British Geological Survey

Mineral Reconnaissance Programme

Platinum-group elements in the Huntly intrusion, Aberdeenshire, north-east Scotland

MRP Report 124
Technical Report WF/92/4

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BRITISH GEOLOGICAL SURVEY

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with a contribution on Geophysics by
P Greenwood

Notes on additional work on the Knock intrusion, north-east Scotland, are contained in Appendix 2

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Maps and diagrams in this report use topography based on Ordnance Survey mapping

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CONTENTS

FIGURES

SUMMARY

This report describes a programme of exploration for the platinum-group elements (PGE) carried out over the Caledonian mafic-ultramafic Huntly intrusion, located in west Aberdeenshire, Grampian region, Scotland. The area was considered as having potential for two principal classes of PGE-bearing mineralisation, namely magmatic reef style in cumulate rocks and hydrothermal type in structurally-controlled settings.

Recent re-mapping of the poorly exposed Huntly intrusion by BGS and Aberdeen University has revealed a complex internal structure and clarified the nature of its external contacts. Several discrete bodies of cumulate rocks have been recognised, while much of the intrusion comprises granular or contaminated gabbroic rocks without cumulate characteristics.

A comprehensive programme of lithogeochemical sampling was carried out over the intrusion and adjacent country rocks, in order to detect any indications of PGE-bearing mineralisation. Olivine cumulate rocks have the highest background concentrations of Pt and Pd. Maximum values of 50 ppb Pt and 25 ppb Pd were recorded in a peridotite from the West Huntly cumulate body. Deformed ultramafic rocks in a tectonically complex zone near the northern margin of the intrusion around Whitehill are locally enriched in precious metals, up to 28 ppb Pt, 63 ppb Pd and 30 ppb Au.

The highest levels of enrichment in precious metals (up to 462 ppb Pt+Pd+Au) were found in discordant mineralised pegmatitic pyroxenites in the West Huntly cumulate body, best exposed in the Bin Quarry. Drilling undertaken in the Bin Quarry showed that these bodies are narrow and impersistent at depth.

The West Huntly cumulate block was investigated for reef style PGE mineralisation using a variety of techniques. In the Dunbennan Wood area, detailed ground magnetic surveys were utilised to guide basal overburden sampling along reconnaissance traverses. Sporadic minor PGE enrichment was detected, with levels generally enhanced in the fine fraction (-100 mesh/ -150 micron) samples, relative to panned material. A biogeochemical orientation survey was conducted over the same area using various sample media from the four principal conifer species present, namely larch, Scots pine, Norway spruce and sitka spruce. The twigs of all species sampled showed a positive response to both Pt and Au. Although no conclusive association with bedrock geology was established, a general enhancement of precious metals is noted in larch twigs over ultramafic cumulates in the Dunbennan zone.

Reconnaissance surveys were conducted over the Central Huntly Shear Zone, a branch of the Portsoy lineament which transects the Huntly intrusion and which is associated with PGE-bearing Cu-Ni sulphide mineralisation on the flank of the Knock intrusion a few kilometres to the north. Magnetic and VLF surveys failed to detect any indications of structurally-controlled sulphide mineralisation in this zone. Soil-gas surveys, involving the measurement of oxygen and carbon dioxide, were conducted along reconnaissance traverses across this structure in order to detect any indications of oxidising sulphide mineralisation. Significant anomalies, with CO_2 content locally in excess of 10%, were revealed in several areas. In most cases these anomalies were attributed to pedogenic or biogenic causes. At Cumrie North, however, soil-gas anomalies investigated by pitting

are ascribed to the tectonic juxtaposition of contrasting lithologies in a complex shear zone in the northern part of the structure. Only traces of sulphide mineralisation are present within this anomalous zone, but deformed ultramafic lithologies with minor enrichment in PGE were revealed by pitting. Soil sampling has indicated that additional bodies of ultramafic rock are also present in this sector of the shear zone.

INTRODUCTION

The investigations described in this report were conducted over the Huntly intrusion and immediately adjacent rocks, lying for the most part north of the town of Huntly in western Aberdeenshire, some 60 km north-west of the city of Aberdeen. The location of the survey area is shown on the regional geological map (Figure 1).

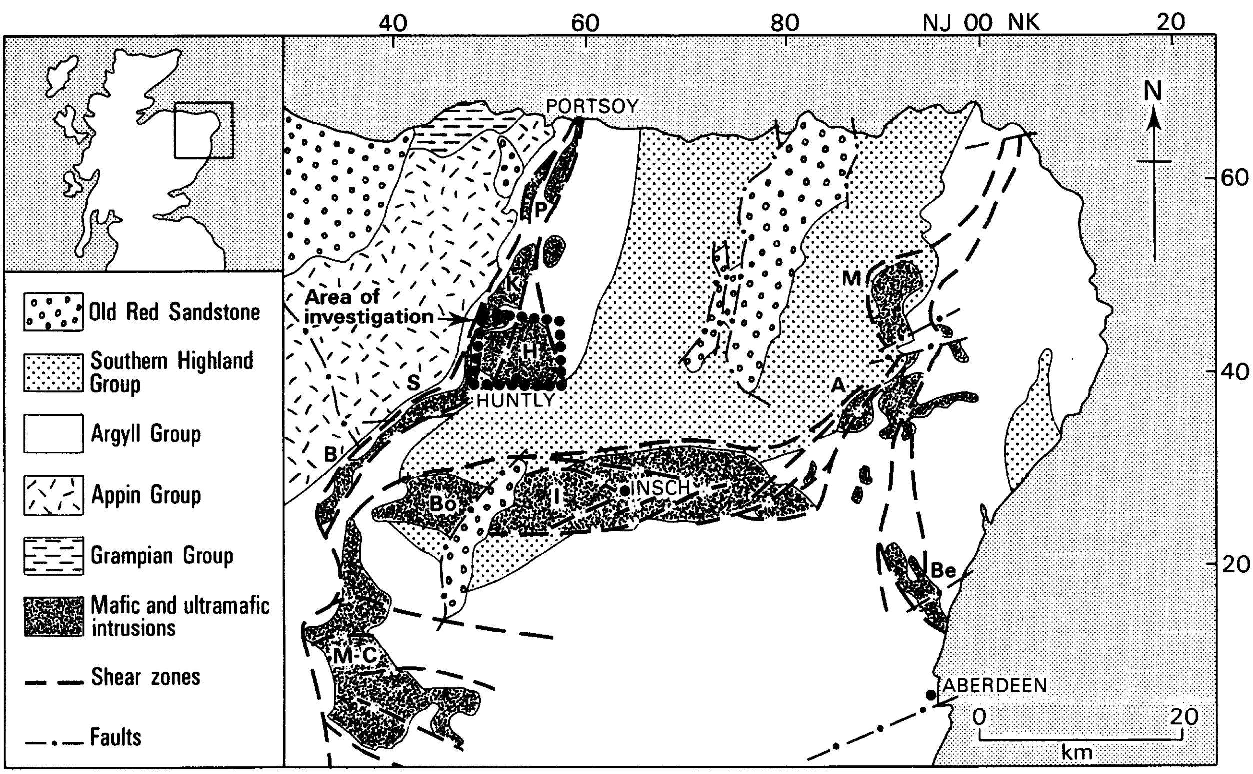


Figure 1 Regional geological map showing the location of the Huntly survey area.

Caledonian basic intrusions are:- K - Knock; P - Portsoy; S - Succoth-Brown Hill; B - Blackwater; M-C - Morven-Cabrach; Bo - Boganclogh; I - Insch; Be - Belhelvie; A - Arnage; M - Maud.

The surveys described were carried out as part of the DTI-sponsored Mineral Reconnaissance Programme. The work was conducted between 1985 and 1988, overlapping in part with that carried out in the Upper Deveron Valley to the south-west of Huntly (Gunn et al., 1990).

The Caledonian layered mafic-ultramafic intrusions of north-east Scotland represent the largest development of rocks of this type in the UK. From the outset these investigations were regarded as being potentially favourable for the occurrence of *magmatic* PGE-bearing mineralisation, either of the stratiform reef style (Merensky type) or in association with marginal Cu-Ni sulphide mineralisation, as developed at Sudbury, Kambalda, Duluth etc. (Naldrett, 1989). However, with the increasing recognition of PGE mobility and enrichments in a wide variety of 'new' settings (Hulbert et al., 1988), it became clear that attention should not be restricted to targets of magmatic origin. Also, during the course of the investigations in north-east Scotland secondary mobilisation and concentration of the PGE was recognised in a number of areas. In particular in the Upper Deveron Belt and on the margin of the Knock intrusion the PGE distributions in certain zones were shown to have been modified by secondary hydrothermal processes (Gunn et al., 1990; Fletcher and Rice, 1989). As a result, investigations were directed towards the examination of structurally-controlled targets in the latter part of the work programme in the Huntly intrusion.

PHYSIOGRAPHY

The survey area is situated within a thinly populated part of west Aberdeenshire, north-east Scotland. With the exception of the flatter floodplain terraces of the River Deveron and its main tributaries the landscape is rolling and in some places hilly, mostly falling within the range 100 to 200 m. The rounded hilltops of the Bin (313 m) and Ordiquhill (249 m) are the highest points in the area (Figure 2).

A large part of the study area (approximately 16 km^2) is planted with a variety of conifer species. The forest is mature and dense, making access on foot difficult. However, vehicle access is facilitated by forestry tracks and peripheral public roads. The remaining land, with the exception of the small town of Huntly, is under agricultural use.

The region has been subjected to glacial and glacio-fluvial processes during periods of maximum glaciation. On the lower ground marginal to the river floodplains these deposits are of significant thickness, exceeding 10 m in places. Over intermediate elevations the drift cover is a lodgement till usually less than 3 m in thickness, with boulders of largely local origin in a clay or sandy clay matrix. On the hill tops the cover is dominantly of residual soils of the order 0-1 m thick.

Bedrock exposure is generally poor due to the widespread drift cover. The disused Bin and Sinsharnie roadstone quarries (Figure 2) provide the best exposures in the western part of the Huntly intrusion. Small exposures and subcrop are also found on higher ground and where forestry operations have disturbed the thinner soils. Exposure is very poor over large areas of the central and eastern parts of the intrusion.

Drainage density over the study area is insufficient for detailed sampling, being generally confined to a few small tributary valleys. The thick drift infilling these valleys makes them unsuitable for geochemical drainage surveys.

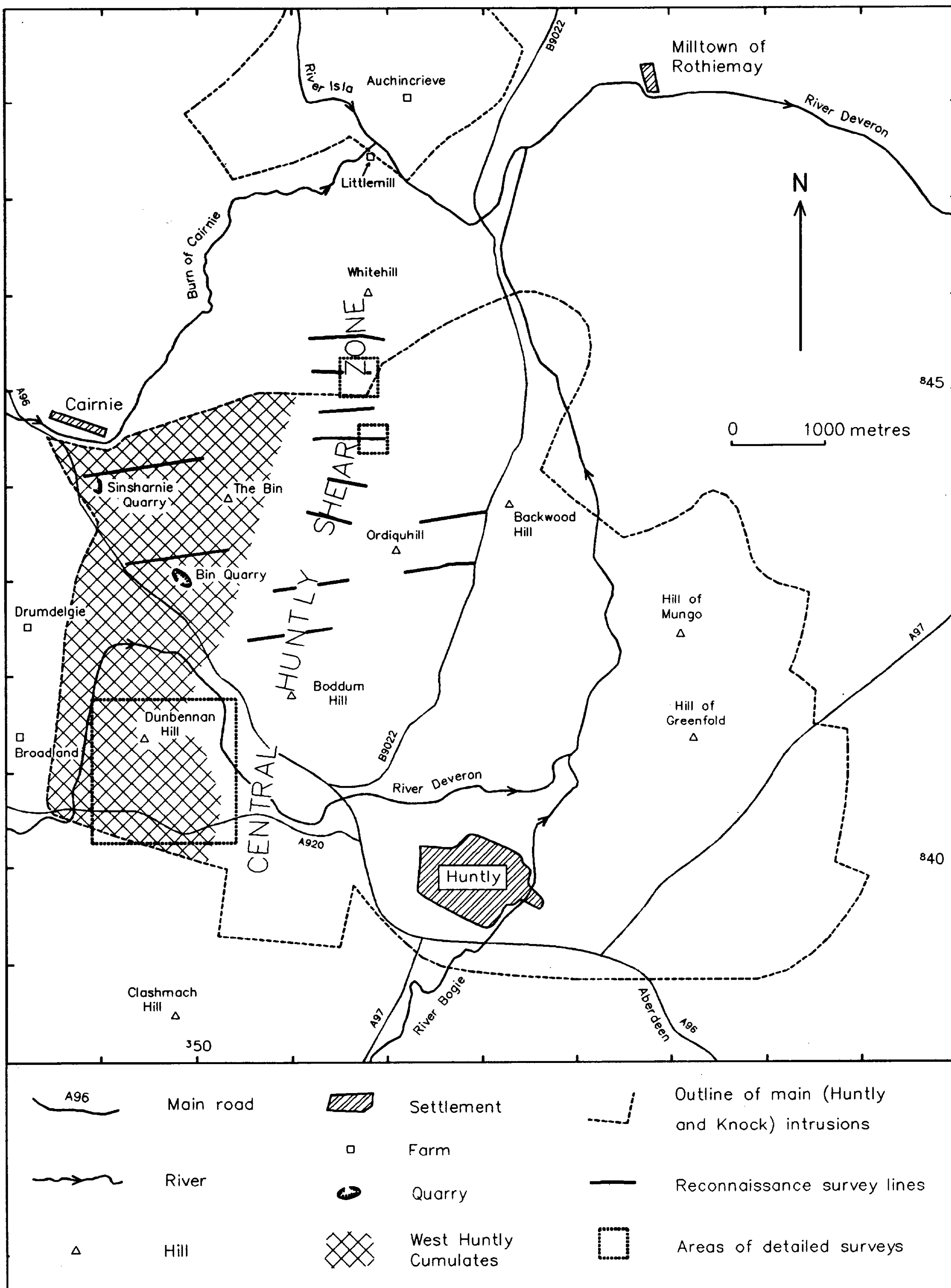


Figure 2 Location of reconnaissance traverses and zones of detailed investigations in the Huntly intrusion survey area

PREVIOUS WORK

Between 1969 and 1973 Rio Tinto Zinc and Consolidated Goldfields operated in the region, as a consortium known as Exploration Ventures Limited (EVL), for the purpose of conducting a programme of exploration for Cu-Ni mineralisation associated with the Caledonian basic intrusions. A limited amount of effort was directed towards evaluating the potential of these bodies for the occurrence of PGE.

The EVL surveys were conducted over a large area bounded by the River Dee to the south and the River Spey to the west. A wide variety of techniques were employed including mapping, geochemistry (mainly drainage and soil sampling) and geophysics (mainly magnetic, electromagnetic and IP). In addition, a substantial programme of core drilling was conducted in zones of potential, focusing mainly on the Huntly - Knock - Portsoy intrusions, but with limited additional drilling in the Belhelvie and Arnage bodies. The records of this programme are incomplete and, as a result of the large scale of the operation, are often difficult to evaluate in detail. Many maps and reports derived from the programme are held on open-file by BGS, but it is often difficult to ascertain what investigations were carried out in any particular zone and what results were obtained. The most useful document is an excellent compilation by Wilks (1974) of the activities in the western part of the survey area.

The Huntly intrusion and its margins were covered by reconnaissance soil sampling and ground magnetic surveys, with more detailed infill in anomalous zones. Reconnaissance ground IP surveys were conducted in zones potentially favourable for the occurrence of Cu-Ni sulphide mineralisation, principally over the main bodies of cumulate rocks and the external boundaries of the intrusion. Detailed IP was undertaken over the most promising anomalies to assist in drill target defintion.

A total of 12 cored boreholes (aggregate depth 1792 m) was drilled in the Huntly intrusion on six separate anomalies. The detailed locations and depths are listed in Table 1 and the sites shown in Figure 3.

Table 1 EVL Cored boreholes in the Huntly intrusion.

Borehole	Area	National Grid Reference	Depth (metres)
HK9*	Dowmin	349550 842170	34.57
HK10	Dowmin	349550 842170	211.35
HK12	Dowmin	349330 842100	199.34
HK14	Bridges	356519 842656	170.28
HK15	Bridges	356425 842384	117.24
HK16	Dunbennan	349469 841257	149.06
HK17	Dunbennan	349688 840767	130.76
HK18	Smithy Hillock	349222 843713	134.11
HK19	Smithy Hillock	349365 843940	153.71
HK20	Mungo Hill/ Corse of Kinnoir	354747 842619	142.04
HK21	Mungo Hill/ Corse of Kinnoir	354952 843100	143.87
CD1	Broadland	348620 840860	205.44

* No drillcore available for this borehole from Information Services, Keyworth

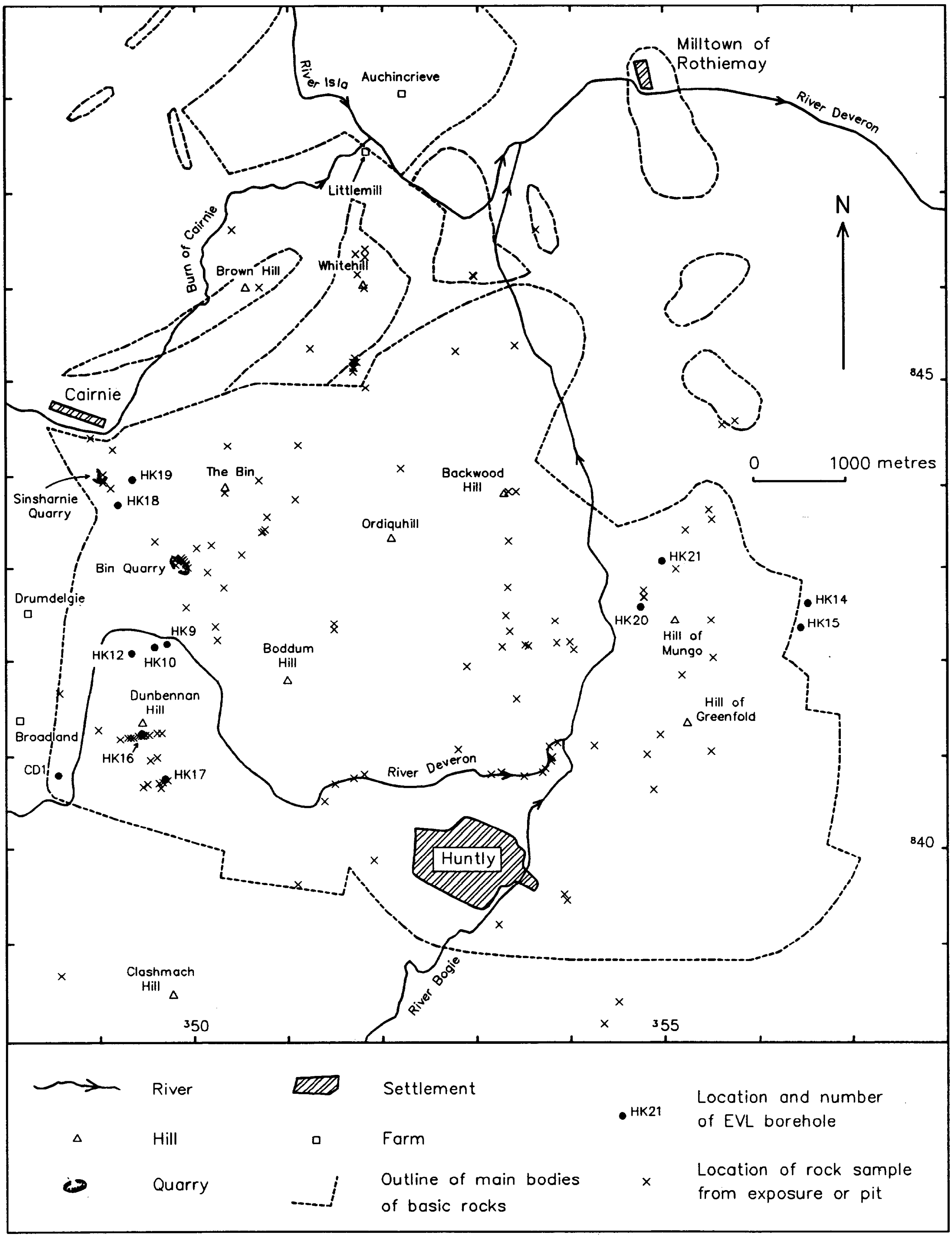


Figure 3 Locations of rock samples collected in this study and EVL borehole sites in the Huntly intrusion survey area

Boreholes HK9, 10 and 11 were drilled to test weak IP anomalies at the contact between olivine cumulates and 'contact facies' rocks (sensu Fletcher, 1989) at the northern end of Dunbennan Hill. Only sparse sulphide mineralisation was detected and it was concluded that the IP anomalies were spurious, derived from fences and buried pipes. Boreholes HK14 and 15 were collared to investigate coincident magnetic and IP anomalies at Bridges farm on the unexposed eastern boundary of the intrusion. The geophysical observations were explained by the presence of minor sulphide, graphite and magnetite occurring in a troctolite - picrite unit within a sequence of gabbros. Boreholes HK16 and 17 were drilled to test a linear IP and magnetic anomaly in the Dunbennan section of the West Huntly cumulate body. Coincident enrichment in soils of Cu (180 ppm maximum) and Ni (1100 ppm maximum) was also present at these sites. Layered sequences of olivine cumulates, principally picrite and troctolite, were encountered in both boreholes. Low sulphide contents, up to 1%, together with secondary magnetite, accounted for the observed IP anomalies. Boreholes HK18 and 19 were drilled in the northern section of the West Huntly cumulate body near Smithy Hillock in a similar setting to the Dunbennan targets. A comparable sequence of weakly mineralised olivine cumulates was intersected, although there were additional discordant xenolithic zones of metasediment carrying up to 5% graphite and 2 - 5% pyrrhotite. Boreholes HK20 and 21 were sited to investigate a coincident IP, magnetic and soil anomaly near the margin of an extensive area of largely unexposed olivine cumulates in the eastern part of the intrusion. Weakly mineralised and serpentinised picrites within a series of olivine gabbronorites and contaminated gabbros were judged to be the source of the observed anomalies. Borehole CD1 was drilled to explore the possibility of the existence of a sulphide accumulation at the base of the thick West Huntly cumulate body, comparable to those developed at Duluth and Sudbury (Naldrett, 1989). The section encountered in this borehole comprised an alternating sequence of olivine gabbros, troctolites and picrites containing only minor sulphides and showing no signs of increasing concentration towards the base of the hole, which was in unhornfelsed metasediments.

