively suggested for the gravity profile along GP-3. This profile exhibits a general (bedrock-related?) eastward decrease in Bouguer anomalies, upon which is superimposed a depression in anomaly values over the eastern half of the profile which coincides closely with a drumlin. The short wavelength gravity variations at the western end of this profile are considered in the following section. On GP-1 the regional gradient is defined by the western half of the profile and superimposed on this (between about -300 and +400) is an eastward decrease of about 0.7 mGal (Figure 20). Local sharp gradients (e.g. between 0 and +100) account for at least half this anomaly amplitude and are probably due to superficial effects.

Some evidence for the cause of the east-north-east - trending residual gravity gradient zone in the vicinity of South Carse [299350 559300] is provided by observations made during the deep overburden sampling. Sites OH 7059 and 7065 lie on either side of this zone and were interpreted to terminate at bedrock, which lies 8.1 m deeper on the northern side of the feature (Table 4). Assuming a density contrast of -0.7 Mg/m^3, such a drift thickness change would cause a gravity effect of -0.24 mGal. The amplitude of the observed gradient zone appears larger than this, perhaps because the northern auger hole did not reach rockhead, although the possibility of a contribution from bedrock contrasts cannot be ruled out. Similarly, the gravity gradient aligning with the north-trending fault at Southerness point appears likely to be due, at least in part, to a drift feature. Even though significant drift contributions to these gravity features seems likely, the observed correlations suggest at least an indirect association with bedrock structure (i.e. a relationship between rockhead topography and faults).

A local residual gravity minimum is centred at [293200 556600] just south of Caulkerbush. This shows correlations with bedrock structures (it occurs over the hanging wall of the North Solway Fault and its eastern termination coincides with a north-west - trending fault), although there is again a distinct possibility that the relationship is only indirect, with local variations in drift thickness playing an important role.

The thin and weathered Birrenswark Volcanic Formation has little discernible gravity effect.

Gravity effects due to the baryte mineralisation

Detailed gravity profiling at the west end of GP-3 (Figure 20) reveals a local Bouguer anomaly high at the location where soil sampling strongly suggests the presence of a baryte and base-metal vein mineralisation (the up-slope end of the soil Ba anomaly and location of baryte boulders). The gravity observations are compatible with the high density of baryte (4.5 Mg/m^3). An interesting feature of the gravity profile is that the vein anomaly is superimposed on a residual low, which has a width of about 100 m. The soil sampling suggested only thin overburden in this area, so a thickening of drift cover appears an unlikely explanation (although not impossible if the thickening occurs on the flanks of a zone of shallow rockhead associated with the vein). An alternative explanation is that the local low is due to low density weathered bedrock associated with the fault zone. Trial modelling, assuming a density contrast of 1.3 Mg/m^3 between unaltered bedrock and the vein, and incorporating alternative models for the source of the residual low, suggests that the vein beneath this traverse may have a width of 5-6 m and a steep eastward dip.

No clear gravity evidence for a southward extension of the baryte mineralisation is seen on profiles GP-1 and GP-2 (Figure 20). However, at the gravity station spacing employed on these profiles it is possible to 'miss' short-wavelength features such as those seen at the western end of GP-3.

Evidence from VLF-EM and magnetic data

VLF-EM data (Figures 17 and 18) indicate a strong anomaly (vertical in-phase 'cross-over' and peak in the horizontal field) over the residual gravity low detected on profile GP-3 (Figure 20), which is probably mainly due to the conductive nature of the fault zone. Baryte is very resistive and cannot explain the inferred conductive response; it may however, be responsible for a slight perturbation in the in-phase profile at the eastern margin of the granodiorite. A component of the anomaly could however arise because of the resistivity contrast between the granodiorite and neighbouring rocks (i.e. a resistivity 'contact' effect in addition to a discrete conductive zone). The profile on GP-2 shows the characteristics of contact anomaly more clearly (in particular a peak in the in-phase profile coinciding with the contact; Telford et al., 1977). Traverses south of GP-2 are largely dominated by cultural noise and display no strong features which can be easily traced from line to line.

Areas underlain by granodiorite are characterised by moderate amplitude magnetic disturbances, whereas the Silurian rocks and Kirkbean Cementstone Formation are typically associated with a flat magnetic response (Figure 19). There is evidence of magnetic disturbances associated with the Birrenswark Volcanic Formation, and of mismatches between the magnetic pattern and existing maps of the sub-outcrop of this formation. The signature of the lavas on profiles GP-B and GP-C is indistinct, but provides some evidence that their western margin on GP-B might lie up to 200 m to the east of its presently mapped location. The very flat magnetic profile along GP-1 suggests that the lava is absent beneath this profile. In contrast, traverse GP-A indicates that lava is present in the subsurface and suggests that the lava-cementstone contact could be moved eastwards to the line defined by a link between the two main north-trending faults in the study area.

CONCLUSIONS AND RECOMMENDATIONS

1) The results of a geochemical soil survey carried out to the north of Kirkbean, together with an outcrop of vein baryte, close to the faulted margin of the Kirkbean Cementstone Formation and the Criffel-Dalbeattie granodiorite, suggests that a vein-style mineralised structure may extend over a strike length of 2.5 km. Weak base-metal enrichment associated with the Ba in soil anomaly may explain the prominent linear zone of stream sediment and panned concentrate anomalies reported by earlier BGS surveys.

2) Examination and sampling of outcrop in Kirkbean Glen confirmed a minor occurrence of fracture-controlled galena mineralisation and also led to the discovery of small amounts of chalcopyrite-pyrite mineralisation. The occurrences, which are all hosted by micritic limestones of the Kirkbean Cementstone Formation, are associated with intense carbonate veining in close proximity to the contact with the Birrenswark Volcanic Formation.

3) Reconnaissance deep overburden sampling over the Lower Carboniferous rocks south of Kirkbean identified a number of base-metal and Ba anomalies, supported by the observation of sulphides and baryte in some of the panned till samples. Ba anomalies in overburden are more strongly developed than base-metals especially near to the intersection of mapped faults. Their presence to the east of Kirkbean may indicate down-strike extension of the baryte vein exposed in Cushat Wood giving a total potential strike length of about 5 km. Elsewhere baryte veining may be widespread in the Lower Carboniferous since coarse fragments of white baryte occur in many of the panned tills containing >2000 ppm Ba.

4) One or two Cu, Zn, and minor Pb anomalies occur in deep overburden samples from over the Southerness Limestone Formation, with low-order Zn anomalies associated with the Kirkbean cementstones. The highest coincident Pb, Zn, Ba, Cu values were recorded at a site over the Birrenswark Volcanic Formation suggesting a source in epigenetic fracture-controlled mineralisation similar in style to the baryte-galena-sphalerite veins recorded in the Birrenswark Lavas west of Langholm (Gallagher et al., 1977).

