British Geological Survey

Mineral Reconnaissance Programme

Investigations for Cu-Ni and PGE in the Hill of Barra area, near Oldmeldrum, Aberdeenshire

Department of Trade and Industry

MRP Report 119
Technical Report WF/91/5

Investigations for Cu-Ni and PGE in the Hill of Barra area, near Oldmeldrum, Aberdeenshire

A G Gunn and M H Shaw

BRITISH GEOLOGICAL SURVEY

Technical Report WF/91/5

Mineral Reconnaissance Programme Report 119

Investigations for Cu-Ni and PGE in the Hill of Barra area, near Oldmeldrum, Aberdeenshire

A G Gunn and M H Shaw

Contributors

T B Colman and D G Cameron

Authors

A G Gunn, BA, MSc
M H Shaw, BSc

BGS Keyworth

This report was prepared for the Department of Trade and Industry

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

Bibliographical reference

Gunn, A G, and Shaw, M H. 1991. Investigations for Cu-Ni and PGE in the Hill of Barra area, near Oldmeldrum, Aberdeenshire. *British Geological Survey Technical Report* WF/91/5 (*BGS Mineral Reconnaissance Programme Report* 119).

Keyworth, Nottingham 1991

BRITISH GEOLOGICAL SURVEY

The full range of Survey publications is available through the Sales Desks at Keyworth and at Murchison House, Edinburgh, and in the BGS London Information Office in the Natural History Museum Earth Galleries. The adjacent bookshop stocks the more popular books for sale over the counter. Most BGS books and reports are listed in HMSO's Sectional List 45, and can be bought from HMSO and through HMSO agents and retailers. Maps are listed in the BGS Map Catalogue and the Ordnance Survey's Trade Catalogue, and can be bought from Ordnance Survey agents as well as from BGS.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as its basic research projects. It also undertakes programmes of British technical aid in geology in developing countries as arranged by the Overseas Development Administration.

The British Geological Survey is a component body of the Natural Environment Research Council.

Keyworth, Nottingham NG12 5GG

☎ Plumtree (06077) 6111 — Telex 378173 BGSKEY G — Fax 06077–6602

Murchison House, West Mains Road, Edinburgh EH9 3LA

☎ 031–667 1000 — Telex 727343 SEISED G — Fax 031–668 2683

London Information Office at the Natural History Museum Earth Galleries, Exhibition Road, South Kensington, London SW7 2DE

☎ 071–589 4090 — Fax 071–584 8270
☎ 071–938 9056/57

19 Grange Terrace, Edinburgh EH9 2LF

☎ 031–667 1000 — Telex 727343 SEISED G

St Just, 30 Pennsylvania Road, Exeter EX4 6BX

☎ Exeter (0392) 78312 — Fax 0392–437505

Bryn Eithyn Hall, Llanfarian, Aberystwyth, Dyfed SY23 4BY

☎ Aberystwyth (0970) 611038 — Fax 0970–624822

Windsor Court, Windsor Terrace, Newcastle upon Tyne NE2 4HB

☎ 091–281 7088 — Fax 091–281 9016

Geological Survey of Northern Ireland, 20 College Gardens, Belfast BT9 6BS

☎ Belfast (0232) 666595 — Fax 0232–662835

Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB

☎ Wallingford (0491) 38800 — Telex 849365 HYDROL G — Fax 0491–25338

Parent Body

Natural Environment Research Council

Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU

☎ Swindon (0793) 411500 — Telex 444293 ENVRE G — Fax 0793–411501

Printed in England for the British Geological Survey by Saxon Printing Limited, Derby

CONTENTS

SUMMARY	1
INTRODUCTION	2
GEOLOGY	2
PHYSIOGRAPHY	4
PREVIOUS WORK	5
FIELD INVESTIGATIONS	
Sample collection and analysis	6
Magnetic survey	6
Lithogeochemistry	8
Overburden geochemistry	10
DISCUSSION AND CONCLUSIONS	15
ACKNOWLEDGEMENTS	17
REFERENCES	17

FIGURES

1 Location map showing sites of detailed investigation	3
2 Simplified geological map of the Insch intrusion	4
3 Location of magnetic traverses and rock sample sites in the Barra area	7
4 Contour map of total field magnetic data for the Barra area (datum 51000 nT)	9
5 Location of Noranda Cu-Ni anomalies and overburden sites from Phases 1 and 2	11
6 Distribution of Cu in basal overburden samples	13
7 Relationship between Cu and Ni in basal overburden samples	14

TABLE

1 Summary statistics for basal overburden samples	12

SUMMARY

Following promising indications from commercial surveys, limited investigations for Cu-Ni mineralisation have been conducted in the vicinity of the Hill of Barra at the eastern end of the Insch intrusion. By analogy with recent findings in the Huntly area, this sheared and disrupted zone of olivine-bearing cumulates was regarded as potentially favourable for the occurrence of PGE enrichment in association with the base-metal mineralisation.