Overall, despite drilling the best anomalies, there was no indication of more than minor Cu and Ni mineralisation in the Huntly intrusion. A small number of samples from these boreholes were analysed by EVL for Pt and Pd. No values above detection limit were reported, although considerable doubt exists over the quality of the analytical data (Wilks, 1974). This uncertainty has been further reinforced by work carried out in MRP investigations elsewhere in the region, where repeat sampling of surface exposures failed to corroborate enhanced PGE concentrations originally reported by EVL. Some core from each of the boreholes drilled in the Huntly intrusion, with the exception of HK9, is held in the BGS archive. However, this material for the most part comprises short discontinuous sections unsuitable for PGE analysis.

During 1976 - 1977 Amax followed up some of EVL's results, re-assessing the early data and carrying out an extensive programme of shallow rotary percussion drilling in the Huntly - Knock area. They concluded that, in view of the structural complexity, the prospects for locating further mineralisation in the Huntly - Knock area were remote.

There is a long history of research into the structure and petrogenesis of the Caledonian basic intrusions at Aberdeen University. Studies carried out over many years by Munro and co-workers greatly improved the understanding of the internal structure of the Huntly intrusion (Munro, 1970; Munro, 1984; Munro and Gallagher, 1984). They also collaborated widely with EVL, particularly in regard to the airborne geophysics and drilling elements of the exploration programme. Subsequently Fletcher (1989) undertook detailed geochemical and isotopic studies of Cu-Ni mineralisation in the Knock intrusion and produced a new geological map of the Huntly and Knock intrusions.

The BGS possesses a substantial archive of open-file material derived from the EVL and Aberdeen University programmes, including many plans and reports as well as numerous specimens and thin sections. In addition, the BGS has recently digitised the results of a helicopter-borne detailed aeromagnetic survey conducted for EVL over a wide area (approximately 2650 km^2) including all the 'Younger' basic bodies. The digital processing has greatly increased the utility of this data, allowing digital enhancement and display and enabling quantitative modelling to be carried out.

The Huntly intrusion is situated entirely within geological map sheet 86 (Huntly) and was last mapped by Read who produced the present one inch to the mile map. The geology is described in the Memoir for sheets 86 and 96 (Read, 1923). The geological map presented in this report (Figure 4) differs substantially from that of Read. The research studies at Aberdeen and evaluation of the data derived from the EVL programme have allowed a more detailed picture of the internal structure of the intrusion to emerge.

Since 1983 a major programme of re-mapping in this region has been undertaken by the BGS. This survey, known as the East Grampian Project (EGP), is a large multi-disciplinary programme, utilising ground geophysical techniques and soil geochemistry to supplement conventional field mapping. The data generated by this work have been invaluable in guiding the investigations described in this report and in the interpretation of the results.

GEOLOGY

Fletcher (1989) and Fletcher and Rice (1989) presented excellent descriptions of the geology of the Huntly intrusion and adjacent rocks based on new observations, pits and shallow boreholes and a detailed re-assessment of earlier commercial surveys. The geological and structural maps (Figures 4 and 5) are based largely on their work with minor modifications from the present surveys. For a detailed geological and mineralogical assessment of the Huntly intrusion the reader is referred in particular to Fletcher (1989).

The Huntly body belongs to a suite of tholeiitic intrusions emplaced near the peak of metamorphism around 489 Ma (Pankhurst, 1970). These intrusions post-date the regional deformation events, but are themselves locally deformed by a system of major, steep, anastomosing ductile shear zones (Ashcroft et al., 1984; Fettes et al., 1991). These shear zones have a varied history of igneous activity associated with them apart from the basic intrusions, including late diorites and granites and later mica-granite sheets with associated tourmaline pegmatites, the latter dated by the Rb-Sr method at 465 Ma (van Breemen and Boyd, 1972).

Read (1919) identified two generations of basic intrusions in this region based on their degree of

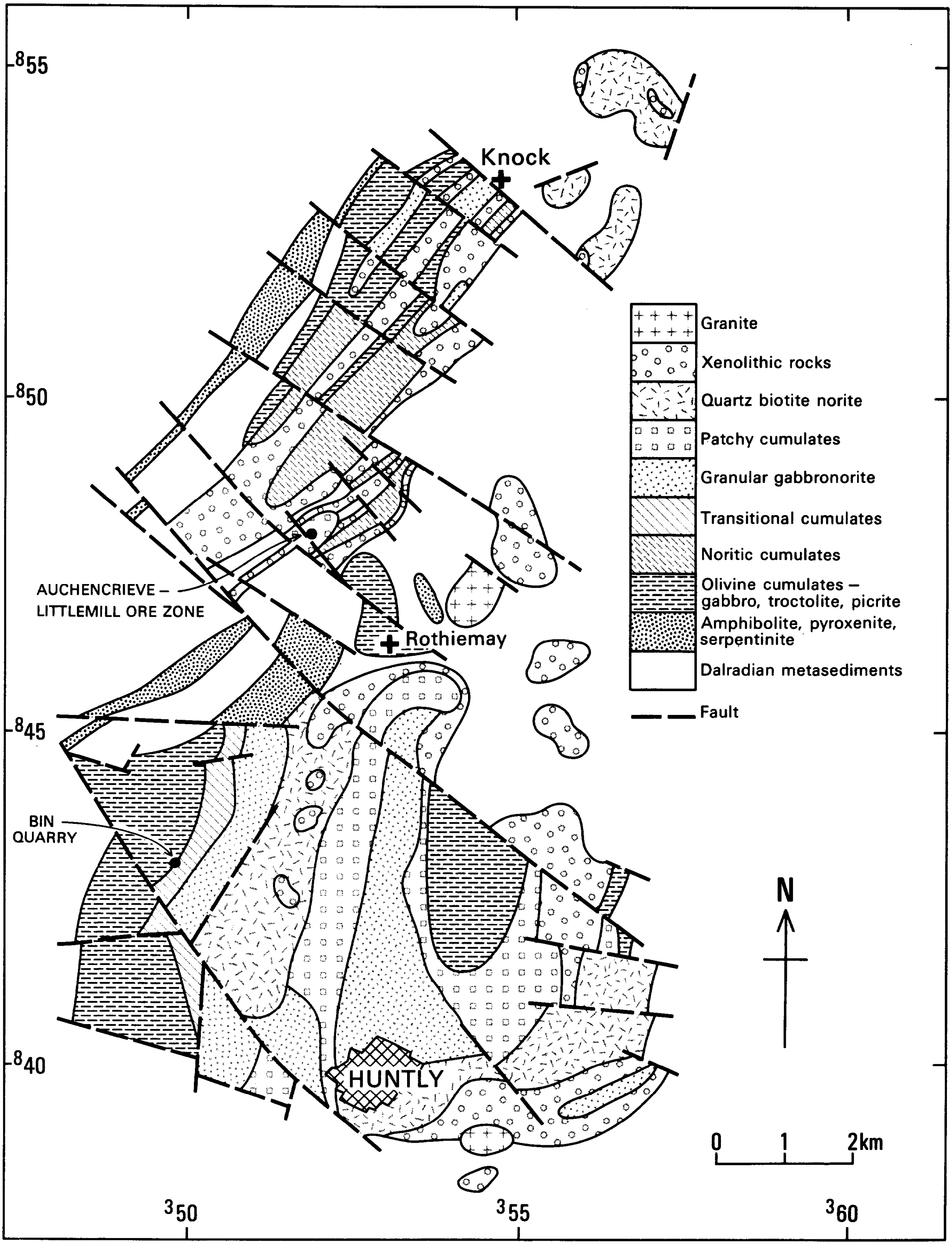


Figure 4 Geological map of the Huntly and Knock intrusions (modified after Fletcher (1989))

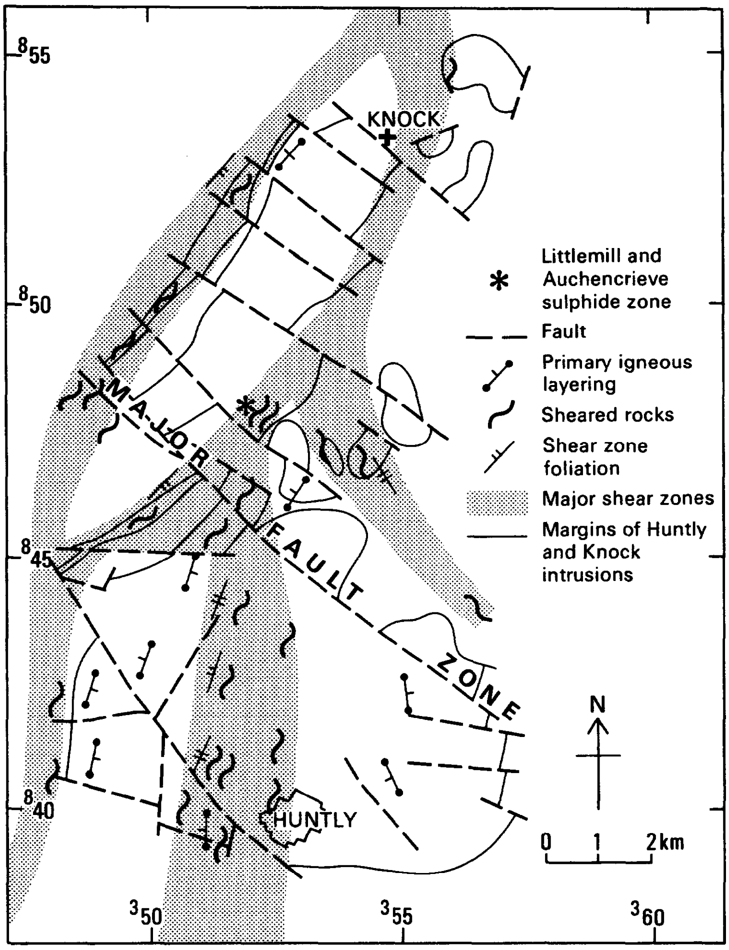


Figure 5 Simplified structural map of the Huntly and Knock intrusions (modified after Fletcher (1989))

deformation and alteration. He distinguished an earlier pre-metamorphic group, the Older Basics, from a younger post-metamorphic group, the Younger Basics. Some doubt has been cast on this distinction due to the influence of the recently recognised later regional shearing events. Many of the masses previously termed Older Basics may in fact be deformed Younger Basic bodies caught up in the shear belts (e.g. Fettes and Munro, 1989). The Huntly intrusion evidently belongs to the Younger Group, but it is disrupted and deformed within one of the major regional shear belts known as the Portsoy Lineament (Ashcroft et al., 1984; Fettes et al., 1991).

The Huntly intrusion outcrops over an area of approximately 40 km^2 lying within Dalradian metasediments, principally pelites and semi-pelites of the Argyll Group and, in the south-east corner, grits and greywackes of the Southern Highland Group. External contacts are not exposed, but observations from borehole and trench sections have provided local control on the nature and position of the boundary of the intrusion in the west and the south (Munro and Gallagher, 1984). In these areas sheared and crushed gabbroic rocks occur in close proximity to unhornfelsed metasediments, demonstrating the sheared nature of the contact. The igneous rock types present in the intrusion vary widely and include cumulates, granular gabbronorites, quartz-biotite norites and a variety cordierite-bearing xenolithic gabbros and partially melted sediments. Munro (1984) identified ten discrete cumulate bodies separated from each other by non-cumulate mafic rocks.

Study of the intrusion is hindered by poor exposure and by the structural and compositional complexity. The intrusion comprises several steeply-dipping, concordant sheets striking approximately north-south. Two broadly similar sequences are separated by a major north-trending shear zone (Figure 2). In the western half, olivine cumulates grade eastwards into granular rocks and then pass into a complex mixed unit, including granular and xenolithic types as well as cumulates. In the eastern sector, olivine gabbros are surrounded by patchy cumulates, granular gabbros and quartz-biotite norites. Internal boundaries are not exposed, but their positions can sometimes be inferred from a study of topographic features and magnetic data, particularly that from the EVL airborne survey. Figure 6 illustrates the data for the Huntly and Knock intrusions. In the Huntly body the complex and discontinuous nature of the magnetic field is readily apparent. The bodies of olivine cumulate rocks produce the highest field intensity and their internal and marginal contacts are clearly shown. The non-magnetic character of the granular, contaminated and xenolithic lithologies present in large parts of the central and southern sectors of the intrusion is also apparent. Also clearly displayed are the traces of north-west - south-east trending faults which split the West Huntly cumulates into two discrete blocks and which bound the intrusion on its north-eastern flank, separating it from the Knock mass. The highly magnetic character of a series of deformed minor serpentinite and pyroxenite pods to the west of the Huntly mass is also clearly demonstrated. Similar developments of deformed ultramafic lithologies, with associated amphibolite, are present in the enclave between the Huntly and Knock masses around Whitehill and Brownhill (Figure 3).

The cumulate rocks of Huntly vary widely in composition. Olivine gabbro is the predominant lithology, with subordinate peridotite, picrite, troctolite and rare anorthosite. The main cumulus phases are olivine, plagioclase, clinopyroxene and orthopyroxene, with the crystallisation sequence varying between cumulate bodies. The most common sequence is olivine, plagioclase, clinopyroxene, othopyroxene. The pattern of cryptic variation is complex and variable. In the largest cumulate body, West Huntly (Figure 2), there is a general trend to increasingly fractionated

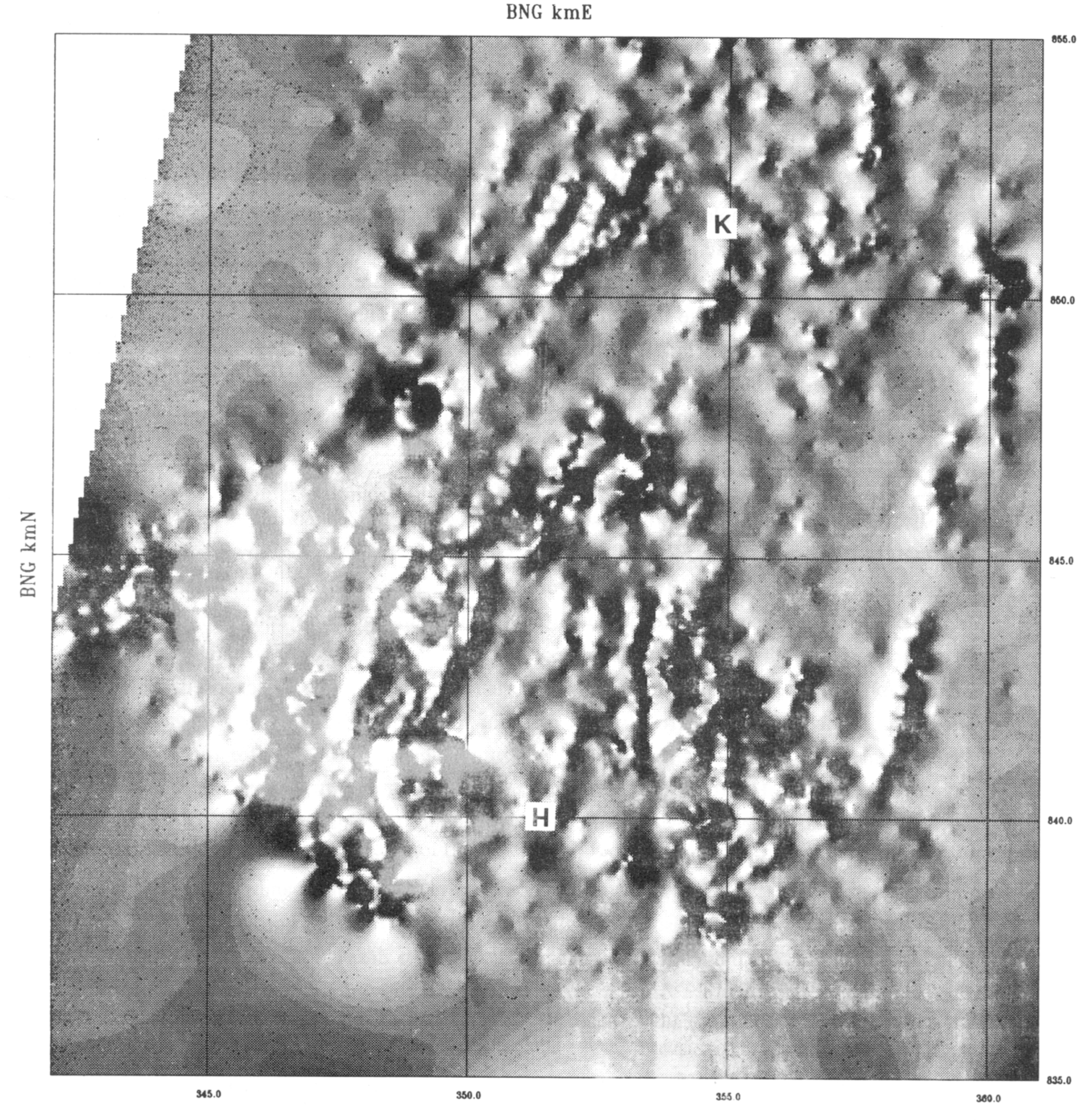


Figure 6 Shaded relief aeromagnetic map for the Huntly-Knock intrusions. The data, gridded at 100 m intervals, are illuminated from an inclination of 45° and azimuth 270°

compositions from west to east across strike. Overall the mineral compositions of the cumulate rocks in the Huntly intrusion are comparable with the Lower and Middle zones of the Insch intrusion (Fletcher, 1989).

Ortho- and meso-cumulate textures dominate. There are, however, local developments of complex heterogeneous, mixed textures, especially associated with olivine-rich cumulates, indicating multiple intrusive or mixing events. Igneous lamination, defined by the alignment of plagioclase and pyroxene, and primary magmatic layering are commonly developed. In West Huntly these generally have a northerly strike and steep or near vertical attitude. The scale of layering ranges from centimetres to metres. The most common type is modal layering due to variations in the proportion of plagioclase to the mafic constituents of the rock. Grain size, phase and textural layering are also occasionally developed. Pseudo-sedimentary structures are locally preserved in the layered sequences. These include scour features, current bedding and rip-up clasts. Overall these features, together with cryptic variation and graded layering, indicate a consistent younging direction to the east, as first suggested by Shackleton (1948). Distinct reversals in the graded layers have however been observed in the present study. Cyclic units, marked by repetitive phase layering with the onset of olivine crystallisation, have been recognised on the metre scale. Fletcher (1989) also identified mega-cyclic units (up to 1000 m thick) in the West Huntly body. These are characterised by ultramafic and troctolitic basal sections passing up into olivine gabbro cumulates.

Fine-grained anhedral granular rocks underlie extensive areas in the Huntly intrusion. They are commonly noritic in composition, with biotite as an important accessory mineral. They have gradational, or occasionally discordant, relationships with the cumulates. In West Huntly their appears to be a gradual transition from olivine cumulates, through a zone with intermediate characteristics and irregular contacts, to the granular type. An origin related to recrystallisation accompanying shearing has been suggested as a possible mechanism for their origin at Huntly. Elsewhere primary magmatic processes related to rapid quenching or to high nucleation rates have been advanced to account for fine-grained granular rocks in mafic intrusions (Parsons, 1979; Thy and Esbensen, 1982).