5) The pattern of residual gravity anomalies reveals gradient zones which correlate closely with mapped faults. Although there is evidence of a bedrock source for some of these features, in other cases it appears likely that the connection between the gravity response and bedrock structure is indirect, at least in part, and associated with variations in drift thickness across topographic features at rockhead. Resistivity or transient electromagnetic soundings would help in resolving drift thickness variations and thus identifying the cause of local gravity variations with greater confidence. The

northerly extension of the vein-style baryte mineralisation exposed in Cushat Wood, inferred from the soil data, has a distinct positive gravity signature and appears to be contained within a relatively low density, conductive fault zone which causes a strong VLF-EM anomaly. There is thus scope for tracing the vein and associated structures by means of further detailed gravity and VLF-EM surveys.

6) Magnetic surveys suggest that, just to the north of Kirkbean, the sub-outcrop of the Birrenswark Volcanic Formation extends further east than is indicated by current geological maps, with an eastern boundary possibly being limited by a southward extension of the structure which contains baryte mineralisation further north. Better delineation of the Birrenswark Volcanic Formation sub-outcrop, and thus of structures affecting it, could be achieved by a grid of closely spaced magnetic traverses.

7) Considering the relatively limited extent of this investigation, and the presence of thick and continuous glacial deposits obscuring all, but a small proportion of the bedrock, the data collected provide evidence that base-metal and baryte mineralisation occurs within the Lower Carboniferous target formations in close proximity to a major basin-margin fault. Even though the evidence is consistent with the presence of several, mostly small epigenetic occurrences, there are good indications of a relatively large, steeply dipping baryte-bearing vein structure, and the possibility that the geochemical data may reflect the distal expression of more substantial stratabound or breccia infill mineralisation. To establish the style and extent of base-metal and baryte mineralisation in the poorly exposed, but most prospective, ground underlain by the Kirkbean Cementstone and the Southerness Limestone formations, further geophysics, deep overburden sampling and/or diamond drilling are recommended.

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Table 1 Stratigraphical succession, Northern margin of the Solway Basin

SERIES	STAGE	KIRKBEAN OUTLIER LITHOSTRATIGRAPHY: KIRKBEAN & SOUTHERNESS-BORRON POINT-HOGUS POINT		COLVEND & RERRICK OUTLIERS, LITHOSTRATIGRAPHY	LANGHOLM BIOSTRATIGRAPHY (after Lumdsen et al., 1967)
VISEAN	ASBIAN	BORDER GROUP	Arbigland Limestone Formation (top not seen)	No strata	UPPER BORDER GROUP Glencartholm Volcanic Beds
	HOLKERIAN		*Thirlstane Sandstone Member* Powillimount Sandstone Formation	Rascarrel Formation	MIDDLE BORDER GROUP
	ARUNDIAN		Gillfoot Sandstone Formation	No strata	
	CHADIAN		*Syringothyris Limestone* Southerness Limestone Formation	Orroland Formation	Harden Beds
TOURNAISIAN	COURCEYAN		Kirkbean Cementstone Formation (not exposed at coast)	Wall Hill Sandstone Formation	LOWER BORDER GROUP
			Birrenswark Volcanic Formation		Birrenswark Lavas
		UPPER OLD RED SANDSTONE (cf. Kinneswood Formation and Stockiemuir Sandstone Formation of the Midland Valley)			UPPER OLD RED SANDSTONE
WENLOCK (SILURIAN)		HAWICK GROUP Ross Formation Carghidown Formation			RICCARTON GROUP

Notes. 1. This table does not show relative thickness of different groups, formations and members. 2. The tripartite division of Border Group of the Langholm area (Lumsden et al., 1967) is biostratigraphically defined. Lithostratigraphical formations of the Kirkbean area are placed within the Border Group as used by Hughes (1995), BGS (1996) and Smith and McMillan (1996). 3. The Rascarrel Formation, Gillfoot Sandstone Formation and Powillimount Sandstone Formation may be lateral equivalents of the diachronous Fell Sandstone Formation, as originally proposed by Craig (1956).

Table 2A Kirkbean Soil Observations

Samp. Ref. No.	Traverse No.	Distance (m)	Easting	Northing	Depth (m)	Horizon	Texture	Clasts	Comments
OHS 6501	1	0	297030	562089	0.65	B	Si, Cl	Gr	SMALL DECAYING FRAGS IN SOIL
OHS 6502	1	50	297075	562075	0.40	B	Si, Cl	Gr	ROTTEN FRAGS
OHS 6503	1	100	297125	562062	0.75	B	Si	Gr, Qtz/Bar vein	SMALL ROTTEN FRAGS,
OHS 6504	1	150	297172	562050	0.45	B	Sa, Si	Qtz/Bar vein	GRITTY SOIL
OHS 6505	1	200	297218	562039	0.75	B	Si	Sltst, Bar, Bas, Gr	CLASTS INDICATE LITHOLOGICAL CHANGE
OHS 6506	1	250	297270	562022	0.55	B	Si	Gwk	
OHS 6507	1	300	297320	562010	0.75	B	Si	Bas, Gr	LARGE BOULDERS OF MASSIVE BARITE IN WALL
OHS 6508	1	350	297370	561999	0.37	B	Sa		LOCALLY DERIVED GRAVEL MOSTLY ROTTEN GRANODIORITE
OHS 6509	1	400	297412	561988	0.80	B	Si, Cl		SOME SMALL DK CLASTS OF INDETERMINABLE LITHO.
OHS 6510	1	450	297463	561971	0.80	B	Si	Bas, Gr, Sltst, Bar	SOME RED FERRUGINOUS MATERIAL AB SMALL CLASTS
OHS 6511	1	500	297510	561961	0.95	B	Si	Gr	SMALL FRAGS
OHS 6512	1	550	297559	561947	0.35	B	Sa, Si	Gr	GRAVELLY WITH ROUNDED PEBBLES
OHS 6513	1	600	297602	561936	0.70	B	Si	Gr	NUMEROUS COARSE CLASTS
OHS 6514	1	650	297655	561921	0.45	B	Si	Sltst, Bas, Gr	AB FRAGS ABRUPT COLOUR CHANGE AT 0.4 FROM DK BR HUMIC 'A'
OHS 6515	1	700	297703	561906	0.50	B	Si, Sa	Sltst, Gr	DOMINANTLY SED CLASTS
OHS 6516	1	748	297740	561895	0.55	B	Si, Sa	Gr, Sltst	AB SMALL CLASTS
OHS 6517	1	800	297800	561880	1.00	B	Sa	Gr	ROTTED CLASTS
OHS 6518	1	850	297850	561870	0.45	B	Si	Gr	V NUMEROUS ROUNDED CLASTS
OHS 6519	1	900	297900	561853	0.50	B	Sa	Gr, Sltst	AB ROTTEN CLASTS GRAVELLY SOIL
OHS 6520	1	950	297949	561840	0.55	B	Si	Gr	NUMEROUS SMALL CLASTS VERY GRITTY
OHS 6521	1	1000	297994	561826	0.50	B	Sa, Si	Gr	LARGE ROUNDED COBBLES
OHS 6522	1	1050	298040	561818	0.50	B	Si	Gr, Sltst	V STONY MUCH FINE GRAINED ROTTEN MATERIAL
OHS 6523	1	1100	298080	561818	0.95	B	Si, Cl	Gr, Sltst	CHANGE FROM DK TO OR BR AT 0.8M SAMPLE IS FROM BOTH
OHS 6524	1	1150	298130	561818	0.75	B	Si, Sa	Gr, Sltst	AB FRAGS
OHS 6525	1	1200	298180	561818	0.75	B	Si, Sa	Gr, Sltst	AB CLASTS V SANDY TEXTURE V LOW CLAY
OHS 6526	1	1250	298230	561818	0.60	B	Si, Cl	Sltst	AB ANG CLASTS
OHS 6527	1	1300	298280	561818	0.80	B	Sa	Gr, Sltst, Sst	AB ROTTEN FRAGS
OHS 6528	2	0	296355	559960	0.45	B	Si	Gr	SMALL ROTTING CLASTS ON BOULDERY STEEP SLOPE
OHS 6529	2	50	296410	559948	0.65	B	Si	Gr	AB FINE CLASTS FEW LARGER CLASTS
OHS 6530	2	100	296451	559938	0.45	B	Si	Sltst, Gr	AB LAMINATED CLASTS ?CLOSE TO BEDROCK
OHS 6531	2	150	296500	559920	0.70	B	Si	Mudst, Gr	DEEP SOIL PROFILE
OHS 6532	2	200	296546	559910	0.45	A/C	Sa	Gr	COARSE SANDY SOIL WATERLOGGED ORG RICH SOIL