The first phase of work, comprising overburden and soil sampling, confirmed the results a the previous commercial survey and defined areas with enhanced Cu-Ni levels. The second phase of investigation was concerned additionally with the evaluation of the PGE potential of the Barra area. Basal overburden sampling and a ground magnetic survey were conducted to elucidate the structure of the area and to examine the trace element distributions and their controls.

The magnetic survey data provided important information on the structure of the survey area, clearly delineating the southern contact of the intrusion and highlighting structural discontinuities within the olivine-bearing cumulate rocks which predominate in the survey area. Enhanced levels of Cu and Cu/Ni ratios in overburden were revealed above these structures indicating their potential as zones favourable for the occurrence of hydrothermal base metal enrichment. The precious metal concentrations were uniformly low. It is however significant to note that the single site with an above background Au concentration also possesses the highest As level observed in the survey area, and is located very close to the contact of the intrusion with the Dalradian metasediments.

A small suite of rock samples was analysed for a wide range of trace elements, including Pt, Pd, Rh and Au. No significant enrichments in base or precious metals were revealed. The depleted levels of Cu and Ni noted in the Barra olivine-rich cumulates relative to those in Huntly may indicate their derivation from a magma from which significant sulphide segregation had already taken place. A possible site for a magmatic sulphide accumulation produced in this way is suggested by the overburden data at the base of the main peridotite body defined by the magnetic data.

The investigations described in this report have failed to identify any significant Cu-Ni or PGE mineralisation in the vicinity of the Hill of Barra. Nevertheless potential remains for PGE enrichment in association with the tectonised pods of ultramafic rocks which are found along the margins of the Insch intrusion further to the west.

The integrated use of overburden geochemistry and ground magnetic surveys has been shown to be particularly effective at elucidating the geological structure of poorly-exposed ground covered by exotic overburden. A similar approach is recommended for use elsewhere in north-east Scotland.

INTRODUCTION

The investigations described in this report were undertaken over an area of approximately 0.5 km^2 situated on the Hill of Barra near Oldmeldrum in the Grampian Region of north-east Scotland. The survey area, hereafter referred to as Barra, is centred on the east flank of the hill, near the south-eastern margin of the Insch mafic-ultramafic intrusion (Figure 1).

This survey was carried out as part of the DTI-sponsored Mineral Reconnaissance Programme (MRP). Limited investigations at Barra for Cu-Ni mineralisation in 1982 (Phase 1) showed localised enhancements of these elements over small areas, but did not warrant further examination at that time.

A programme of exploration for the platinum-group elements (PGE) was initiated in the mid-1980s in the East Grampian region. Following recognition of PGE enrichment associated with Cu-Ni mineralisation in a shear zone setting in the Knock basic intrusion, near Huntly (Fletcher, 1989), a second programme of MRP work (Phase 2) was conducted at Barra in 1989.

GEOLOGY

The survey area is located near the eastern end of the Insch intrusion, the largest of a suite of synorogenic tholeitic basic-ultrabasic plutons of early Ordovician age (490 Ma) present in the Grampians. These bodies were emplaced within Middle and Upper Dalradian sediments which had already been subjected to two regional metamorphic events. The intrusions themselves are locally deformed by regional shearing episodes which produced mylonite zones and hydrous mineral assemblages over linear belts up to a few kilometres in width. Study of these intrusions is hindered by their poor exposure, their structural complexity and the wide variety of rock types present.