A heterogeneous group of rocks, probably related to former margins of the intrusions ('contact facies' of Fletcher and Rice, 1989), is developed in several zones, especially on the eastern flanks of both Huntly and Knock masses. These rocks range from partially melted metasediments to xenolithic gabbros, and are commonly associated with heterogeneous quartz-biotite norites. Their origin has been ascribed to contamination of gabbroic magma by the incorporation of Dalradian metasedimentary material in a marginal zone or the roof of the magma chamber.

Late magmatic alteration was locally responsible for the replacement of pyroxene by amphibole and/or biotite, with olivine commonly hydrated to serpentine and magnetite. Fletcher (1989) relates most of the serpentinisation of the cumulates to later events.

The effects of the late major regional shear zones are often intense, giving rise to a range of alteration assemblages and deformation fabrics on a variety of scales. A branch of the Portsoy Lineament, termed here the Central Huntly Shear Zone, transects the central part of the Huntly mass and extends northwards along the east flank of the Knock body. Mylonite and shear-zone foliations are developed as steeply dipping fabrics within these structures, manifest in exposure, trenches and boreholes. Attendant alteration produces an assemblage comprising amphibole, carbonate, quartz, biotite, garnet, graphite and sulphide (Munro and Gallagher, 1984).

A conspicuous series of north-west - south-east trending faults is widely developed in both the Huntly and Knock intrusions. A major zone of faulting with this orientation separates the two intrusions. Late phases of chlorite-carbonate and serpentine-carbonate-pyrite fracture veins are developed in association with these faults.

CHEMICAL ANALYSIS

From the outset of MRP investigations for PGE in north-east Scotland it was considered important to obtain high quality chemical data to detection limits of a few ppb in order to establish a basis for PGE exploration in the region. This was particularly important in view of the general lack of knowledge concerning the dispersion of the PGE in the secondary environment and the availability of little published data on exploration methodology for the these elements.

Due to the very low levels of PGE present in geochemical samples, the importance of the 'nugget effect' in sampling and sub-sampling cannot be overemphasised. Great care was taken in all field and laboratory procedures to minimise these effects. The great diversity of PGE-bearing species and the lack of detailed knowledge regarding the behaviour of these elements in the secondary environment combine to make the sample collection and analysis stages the most crucial in any programme of geochemical exploration for the PGE.

The majority of samples analysed in the early part of the programme in the Huntly intrusion were analysed for Pt and Pd only, by lead fire assay of 30 g samples followed by graphite furnace AAS determination (GFAAS). The analyses were conducted by Alfred H. Knight International of St. Helens, Merseyside with lower reporting limits of 5 ppb Pd and 10 ppb Pt. One batch was analysed by Bondar Clegg of Ottawa using lead fire assay with DC plasma finish yielding detection limits of 2 ppb Pd and 15 ppb Pt.

During the late 1980s there was a high level of commercial exploration for the PGE which led to a demand for cheaper high quality PGE analyses. As a result there were significant improvements in the field of PGE analysis, in particular the application of ICP mass spectometry (ICP-MS) which allows rapid and highly sensitive determination of Pt, Pd, Rh and Au down to levels of 1-2 ppb. Accordingly, since 1987 most samples generated by the PGE studies in the MRP have been analysed by Acme Analytical of Vancouver employing a lead fire assay on 30 g samples followed by either a GFAAS or ICP-MS finish.

Gunn et al., (1990) reported the estimated analytical precision of the GFAAS method employed by Acme, based on the replicate analysis of 40 samples with a wide range of PGE contents and sample matrices. The precision levels for Pt, Pd and Au were in the range 22 - 30 % at the 95% confidence level and were considered satisfactory for exploration purposes. In any case where high values are reported they are checked, either by a repeat analysis at Acme or at another laboratory.

The availability of low cost reliable PGE analyses has enabled exploration work of the type described herein to generate good quality exploration data on large numbers of samples. It has allowed the avoidance of undue reliance on potential pathfinder elements which will not only differ from area to area but also, in many cases, according to the sample types collected.

XRF analysis on pressed powder pellets was the usual method of trace element analysis. Samples were analysed using this technique either by the Analytical Chemistry Group of the BGS or by MESA, formerly of Long Eaton, Nottingham. Major element data derived in this way is neither complete nor wholly quantitative but is adequate for exploration work. Limited whole rock major element analysis on fused beads was carried out on a representative suite of the rock and borehole samples to assist in the petrogenetic and metallogenic studies of the area.

LITHOGEOCHEMISTRY AND DRILLING

Rock samples were collected and analysed from 155 sites within the Huntly intrusion and adjacent metasediments. At each site 2-4 kg of unweathered rock was taken from several points on a single outcrop, or from a number of closely-spaced outcrops, in order to obtain a representative sample. Rock samples were collected at exposures identified during re-mapping of the area and from bedrock exposed in pits excavated in zones of detailed investigations.

The distribution of rock sample sites is shown in Figure 3. Samples representative of each unit of the intrusion were analysed for PGE and a range of trace elements. Emphasis was placed on the cumulate types which were regarded as most prospective for magmatic PGE mineralisation. Particular attention was directed towards sites where features indicative of increased potential for PGE enrichment were observed. Such features included the presence of enhanced base-metal sulphide contents, heterogeneous textures (possibly related to magmatic mixing) and coarse volatile-rich pegmatitic assemblages. Fine disseminated sulphide mineralisation of primary magmatic origin is widespread in the cumulate lithologies, averaging about 0.5 - 1 volume percent. Local concentrations of up to 15% are present in olivine-bearing units. The sulphides are generally interstitial, but also occur as fine blebs within olivine and, to a lesser extent, chromite, plagioclase and pyroxene. Pyrrhotite is the predominant species, but variable generally minor proportions of pentlandite and chalcopyrite are also present locally. The non-cumulate lithologies present in the intrusion normally contain only trace quantities of base metal sulphides.

The mean concentrations of Pt and Pd in 24 samples of ultramafic rock are 9.4 and 15.1 ppb respectively, with a mean Pt/Pd value of 0.85 (Appendix 1, Table 1). The maximum Pt value (50 ppb) was derived from a peridotite in the Bin Quarry which contained up to about 2% of interstitial magmatic sulphide, principally pyrrhotite with subordinate chalcopyrite. This sample also contains the highest Cu level (978 ppm) in the suite, but the correlation between Cu and the PGE in ultramafic cumulates is generally only weak. Other samples with enhanced Pd levels are derived from similar, weakly mineralised lithologies in Dunbennan Wood. In the ultramafic suite as a whole, Pt and Pd are strongly correlated with each other and with Ni, and to a lesser extent with Co. Ni levels are generally low and not indicative of significant Ni sulphide mineralisation. No correlation between Cr and the PGE is observed.

A suite of ultramafic rock samples was collected from the deformed and altered mafic-ultramafic bodies at the northern end of the intrusion around Whitehill and Brown Hill and at the extreme northern end of the Central Huntly Shear Zone within the main Huntly intrusion itself. A pyroxenite sample collected from the base of a pit excavated in the Cumrie North area [351710 845210] was found to contain enhanced Pd (63 ppb) and Pt (28 ppb). Another sample from a pit in the same area was found to contain the highest Au concentration (30 ppb) recorded in the ultramafic suite of rocks from the Huntly intrusion. The relative enrichments in Pd and Au in these samples may be compared with those present in deformed clinopyroxene-rich ultramafic rocks in the Succoth - Brown Hill intrusion and may be due to re-distribution by hydrothermal alteration accompanying deformation (Gunn et al., 1990). One sample from a small serpentinite pod, located approximately 0.75 km to the south-west of Whitehill at [3513 8454] was found to contain 57 ppb Pd, 18 ppb Pt and 10 ppb Au. It is also notable that this sample contains the highest Cr level, 4216 ppm, in all the ultramafic rocks analysed. Similar enhanced PGE levels in high-Cr serpentinites have been reported from the Kelman Hill area, 15 km south-west of Huntly (Gunn et al., 1990). Two samples of ultramafic lithologies from the immediate vicinity of Whitehill itself do not show any enrichment in precious metal contents.

The mean PGE concentrations in 23 samples of olivine gabbro are 3.2 ppb Pt and 2.4 ppb Pd, with few values greater than the analytical detection limits (2 ppb and 1 ppb respectively)(Appendix 1, Table 2). These levels are similar to normal background values for gabbroic rocks (Crocket, 1982). Au concentrations are very low, with a single value of 80 ppb reported from the north-west side of Mungo Hill [35477 84271]. However, replicate analysis failed to verify the original determination and another sample from an adjacent exposure showed no Au enrichment. The initial anomalous Au value may be explained by the nugget effect or by an error in preparation or analysis. In view of the low precious metal contents in the olivine gabbro suite it is not possible to deduce any relationships with other trace elements determined.

The precious metal contents of troctolite samples are intermediate between those present in ultramafic rocks and those in the olivine gabbro suite. The mean Pt and Pd levels in 17 samples are 6 ppb and 10 ppb respectively. The maximum values of 13 ppb Pt and 26 ppb Pd were derived from a mineralised troctolite sample from the Dunbennan sector of the West Huntly cumulate body.

A suite of 58 samples of non-cumulate rocks was collected from the granular, contaminated and xenolithic lithologies of the intrusion. Few of these samples have precious metal contents above the analytical detection limits. Ninety percent of the samples contain 3 ppb Pt or less and 4 ppb Pd or less. The maximum PGE contents (30 ppb Pd and 15 ppb Pt) are present in two samples of altered, graphitic granular gabbronorite derived from the bank of the River Deveron approximately 300 m above the confluence with the River Bogie [3538 8410]. The maximum reported Au content was 4 ppb.

Gabbroic pegmatites of two varieties have been located within the Huntly intrusion. One type comprises irregular or sheet-like bodies, varying from patches a few tens of cm in size to sheets with exposed thicknesses up to 10 m. These consist essentially of plagioclase, clinopyroxene and ilmenite, locally with olivine, coarse blebby sulphide, amphibole and biotite. Analysis of six samples of this type from the West Huntly cumulate zone and from a discordant sheet within non-cumulate rocks in East Huntly [35510 84300] did not reveal any precious metal enrichment. In contrast, irregular discordant dykes of graphite- and sulphide-bearing orthopyroxene-rich pegmatites are present within the West Huntly cumulates. These bodies are heterogeneous in grain size and modal mineralogy, varying from almost orthopyroxenitic to noritic over distances of a few cm with local highly feldspathic zones. The graphite and sulphide contents are also highly variable, each locally comprising up to 50% of the rock. The sulphide mineralogy is dominated by pyrrhotite (90 - 100%) with subordinate amounts of chalcopyrite and pentlandite. Disseminated sulphides are generally interstitial to the silicate matrix, while sub-massive sulphide contains (and often appears to be replacing) euhedral silicates. Chalcopyrite is sporadically remobilised into net texture and fine veinlets. Graphite occurs as fine to coarse patches, laths and networks. It is commonly intergrown with, and replaces, sulphide. Biotite and ilmenite are common accessory constituents. Adjacent to these bodies the host olivine gabbro is altered, over distances up to 0.5 m, with the development of biotite and chlorite. The pyroxene also changes to a pale buff orthopyroxene, either with a platy equant or lath-like habit and without any planar lamination. Sulphide content is generally very low in the altered gabbro, while there is often a few percent graphite close to the contacts. These bodies are best exposed in the Bin Quarry from which most samples have been derived for study. They have also been recorded from the River Deveron near Huntly Castle [3538 8410] and from EVL boreholes in Dunbennan Wood (HK 16 and 17) and the Bin Forest (HK 18). Mean concentrations of Pt, Pd and Au in eight samples are 82 ppb, 36 ppb and 14 ppb respectively (Appendix 1, Table 3). The values however are highly variable indicating the sporadic nature of the PGE enrichment in these bodies. The maximum levels reported in the Bin Quarry pegmatitic pyroxenites are 323 ppb Pt and 119 ppb Pd. This compares with the maxima for these elements reported by Fletcher and Rice (1989) for the same bodies of 584 ppb and 93 ppb. The maximum Au contents recorded in these samples is 29 ppb. A single pyrrhotite- and graphite-rich sample from the River Deveron near Huntly Castle yielded 114 ppb Pt and 60 ppb Pd. Pt has a highly significant correlation with the Cu content of these samples, and a weaker positive correlation with Co. Pd on the other hand shows a strong correlation with Co, and a weaker one with Cu. On account of the small size of the dataset and the nugget effect these relationships should be treated with caution. Nevertheless they are consistent with the experimental observations of high solubility of Pt and Pd in pyrrhotite and in melts rich in Cu and Fe at temperatures between 500 and 900 C (Makovicky et al., 1988).

In an attempt to elucidate the nature of the precious metal enrichment in the mineralised pyroxenites of the West Huntly body, automated searching for PGE- and Au-bearing phases was carried out on the Cameca microprobe at BGS Keyworth. Six samples from the Bin Quarry were searched using the Turboscan method previously described (Gunn et al., 1990). However, no Au- or PGE-bearing phases were located. Additional searching of many more thin sections would be required to provide an appraisal of this sporadic low grade precious metal enrichment.

Drilling in the Bin Quarry

The elevated PGE levels in pyroxenitic pegmatites from the Bin Quarry were the first evidence of significant enhancement of these elements above normal background levels for basic rocks in the Huntly intrusion. The operation of processes leading to PGE mobilisation and concentration was regarded as encouraging evidence for potential PGE-bearing mineralisation in bodies of larger size.

Two gossanous pegmatitic pyroxenite dykes are exposed in the north-eastern face of the Bin Quarry. These bodies are referred to as gossans 1 and 2, the latter occurring some 50 m north-west of gossan 1. A series of boreholes was drilled in order to investigate the continuity and thickness of these bodies at depth (Figure 7).

The principal units diplayed in the main (north-east) quarry face are also delineated in Figure 7. These units dip at around 55° to the north-west or west-north-west. They comprise, in turn, from north-west to south-east:

1) laminated olivine gabbro (34 m exposed true thickness) - locally well layered on a scale of up to 10 cm.
2) olivine-rich cumulates (26 m true thickness) - dominantly peridotite, becoming more picritic and troctolitic to the south-east. This section displays good examples of primary igneous textures as well as conspicuous textural heterogeneities such as patchy or amoeboidal picrites and peridotites. These variants exhibit irregular troctolitic patches up to a few cm in size which have sharp contacts with the enclosing ultramafic host. They may indicate influx of new primitive magma pulses disrupting partially consolidated layers of more evolved character (ie troctolites).
3) olivine gabbros (55 m true thickness) - generally massive, local fine scale layering, locally sheared.
4) porphyritic olivine gabbro (45 m exposed true thickness) - olivine gabbro in which olivine is the coarsest silicate phase, with sporadic fine scale layering, occasionally sheared and veined by carbonate.

Minor sulphide mineralisation is widespread in all lithologies as fine disseminated grains interstitial to the silicates. Commonly these grains are concentrated as fine aggregates or networks in patches, up to 2-3 cm in size, with diffuse margins. These patches, termed 'clouds' by Fletcher (1989), give rise to conspicuous rusty spots on weathered surfaces in the Bin Quarry. Locally the clouds are concentrated within individual layers, or parts of layers, up to a few decimetres thick known as 'sulphide-splash' zones .

Boreholes 1 and 2 were drilled to investigate the south-easterly of the two gossans (no. 1). The geometry of the mineralised pegmatitic pyroxenite exposed in this zone is unclear from the exposures in the quarry face. As a result of the presence of extensive rusty discolouration parallel to the igneous layering exposed in the inaccessible face above gossan 1, it was thought that the body was, at least in part, concordant with the layering (strike 035°, dip 60°W). Accordingly, borehole 1 was drilled in a near south-easterly direction inclined at an angle of 58° from horizontal. The pegmatitic body at gossan 1 also has a significant component of discordant character, cross-cutting the layering and trending in an irregular path towards the north-north-west. Borehole 2 was therefore drilled towards the east-north-east inclined at an angle of 60° from the horizontal in order to investigate the continuity at depth of this part of the pegmatite.

Summary graphic lithological logs of boreholes 1 and 2 are shown in Figure 8. Borehole 1 intersected a sequence comprising dominantly laminated olivine gabbros with numerous thin (usually less than 10 cm) layers of troctolite and troctolitic gabbros. There is a conspicuous lack of picritic and peridotitic units. Porphyritic olivine gabbro units are common in the upper 20 m of this borehole. Thin carbonate and serpentine veinlets are widespread and locally concentrated in

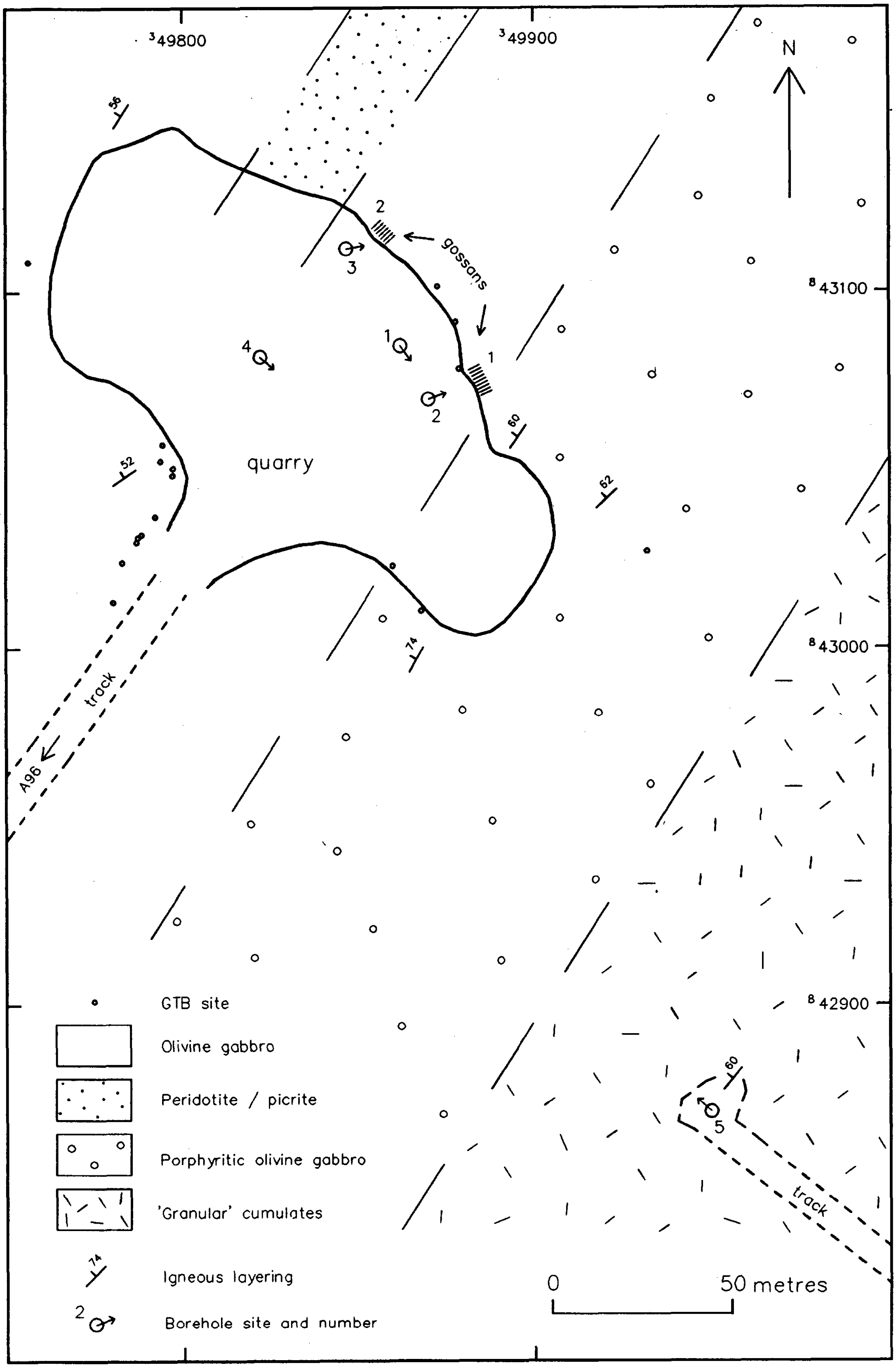


Figure 7 Geological sketch map of the Bin Quarry area showing location of borehole sites