Table 2A continued

Samp. Ref. No.	Traverse No.	Distance (m)	Easting	Northing	Depth (m)	Horizon	Texture	Clasts	Comments
OHS 6533	2	250	296597	559898	0.60	B	Si	Sltst, Gr	FEW ANG CLASTS
OHS 6534	2	300	296641	559882	0.55	B	Si	Sltst, Mudst, Gr	AB CLASTS
OHS 6535	2	350	296693	559870	0.50	B	Si	Andesite	V FRAGMENTED ANG CLASTS ?CLOSE TO BEDROCK
OHS 6536	2	400	296740	559858	0.25	A/C	Si	Fel	AB COARSE ANG FRAGS-TOP OF BEDROCK
OHS 6537	2	450	296787	559849	0.55	B	Si	Fel, Sltst	AB COARSE ANG FRAGS
OHS 6538	2	500	296838	559832	0.55	B	Si	Gr, Qtz, Siltst, Fel	MARKED A/B INTERFACE
OHS 6539	2	550	296883	559821	0.50	B/C	Si	Mudst	AB SMALL FRAGS V STONY
OHS 6540	2	600	296932	559810	0.45	B	Si, Sa	Gwk	AB SMALL FRAGS
OHS 6541	2	650	296985	559796	0.55	B	Si	Gr, Sltst, Fel	AB ANG CLASTS
OHS 6542	2	706	297038	559781	0.40	B	Si	Gwk	AB ANG FRAGS ?CLOSE TO BEDROCK V STONY
OHS 6543	2	750	297087	559770	0.55	B	Si	Sltst	NUMEROUS ANG CLASTS FRAGMENT OF BRICK IN TOP 10CM
OHS 6544	2	800	297128	559758	0.50	B	Si, Cl	Porph	GREEN/GREY CLAY AT BOTTOM OF HOLE ?ROTTED BEDROCK
OHS 6545	2	850	297173	559745	0.65	B	Si	Mudst, Gr	NUMEROUS ANG CLASTS
OHS 6546	2	900	297222	559731	0.50	B	Sa	Fel, Porph	NUMEROUS ANG FRAGS ?CLOSE TO BEDROCK
OHS 6547	2	950	297272	559720	0.85	B	Si, Cl	Sst, ?Porph	FEW CLASTS
OHS 6548	2	1000	297321	559708	0.80	B	Si, Cl	Sltst, Fel	FEW SMALL ANG CLASTS
OHS 6549	2	1050	297365	559698	0.70	B	Si	Bas	FEW CLASTS/COBBLES
OHS 6550	2	1100	297417	559683	0.65	B	Si, Cl	Sst, Gr, Grits	AB CLASTS
OHS 6551	2	1150	297462	559672	0.75	B	Si, Sa	Sltst, Gr	AB SMALL CLASTS
OHS 6552	2	1200	297520	559656	0.80	B	Lo	Mudst	VARIEGATED CLAY MANY ROTTEN SMALL ANG FRAGS
OHS 6553	2	1250	297569	559658	0.60	B	Sa	Porph	ANG FRAGS
OHS 6554	2	1300	297620	559659	0.70	B	Grit	Calc, Sltst, Gr	GRITTY DUE TO AB ROCK FRAGS IN SLTY MATRIX
OHS 6555	2	1350	297670	559659	0.60	B	Si, Cl	Sltst, Mudst	AB MED FRAGS
OHS 6556	2	1400	297720	559659	0.80	B	Si	Sltst, Lst	ROUNDED AND SUBROUNDED FRAGS
OHS 6557	2	1450	297770	559659	0.85	B	Lo	Qtz	SMALL FRAGS
OHS 6558	3	0	297237	560771	1.15	B	Sa	Gr	AB ROTTEN FRAGS GRITTY SOIL WITH DK BR MATRIX. PEATY TOP
OHS 6559	3	50	297282	560770	0.55	B	Si, Sa	Gr, Sltst	AB ROTTEN CLASTS DEEP PROFILE
OHS 6560	3	100	297333	560769	0.80	B	Si, Sa	Qtz, ?Gr	
OHS 6561	3	150	297380	560768	0.90	B	Sa, Cl	Gr, Sltst	AB ROTTEN CLASTS-MORE GRANODIORITE AT BASE OF HOLE
OHS 6562	3	200	297429	560763	0.65	B	Si, Sa	Gr	AB ROTTEN CLASTS
OHS 6563	3	250	297479	560761	0.90	B	Lo	Gr, Fel, Grits	FEW ROUNDED COARSE ?GRITS. ON STEEP SLOPE
OHS 6564	3	300	297530	560750	0.60	B	Si, Sa	Gr, Sltst	ROTTEN GD FRAGS OCC SLTST FRAGS AT BASE. ON FLAT SLOPE