The Insch intrusion (Figure 2) is an elongate body, trending east - west, approximately 30 km in length and up to 8 km across. The cumulate sequence in this mass is the most complete and extensively fractionated of any found in the region. The cumulate rocks were divided by Clarke and Wadsworth (1970) into three successive fractionation stages, the Lower, Middle and Upper Zones (LZ, MZ, UZ), the distribution of which is shown in Figure 2 . The Lower Zone is characterised by cumulus olivine and consists of peridotites, picrites, troctolites and olivine gabbros. The Middle Zone is olivine-free and consists of gabbros and gabbronorites, while the Upper Zone is marked by the re-appearance of olivine (Fe-rich) and the presence of cumulus alkali feldspar. The UZ lithologies range from olivine gabbros to syenogabbros and syenites. Plagioclase, olivine and pyroxene show progressive cryptic variation to more evolved compositions through the cumulus sequence. Non-cumulate norite and granular gabbros of uncertain origins are also present over extensive areas within the intrusion, mainly in association with the Middle Zone cumulates.

The Lower Zone cumulates are essentially confined to the eastern end of the pluton, although sheared serpentinite bodies of uncertain affinity are present near the southern margin of the intrusion further west. Ashcroft and Munro (1978) studied the eastern end of the mass, utilising

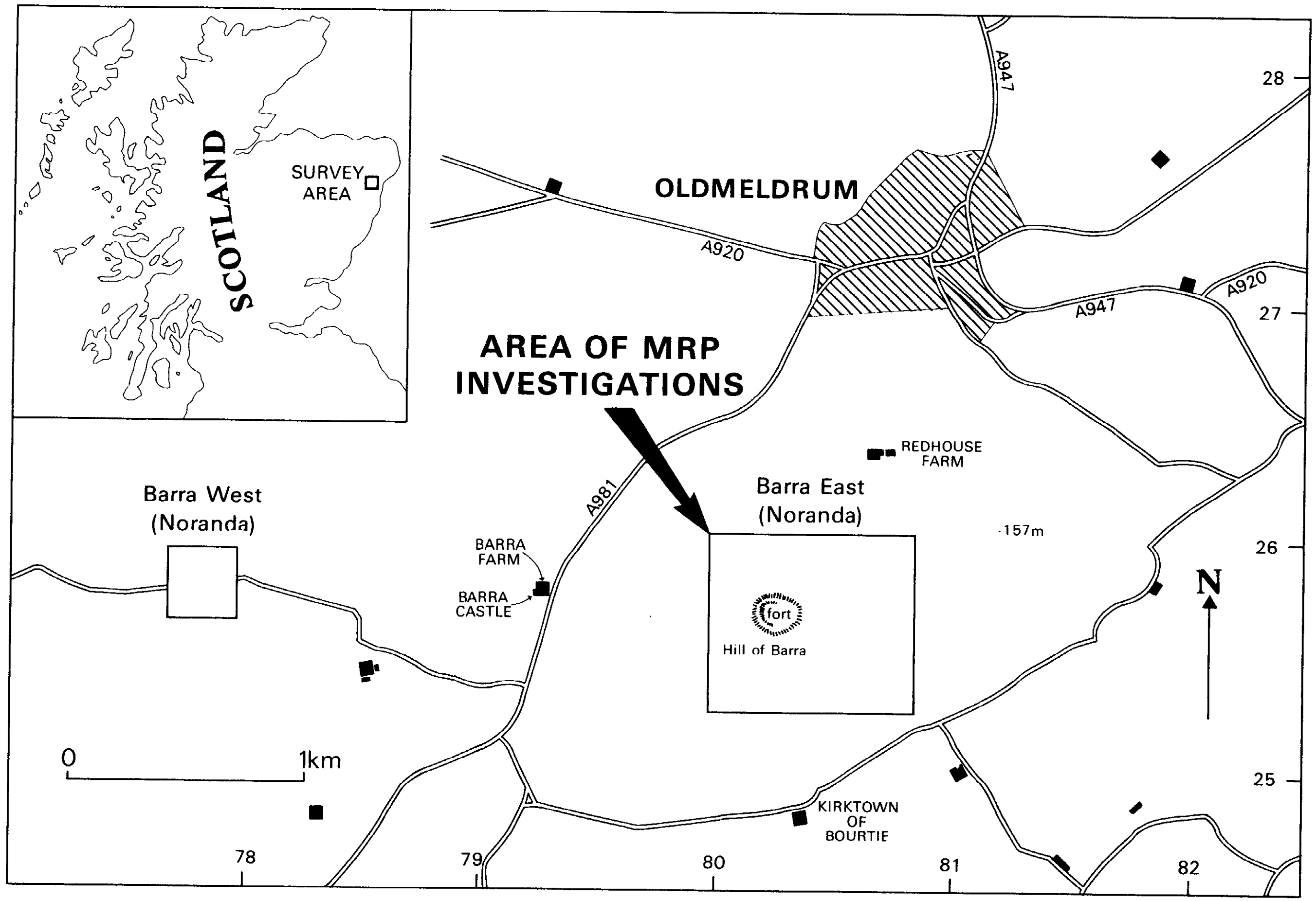

Figure 1 Location map showing sites of detailed investigation