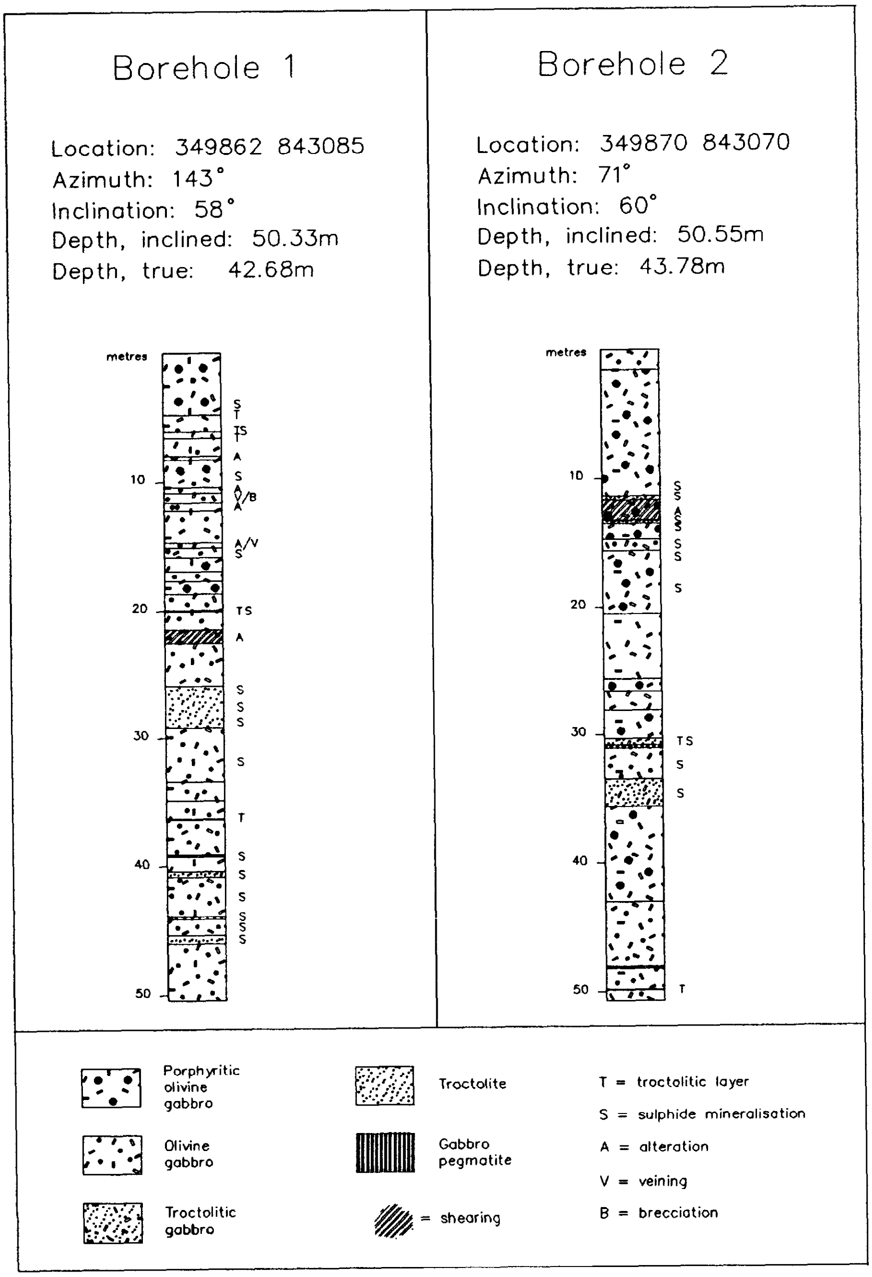


Figure 8 Summary lithological logs for Bin Quarry boreholes 1 and 2

narrow intervals. One section between 21.5 and 22.65 m is highly veined and sheared. Attendant alteration in this interval comprises serpentinisation of the olivines and a marked change in the appearance of the clinopyroxenes. In this section, and similar narrow intervals with intense veining, the pyroxene takes on a distinctive pale buff-brown colouration. Fine interstitial sulphide, predominantly pyrrhotite with traces of chalcopyrite, is ubiquitous in concentrations of around 1-2 vol%. Olivine-rich and troctolitic units are often significantly enriched in sulphide content, with concentrations up to 5 vol% over widths of a few cm.

Borehole 2 also intersected a sequence comprising dominantly laminated olivine gabbro, sometimes porphyritic in character. Minor units of mela-olivine gabbro and troctolitic gabbro are also present. Some units are heterogeneous in character, displaying rapid variation in grain size and mineralogy. For example, the interval between 13 and 21 m consists of small scale irregular alternations between weakly laminated olivine gabbro and troctolitic gabbro, locally with irregular patches and layers of troctolite or anorthosite. Sporadic narrow zones of shearing and veining are present as in borehole 1, with similar attendant changes in the appearance of the clinopyroxene. Sulphides are also widespread in minor amounts, again showing relative enrichment in olivine-rich zones. A distinctive zone comprising heterogeneous gabbroic pegmatite occurs between 30.70 and 30.98 m. This is unlike the mineralised pyroxenitic pegmatite exposed beneath gossan 1 and is more comparable with irregular pegmatitic patches exposed within the olivine gabbro sequence towards the north-west end of the main face of the quarry and locally within the Bin Forest to the north.

In neither borehole 1 or 2 was the sulphide- and graphite-bearing orthopyroxene pegmatite exposed in gossan 1 intersected. This may be explained either due to its impersistence at depth or because it has been removed by deformation.

Borehole 3 was sited to investigate the sub-surface extent of the pegmatite exposed beneath gossan 2. This body has an irregular discordant geometry, trending between north-north-east and north-north-west and varying in thickness up to a maximum exposed width of about 0.5 m. The borehole was drilled at an angle of 60° from horizontal with an azimuth of 259°. The sequence intersected comprises predominantly laminated olivine gabbros with some small scale (1 - 30 cm) picritic or troctolitic layers (Figure 9). Below 32 m the olivine is locally porphyritic, while other textural heterogeneities, principally development of troctolitic and gabbroic troctolite patches, are commonly developed in the bottom half of the borehole. Orthopyroxene-bearing sulphide- and graphite-bearing pegmatites, similar to those exposed beneath gossan 2, were intersected in three sections. The thickest interval, between 22.42 and 23.22 m, consists of a heterogeneous feldspathic unit, varying from fine to very coarse grained, with variable proportions of orthopyroxene, graphite and sulphide. One 20 cm section comprises sub-massive pyrrhotite with minor chalcopyrite intergrown with graphite. For a distance of up to two metres on either side of this body the host olivine gabbro is conspicuously altered and veined. The pyroxene takes on a conspicuous pale buff-brown colour, while various hydrous phases amphibole, chlorite and biotite are sporadically developed. Irregular pegmatitic patches and veins of plagioclase, biotite and graphite, up to 3 cm in size, are sporadically developed within the altered gabbro. Minor developments of comparable pyroxene - plagioclase - biotite pegmatites were also intersected between 10.84 - 11.11 m and 12.14 - 12.26 m. These are generally poorer in graphite and sulphide than the thicker unit around 23 m, but nevertheless they give rise to comparable marginal alteration assemblages.

Borehole 4 was collared near the centre of the quarry, approximately 40 m along strike to the south-south-west from borehole 3, to test for continuity of the gossan 2 pegmatite and for the presence of any others not exposed in the quarry faces. It was drilled at an inclination of 60° from horizontal in a direction near normal to the strike (130° azimuth). The section encountered in this borehole is similar to those in the other boreholes, but no mineralised pegmatites were intersected (Figure 9). There are numerous small scale layers (up to 50 cm thick) of picritic or mela-olivine gabbros which are generally preferentially enriched in fine interstitial sulphide. Modal grading in olivine content is commonly developed, occasionally showing clear examples of increased olivine content both up and down the section. Several intervals, notably between 20 and 30 m, show rapid textural and mineralogical changes in layers and irregular patches producing a heterogeneous appearance. Veining by serpentine and carbonate is widespread. It is usually accompanied by hydrous alteration, as described in the other boreholes, and sometimes by brecciation. A narrow zone of gabbroic pegmatite is present between 33.90 and 34.23 m. This section shows marked variations in modal mineralogy and is generally devoid of graphite. Minor fine blebs of interstitial sulphide are widespread.

A total of 307 samples of drillcore from boreholes 1 - 4 were analysed for a wide range of trace elements by XRF. Pt and Pd were determined on 146 samples from boreholes 2 and 3 only by lead fire assay with a DCP finish providing detection limits of 15 ppb and 2 ppb respectively. This data is summarised in Appendix 1, Table 4.

Few values above detection limit were reported for Pt and Pd in boreholes 2 and 3. Three samples of the mineralised pegmatitic pyroxenite encountered in borehole 2 at around 23 m depth have Pd contents above background levels with values of 12 - 14 ppb. Check analyses with an ICP-MS finish corroborated this data and confirmed the low Pt contents (maximum 6 ppb). Au concentrations in these samples were also shown to be slightly enriched, up to a maximum of 27 ppb.

A suite of samples from boreholes 1 - 4 comprising mineralised pegmatites, altered sections and sulphide-enriched zones was checked for Pt, Pd, Rh and Au by lead fire assay and ICP-MS. The original determinations of Pt and Pd were confirmed for samples from borehole 2 and 3. No precious metal enrichment was reported in samples from boreholes 1 and 4 not previously analysed.

In view of the disappointing precious metal data from these boreholes little petrographic and mineralogical study has been conducted on this drillcore. No Turboscan searching was undertaken on thin sections from the boreholes.

An additional borehole, number 5, was drilled to investigate the transition from the olivine cumulate lithologies present in the quarry to the anhedral granular types exposed further east. Munro (1984) described the contrasting mineralogical and textural features of these rock types and suggested that a gradual transition exists on the south slopes of the Bin between the two. This suggestion has been confirmed, as far as exposure permits, by recent BGS mapping. Borehole 5 was funded in part by the BGS East Grampian Project to investigate the nature of this transition and to address the problem of the origin of granular rocks in the Huntly intrusion. The borehole, collared approximately 150 m south-east of the quarry at NGR 34995 84287, was drilled at an

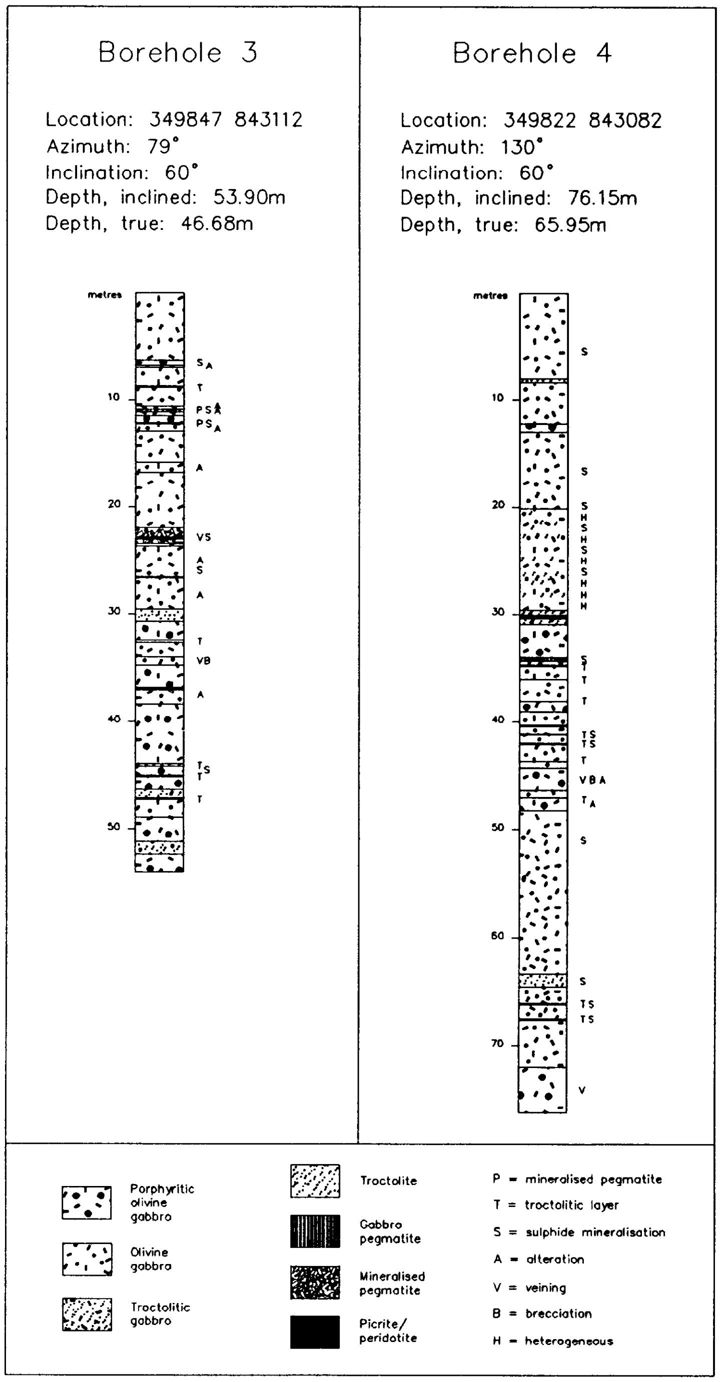


Figure 9 Summary lithological logs for Bin Quarry boreholes 3 and 4

inclination of 60° from horizontal with an azimuth of 310°, approximately at right angles to the strike. The final depth of the borehole was 157.71 m. The sequence intersected comprises predominantly fine-grained massive olivine gabbros, olivine gabbronorites and gabbronorites in the upper 80 m. Extensive recrystallisation is widespread leading to the development of fine granular textures and a pervasive foliation. Relicts of coarse ophitic olivine as ragged irregular grains are widespread. Below 80 m the grain size increases to medium grained and there are common textural heterogeneities with coarse-grained patches, up to several decimetres in size, set in a granular host. These coarse variants have suffered little recrystallisation and often retain primary magmatic textures. Porphyritic olivine gabbros, comparable to those exposed in the south-east corner of the Bin Quarry and present in the other boreholes, are present in the basal 10 m of borehole 5. Sulphide mineralisation, mainly fine pyrrhotite with minor chalcopyrite and pentlandite, is common throughout the borehole. It is especially enriched in the lower half associated with the zones of marked textural heterogeneity.

In view of the high sulphide content a suite of 86 samples was analysed for Pt, Pd, Rh and Au by lead fire assay and ICP-MS. Less than 10% of the samples reported values of Pt, Pd and Au greater than the analytical detection limits. Maximum levels are 4 ppb Pt, 6 ppb Pd and 8 ppb Au. No values above 2 ppb Rh were reported.

The boreholes drilled within the Bin Quarry failed to identify any primary magmatic enrichment in the olivine cumulate lithologies intersected. The mineralised pyroxenitic pegmatites exposed in the quarry have been shown to be impersistent at depth and of only small size. The transition zone between cumulate and granular gabbroic rocks has been investigated by means of boreholes 4 and 5. These sections have confirmed the existence of an irregular transition. The juxtapostion of contrasting textural types and the intermediate nature of many sections suggest an origin related to alteration and recrystallisation probably accompanying deformation. Whole rock XRF geochemistry, however, indicates clear chemical contrasts between boreholes 4 and 5. Olivine gabbronorites from borehole 5 are markedly enriched in SiO_2, Fe_2O_3, TiO_2, MnO, Na_2O and K_2O relative to olivine- and porphyritic olivine gabbros present in borehole 4. Detailed trace element geochemistry and mineralogical studies are required to clarify the nature of the transition zone and the processes responsible for the genesis of the granular gabbros.

INVESTIGATIONS IN CUMULATE ROCKS IN THE WEST HUNTLY BODY

In order to examine the PGE potential of the olivine cumulate rocks in the West Huntly body outside the Bin Quarry a combined overburden sampling and ground magnetic survey was conducted in the Bin Forest and Dunbennan Wood. Attention was directed towards zones showing enhanced Cu and Ni levels in EVL soil data, possibly indicative of the presence of magmatic base metal sulphides. Five reconnaissance traverses oriented approximately east - west, normal to the direction of igneous layering, were examined (lines 87-1 to 87-5 in Figure 2).

Magnetic survey

Total field magnetic measurements were made at 2 m above ground level using a proton precession magnetometer. Observations were made at 10 m intervals along five traverse lines of aggregate length 4.95 km. The diurnal variation in total magnetic field was monitored by repeated observations at a local base station. The diurnal fluctuations were insignificant relative to the amplitude of the anomalies in this zone and, therefore, no corrections have been applied to the data.

The magnetic data in Dunbennan Wood (87-1, -2, -3, in Figure 10) show a clearly defined north-trending anomaly corresponding to a unit of olivine-rich cumulates, mainly peridotites and picrites (Figure 11). The total field intensity over these lithologies generally exceeds 49 600 nT, reaching a maximum value around 51 000 nT. To the east of this main anomaly, the bedrock is dominantly transitional olivine gabbro which is characterised by field intensities below 49 500 nT. Subordinate interlayered picrites and troctolites are reflected by local high frequency anomalies exceeding 49 600 nT. The variation in magnetic field intensity along the western sections of traverses 87-1 and 87-3 also clearly reflects variations in bedrock geology. Normal olivine gabbros give rise to values around 49 500 nT, while minor interlayered picrite and troctolite correspond to field intensities up to 50 200 nT.

Overburden survey

A detailed programme of overburden and bedrock sampling was undertaken in order to investigate the PGE distribution along the four reconnaissance traverses in the Dunbennan Wood/Bin Forest area (87-1, -2, -3, -4). The sampling was guided by the results of the magnetic survey and by geological observations made as the survey proceeded.

Basal overburden samples were collected either by a Minuteman power auger or by excavation of pits. The former method allows collection of samples beneath thick overburden cover, but suffers from uncertainty as to whether the till-bedrock interface has actually been reached. To ensure collection of a representative sample of adequate size it is the usual practice to sample from 2-3 closely-spaced holes. At shallow sites pitting the preferred technique, permitting the retrieval of larger samples from accurately determined positions in the overburden profile. It is also possible to collect bedrock samples from sites where rockhead has been reached. In the Dunbennan Wood area pits were excavated using a mini-digger or, where overburden cover was thin, by hand. Samples were processed by the method described by Gunn (1989) in which a partial pan concentrate is collected by constant reduction from a known starting volume. Where sufficient material was available, 4 litres of -2 mm material was washed and panned down to a final volume of 150 ml. A -150 micron fine fraction sample was also collected from each site. In addition, observations of the composition and relative proportions of clasts in the +2 mm fraction were recorded in the field to determine the nature and influence of exotic material, and to evaluate the contribution from, and the nature of, the bedrock.