Table 2A continued

Samp. Ref. No.	Traverse No.	Distance (m)	Easting	Northing	Depth (m)	Horizon	Texture	Clasts	Comments
OHS 6565	3	350	297579	560748	0.35	B	Si, Sa	Fel, Sltst, Gr	ON STEEP SLOPE. V ABRUPT CHANGE A TO B
OHS 6566	3	405	297630	560742	0.90	B	Si, Cl	Sltst, Gr	OR MOTS. GLEY SOIL. AB LG CLASTS AT TOP
OHS 6567	3	453	297672	560742	0.80	B	Sa, Cl	Sltst, ?Bas	AB CLASTS SLTST/VOLCANIC CLASTS FOLIATED AND ANG. FLAT GROUND
OHS 6568	3	500	297720	560740	0.60	B	Lo	Sltst, Bas	AB ANG AND ROUNDED CLASTS
OHS 6569	3	550	297772	560738	0.65	B	Lo	Sltst	FEW SMALL FRAGS. MICACEOUS SOIL
OHS 6570	3	600	297819	560737	0.50	B	Lo	Gr	V STONY
OHS 6571	3	650	297869	560737	0.50	B	Lo	Sltst, Gr, Sst	LAYER OF COARSE GRAVEL AT 0.3. AB CLASTS
OHS 6572	3	700	297920	560733	0.60	B	Lo	Diorite, Sltst	AB FRAGS ROTTEN GRANODIOR. AND HORNFELS COBBLES
OHS 6573	3	755	297975	560755	0.50	B	Lo	Gr	AB ROTTEN CLASTS
OHS 6574	3	800	298020	560751	0.65	B	Si, Sa	Sltst	DEEP PLOUGHED SOIL. MICACEOUS AND GRITTY SOIL AT BASE
OHS 6575	3	850	298065	560750	0.85	B	Si, Sa	Sltst, Gr, Sst	AB ROUNDED CLASTS
OHS 6576	3	900	298120	560745	0.80	B	Lo	Sst	GN YELL MOTS. FEW SUBANG CLASTS. SOIL IS MICACEOUS.
OHS 6577	3	950	298170	560742	0.90	B	Si, Cl	Sltst	YELL MOTS. FEW SUBRNDED CLASTS. CLAY SOIL ?ALLUVIAL DEPOSIT
OHS 6578	3	1000	298220	560738	1.10	B	Cl	Sst, Sltst	FEW RNDED CLASTS. CLAY RICH TOP SOIL, SALT MARSH TO EAST

Texture

Cl=Clay
Lo=Loam
Sa=Sand
Si=Silt

Clast Lithology

Ba=Baryte
Bas=Basalt
Fel=Felsite
Gr=Granodiorite
Gwk=Greywacke

Lst=Limestone
Mudst=Mudstone
Porph=Porphyrite
Qtz=Quartz
Sst=Sandstone
Sltst=Siltstone

Table 2B Kirkbean Soil Data

Samp. Ref. No.	Traverse No.	Distance (m)	Easting	Northing	Cu ppm	Pb ppm	Zn ppm	Ba ppm	Ni ppm	Co ppm	Fe ppm	Mn ppm	Al ppm
OHS 6501	1	0	297030	562089	11	34	30	79	11	7	22371	83	24995
OHS 6502	1	50	297075	562075	16	30	49	60	25	11	27563	251	32064
OHS 6503	1	100	297125	562062	16	31	38	74	14	12	25677	478	31080
OHS 6504	1	150	297172	562050	18	41	54	1687	32	12	26533	296	38345
OHS 6505	1	200	297218	562039	123	124	188	1190	40	20	32147	2500	43142
OHS 6506	1	250	297270	562022	52	126	183	841	64	21	39670	680	48535
OHS 6507	1	300	297320	562010	48	63	96	1005	51	16	36727	1718	40666
OHS 6508	1	350	297370	561999	26	82	93	394	33	18	28364	839	33181
OHS 6509	1	400	297412	561988	33	88	97	1393	42	17	32452	593	44309
OHS 6510	1	450	297463	561971	24	64	63	2310	48	17	37356	347	58878
OHS 6511	1	500	297510	561961	20	90	38	903	33	10	21878	131	45253
OHS 6512	1	550	297559	561947	14	53	47	206	26	12	30742	302	47687
OHS 6513	1	600	297602	561936	13	32	44	81	26	11	26191	277	32551
OHS 6514	1	650	297655	561921	10	29	39	90	30	12	21293	313	21472
OHS 6515	1	700	297703	561906	10	22	34	71	24	9	18292	331	15819
OHS 6516	1	748	297740	561895	17	37	58	133	39	15	31993	375	32713
OHS 6517	1	800	297800	561880	15	43	66	151	42	18	35783	533	41077
OHS 6518	1	850	297850	561870	21	64	66	124	27	12	28534	403	34038
OHS 6519	1	900	297900	561853	25	63	75	154	40	16	35064	642	58045
OHS 6520	1	950	297949	561840	18	36	64	111	31	12	29621	291	39373
OHS 6521	1	1000	297994	561826	17	48	61	148	46	16	32156	372	42826
OHS 6522	1	1050	298040	561818	19	47	80	125	35	13	31124	437	39643
OHS 6523	1	1100	298080	561818	12	25	45	108	19	9	22905	386	32337
OHS 6524	1	1150	298130	561818	13	14	56	126	37	12	29272	295	38534
OHS 6525	1	1200	298180	561818	22	47	69	723	47	19	32856	644	34369
OHS 6526	1	1250	298230	561818	12	32	47	122	22	10	29468	438	32477

Table 2B continued

Samp. Ref. No.	Traverse No.	Distance (m)	Easting	Northing	Cu ppm	Pb ppm	Zn ppm	Ba ppm	Ni ppm	Co ppm	Fe ppm	Mn ppm	Al ppm
OHS 6527	1	1300	298280	561818	14	35	46	118	26	12	31046	314	30935
OHS 6528	2	0	296355	559960	17	66	40	60	16	15	26590	327	23848
OHS 6529	2	50	296410	559948	21	38	57	98	33	16	35837	314	38005
OHS 6530	2	100	296451	559938	29	35	65	81	26	15	33093	324	40443
OHS 6531	2	150	296500	559920	23	34	58	56	17	18	36888	727	35914
OHS 6532	2	200	296546	559910	32	35	87	104	51	25	35363	405	33959
OHS 6533	2	250	296597	559898	17	33	49	83	29	13	32208	318	37428
OHS 6534	2	300	296641	559882	16	62	68	108	29	14	30468	595	35474
OHS 6535	2	350	296693	559870	26	49	102	124	71	21	45677	920	51991
OHS 6536	2	400	296740	559858	13	71	41	87	12	6	14637	266	28241
OHS 6537	2	450	296787	559849	20	52	69	127	38	15	33948	357	41507
OHS 6538	2	500	296838	559832	11	34	63	118	33	14	37834	387	40878
OHS 6539	2	550	296883	559821	20	64	90	159	63	27	50993	1086	45061
OHS 6540	2	600	296932	559810	15	30	44	118	31	13	20966	366	22432
OHS 6541	2	650	296985	559796	21	42	66	137	45	18	27489	488	32163
OHS 6542	2	706	297038	559781	69	64	74	209	62	24	37292	789	43730
OHS 6543	2	750	297087	559770	28	42	80	210	49	19	38504	785	45913
OHS 6544	2	800	297128	559758	20	51	78	187	42	17	45216	523	47259
OHS 6545	2	850	297173	559745	17	35	61	193	25	14	33121	1325	42405
OHS 6546	2	900	297222	559731	22	56	87	216	46	18	33307	1176	42782
OHS 6547	2	950	297272	559720	23	24	78	307	38	12	28862	843	38934
OHS 6548	2	1000	297321	559708	20	35	84	350	51	16	31948	692	42907
OHS 6549	2	1050	297365	559698	23	40	95	339	41	17	33790	1103	43581
OHS 6550	2	1100	297417	559683	21	44	66	157	64	21	38168	973	41618
OHS 6551	2	1150	297462	559672	15	28	54	377	51	18	33984	424	37568
OHS 6552	2	1200	297520	559656	21	37	93	402	72	22	52581	213	63656