ground magnetic surveys and shallow drilling. They redefined the contacts of the intrusion and recognised major linear discontinuities within the body, which were identified as shear zones or faults. In particular, a significant shear belt, containing deformed and altered lithologies, was revealed trending south-south-west from Oldmeldrum. This zone was shown to separate undeformed olivine-rich cumulates (LZ) to the south, exposed around Hill of Barra and Barra Castle, from Middle Zone gabbros to the north. Observations in a pipeline trench by Munro (1986) subsequently confirmed these findings.

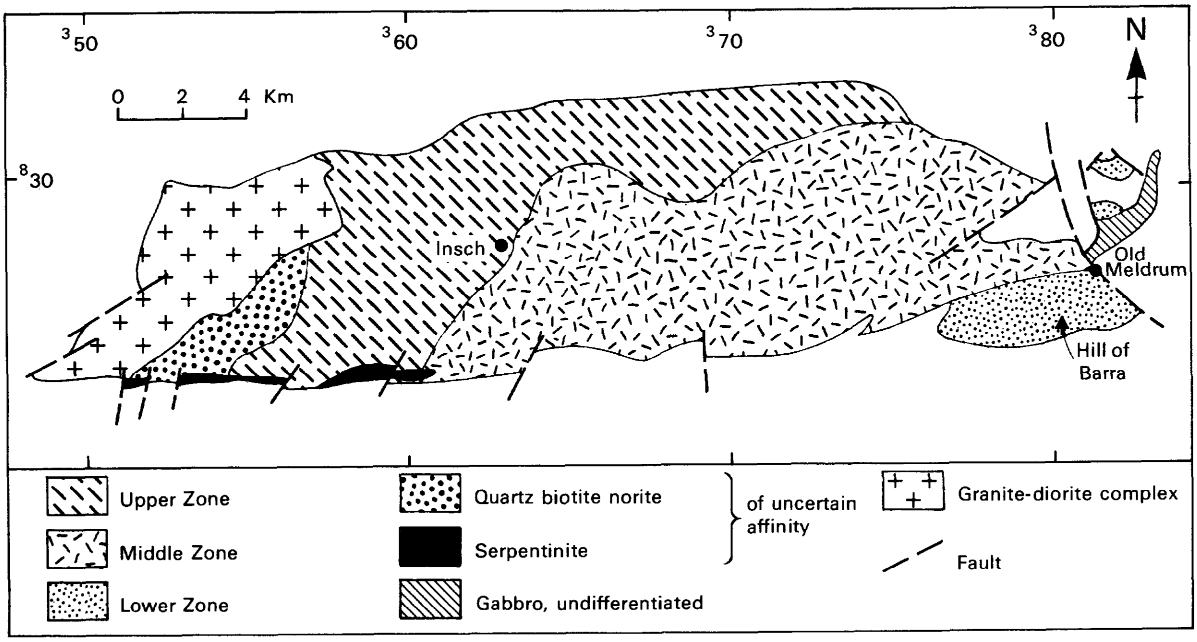

Figure 2 Simplified geological map of the Insch intrusion

The outcrop pattern of the LZ rocks south of this shear belt was shown to be complicated as a result of disruption by later shearing and faulting. The present survey area lies at the eastern end of a relatively coherent block of LZ cumulates, extending some 2.2 km west from the Hill of Barra. In this block, the cumulates are overturned, exhibiting weakly defined north-north-east-trending layering dipping steeply east-south-east and consisting of peridotites passing westwards into troctolites and gabbros. To the east of Hill of Barra olivine-rich cumulates were also revealed in several boreholes over a wide area. However, within this area an elongate magnetic low, trending north-west for about 1 km from around 3810 8260, was shown by drilling to be underlain by troctolites and pegmatitic gabbros. This zone, interpreted as fault-bound, passes through the north-east corner of the present survey area. Further east, near the contact with the country rocks, a complex north-west-trending, fault-bound zone of gabbroic cumulates was recognised.