In the Dunbennan Wood area a total of 66 sites, spaced at 25 m intervals, were sampled. 25 sites were investigated by digger, 32 by hand pitting and the remainder by Minuteman. The overburden thickness was generally in the range 1 - 2 m, increasing to 3 m on the flanks of Dunbennan Hill. Rockhead was reached at all sites, allowing a detailed examination of bedrock geology and mineralisation to be carried out. Bedrock samples were collected for analysis from exposure and pit sites as shown in Figure 10. The bedrock comprises a central north-trending zone of peridotites, interlayered with picrites, troctolites and subordinate olivine gabbros. Near vertical modal layering on a scale of a few cm is sometimes developed. Irregular, heterogeneous mixing textures, similar to

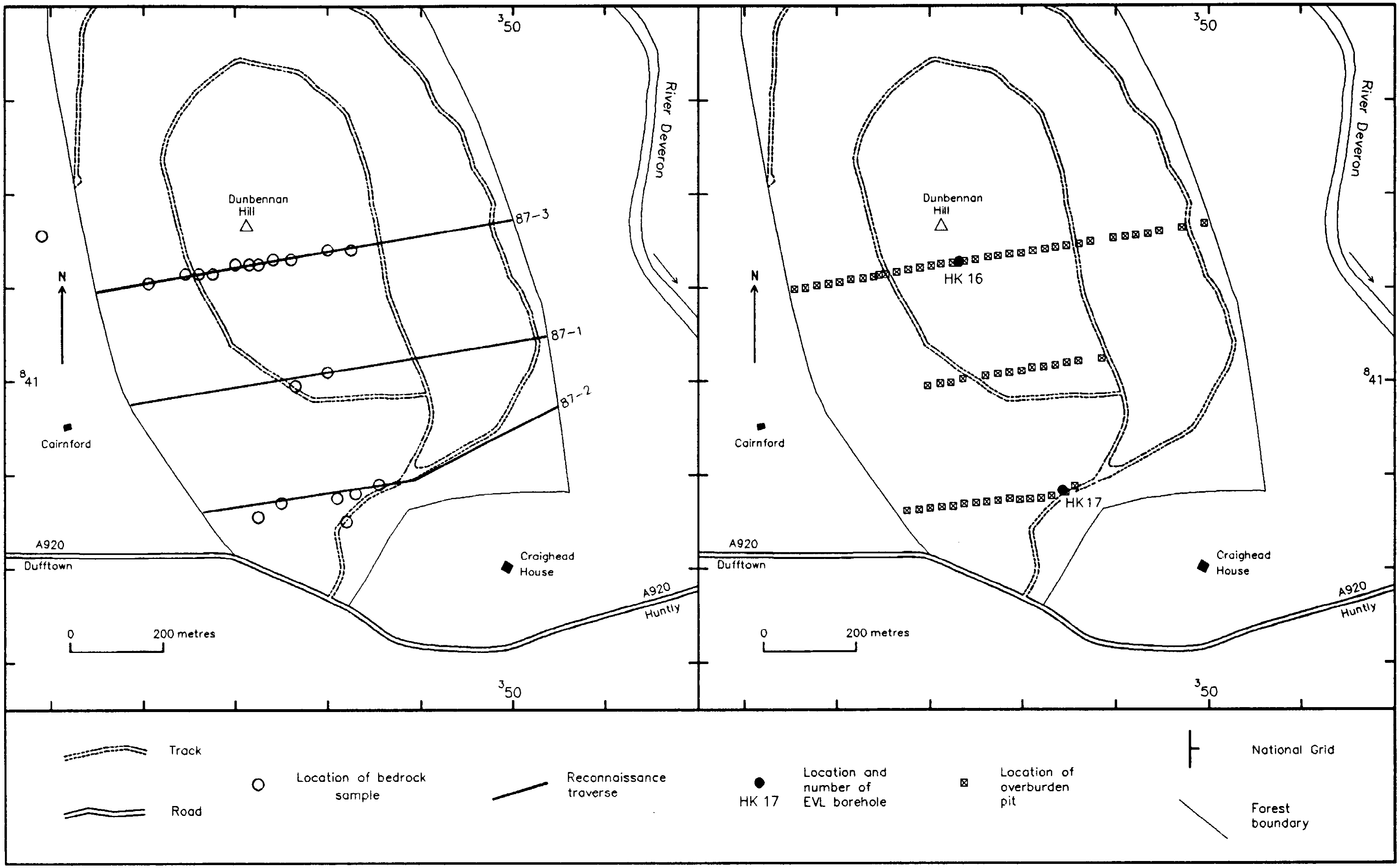


Figure 10 Location of rock sites, overburden sample sites, magnetic survey lines and EVL boreholes in the Dunbennan Wood area

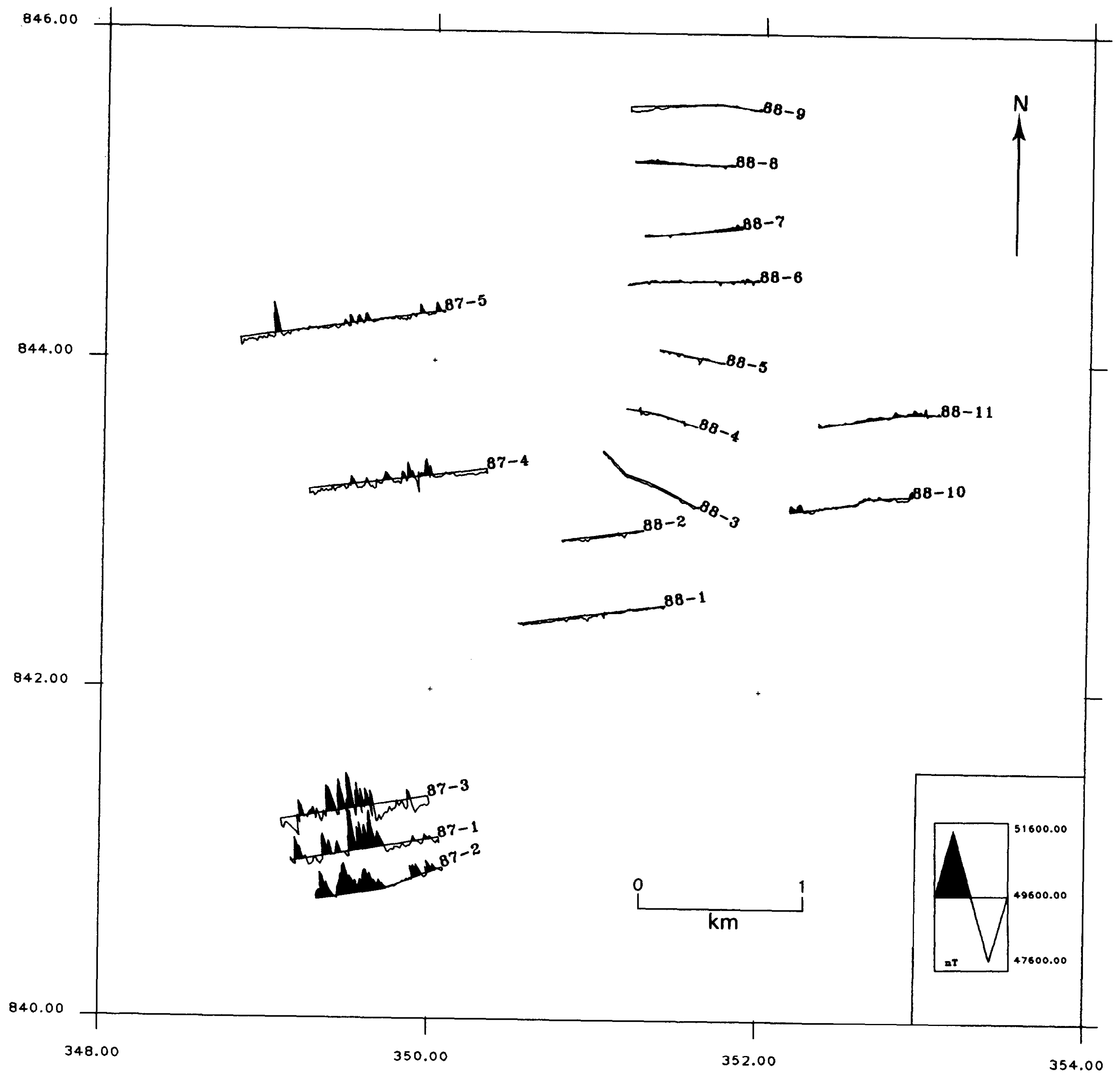


Figure 11 Total field magnetic data for the Huntly intrusion reconnaissance traverses

the amoeboidal picrites present in the Bin Quarry, are also common. Considerable grain size variation is also observed, with pegmatoidal troctolites present sporadically. A more extensive unit of olivine gabbro is found at the western end of traverse 87-3, while further to the west a fine example of laminated troctolite was sampled from an exposure situated c. 400 m north of Cairnford (Figure 10). At the eastern end of 87-3 olivine gabbro of transitional type was exposed in the pits and is reflected in the lower magnetic field intensities recorded. Sulphide mineralisation, pyrrhotite and subordinate chalcopyrite, is widespread in trace and minor quantities. It is most abundant in the mafic rock types in which it occurs as fine interstitial grains and aggregates which coalesce to form sulphide 'clouds' as observed in the Bin Quarry. Traverse 87-4, located to the north and west of the Bin Quarry, was investigated by pitting at 13 sites only. The bedrock present in these pits was exclusively olivine gabbros.

Summary statistics for panned and -150 micron basal overburden samples are presented in Appendix 1, Tables 5 and 6. Panned samples were analysed for Pt and Pd by lead fire assay and graphite furnace AAS, yielding detection limits of 10 ppb and 5 ppb respectively. Fine fraction samples were analysed for Pt, Pd, Rh and Au by a similar fire assay but with an ICP-MS finish. In panned samples the highest Pt content (50 ppb) is derived from a site over troctolite - picrite bedrock (on line 87-2) about 75 m west of borehole HK17 (Figure 10). Most other sites with enhanced Pt contents are from the central ultramafic zone on line 87-3, with the highest value of 45 ppb derived from a peridotite located approximately 60 m west of borehole HK16 (Figure 10). Pd concentrations from the panned overburden samples are generally close to the analytical detection limit, with a maximum value of 10 ppb. Pt correlates weakly with Cu and Ni in panned samples, while Pd has a weak association with Co. No correlation with As or Sb is observed.

In fine fraction overburden samples Pt has a highly skewed distribution with a maximum concentration of 204 ppb, while the second highest value is only 10 ppb. Only 10% of the 81 samples analysed have Pt concentrations greater than 5 ppb. The highest Pt concentration is derived from the same site on line 87-3 which contains 45 ppb Pt in the corresponding panned sample, referred to above. In contrast Pd has its maximum concentration of 12 ppb at 2 sites, but only 10% of samples greater than 6 ppb. Au concentrations in these samples are very low, with the maximum value of 10 ppb occurring in the sample with the highest Pt content (204 ppb).

Biogeochemistry

Attention has increased over recent years on the suitability of biogeochemistry as an exploration technique for PGE (Dunn, 1991). Biogeochemical sampling has been used sucessfully in areas where extensive superficial cover modifies or masks the geochemical signature of the bedrock. In this respect this technique offers an inexpensive and logistically convenient alternative to other alternatives of deep sampling. The root systems of tree species provide a means of sample coverage often within close reach of bedrock. However, the selectivity of different plants or plant media in the absorption of elements or minerals can be problematical and necessitates careful orientation studies to determine the optimum species and component for exploration purposes.

The Huntly complex is planted with four principal coniferous species over an area of approximately 16 km^2, including most of the West Huntly cumulate body. It was therefore regarded as suitable for a biogeochemical orientation survey. In order to avoid seasonal influence samples were collected during June in 1987 and 1988. Most of the samples were collected over the olivine cumulates of West Huntly, specifically Dunbennan Wood (37 sites) and the Bin Forest (22 sites). Additionally, 11 sites were sampled in the Central Huntly Shear Zone and a further 7 over a lineament on the east side of Ordiquhill. The tree species sampled were European or common larch *(Larix decidua)*, sitka spruce *(Picea sitchensis)*, Norway spruce *(Picea abies)* and Scots or silver pine *(Pinus sylvestris)*. At only a few localities was it possible to sample more than one species for direct comparative purposes. Sample materials collected from each tree were of four types, namely new needles (from near the growing tips of branches), twigs, outer bark and forest floor litter.

Samples were returned to the laboratory for drying. They were then pulverised with a Waring blender and the weights of the pulverised, dry samples recorded. Splits around 75 g in weight were then ashed at 475 C. The mean percentage ash varied markedly between species, and sample types, but was generally in the range 1-2% for twigs, new needles and bark. The proportion produced from litter (5-16%) was consistently higher than for other sample materials, indicating a higher percentage of non-combustible material. This is consistent with the introduction of mineral soil into the litter sample.

Pt, Pd and Au analysis was conducted at Acme Analytical, Vancouver by ICP-MS following lead fire assay of the ash. A wide range of other trace elements was also determined using ICP.

Summary statistics for Au and Pt in all species sampled are shown in Table 2. Significant enrichment in Au is found in larch twigs and the new needles of larch, Norway spruce and sitka spruce. In contrast, Pt levels in new needles are generally at or close to detection limit. The highest concentrations of Pt are found in twigs of Scots pine, Norway spruce and sitka spruce. Enhanced Pt levels are also present the bark of Scots pine. Larch shows a preferential concentration of Pt in bark samples (mean 7 ppb), with a lesser enrichment in twigs (mean 5 ppb). It should be stressed, however, that in some cases the number of analyses of particular components of specific species is very small. It is not therefore possible to draw reliable conclusions about the optimum sample type for precious metal exploration or to identify particular targets for follow-up in the survey area.

Pd concentrations in eighty-five percent of all samples, regardless of species, are at or below the analytical detection limit of 2 ppb and are not, therefore, presented.

As noted above a favourable response to Pt is shown in the twigs of all species, with values commonly attaining 8 ppb, up to a maximum of 28 ppb. There is a significant association between Pt and Cu in the twigs of sitka spruce (Figure 12). Samples of this type with enhanced Pt and Cu are not however confined to any particular part of the survey area.

In the Dunbennan Wood area levels of Au, Pt and Cu are locally enhanced in larch twigs. This suggests an association with the underlying olivine cumulates, which have enhanced background levels of PGE and Cu relative to other lithologies present in the intrusion. Pitting to bedrock in the Dunbennan Wood helped to elucidate the bedrock geology, but, because of the spatial distribution of species and the small number of sites sampled (37), no conclusive association between the biogeochemical anomalies and bedrock lithology can be established.

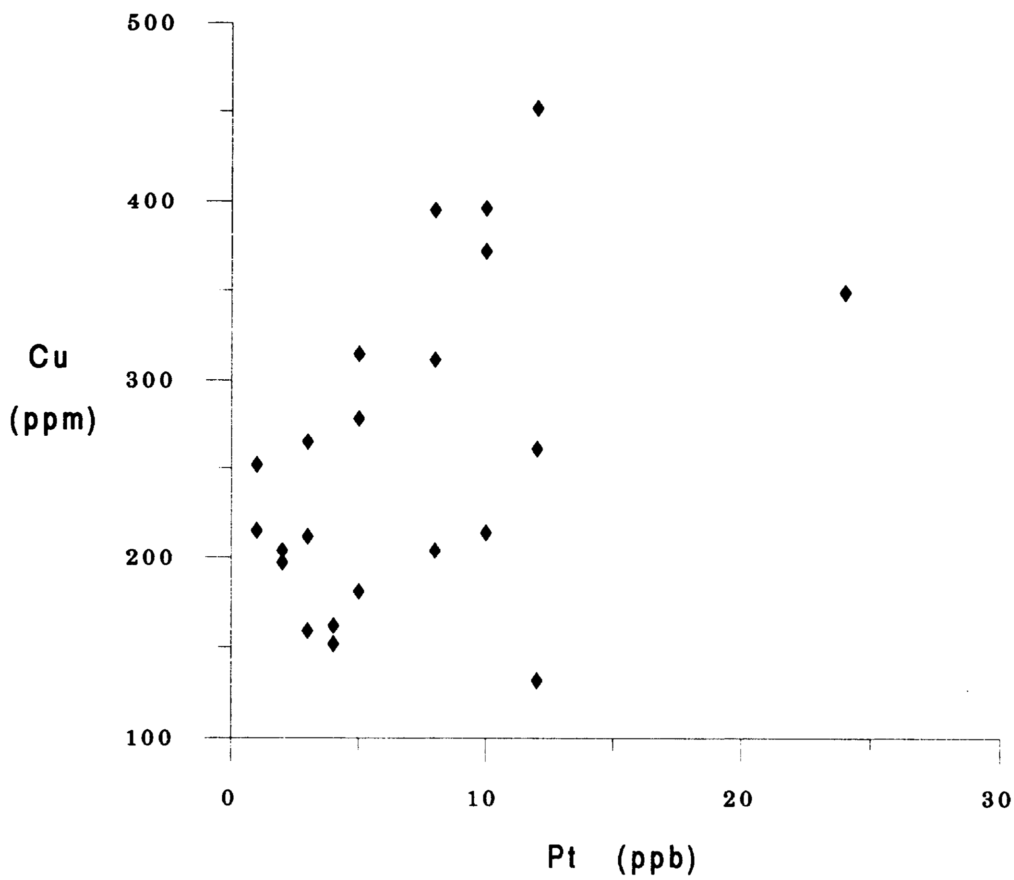


Figure 12 Relationship between Pt and Cu contents of Sitka Spruce twigs

Table 2 Summary statistics for precious metals in biogeochemical samples

	No	Au (ppb) Mean	St Dev	Max	Min	Pt (ppb) Mean	St Dev	Max	Min
LARCH									
Twigs	*20*	14	18	66	1	5	4	16	1
Litter	*17*	4	4	16	1	3	1	5	2
New needles	*9*	9	9	32	1	3	2	6	2
Bark	*17*	3	2	8	1	7	7	24	1
SCOTS PINE									
Twigs	*2*	3	1	4	2	14	12	23	6
Litter	*15*	3	2	8	1	3	2	6	1
Bark	*19*	3	2	11	1	10	8	28	1
NORWAY SPRUCE									
Twigs	*1*	4		4	4	15		15	15
Litter	*21*	1	1	4	1	2	0.5	4	1
New needles	*11*	7	9	29	1	2	0.3	3	2
SITKA SPRUCE									
Twigs	*22*	4	2	8	1	7	5	24	1
Litter	*25*	2	1	3	1	3	2	6	1
New needles	*3*	11	9	18	1	2	0	2	2
Bark	*8*	2	1	3	1	4	3	9	1

Discussion

The reconnaissance overburden survey carried out in the West Huntly cumulate body demonstrated sporadic minor Pt enrichment in the Dunbennan Wood area, but failed to identify any zones with generally enhanced levels. This was confirmed by the geochemical data obtained for rock samples of the cumulate lithologies which generally indicate Pt and Pd contents comparable with those normally expected for these rock types.

The biogeochemical sampling programme demonstrated a significant uptake of PGE and Au in the twigs of the four species sampled. For Au alone, new needles appear to be the favoured sampling medium in this area. It is recognised that more extensive sampling of those sample types and species showing the most favourable response to Pt and Au could be undertaken. However, the irregular distribution of each species in the survey area restricts the extent to which this objective might be attained and precludes a detailed evaluation of the data with respect to the underlying geology.

In view of the generally poor exposure and the results of the surveys described above, it was concluded that the potential for locating stratiform magmatic PGE-bearing mineralisation in the West Huntly cumulate body is low. Similarly, the prospects for finding PGE-bearing mineralised pyroxenitic pegmatites of the type exposed in the Bin Quarry were considered to be remote on account of their size. In addition, EVL had searched without success for magmatic sulphide mineralisation in the olivine cumulates in the Huntly intrusion using a combination of IP and core drilling.

INVESTIGATIONS IN THE CENTRAL HUNTLY SHEAR ZONE

Reconnaissance surveys

Following recognition of precious metal enrichments in deformed mafic-ultramafic rocks in the Upper Deveron Belt (Gunn et al., 1990) and at the sheared south-eastern margin of the Knock intrusion (Fletcher and Rice, 1989), attention was directed towards the location of structurally-controlled PGE mineralisation within the Huntly intrusion. Investigations were focused on the Central Huntly Shear Zone which transects the Huntly intrusion and continues northwards along the eastern flank of the Knock intrusion, where it is associated with sulphide ores at Littlemill and Auchencrieve (Figures 2 and 5). As noted above, Fletcher and Rice (1989) reported up to about 600 ppb combined precious metals in samples of deformed and altered Cu-Ni sulphide mineralisation from this zone.

The Central Huntly Shear Zone occupies a well-defined linear valley infilled with generally thin (<2 m) deposits of till. Exposure is sparse, being restricted to a few outcrops of deformed, sometimes mylonitised, altered mafic rocks. Reconnaissance survey lines (88-1 to 88-9) across this structure were investigated by a variety of geochemical and geophysical methods to test for any indications of Cu-Ni sulphide mineralisation (Figure 2). Additional traverses (88-10 and 88-11) across a lineament trending N-S on the east side of Ordiquhill were also investigated.

Magnetic and electromagnetic surveys

Because of the massive/sub-massive nature of the PGE-bearing sulphide mineralisation at Littlemill and Auchencrieve, the electromagnetic method was utilised in the Central Huntly Shear Zone. This system is rapid in operation and requires only two operators. Both horizontal loop electromagnetic (HLEM) and VLF electromagnetic techniques were used, supplemented by magnetic total field measurements. The HLEM system uses a "near field" transmitter (i.e. some tens of metres away from the receiver) whilst the VLF uses a "far field" transmitter (ie hundreds of kilometres away from the receiver); because of this wire fences, cables, etc., both overhead and underground, distort the VLF data much more than the HLEM data, giving rise to very large amplitude, but characteristic anomalies. The HLEM technique was therefore considered to be potentially the most useful in the Central Huntly Shear Zone. Unfortunately the transmitter failed after the completion of only 2.5 of the total of 13 lines and could not be repaired in time to complete the survey.

The survey described in this report is thus considered not to have achieved its objectives because of the failure of the HLEM transmitter. The full survey results are available on open-file from the BGS.

The Scintrex digital equipment used for the survey was the IGS-2 system comprising the MP4 total field magnetometer, VLF4 VLF receiver, and the EM4 HLEM/GENIE receiver. All three geophysical sensors are mounted in one console so the survey line need be traversed once only to collect all the data. The source of the VLF primary field was GBR Rugby transmitting at 16.0 Khz. The HLEM requires an associated Scintrex transmitting unit, the TM2, which is carried by a second geophysicist. Frequency pairs of 112.5 Hz - 3037.5 Hz and 1012.5 Hz - 112.5 Hz were used for this survey.

Observations of all three geophysical parameters were made at 10 m intervals along the survey lines. The HLEM survey used a coil separation of 75 m between the receiver (IGS-2/EM4) and the transmitter (TM2) units. In general terms this is equivalent to a depth of investigation of about 30 m. The Scintrex equipment has a solid state memory for data capture and is off-loaded onto a computer at the end of the day's fieldwork for subsequent data reduction and plotting.

The HLEM profiles are particularly featureless, indicating the absence of linear conductors such as might be expected from a planar shear zone or fracture containing conductive sulphides. The few minor perturbations that occur in the HLEM profiles are solely due to cultural effects. For this reason, together with the incomplete HLEM cover, these data are not presentd here. It is worthwhile to note, however, that the distortive effect of wire fences and cables is much less marked in the HLEM data than in the VLF data.