Table 2B continued

Samp. Ref. No.	Traverse No.	Distance (m)	Easting	Northing	Cu ppm	Pb ppm	Zn ppm	Ba ppm	Ni ppm	Co ppm	Fe ppm	Mn ppm	Al ppm
OHS 6553	2	1250	297569	559658	20	30	78	363	59	22	39630	971	46079
OHS 6554	2	1300	297620	559659	20	36	102	234	42	19	36283	952	44948
OHS 6555	2	1350	297670	559659	28	131	206	417	56	21	45330	2029	51323
OHS 6556	2	1400	297720	559659	22	29	82	357	33	13	29703	930	36125
OHS 6557	2	1450	297770	559659	18	31	59	425	30	13	38177	260	35214
OHS 6558	3	3	297237	560771	12	29	43	74	19	10	10039	106	31388
OHS 6559	3	50	297282	560770	19	32	48	156	27	12	22011	254	24610
OHS 6560	3	100	297333	560769	14	26	51	106	33	12	31257	235	37037
OHS 6561	3	150	297380	560768	17	37	73	174	32	14	28480	727	40660
OHS 6562	3	200	297429	560763	17	29	61	142	29	13	26416	679	37358
OHS 6563	3	250	297479	560761	18	25	60	127	29	11	31147	369	36818
OHS 6564	3	300	297530	560750	22	38	70	438	38	16	20523	199	35842
OHS 6565	3	350	297579	560748	18	15	67	254	49	17	31000	415	39850
OHS 6566	3	405	297630	560742	14	30	25	379	15	7	10278	60	30485
OHS 6567	3	453	297672	560742	17	33	36	512	28	10	8784	83	30103
OHS 6568	3	500	297720	560740	17	38	61	232	42	15	26720	323	41964
OHS 6569	3	550	297772	560738	12	33	55	183	35	11	17892	128	34238
OHS 6570	3	600	297819	560737	19	29	58	124	38	14	27938	455	35489
OHS 6571	3	650	297869	560737	29	49	73	155	72	22	42613	1112	50880
OHS 6572	3	700	297920	560733	23	49	82	133	54	20	37179	504	52744
OHS 6573	3	755	297975	560755	21	55	91	199	51	26	42133	670	58930
OHS 6574	3	800	298020	560751	15	23	73	277	49	18	47555	279	43348
OHS 6575	3	850	298065	560750	13	31	74	275	48	17	26830	234	33068
OHS 6576	3	900	298120	560745	11	29	76	247	57	17	37746	232	42619
OHS 6577	3	950	298170	560742	13	51	65	274	44	16	32341	189	51906
OHS 6578	3	1000	298220	560738	11	54	65	272	34	13	28244	191	50473

Table 3a Kirkbean Surface Rock Observations

Sample Ref. No.	Easting	Northing	Locality	Comments
OHR6101	297509	559149	KIRKBEAN GLEN 400M UPSTM A710 15M ABOVE ?FAULT IN LAVAS	CALCITE VEINING SLICKENSIDED CARBONATE-COATED SURFACES.
OHR6102	297390	559130	KIRKBEAN GLEN 500M UPSTM A710	TOP OF SHALE SEQUENCE 2 M FROM BASE OF BASALT. V. HEMATISED
OHR6103	297390	559130	KIRKBEAN GLEN 500M UPSTM A710	BASE OF LAVA FLOW CONFORMABLE ON ORS WITHIN GENTLE SYNCLINE
OHR6104	297390	559130	KIRKBEAN GLEN 500M UPSTM A710	BRECC. LAVA/SED. HEMATISED AND CARBONATED BELOW BASE OF FLOW
OHR6105	297556	559122	KIRKBEAN GLEN 250M UPSTM A710	V. VEINED LMST WITH MINOR CU-FE < 2M FROM LAVA/LMST CONTACT.
OHR6106	297580	559121	KIRKBEAN GLEN 180M UPSTM A710	BUFF 0.5M THICK CMNTST. UNIT WITH CARB. VEINING AND RARE COARSE PBS
OHR6107	297582	559143	KIRKBEAN GLEN, 50M DWNSTM OF SMALL DAM	0.5M LMST ABOVE SHALES. MINOR CU-CUFES VNING
OHR6108	297615	559118	KIRKBEAN GLEN 15M UPSTM OF DERELICT HOUSE 150M UPSTM A710	MED GREY LMST WITH ABUN. CALCITE VEINING, MINOR CUFES
OHR6109	297191	562641	GILLARTHUR WOOD GLEN, WEST BANK ABOVE TRACK	METAGREYWACKE
OHR6110	297205	562618	GILLARTHUR WOOD GLEN, WEST BANK	LAVA IN NEAR VERTICAL CONTACT WITH SILTY METASEDIMENT
OHR6111	297279	562511	GILLARTHUR WOOD GLEN, WEST BANK	PINK FELDSPAR IN SCHIST ?THERMALLY ALTERED AND RECRYSTALLISED
OHR6112	297292	562464	GILLARTHUR WOOD GLEN, WEST BANK	HORNFELSED SILTY METASEDIMENT
OHR6113	297420	562425	EAST SIDE DRUM BURN AR S END OF GILLARTHUR GLEN	FINE GRAINED METASEDIMENT WITH SHATTER ZONES
OHR6114	288480	554140	BASE OF CLIFF AT BRANDY COVE	MILLER AND TAYLOR ?U-CU. 20CM BRECC. VEIN WITH 2Y-CU IN PORPYRITE
OHR6115	297218	562039	ON LINE 1 OF SOIL TRAVERSES, S OF DRUM BURN	BARYTE VEIN MATERIAL (FLOAT) ON SOIL TRAV. ALSO IN WALL MATERIAL.
OHR6116	296693	559870	COLLECTED FROM SOIL PIT ON LINE 2, 350M N OF KIRKBEAN GLEN	COMPOSITE SAMPLE OF ANG. WEATHERED ?MINERALISED ROCK FRAGS
OHR6118	297255	561909	STREAM AT NORTH EAST CORNER OF CUSHAT WOOD	BARYTE BLOCK FROM 'LEEDER'S VEIN' IN CUSHAT WOOD
OHR6119	288440	554098	BASE OF CLIFF AT BRANDY COVE	MILLER AND TAYLOR VEIN. ?U-CU MINS. ASSOCIATED BA AND HEM. CHERT.