PHYSIOGRAPHY

The Hill of Barra (193 m AOD) is situated 1.3 km south of the town of Oldmeldrum. Land use is given to livestock grazing, with the lower ground additionally supporting arable farming.

Improvement of some pastures has resulted in minor disturbance to the soil structure, but this has not significantly affected the basal soil except possibly in the shallowest profiles.

Soils over most of Barra are well-drained and of a loamy texture, although locally thicker clay-rich pockets are found on the higher ground. Over much of the hill area the overburden thickness ranges from 1 to 2 m. The deeper soils of the lower-lying ground, particularly on the northern and southern margins of the survey area, are characteristically heavier and sometimes waterlogged.

Boulders of gabbro and peridotite, together with minor metasediments, are found heaped up in the lower fields, as a result of field clearance during land-use improvement. Many of these boulders are of local origin, although glacial transportation of exotic superficial material over the Barra area did occur during glacial maxima.

Surface drainage is limited to a few ditches and stream courses. These are however unacceptable for sampling due to paucity of flow and livestock disturbance.

PREVIOUS WORK

In 1967 Rio Tinto Zinc and Consolidated Goldfields formed a consortium known as Exploration Ventures Limited (EVL) for the purpose of conducting a major programme of mineral exploration over a large part of the Grampian region. The principal target for this programme, which ended in 1973, was Cu-Ni mineralisation associated with Caledonian basic-ultrabasic intrusive rocks. A limited amount of effort was directed towards investigating the potential of these bodies for the occurrence of the PGE. EVL's work on the Insch mass was however confined to areas west of Barra, the nearest survey being some 3 km away from the present survey area.

In 1972-3 Noranda-Kerr conducted exploration for Cu-Ni mineralisation over an area of approximately 9 km^2, south of Oldmeldrum, including the Hill of Barra (Noranda-Kerr, 1973). Initial shallow soil sampling on a 200 ft grid revealed anomalous Cu and Ni values at two localities, Barra East and Barra West (Figure 1). At Barra West an anomaly of very small areal extent, reaching 410 ppm Cu and 880 ppm Ni, was defined. At Barra East values greater than 100 ppm Cu and 350 ppm Ni were more widely distributed but not always coincident.

Basal overburden samples were collected to further investigate the Cu-Ni soil anomalies. A marked downhole increase in Cu and Ni, together with an enhancement in peak to background levels, established that basal overburden sampling was the preferred technique for delineating enrichments in bedrock in this area. Peak values reported from 49 sites at Barra East were 820 ppm Cu and 3140 ppm Ni. For the 12 augered sites at Barra West the maximum values for Cu and Ni were 220 ppm and 1600 ppm respectively.

Gallagher (1983) made a detailed study of the basic-ultrabasic intrusive rocks of the region. He utilised the detailed aeromagnetic data produced for EVL, supplemented by ground geophysics, geochemistry and drilling data from the EVL programme and from Aberdeen University. He confirmed the findings of Ashcroft and Munro (1978) regarding the fragmented nature of the eastern end of the Insch intrusion and noted the presence of similar magnetic discontinuities within and marginal to the rest of the mass which he interpreted as shear zones.

FIELD INVESTIGATIONS

Sample collection and analysis

Overburden samples were collected with a Cobra percussion drill from the till-bedrock interface with a hollow sampling tube driven into the ground. In most cases the sample included a plug of weathered bedrock, which could readily be disaggregated and included for analysis. Samples were derived from a cluster of holes drilled within 50 cm of each surveyed site. This method allowed collection of a representative sample of adequate size (100 - 200 g) for study.

In Phase 1 the entire sample was crushed and milled for analysis. Chemical data for these samples, together with subsequent field observations, indicated the presence of exotic material within overburden. High levels of certain elements such as Zr and Ti, likely to be mainly derived from resistate minerals in metasediments, were recorded from several holes. Mn levels were also enhanced, probably as a result of processes occurring in the supergene environment.