There are few geologically significant magnetic anomalies present on the reconnaissance traverses 88-1 to 88-11. Similarly few features in the VLF electric field (Figure 13) or VLF magnetic field (Figure 14) are easily related to the geological environment. Zones marked as a change in rock types are tentative since the actual change is that of the near surface conductivity and could reflect a change in the thickness of the overburden. Where the VLF magnetic and electric field anomalies are coincident a change in rock type is more probable.

It should be noted that the resistivity values representing the electric field measurements are in fact calculated from both the VLF electric and magnetic field data so, to an extent, the profiles seen in Figures 13 and 14 are related. This is well illustrated on line 88-8 where zones of high resistivity are inferred to occur under a fence and power line respectively. Although suspect, they cannot be dismissed completely. The eastern end of lines 88-6 and 88-7 also display zones of high resistivity but the magnetic field measurements are not excessively anomalous except at the very end of the lines where the wire fence occurs.

Although the IP technique would have been the ideal method for this reconnaissance phase of investigations, it is labour intensive and expensive to survey. Because of the anticipated massive nature of the sulphide mineralisation, HLEM surveys using a variety of frequency pairs and receiver-transmitter separations are quite adequate. The limitations of the VLF method, especially in a 'noisy' setting, have been demonstrated. The existing VLF data do not give encouragement for

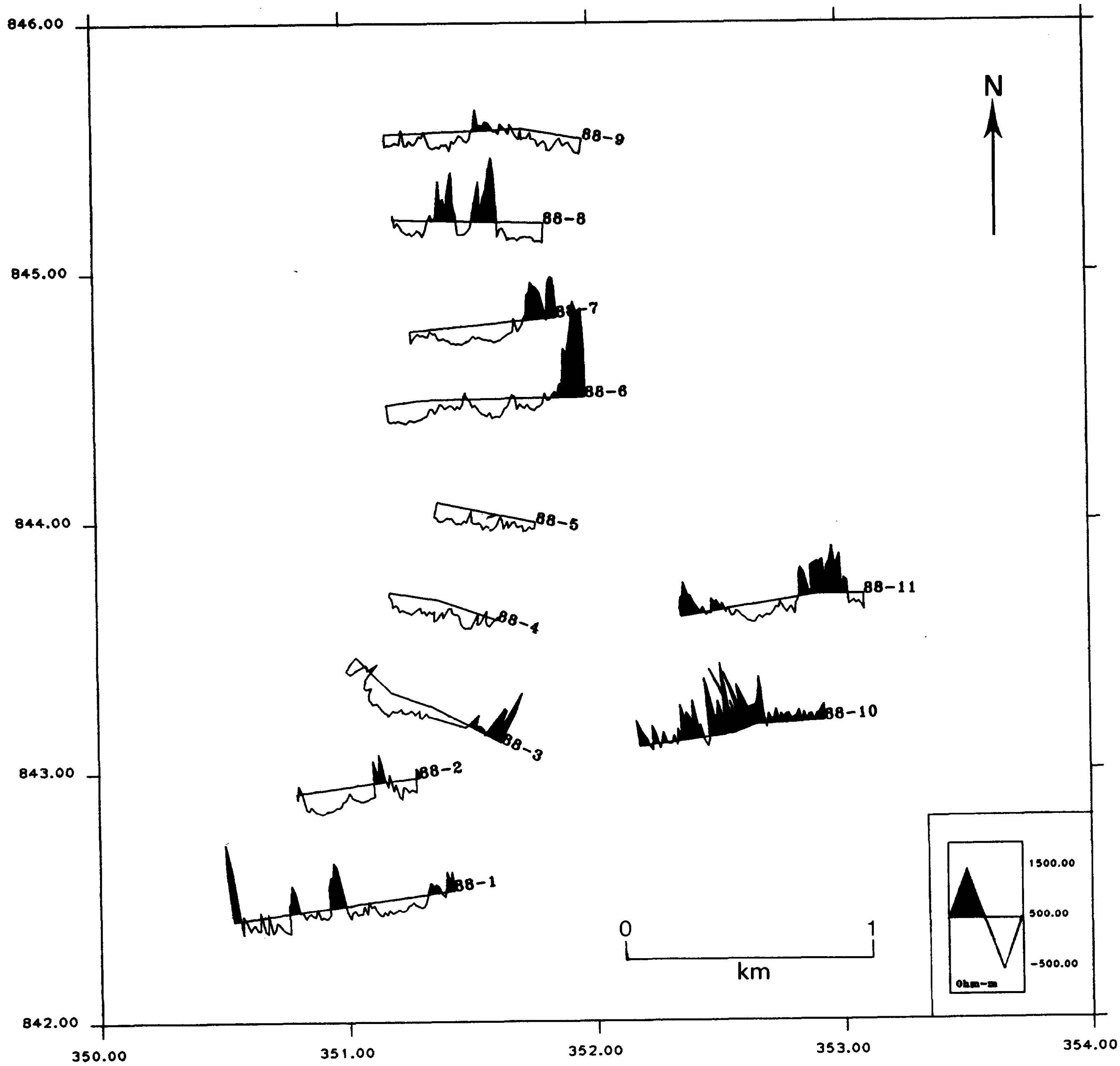


Figure 13 VLF electric field apparent resistivity profiles for the Huntly intrusion

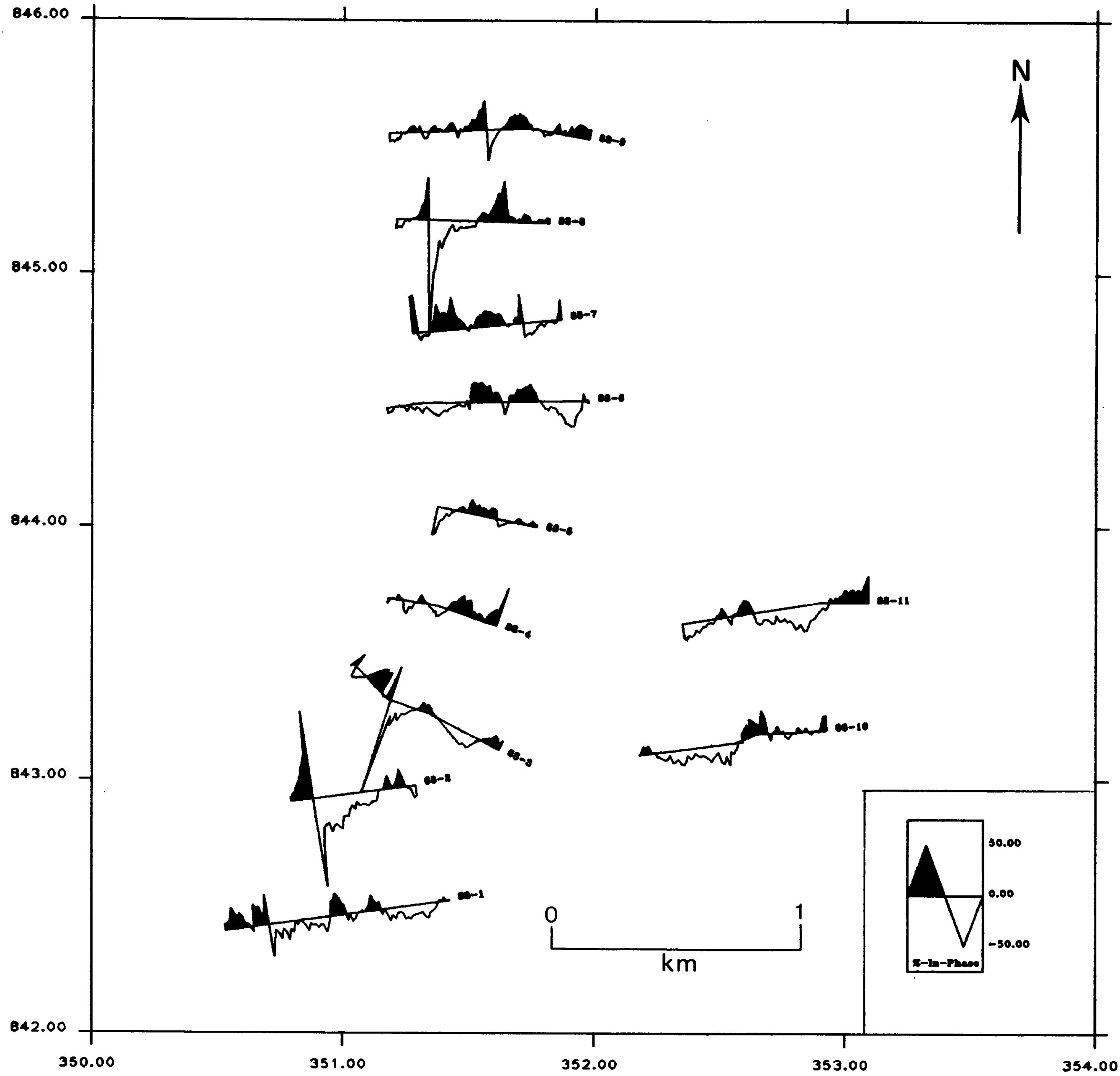


Figure 14 VLF magnetic field in phase component profiles for the Huntly intrusion

continuation of the HLEM survey over the lines that were unsurveyed as a result of the HLEM transmitter failure.

Overall the results obtained from this limited survey have not indicated the presence of any significant sulphide mineralisation with which an enrichment in PGE could be associated. This is due principally to the HLEM equipment failure and cultural noise generated by fences and cables.

Soil gas surveys

Field methods of analysis of CO_2 and O_2 in soils have been successfully used in the detection of concealed sulphide mineralisation (Ball et al., 1990). Carbon dioxide may be produced in soil or overburden by the reaction between sulphuric acid (derived from sulphide weathering) and carbonate minerals. Additionally, CO_2 is produced by the metabolic action of micro-organisms on oxidising organic and mineral material, including sulphides. These mechanisms are capable of generating soil-gas compositions departing markedly from mean atmospheric contents (20.96 vol% O_2, 0.03 vol% CO_2). Typically anomalies are manifest as enhanced CO_2 contents with attendant depletion in O_2.

As an exploration technique for detection of buried mineralisation soil-gas analysis offers logistical and economic advantages over most alternatives. Furthermore, in areas of thick overburden it may offer a more sensitive response to mineralisation than more conventional geochemical or geophysical techniques. The main disadvantage is that of "noise" resulting from biogenic and pedogenic influences such as soil permeability, drainage and vegetation cover. Consideration of these factors is essential when evaluating data.

Soil gas is collected by means of a hollow spike driven into the ground to a depth of about 0.5 m. The gas is collected using a hand pump via rubber tubing in a calibrated burette. A modified Orsat gas analysis apparatus comprising two absorption vessels for the selective removal of carbon dioxide and oxygen is used for the measurement of the composition of the soil gas (Ball et al., 1983). The absorbent for CO_2 is 40% aqueous potassium hydroxide, while for O_2 a mixture of ammonium chloride and ammonia in contact with copper coils is employed. Each gas can be determined in the field by this method to a lower detection limit of 0.1%. Up to 30 stations may be occupied per day depending on terrain conditions and station spacing. The equipment can be carried and operated by a team of two without difficulty. The generation of data in the field is of major benefit to survey planning, allowing rapid reconnaissance and identification of areas for detailed follow-up.

Soil gas determinations of CO_2 and O_2 were carried out in June 1988 during preliminary investigations over the Central Huntly Shear Zone and the subsidiary tectonic dislocation to the east of Ordiquhill. Measurements were made along eight traverses spaced at 200-300 m intervals spanning the main shear zone, with a further two to the east (Figure 2, Lines 88-1, 88-2 and 88-4 to 88-11). The orientations of several lines were modified to take account of terrain difficulties. A total length of 6.7 km was covered, with readings taken at 25 m intervals. Recording of ground conditions and surface features formed an integral part of field observations.

Monitoring of rainfall was undertaken in order to evaluate its possible influence on soil gas levels. Prior to the survey a prolonged period of several weeks without rain had rendered the soil moisture levels low at and near surface. The weather remained dry throughout the study period and its influence on the results at the reconnaissance phase is therefore discounted.

Data from the reconnaissance traverses, shown in Figure 15 (a) and (b), indicate a number of high amplitude CO_2 anomalies coincident with boggy ground (B) or adjacent to streams (S). The amplitude of these anomalies was commonly in the order of 5% and occasionally up to 10%, relative to background levels of 1-3% CO_2. At these locations complementary low O_2 levels were also recorded. The source of these anomalies is ascribed to the increased impermeability due to waterlogging. This leads to impedance of gaseous exchange with the atmosphere and hence to presence of reducing conditions at shallow depths within the overburden profile. The only exception was found on line 88-1, where a sharp fall in O_2 shows no corresponding rise in CO_2.

Anomalies of similar amplitude are also found at other sites not coincident with surface drainage features. These anomalies which could not be ascribed to drainage conditions were investigated further by a limited programme of manual pitting.

Overburden sampling

A total of 20 pits was dug by hand over anomalies on five traverses, namely 88-1, 88-5, 88-6, 88-7 and 88-11. Pit depths ranged from 0.7 to 1.2 m, but in no case was it possible to reach bedrock by this technique. Partial pan concentrates and fine (-150 micron) fraction samples were collected from the base of each pit, as described in the overburden survey conducted in the cumulate zone.

Panned overburden samples were analysed for Au, Pt, Pd and Rh, but very few values above the analytical detection limits were reported. The maximum Pt concentration (13 ppb) is present in a sample from traverse 88-11 spanning the lineament east of Ordiquhill. Maximum Au and Pd values are 10 ppb and 12 ppb respectively. These occur in a sample from line 88-5 which also contains the highest As level in the reconnaissance dataset. This association of elements may be indicative of minor small-scale precious metal-bearing mineralisation. In other samples As levels do not exceed 4 ppm. No other associations between precious metals and potential pathfinder elements are observed. In view of these results only four of the fine fraction samples were analysed for precious metals. Those selected were from, or adjacent to, the sites with the highest levels in panned material. The PGE and Au contents in the fine fractions were found to be generally comparable to or lower than those in the panned samples.

Biogeochemistry

A limited amount of biogeochemical sampling was carried out along the reconnaissance traverses across the southern forested section of the Central Huntly Shear Zone and the lineament east of Ordiquhill. A total of 38 samples was collected from 18 sites within this area. Scots pine is the most widespread species and was sampled at 13 sites in this area.

Enrichment in the Pt contents of biogeochemical samples was noted at several sites. The mean concentration in 12 samples of Scots pine bark is 10.5 ppb Pt, with the highest levels occurring in the main shear zone itself. In one section of traverse 88-1, three adjacent sites have enhanced levels of Pt in Scots pine bark, up to a maximum of 28 ppb. These sites are coincident with the soil-gas anomaly described above on traverse 88-1 which was investigated by pitting. No evidence of any

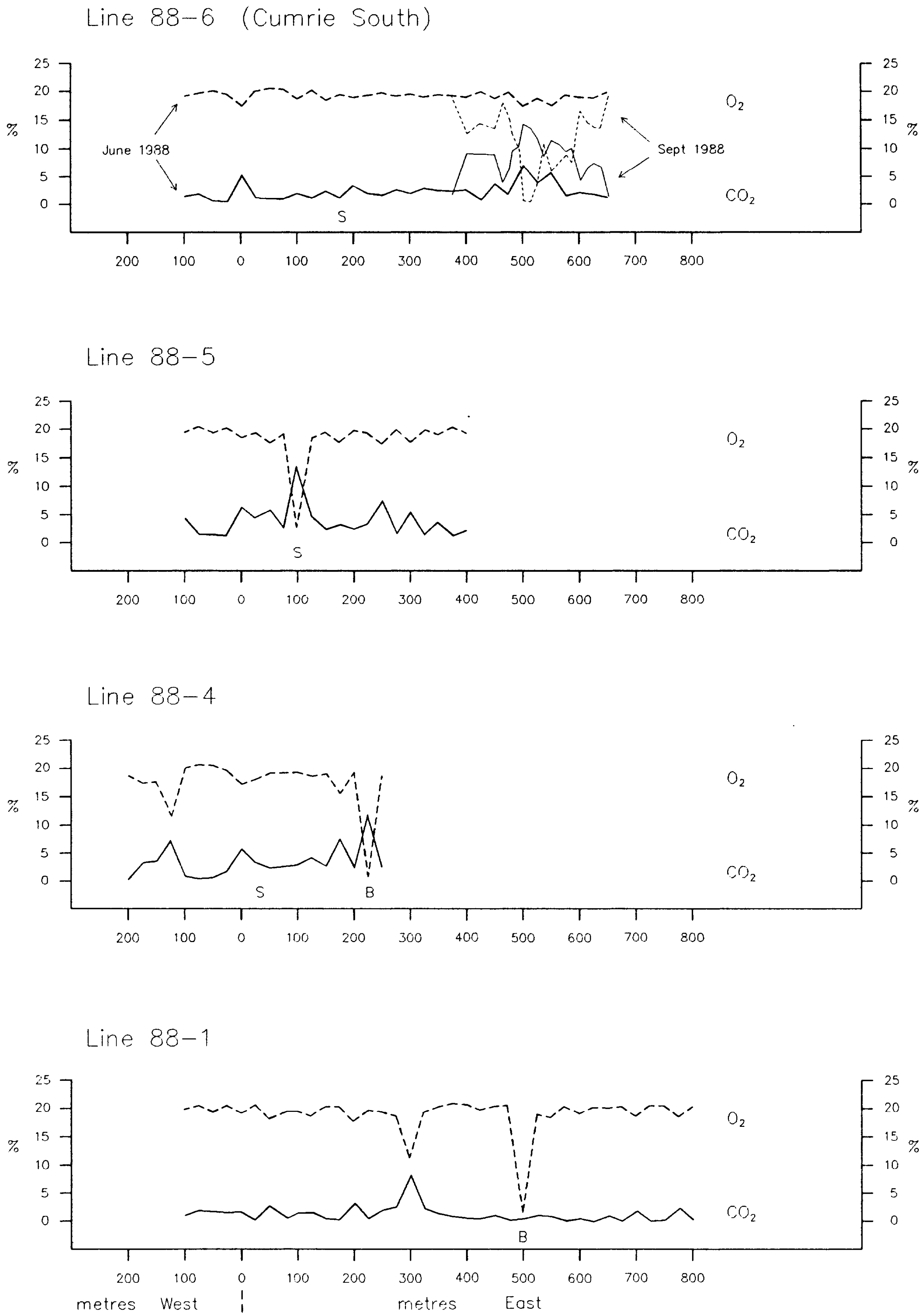
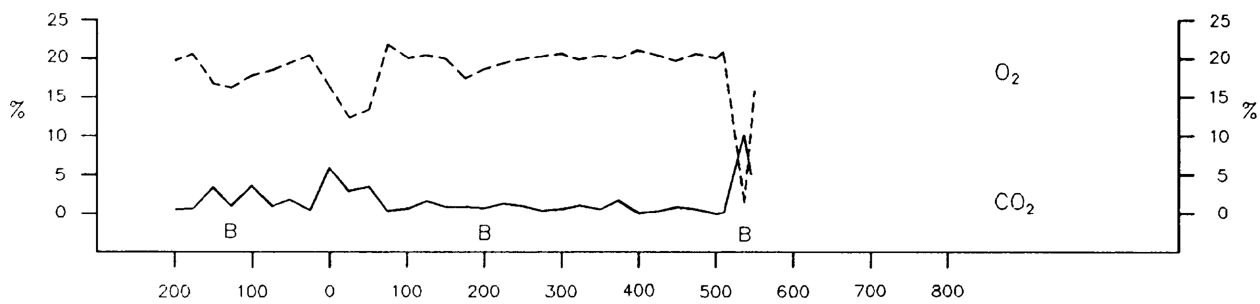
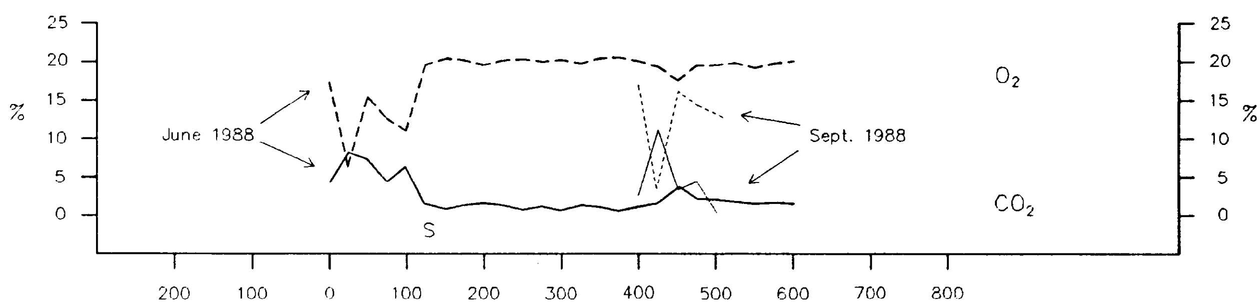


Figure 15 (A and B) Soil gas data for reconnaissance traverses in the Central Huntly Shear Zone

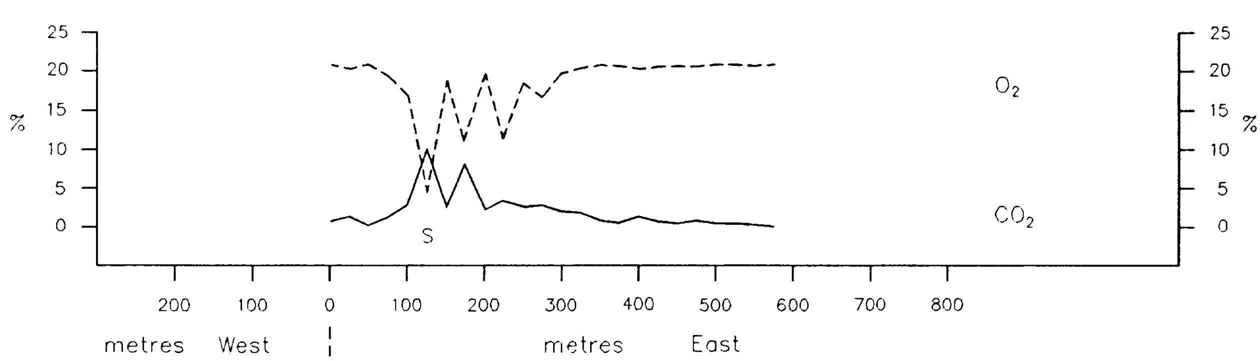
Line 88–11



Line 88–8 (Cumrie North)



Line 88–7



PGE enrichment in overburden samples was revealed, but the excavations did not reach bedrock at these localities.