Table 3B Kirkbean Surface Rock Data

Sample Ref. No.	Easting	Northing	Cu ppm	Zn ppm	Pb ppm	Ba ppm	Ni ppm	Sb ppm	U ppm	Fe_2O_3 %	MnO %	CaO %
OHR6101	297509	559149	14	142	19	331	221	6	5	9.93	0.155	8.75
OHR6102	297390	559130	12	52	7	293	67	6	6	10.71	0.083	1.56
OHR6103	297390	559130	34	85	5	341	223	2	4	8.32	0.07	1.73
OHR6104	297390	559130	10	6	0	86	6	4	3	1.25	0.265	26.12
OHR6105	297556	559122	143	71	8	302	54	0	6	4.61	0.166	10.44
OHR6106	297580	559121	93	114	1434	166	21	2	7	2.31	0.822	36.42
OHR6107	297582	559143	16	53	16	286	106	4	6	4.06	0.106	7.69
OHR6108	297615	559118	106	46	56	312	118	2	4	3.17	0.405	14.09
OHR6109	297191	562641	24	117	52	965	98	5	5	8.43	0.09	0.88
OHR6110	297205	562618	10	15	19	882	16	1	4	3.03	0.063	0.28
OHR6111	297279	562511	22	83	19	1103	114	4	5	8	0.152	2.05
OHR6112	297292	562464	9	32	7	842	33	1	3	3.32	0.058	0.26
OHR6113	297420	562425	11	62	5	465	71	4	5	6.11	0.067	0.13
OHR6114	288480	554140	707	29	18	470	28	4	8	4.91	0.187	5.54
OHR6115	297218	562039	93	22	-97	483000	20	0	-98	0.08	0.012	0.02
OHR6116	296693	559870	13	48	5	802	65	1	4	4.92	0.194	0.17
OHR6118	297255	561909	62	17	10	298000	18	17	-98	1.1	0.022	0.05
OHR6119	288440	554098	1205	28	17	1387	16	6	8	3.24	0.049	0.57

Value of -97; element not determined due to interference, probably of low concentration
Values of -98; element not determined due to interference, no estimate

Table 4 Kirkbean Panned Till Data

Samp. Ref. No.	Easting	Northing	Depth (m)	Pan Minerals	Cu ppm	Pb ppm	Zn ppm	Ba ppm	Ni ppm	Fe_2O_3t %	MnO %
OHU 7001	296430	556700	2.30	Ba	13	13	18	1372	17	4.59	0.025
OHU 7002	296400	556845	2.70	Ba	57	28	88	1116	78	19.50	0.084
OHU 7003	296360	557027	2.70		25	18	47	455	34	10.06	0.064
OHU 7004	296300	557155	1.50		24	30	55	451	40	7.05	0.053
OHU 7005	296300	557155	2.20		22	22	54	485	35	5.72	0.059
OHU 7006	296270	557250	2.75		18	16	41	434	30	7.93	0.038
OHU 7007	296245	557440	4.50		29	35	65	668	54	15.00	0.071
OHU 7008	296170	557640	3.50	*Ba*	63	563	430	15429	75	10.84	0.077
OHU 7009	296748	557385	5.70		36	28	73	690	84	21.90	0.087
OHU 7010	296778	557290	6.00		24	28	73	493	51	17.89	0.097
OHU 7011	296805	557188	4.90		14	15	53	513	33	6.51	0.051
OHU 7012	296680	557600	2.40	Ba	31	42	68	2686	79	15.82	0.085
OHU 7013	296630	557755	3.70		55	29	89	713	126	31.80	0.127
OHU 7014	296630	557755	1.60		34	23	74	598	121	21.56	0.084
OHU 7015	296870	556980	1.80		10	12	39	477	23	3.49	0.038
OHU 7016	296930	556820	1.80		9	5	34	347	16	4.52	0.038
OHU 7017	297260	557310	2.50		11	9	23	285	18	4.48	0.024
OHU 7018	297395	557165	4.00		43	36	42	368	47	13.57	0.063
OHU 7019	297340	556980	3.40		16	22	33	458	27	6.85	0.043
OHU 7020	297600	557060	3.40	Ba	33	14	42	2232	23	5.36	0.037
OHU 7021	297100	557765	1.50		8	15	32	435	20	4.76	0.041
OHU 7022	296945	557960	0.90		38	19	66	473	116	12.33	0.065
OHU 7023	297005	557875	1.50		15	35	55	505	55	10.31	0.056
OHU 7024	297160	557670	3.20		8	16	38	391	17	4.12	0.050
OHU 7025	297210	557510	3.90	Fe	25	36	60	398	38	7.22	0.054
OHU 7026	297950	557075	3.40	Fe	18	9	29	263	23	4.25	0.024
OHU 7027	297825	557285	3.40	Fe, Cu, *Ba*	34	21	63	12825	35	7.15	0.043
OHU 7028	297725	557495	3.80	Ba	14	14	43	1403	21	4.64	0.029
OHU 7029	297690	557580	3.60	Zn, Ba	56	16	45	479	25	6.29	0.051
OHU 7030	297450	558065	5.20	*Fe*, Zn, Ba	21	26	175	2785	38	7.97	0.050
OHU 7031	297330	558130	2.50	Ba	23	37	77	536	49	9.94	0.059
OHU 7032	297490	558315	4.40	Zn	28	27	58	525	24	6.97	0.044
OHU 7033	297425	558510	1.80	Ba	24	25	75	1193	99	17.43	0.070
OHU 7034	297380	558660	1.00		50	25	84	828	124	13.78	0.063
OHU 7035	297665	557275	2.60		43	19	50	306	34	8.72	0.044
OHU 7036	297610	557660	3.40	*Fe*	23	13	67	952	26	5.55	0.043
OHU 7037	297630	557870	3.50	*Fe*	43	26	179	1085	32	9.08	0.051
OHU 7038	297380	557495	3.30	Fe	11	15	40	314	19	4.34	0.029
OHU 7039	298160	557380	2.60	*Fe*, Cu, Pb,	470	76	33	358	121	9.49	0.027
OHU 7040	298320	557090	3.00		14	17	54	339	25	4.58	0.033
OHU 7041	298120	557570	3.10		24	24	77	446	39	5.41	0.046
OHU 7042	298165	557660	2.80	Fe	94	29	833	255	41	6.66	0.074
OHU 7043	298150	557755	2.70	Fe	24	36	62	339	31	6.47	0.027
OHU 7044	298060	557955	2.10		33	14	29	314	32	3.46	0.027
OHU 7045	298015	558160	7.00	Fe	17	31	80	823	27	9.42	0.073
OHU 7046	298015	558160	7.70	*Fe*, Ba	28	20	82	1788	24	5.99	0.049
OHU 7047	297990	558330	8.50	Ba, Fe	15	23	46	601	28	9.40	0.056