Overburden sample collection and preparation procedures were modified for Phase 2. The bedrock component of the sample was increased, in order to reduce the proportion of exotic material. Furthermore, following drying and disaggregation, the samples were sieved through 2 mm mesh to remove coarser exotic material, such as clasts of quartzite, sometimes found in the overburden.

Samples from both phases of investigation were analysed for trace elements by XRF on pressed powder pellets. Analysis of Phase 1 samples was conducted by MESA, formerly of Long Eaton, Nottingham. Phase 2 samples were analysed by the Analytical Geochemistry Group of the BGS.

Samples collected in Phase 2 were also analysed for the PGE and Au by Acme Analytical of Vancouver, using a lead fire assay on 30 g of sample powder. Pt, Pd and Au were then determined using graphite furnace atomic absorption spectrophotometry (GFAAS), with Rh analysed by ICP. Detection limits of 1 ppb for Pd and Au and of 2 ppb for Pt and Rh are achieved by these methods.

An estimate of the analytical precision of the GFAAS methods using a 30 g sample powder is given in MRP Report No. 115 (Gunn et al. 1990). For the concentration range 2-1000 ppb, the analytical precision at the 95% confidence level for Pt and Pd was better than 26%.

A suite of rock samples was also collected at Barra from exposed bedrock and float boulders and was analysed for the same elements. This allowed background levels for the trace and precious metals to be established and facilitated interpretation of the overburden geochemistry.

Magnetic survey

Total field magnetic measurements were made at 2 m above ground level along 18 traverses, totalling 7.5 km, using a proton precession magnetometer (Figure 3). Observations were made at