Pd and Au concentrations in Scots pine bark samples are generally very low. In litter samples derived from Scots pines in this area the levels of Pt, Pd and Au are uniformly low, with mean concentrations 2 and 3 ppb.

Larch bark and twig samples for the intrusion as a whole have their maximum Pt concentrations of 24 ppb and 16 ppb respectively in the Central Huntly Shear Zone. The areal extent and significance of this enrichment cannot, however, be estimated due to the fact that samples of larch were collected from only two sites.

Detailed Surveys

A detailed soil gas and overburden sampling survey was conducted in September 1988 to investigate the locally enhanced CO_2 levels, coincident with minor enrichment in Au and PGE, on lines 88-6 and 88-8. The two areas, hereafter referred to respectively as Cumrie South and Cumrie North, are situated in open farmland, in the northern part of the Central Huntly Shear Zone (Figure 2).

All soil gas sites sampled in June were repeated in September. Similar soil gas signatures were recorded, but the amplitude of anomalies increased by a factor of two or more (Figure 15). Periods of predominantly light rainfall occurred prior to and during the September survey resulting in an increase in soil moisture. The increase in CO_2 may be linked to higher microbiological or chemical activity due to wetting. A decrease in gaseous exchange with the atmosphere as a result of reduced permeability may also be significant.

Overburden samples collected from both areas were analysed for a range of trace elements by XRF and for Au, Pt, Pd and Rh by lead fire assay and GFAAS or ICP-MS. Soil samples collected from Cumrie North were analysed for trace elements only by XRF.

Cumrie South

Soil gas readings were taken at 25 m intervals along 6 east-west traverses spaced 50 m apart. Station intervals were reduced to 12.5 m along line 2500N (88-6) to provide detailed information. The location of the Cumrie South survey area is shown in Figure 2 and the soil gas results in Figure 16.

Enhanced CO_2 and coincident depleted O_2 levels were found to repeat with the June survey on line 2500N. Elsewhere the complex pattern of variation contains few discrete anomalies, but adjacent zones within the survey area are characterised by markedly contrasting soil gas signatures. For example the relatively low CO_2 recorded at sites close to Cumrie Plantation (0.8 and 2.2%), probably reflects a biogenic influence (Peachey et al., 1985). Anthropogenic influence is evident in the south-east field. Here subsurface waterlogging, coincident with a patchy distribution of dry, intermediate and wetland species reflect the unimproved state of the field. The remaining ground at Cumrie South has been improved by subsurface drainage. Here the greater uniformity of soil gas values is seen as a reflection of a more consistent soil moisture pattern.

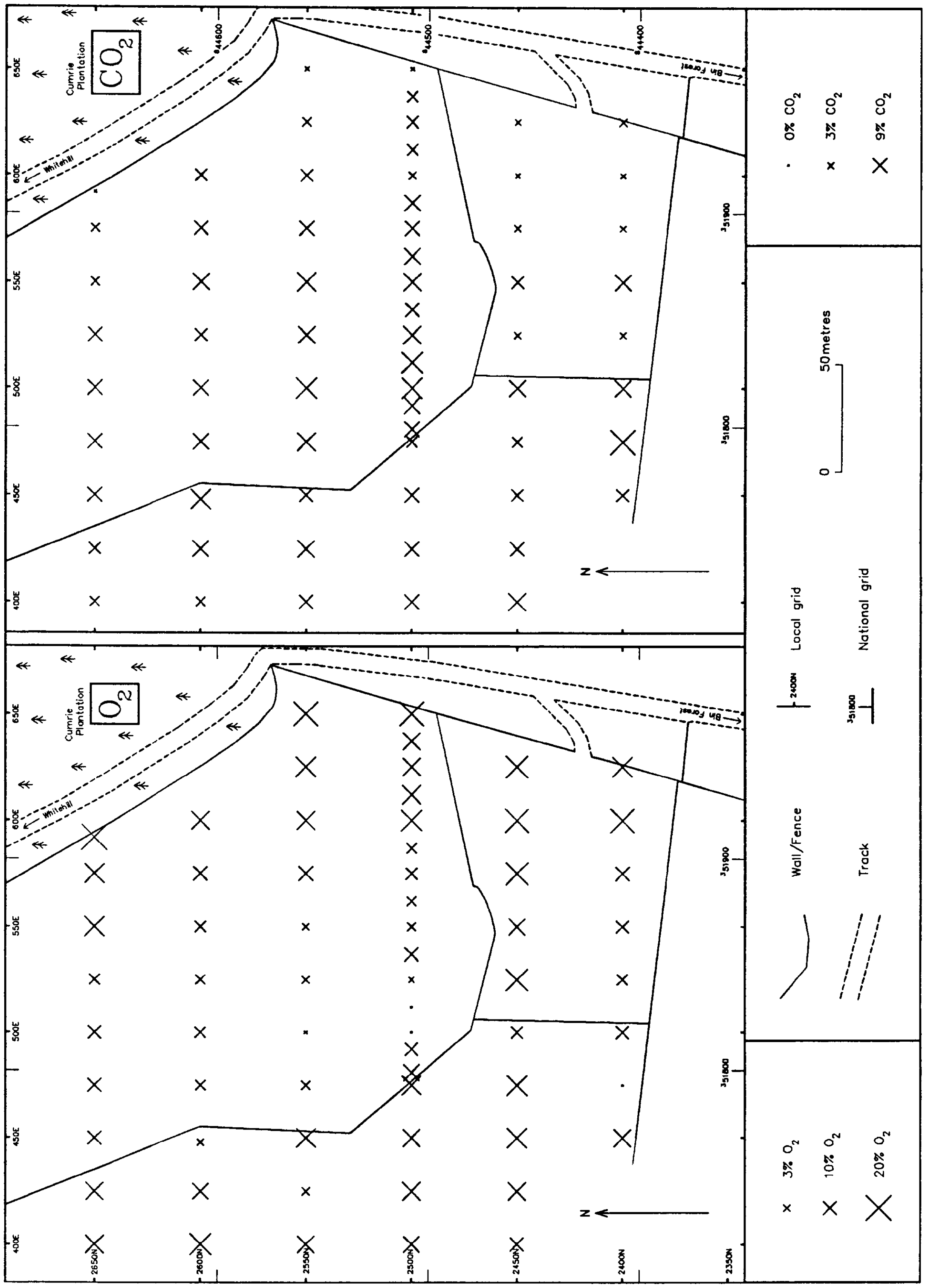


Figure 16 Soil gas data (O_2 and CO_2) for Cumrie South

Overburden sampling was carried out to elucidate the soil gas anomalies possibly related to bedrock causes. Attention was focused on zones of high contrast in soil gas contents which might indicate the existence of oxidising sulphide mineralisation.

In view of the failure to reach bedrock by pitting in the reconnaissance surveys, overburden sampling was carried out using a Minuteman power auger and a Kubota mini-digger. A Cobra percussion drill was used to define overburden thickness and thus to determine which equipment was used at each site. However, the depths to rockhead indicated by this method were not always reliable due to obstruction by large boulders and the locally heavy nature of the overburden. In general, the digger was utilised in zones where overburden thickness was less than 2.5 m.

In addition to basal samples, channel samples were collected from the overburden profile at selected pit sites. A total of 53 samples were collected from 21 sites. Rockhead was reached in six of the twelve pits excavated by the digger. In each case the bedrock consisted of biotite gabbronorite. The dominant clast lithology at other pitted sites was also biotite gabbronorite, suggesting proximity to bedrock, but mixed with varying proportions (up to 40%), of quartzite and mica schist. As discussed previously it is more difficult to ensure that samples collected with the Minuteman are derived from the till-bedrock interface.

Analyses from the 53 samples show highly significant correlations between Fe, Mn, Cu, Zn and Zr in panned samples. Spearman rank correlation coefficients fall in the range 0.7 - 0.96, significant at the 99.9% confidence level. Profile sampling indicates a progressive increase in these elements with depth, with the highest levels in basal tills. Results for the precious metals are uniformly low, with only Au (5 ppb maximum) and Pd (6 ppb maximum) showing enhancement above the detection limits of 1 and 2 ppb respectively. Similarly low levels of PGE and Au were reported in a small suite (5) of -150 micron samples from selected sites.

Sporadic high concentrations of Zr (maximum 8344 ppm) and Zn (maximum 211 ppm) in panned samples are not consistent with levels likely to be derived from underlying gabbronorite bedrock. These elements are indicative of a metasedimentary source which may be tectonically intercalated with the basic igneous lithologies or, alternatively, reflect a more distal source of glacially-transported material.

Cumrie North

Repeat measurements along line 88-8 at Cumrie North confirmed the presence of a zone with enhanced CO_2 levels. The anomaly defined by the survey in September was higher in amplitude than that recorded in June, and displaced by 25 m to the west (Figure 15b). Soil gas readings were made at 25 m intervals along six short traverses, totalling 0.65 km in length, in the vicinity of this anomaly.

Soil-gas measurements on lines adjacent to 88-8 showed similar highly variable and locally enhanced CO_2, up to a maximum level of 11%, accompanied by depletion in O_2 to around 3.5% (Figure 17). The O_2 contents at other sites on this grid are more uniform and generally higher than those present in Cumrie South. This could be due to the more rapid rate of exchange between soil and atmospheric gas in the slightly more permeable and better drained soils developed over much of the Cumrie North zone.

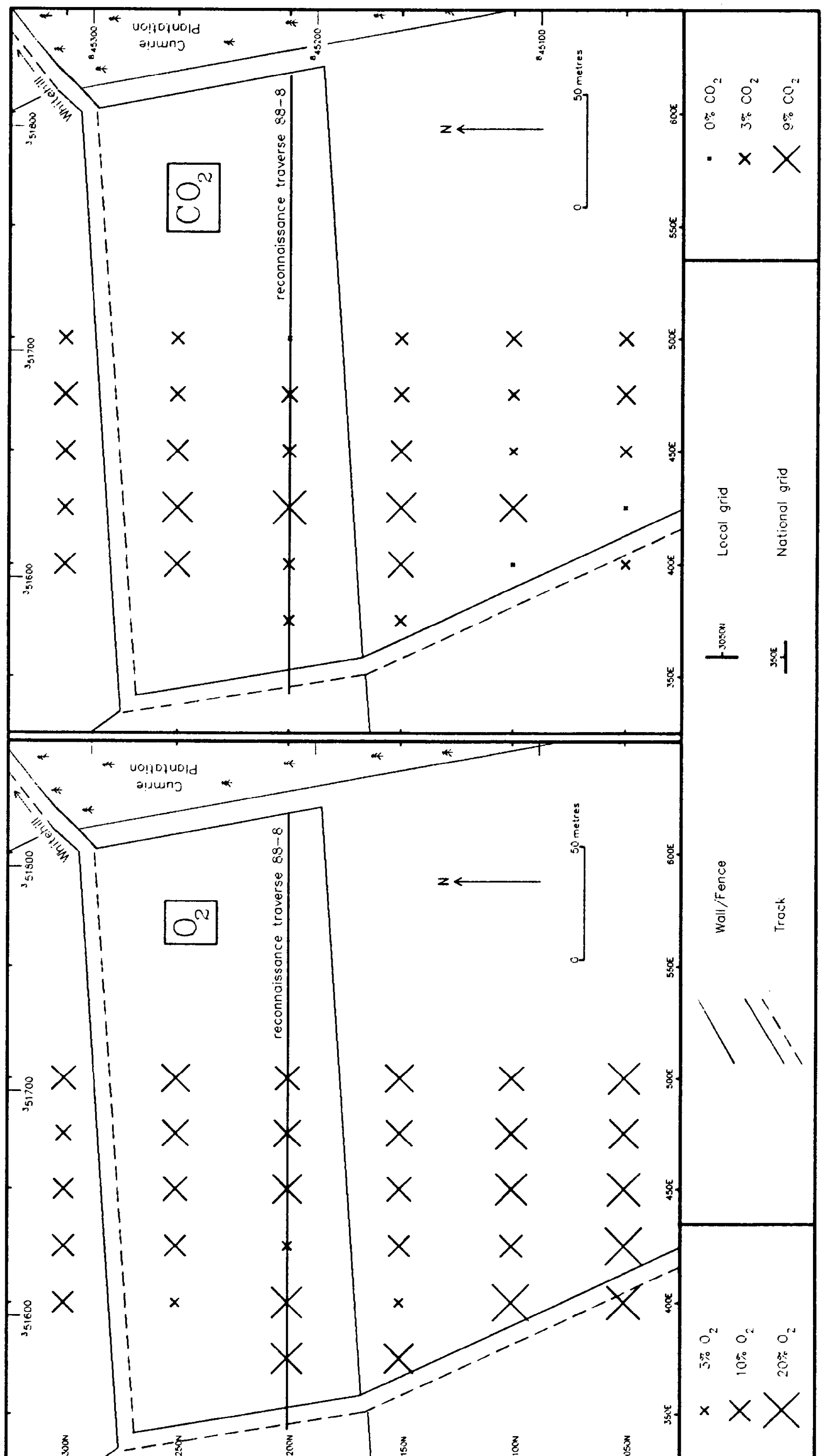


Figure 17 Soil gas data (O_2 and CO_2) for Cumrie North

In contrast to Cumrie South, this zone is characterised by more uniform vegetation and surface drainage. Consequently the irregular and anomalous variations in soil-gas were attributed to sub-surface causes and were, therefore, regarded as worthy of further investigation.

A Cobra percussion drill was used to define overburden depth. Rockhead was reached at all sites, with overburden thickness increasing from less than 1 m in the northern part of the grid to 2.5 m in the south and west of the survey area. The consistently shallow overburden depth allowed the use of the Kubota mini-digger for sampling in preference to the Minuteman.

A total of 22 pits were excavated at sites along traverse lines with anomalous soil gas values. The spacing between pits was normally 25 m, reduced where prospective lithologies were intersected. Basal overburden and bedrock samples were collected and processed as previously described. Variations in overburden composition were marked, ranging from clay to highly permeable sandy loams. Some profiles developed over biotite gneisses were characterised by abundant coarse mica.

Three distinct lithological zones were defined in the survey area from the bedrock observed in the pits (Figure 18). Biotite gabbronorites occupy the north-western sector, while a narrow zone of deformed mafic and ultramafic rocks (serpentinite, pyroxenite and amphibolite) runs in a near northerly direction through the centre of the area. Adjacent to and between these zones are paragneisses and semi-pelitic schists. Sulphide mineralisation was observed only in sporadic trace quantities confined to pyroxenites and serpentinites within the narrow band of ultramafic rocks in the central part of the grid area.

The distribution patterns of Cr and Ni in panned overburden correspond closely with the ultramafic zone. Localised enhancement of Cr (maximum 4148 ppm) and Ni (maximum 1715 ppm) are coincident with olivine pyroxenite and serpentinite lithologies. Minor enrichments in the PGE content of panned samples derived from the ultramafic lithologies was recorded, up to maximum values of 13 ppb Pd and 16 ppb Pt (Figure 18). Panned samples derived from other rock types are uniformly low in PGE with concentrations at or below the analytical detection limits. One exception was derived from a site on the biotite gabbronorite in the north-west of the grid which yielded 13 ppb Pt.

Precious metal determinations on fine fraction (-150 micron) basal overburden samples from the pits yielded PGE distribution patterns similar to those in panned samples. Pt is enhanced over the ultramafic lithologies up to a maximum of 35 ppb, while concentrations over the other rock types generally fall below 3 ppb (Figure 19). The Pd and Au distribution patterns are more complex, showing sporadic minor enrichments, up to 43 ppb and 11 ppb respectively, over both ultramafic and metasedimentary rocks (Figure 19). The absolute concentrations in the fine fraction samples from all rock types are generally higher for both Pt and Pd, by a factor of between two and three, relative to the levels present in the panned samples. The fine fraction samples were not analysed for any elements other than the PGE and Au. Summary statistics for panned and -150 micron basal overburden samples are shown in Appendix 1, Tables 7 and 8.

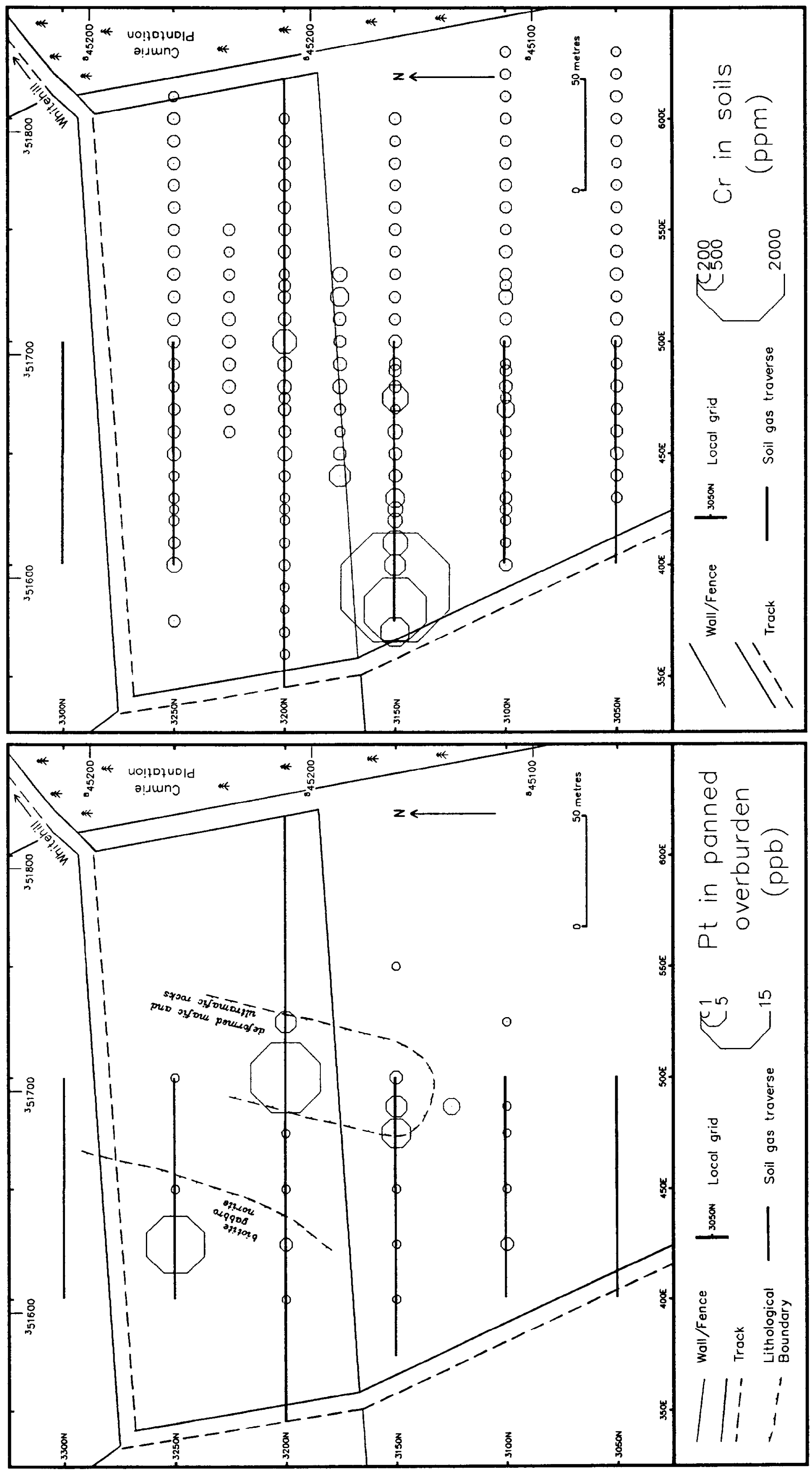


Figure 18 Distribution of Pt in panned overburden and Cr in soil samples from Cumrie North