Table 4 continued

Samp. Ref. No.	Easting	Northing	Depth (m)	Pan Minerals	Cu ppm	Pb ppm	Zn ppm	Ba ppm	Ni ppm	Fe_2O_3t %	MnO %
OHU 7048	298025	558660	5.00	Fe	20	31	129	1340	36	11.56	0.087
OHU 7049	297920	558765	3.80	Fe	16	28	50	4375	32	8.78	0.068
OHU 7050	297815	558660	2.70		15	19	43	531	28	5.98	0.043
OHU 7051	298195	559020	5.00		17	29	50	1527	34	11.27	0.070
OHU 7052	298240	559260	7.20	Fe	17	24	57	1179	44	12.43	0.080
OHU 7053	298395	558680	6.00	*Ba*	19	21	116	30233	23	6.19	0.032
OHU 7054	298360	558775	6.00	Fe	61	36	116	1933	34	11.22	0.064
OHU 7055	298330	558870	11.00	Fe, Ba	15	18	58	3361	28	6.30	0.053
OHU 7056	298440	558490	5.40	*Fe*	17	29	53	1008	30	10.94	0.068
OHU 7057	298480	558350	2.10	*Fe*	40	25	77	338	37	4.78	0.040
OHU 7058	298940	558475	3.80	*Fe*	17	18	36	842	26	6.62	0.033
OHU 7059	298880	558730	3.10	Fe	20	18	51	453	26	6.03	0.028
OHU 7060	298870	558785	2.80	Fe	7	8	31	245	14	5.59	0.036
OHU 7061	298850	558900	7.50	Fe	11	12	24	491	17	3.44	0.036
OHU 7062	298820	558985	11.20	Fe	7	8	21	361	18	2.66	0.071
OHU 7063	298780	559080	9.20	Fe	9	10	24	417	16	3.97	0.035
OHU 7064	298730	559280	8.70	*Fe*	7	40	23	379	17	5.33	0.037
OHU 7065	298670	559470	11.20	Fe	10	18	39	559	25	12.10	0.051
OHU 7066	299200	559275	8.70	Fe	16	34	38	314	96	17.94	0.127
OHU 7067	299220	559110	10.50		8	18	22	505	18	3.00	0.031
OHU 7068	297610	559050	2.10	Ba	19	41	78	608	31	5.69	0.075
OHU 7069	297710	558920	5.20	Fe, Ba	22	26	58	640	47	15.37	0.109
OHU 7070	295070	556980	3.00	Ba	25	38	94	3602	50	18.24	0.059
OHU 7072	295240	556910	7.80	Ba	21	34	65	1007	41	10.53	0.072
OHU 7073	295430	556790	4.00		23	29	72	570	43	11.08	0.055
OHU 7074	295610	556705	2.80	Fe	18	22	69	528	42	9.13	0.046
OHU 7075	295805	556605	2.30		35	25	105	393	48	11.90	0.057
OHU 7076	295950	556510	3.70	Fe	53	14	112	340	49	6.06	0.049
OHU 7077	293740	557800	0.90		13	26	44	585	27	11.17	0.067
OHU 7078	293780	557610	1.30	Fe	10	24	33	616	20	6.34	0.055
OHU 7079	293800	557420	1.40	Fe	16	27	44	574	30	10.72	0.071
OHU 7080	293840	557200	0.80		8	19	32	574	17	4.13	0.052
OHU 7081	293880	557045	3.30		22	26	54	646	35	18.12	0.085
OHU 7082	298080	557300	2.40	Fe	32	27	150	308	24	4.55	0.058
OHU 7083	298130	557470	2.40	Fe	18	18	35	301	27	4.39	0.026
OHU 7084	298290	556860	2.70	Fe	8	11	27	282	14	3.33	0.027

Fe = Pyrite, Ba = Baryte, Pb = Galena
Zn = Sphalerite, Cu = Chalcopyrite

Italicised text (e.g. *Ba*);estimated panned minerals present in moderate abundance (i.e. 1-3 %)
Underlined text (e.g. Fe); estimated panned minerals present in high abundance (i.e. >20 %)

Table 5 Kirkbean Sieved Till Data

Sample Ref. No.	Easting	Northing	Samp. Depth	Cu ppm	Pb ppm	Zn ppm	Ba ppm	Ni ppm	MnO %	Fe_2O_3 %	CaO %
OHT7001	296430	556700	2.30	40	43	62	299	64	0.07	7.39	0.24
OHT7002	296400	556845	2.70	43	38	131	236	112	0.08	8.71	1.12
OHT7003	296360	557027	2.70	38	53	67	250	67	0.09	7.32	0.53
OHT7005	296300	557155	2.20	23	37	69	179	53	0.07	4.66	1.36
OHT7006	296270	557250	2.75	41	47	88	254	68	0.15	7.94	0.88
OHT7007	296245	557440	4.50	31	35	147	314	53	0.10	5.42	8.86
OHT7008	296170	557640	3.50	48	264	382	661	76	0.14	7.75	0.62
OHT7009	296748	557385	5.70	28	44	123	238	89	0.07	6.98	0.89
OHT7010	296778	557290	6.00	41	52	148	237	59	0.10	6.87	1.34
OHT7011	296805	557188	4.90	25	33	77	351	50	0.06	4.18	9.34
OHT7012	296680	557600	2.40	45	106	117	586	106	0.05	7.43	0.86
OHT7013	296630	557755	3.70	45	40	89	247	77	0.07	5.97	0.78
OHT7015	296870	556980	1.80	23	38	105	280	62	0.03	5.84	0.85
OHT7016	296930	556820	1.80	24	52	83	234	67	0.03	6.02	0.88
OHT7017	297260	557310	2.50	38	37	89	248	65	0.06	6.90	0.39
OHT7018	297395	557165	4.00	35	48	54	261	71	0.12	7.13	5.01
OHT7019	297340	556980	3.40	19	34	54	467	43	0.05	4.19	2.70
OHT7020	297600	557060	3.40	10	23	146	239	56	0.04	4.13	3.72
OHT7021	297100	557765	1.50	19	38	79	172	41	0.03	4.34	0.43
OHT7022	296945	557960	0.90	61	24	120	93	210	0.11	9.70	0.57
OHT7023	297005	557875	1.50	28	87	112	138	94	0.08	6.48	0.40
OHT7024	297160	557670	3.20	28	59	202	294	46	0.14	5.59	0.82
OHT7025	297210	557510	3.90	36	65	95	260	71	0.09	6.65	1.60
OHT7026	297950	557075	3.40	25	23	54	288	67	0.03	5.24	0.39
OHT7027	297825	557285	3.40	10	27	39	265	49	0.02	3.92	2.81
OHT7028	297725	557495	3.80	16	20	56	291	55	0.06	4.56	0.34
OHT7029	297690	557580	3.60	22	21	44	171	37	0.04	3.19	6.04
OHT7030	297450	558065	5.20	22	25	67	451	44	0.05	4.18	5.68
OHT7031	297330	558130	2.50	33	147	194	165	86	0.11	6.91	1.03
OHT7032	297490	558315	4.40	25	28	137	260	50	0.06	4.82	9.11
OHT7033	297425	558510	1.80	10	32	79	236	124	0.03	8.94	0.35
OHT7034	297380	558660	1.00	73	33	129	315	183	0.17	9.74	0.87
OHT7035	297665	557275	2.60	26	26	95	224	52	0.06	5.19	0.22
OHT7036	297610	557660	3.40	23	31	68	366	56	0.07	5.15	4.91
OHT7037	297630	557870	3.50	23	41	61	305	50	0.04	4.30	6.20
OHT7038	297380	557495	3.30	37	60	125	286	71	0.11	6.69	0.38
OHT7039	298160	557380	2.60	27	50	63	336	61	0.02	5.66	0.53
OHT7040	298320	557090	3.00	20	49	60	294	66	0.03	5.21	3.03
OHT7041	298120	557570	3.10	22	48	51	329	58	0.04	4.72	4.75
OHT7042	298165	557660	2.80	24	57	106	364	64	0.04	4.99	5.10
OHT7043	298150	557755	2.70	19	54	77	307	58	0.04	4.71	0.40
OHT7044	298060	557955	2.10	52	41	54	343	72	0.07	5.81	0.39
OHT7046	298015	558160	7.70	17	27	47	388	38	0.05	3.51	4.55
OHT7047	297990	558330	8.50	18	30	51	330	41	0.05	3.56	4.32
OHT7048	298025	558660	7.80	19	41	54	388	39	0.04	3.63	7.03
OHT7049	297920	558765	5.00	23	31	64	673	50	0.06	4.39	3.86

Table 5 continued

Sample Ref. No.	Easting	Northing	Samp. Depth	Cu ppm	Pb ppm	Zn ppm	Ba ppm	Ni ppm	MnO %	Fe_2O_3 %	CaO %
OHT7050	297815	558660	3.70	27	34	115	166	52	0.06	4.83	1.60
OHT7051	298195	559020	5.00	23	34	62	392	50	0.06	4.57	2.51
OHT7052	298240	559260	7.20	26	51	71	319	55	0.07	4.83	1.81
OHT7053	298395	558680	6.00	18	34	54	890	39	0.05	3.50	8.64
OHT7054	298360	558775	6.00	10	11	35	272	28	0.03	2.61	3.95
OHT7055	298330	558870	5.00	16	29	48	338	38	0.05	3.29	3.19
OHT7056	298440	558490	4.50	14	27	37	167	31	0.04	2.92	2.00
OHT7057	298480	558350	1.00	23	63	47	226	59	0.03	4.62	2.31
OHT7058	298940	558475	1.50	19	36	62	401	51	0.03	4.85	2.03
OHT7059	298880	558730	3.10	12	29	78	189	41	0.05	5.01	0.17
OHT7060	298870	558785	2.80	17	21	77	306	50	0.03	5.99	0.40
OHT7061	298850	558900	7.50	26	35	60	157	55	0.04	3.99	8.30
OHT7062	298820	558985	11.20	8	17	31	81	20	0.04	1.98	6.88
OHT7063	298780	559080	9.20	14	19	58	172	33	0.04	3.82	3.11
OHT7064	298730	559280	8.70	14	19	48	183	35	0.04	3.41	3.66
OHT7065	298670	559470	11.20	21	26	63	267	47	0.04	4.38	0.84
OHT7066	299200	559275	8.70	11	25	50	148	28	0.03	3.16	1.72
OHT7067	299220	559110	10.50	7	13	37	95	20	0.03	2.49	3.25
OHT7068	297610	559050	2.10	29	78	239	233	66	0.09	5.29	0.83
OHT7069	297710	558920	5.20	23	26	66	272	53	0.07	4.53	1.43
OHT7070	295070	556980	3.00	24	33	71	254	40	0.04	4.65	3.67
OHT7071	295070	556980	1.50	27	39	142	187	55	0.05	9.87	0.47
OHT7072	295240	556910	7.80	33	44	148	286	53	0.09	5.45	2.98
OHT7073	295430	556790	4.00	36	45	136	309	56	0.09	5.71	2.05
OHT7074	295610	556705	2.80	38	53	146	299	61	0.11	6.51	4.29
OHT7075	295805	556605	2.30	43	52	171	259	79	0.16	7.90	3.52
OHT7076	295950	556510	3.70	34	42	89	236	60	0.06	6.36	4.29
OHT7077	293740	557800	0.90	15	15	57	75	27	0.04	3.20	0.58
OHT7078	293780	557610	1.30	21	30	50	61	23	0.04	3.76	0.28
OHT7079	293800	557420	1.40	24	32	49	66	21	0.03	3.91	0.24
OHT7080	293840	557200	0.80	28	51	95	95	27	0.07	4.08	0.43
OHT7081	293880	557045	3.30	28	21	68	171	34	0.03	3.47	0.59
OHT7082	298080	557300	2.40	25	43	111	280	61	0.05	4.99	8.11
OHT7083	298130	557470	2.40	21	33	49	233	53	0.03	4.00	2.87
OHT7084	298290	556860	2.70	19	39	56	219	50	0.05	4.73	5.30

Table 6 Comparison of percentile values for 80 samples of sieved and panned till

Percentile	*25*	*50*	*75*	*95*	*97.5*	*Outliers(>> 97.5%)*
Sieved till (ICPAES): collected at base of hole						
Cu	19	24	33	45	52	
Pb	27	36	48	78	105	147, 264
Zn	54	69	112	171	202	382
Ba	189	260	314	467	661	
Panned till (XRF)						
Cu	15	21	32	57	63	470
Pb	17	24	29	40	42	563
Zn	39	55	75	150	179	430, 833
Ba	393	528	1007	3602	12825	15429, 30233