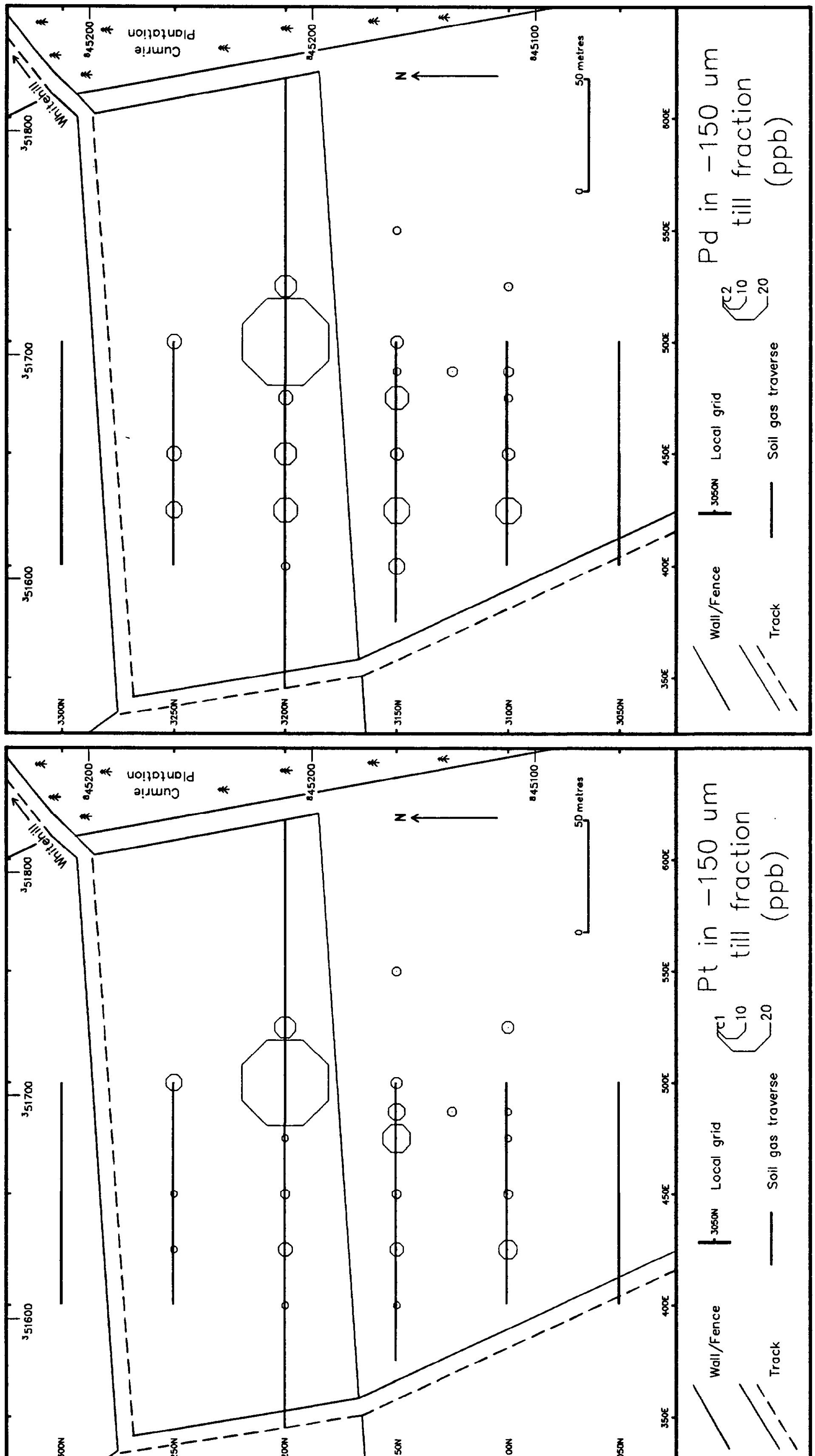


Figure 19 Distribution of Pt and Pd in -100 mesh fraction overburden samples from Cumrie North

In order to map geological boundaries within a larger area than was covered by pitting and to delineate the zone of deformed mafic-ultramafic rocks in particular, a programme of shallow soil sampling was conducted (Figure 18). A total of 148 soils was collected at 10 m intervals along 7 traverses using a hand auger.

The soil geochemistry indicates a zone of enhanced Cr and Ni running through the central part of the grid (Figure 18). This conforms closely with the band of deformed mafic-ultramafic rocks defined by the overburden sampling. The presence of another ultramafic body is indicated by a Cr-Ni anomaly present at the western end of line 3150N, on the margin of the area investigated by pitting. Five adjacent sites show enhanced Cr and Ni, with maximum values of 2500 ppm and 2000 ppm respectively. Soil-gas levels over this anomaly are near normal background levels for the Cumrie North area, around 3% CO_2 and 17% O_2 and so only a single pit (3150N, 400E) was excavated. This revealed bedrock consisting of friable, altered amphibolite. Higher Cr and Ni levels in soils at adjacent sites to this pit suggest that ultramafic lithologies are also present in close association with the amphibolite. Panned and fine fraction basal overburden samples derived from the amphibolite pit site show no enhancement in PGE concentration.

Chemical data for the other trace elements determined in soils from the Cumrie North area (Ca, Ti, Mn, Mn, V, Co, Cu, Zn, Rb, Sr, Sb, Ba and Pb) is more difficult to interpret in terms of bedrock geology. This is due the presence of till cover over the grid area and the derivation of the soil samples from shallow depths, normally 50 - 75 cm.

A total of 11 bedrock samples collected from pits were analysed for PGE and trace elements by XRF. Six of these samples were ultramafic lithologies from the band in the centre of the grid area, while the others comprised three amphibolites and two metasediments. One sample of massive serpentinite was found to contain enhanced levels of Pt, Pd and Au - 17, 19 and 30 ppb respectively, while a heterogeneous, variably foliated, pyroxenite sample gave values of 28 ppb Pt, 63 ppb Pd and 4 ppb Au. Other samples of ultramafic rock types show only minor PGE enrichments. The precious metal contents of the other lithologies are below or close to the analytical detection limits.

Discussion

Localised enhancements in soil CO_2 in the Central Huntly Shear Zone are not related to significant grades of sulphide mineralisation. Many factors appear to contribute to the generation of significant CO_2 anomalies in this environment. Anthropogenic influences, such as subsurface drainage improvement and forestry planting, as well as natural variability within the soil are important. In a complex shear zone at Cumrie North the tectonic juxtaposition of several contrasting rock types has led to considerable variation of soil permeability and composition in a small area. This has resulted in the generation of the observed irregular soil-gas anomalies.

The presence of two composite bodies of olivine pyroxenite and serpentinite at Cumrie North is indicated by soil and overburden geochemistry. Slight enrichments in Pt and Pd in overburden were shown to reflect similar enhancements in bedrock collected from excavated pits. The soil anomaly remains open to the south and west so it is possible that a larger composite mafic-ultramafic body is present.

No other indications of enhanced PGE levels have been revealed by the investigations in the Central Huntly Shear Zone. It is stressed however that the surveys were essentially of a reconnaissance nature and it is not possible to write off the whole zone conclusively.

CONCLUSIONS

In spite of its relatively small size, the Huntly intrusion presents a difficult exploration problem on account of its complex geology and poor exposure. Recent re-mapping by BGS and workers at Aberdeen University has been most useful in guiding exploration in this intrusion. The archive of EVL material held by BGS has also been valuable in target selection. The value of this material to mineral exploration, mapping and research studies on the Caledonian basic intrusions of north-east Scotland is stressed.

In common with data reported from other synorogenic tholeiitic intrusions (Boyd et al., 1987), there appears to be little evidence of significant enrichment of the PGE in the Huntly intrusion. This may be due to magma derivation from a depleted mantle or, as favoured by Boyd et al. (1987), due to depletion of PGE in the crust. In the Huntly cumulates, interstitial magmatic sulphide is widespread at all levels in the sequence, indicating that the parent magma was continuously at or near sulphur saturation. This has resulted in the removal of the chalcophile PGE from the melt to produce the observed low concentrations in the cumulate rocks. A single sulphur saturation event, under appropriate conditions, is more likely to yield high PGE concentrations over a narrow interval, resulting in the production of potentially economic mineralisation. If such a body were present in the Huntly intrusion it would be particularly difficult to detect, because of its narrow width and limited geophysical response.

An extensive lithogeochemical sampling programme in the Huntly intrusion established a relative enrichment in the ultramafic cumulates, similar to background levels reported for similar lithologies worldwide (Crocket, 1982). Late magmatic volatile-rich pyroxenitic pegmatites exposed in the West Huntly cumulate body, however, were found to contain enhanced PGE concentrations. These heterogeneous graphitic sulphide-bearing bodies have been shown by drilling to be of small size and impersistent at depth. They do not, therefore, merit further exploration effort.

Exploration for hydrothermal PGE mineralisation in the Central Huntly Shear Zone was conducted using a variety of techniques. No indications of PGE-bearing Cu-Ni sulphide mineralisation were found similar to that on the south-eastern margin of the Knock intrusion within the same structure. Minor Pt, Pd and Au enrichments have, however, been located in deformed ultramafic rocks with low sulphide contents in the vicinity of Whitehill. These levels are comparable to those observed in similar lithologies in the Upper Deveron valley for which a hydrothermal origin has been proposed (Gunn et al., 1991).

Soil-gas surveys across the Central Huntly Shear Zone yielded complex patterns of CO_2 and O_2 distribution, which could largely be explained in terms of processes unrelated to bedrock geology. In the Cumrie North area of the Central Huntly Shear Zone the intimate juxtaposition of contrasting lithologies has given rise to anomalous CO_2 levels. The process responsible for these patterns is not understood. None of the lithologies exposed by pitting in this area contains more than trace quantities of sulphide mineralisation. Further orientation surveys over sulphide mineralisation and over zones similar to the Central Huntly Shear Zone in terms of structural and lithological complexity are required, in areas of glaciated terrain, before this method can be shown to be a useful exploration tool in this environment.

Biogeochemical surveys conducted over the Huntly intrusion have revealed considerable variation in the Pt and Au concentrations present in different sample types and different species. From the studies carried out twigs appear to offer most potential for PGE exploration. Orientation surveys over known mineralisation are required to determine the optimum methods of biogeochemical exploration in this environment.

The available data combine to indicate a low potential for the occurrence of PGE-bearing mineralisation in the Huntly intrusion. However, given the reconnaissance nature of the surveys conducted and the need for further development of some of the methods employed, the Huntly intrusion cannot be written off altogether.

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APPENDIX 1: Summary tables of geochemical data

Table 1 Summary statistics for ultramafic rocks from the Huntly intrusion survey area

Element		No Samples	Mean	Standard Deviation	Minimum	Maximum
Pt	(ppb)	24	9	11	1	50
Pd	(ppb)	24	15	17	1	63
Rh	(ppb)	20	2	1	2	7
Au	(ppb)	20	7	7	1	30
Ca	(ppm)	24	25068	30892	200	102100
Ti	(ppm)	24	843	1078	20	5480
V	(ppm)	24	67	54	27	276
Cr	(ppm)	24	2015	1151	64	4216
Mn	(ppm)	22	1417	282	1070	2170
Fe	(ppm)	24	91705	29838	39900	154288
Co	(ppm)	24	131	43	44	196
Ni	(ppm)	24	1151	561	76	2003
Cu	(ppm)	24	187	266	0	978
Zn	(ppm)	24	53	19	19	97
Zr	(ppm)	24	8	13	0	51
Sb	(ppm)	22	0.5	1.3	0	5
Pb	(ppm)	24	4	5	0	24
Bi	(ppm)	20	0.4	0.6	0	2
Pt/Pd		24	0.85	0.62	0.17	2

Table 2 Summary statistics for olivine gabbro rocks from the Huntly intrusion survey area

Element	No Samples	Mean	Standard Deviation	Minimum	Maximum
Pt (ppb)	25	3	3	2	15
Pd (ppb)	25	2	1	1	5
Rh (ppb)	21	2	0	2	2
Au (ppb)	21	5	17	1	80
Ca (ppm)	25	77444	9027	53888	93000
Ti (ppm)	25	2103	1652	530	7520
V (ppm)	25	131	63	37	256
Cr (ppm)	25	860	620	204	2727
Mn (ppm)	25	687	163	410	1136
Fe (ppm)	25	42686	11044	24700	77284
Co (ppm)	25	47	14	26	88
Ni (ppm)	25	248	209	19	830
Cu (ppm)	25	105	100	8	352
Zn (ppm)	25	32	14	12	76
Zr (ppm)	25	14	12	1	42
Sb (ppm)	23	0.6	1.1	0	4
Pb (ppm)	25	3	3	0	10
Bi (ppm)	23	0.2	0.4	0	1
Pt/Pd	25	1.66	2.8	0.5	15

Table 3 Summary statistics for mineralised pegmatitic pyroxenites from the Huntly intrusion survey area

Element	No Samples	Mean	Standard Deviation	Minimum	Maximum
Pt (ppb)	8	82	120	2	323
Pd (ppb)	8	36	40	2	119
Rh (ppb)	6	2	1	2	4
Au (ppb)	6	14	11	1	29
Ca (ppm)	8	30673	11927	13400	52400
Ti (ppm)	8	2852	1232	1370	4960
V (ppm)	8	331	148	59	488
Cr (ppm)	8	1537	747	100	2244
Mn (ppm)	8	1062	518	190	1610
Fe (ppm)	8	142371	51814	80700	209610
Co (ppm)	8	273	153	52	429
Ni (ppm)	8	1404	832	83	2185
Cu (ppm)	8	800	562	39	1459
Zn (ppm)	8	78	37	27	127
Zr (ppm)	8	40	19	9	59
Sb (ppm)	5	0.2	0.4	0	1
Pb (ppm)	8	5	3	0	9
Bi (ppm)	5	0.6	0.9	0	2
Pt/Pd	8	1.45	1.25	0.14	3.76

Table 4 Summary statistics for Bin boreholes 1-4

Element	No Samples	Mean	Standard Deviation	Minimum	Maximum
Pt (ppb)	136	2	0	2	2
Pd (ppb)	136	1	1	1	14
Ca (ppm)	307	90662	14281	14008	217126
Ti (ppm)	307	1427	655	60	8393
V (ppm)	307	135	44	10	286
Cr (ppm)	307	693	215	68	1468
Fe (ppm)	307	39042	10747	14827	140999
Co (ppm)	307	47	23	4	298
Ni (ppm)	307	122	125	11	1383
Cu (ppm)	307	81	97	9	907
As (ppm)	307	5.3	3.9	0.2	16
Na (ppm)	108	10960	1473	5632	13857
K (ppm)	307	150	423	10	4981
Mg (ppm)	307	72327	17193	7117	148905
Al (ppm)	307	80526	9502	12961	106488
Si (ppm)	307	212500	15232	179982	335026
S (ppm)	307	4160	8447	105	122074
Zn (ppm)	108	17	7	5	41
Ba (ppm)	307	9	12	2	109
Zr (ppm)	108	20	10	9	116

Table 5 Summary statistics for panned overburden samples from Dunbennan					
Element	**No Samples**	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Pt (ppb)	75	4	8	2	50
Pd (ppb)	75	2	2	1	10
Ca (ppm)	81	52135	17014	20100	105600
Ti (ppm)	81	9653	5050	1870	28750
V (ppm)	81	196	49	78	362
Cr (ppm)	81	3094	2057	948	13063
Mn (ppm)	81	1873	677	690	4330
Fe (ppm)	81	62419	14251	34100	120600
Co (ppm)	81	57	30	24	243
Ni (ppm)	81	275	197	57	810
Cu (ppm)	81	55	45	114	253
Zn (ppm)	81	72	23	24	136
As (ppm)	81	0.7	0.9	0	3
Rb (ppm)	81	11	6	1	26
Sr (ppm)	81	104	24	57	170
Zr (ppm)	81	239	219	23	1058
Ba (ppm)	81	124	69	17	320
Sb (ppm)	81	0.8	1.2	0	4
Pb (ppm)	81	7	15	0	121

Table 6 Summary statistics for fine (-150 micron) fraction overburden samples from Dunbennan

Element	No Samples	Mean	Standard Deviation	Minimum	Maximum
Pt (ppb)	81	5	22	2	204
Pd (ppb)	81	3	2	2	12
Rh (ppb)	81	2	0	2	5
Au (ppb)	81	2	2	1	10
Ca (ppm)	81	24296	9318	6200	49900
Ti (ppm)	81	4704	1482	920	7970
V (ppm)	81	106	27	37	159
Cr (ppm)	81	879	633	199	3986
Mn (ppm)	81	894	298	510	2120
Fe (ppm)	81	61204	14667	34000	107900
Co (ppm)	81	62	37	18	202
Ni (ppm)	81	400	278	69	1343
Cu (ppm)	81	96	51	24	295
Zn (ppm)	81	73	19	32	121
As (ppm)	81	1.7	1.2	0	5
Rb (ppm)	81	44	19	5	79
Sr (ppm)	81	142	31	45	212
Zr (ppm)	81	354	237	30	1091
Ba (ppm)	81	255	97	56	499
Sb (ppm)	81	0.5	0.8	0	3
Pb (ppm)	81	11	5	0	20

Table 7 Summary statistics for panned overburden samples from Cumrie North

Element	No Samples	Mean	Standard Deviation	Minimum	Maximum
Pt (ppb)	22	3	4	1	16
Pd (ppb)	22	3	3	2	13
Rh (ppb)	22	2	0	2	2
Au (ppb)	22	1	0	1	2
Ca (ppm)	22	32882	22280	5300	71800
Ti (ppm)	22	11408	12410	1000	48070
V (ppm)	22	166	89	49	363
Cr (ppm)	22	1136	2418	143	11551
Mn (ppm)	22	3278	3019	890	11760
Fe (ppm)	22	70536	31231	39700	165900
Co (ppm)	22	30	16	9	75
Ni (ppm)	22	120	186	7	770
Cu (ppm)	22	19	12	1	51
Zn (ppm)	22	82	65	43	354
As (ppm)	22	1.6	2.3	0	9
Rb (ppm)	22	32	30	1	88
Sr (ppm)	22	114	1343	51	198
Zr (ppm)	22	333	285	13	948
Ba (ppm)	22	321	493	33	2394
Sb (ppm)	22	0.4	0.7	0	3
Pb (ppm)	22	13	12	3	58

Table 8 Summary statistics for fine (-150 micron) fraction overburden samples from Cumrie North

Element	No Samples	Mean	Standard Deviation	Minimum	Maximum
Pt (ppb)	22	5	7	1	35
Pd (ppb)	22	7	9	2	43
Rh (ppb)	22	2	0	2	3
Au (ppb)	22	5	2	1	11
Pt/Pd	22	0.66	0.53	0.17	2.5

APPENDIX 2:

Data arising from drilling investigations of the Knock intrusion, at Claymires, north-east Scotland. STYLES M T. 1992. *BGS Mineral Reconnaissance Programme Open File Report No.9.*

Exploration Ventures Ltd (EVL) outlined two Cu-Ni sulphide zones of mineralisation on the complex sheared SE margin of the Knock intrusion, on the farms of Littlemill and Auchencrieve. Fletcher (1989) evaluated the mineralisation and its geological setting and presented new maps for the Huntly and Knock intrusions and a detailed map of the Littlemill-Auchencrieve area based on borehole sections. Fletcher and Rice (1989) presented a model for this mineralisation based on a primary magmatic origin with substantial modification by shear deformation and attendant hydrothermal alteration. Fletcher (1989) also reported precious metal data for a suite of samples from the two ore zones. Precious metal levels showed sporadic enrichment up to 575 ppb Pt+Pd+Au. They concluded there was potential for further precious metal enrichment in similar settings within/ adjacent to other Caledonian mafic-ultramafic intrusions of the region.

MRP investigations were carried out to investigate the potential for PGE mineralisation on the eastern margin of the Knock intrusion, along strike from the mineralisation at Littlemill-Auchencrieve, in the vicinity of Claymires Farm, National Grid Reference [NJ 353 849]. The following information arising from investigations in this area is available from the Mineral Reconnaissance Programme Manager, BGS, Keyworth, in the form of a BGS Open File Report. The data comprises:

1 Maps showing the location of the Claymires boreholes (Maps 1-3)

2 Graphic logs of the Claymires boreholes 1-3

3 Full logs of the Claymires boreholes 1-3

4 Trace element, PGE and Au determinations of 175 samples from Claymires boreholes 1-3

5 Technical Report WK/90/7/C (Engineering & Geophysics Group) on the geophysical investigations in the Claymires area

6 Project note 92/6 (Engineering & Geophysics Group) on downhole geophysical logs of the Claymires boreholes 1-3