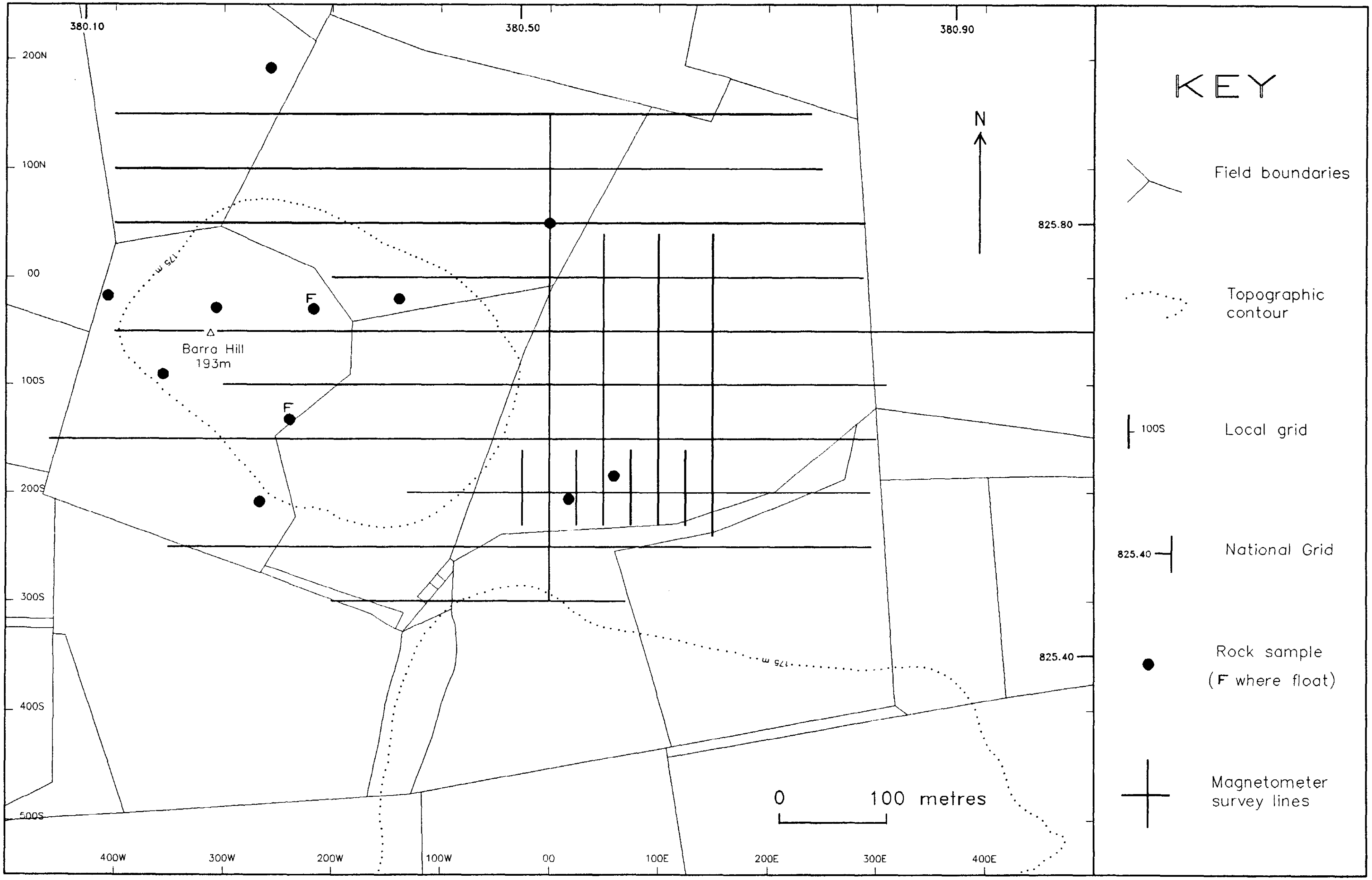

Figure 3 Location of magnetic traverses and rock sample sites in the Barra area

intervals of 10 m along traverse lines spaced 50 m apart, surveyed by tape and compass and caned at 25 m intervals. Closely-spaced infill traverses were added in zones of special interest. The diurnal variation in magnetic intensity was recorded at a base station. Since the maximum amplitude of the total field anomaly in the area is approximately 5000 nT, and the maximum diurnal variation observed was 110 nT, no diurnal corrections have been applied to the data.

Magnetic susceptibility measurements were recorded with a kappameter on exposed bedrock and on blocks in boulder piles. The observed values varied according to the content of serpentinised olivine, the peridotites averaging 30 - 40 x 10^{-3} SI units, with values decreasing to 10 - 20 in troctolites and to 1 - 5 in olivine gabbros. Very low values (< 1) were recorded from the metasediments and from a block of sheared, altered gabbronorite.

A contour plot of the ground magnetic data relative to 51000 nT is shown in Figure 4. The margins of the ultramafic body on its eastern and southern sides are clearly defined by steep magnetic gradients. Total field intensity increases from below 49500 nT on the metasediments to greater than 51000 nT over much of the peridotite, reaching a maximum value in excess of 55000 nT. In the light of the geological data provided by Ashcroft and Munro (1978), indicating a near north-south strike for the layering in the olivine cumulates, the steep magnetic gradient running along line 50W (A - A' in Figure 4) may be interpreted as the base of the peridotite exposed on the Hill of Barra. In the south of the survey area the contact of the intrusion with the Dalradian metasediments is well defined by the magnetic data. Its position, shown in Figure 4, is corroborated by overburden geochemistry and bedrock exposure.

In the east of the area (east of line 50W) the total field intensity is more variable and patterns are complicated, indicating the complexity of the underlying geology. Low amplitude linear discontinuities of limited extent may indicate the presence of structural features. The best example runs in a north-westerly direction from around 250E 200S, over a distance of at least 600 m (B - B' in Figure 4). This feature is parallel to a fault, located by Ashcroft and Munro (1978), which runs through the north-east corner of the present survey area. Drilling to the east of this structure revealed bedrock comprising troctolites and pegmatitic gabbros. The overall complexity of the eastern zone of the present survey area however precludes accurate delineation of other internal structures and boundaries.

Lithogeochemistry

Exposure of bedrock is generally very poor in this part of the Insch intrusion. In the survey area, it is located principally on the flanks of the Hill of Barra itself, with limited additional exposure near the southern contact of the intrusion with Dalradian metasediments. The exposures are dominated by serpentinised, largely undeformed olivine-rich cumulates, mainly peridotites and picrites, with subordinate troctolites on the western margin of the hill. Exposure of gabbroic types is very poor and these are best examined in the boulder piles where they have been cleared from the fields. Visible sulphide mineralisation is largely confined to the olivine-poor rock types. Twelve samples, representative of the various lithologies present, were collected for analysis from the sites shown in Figure 3. This suite, including two samples from float boulders, comprised six olivine-rich cumulates, five gabbros/troctolites and one sample of metasediment.

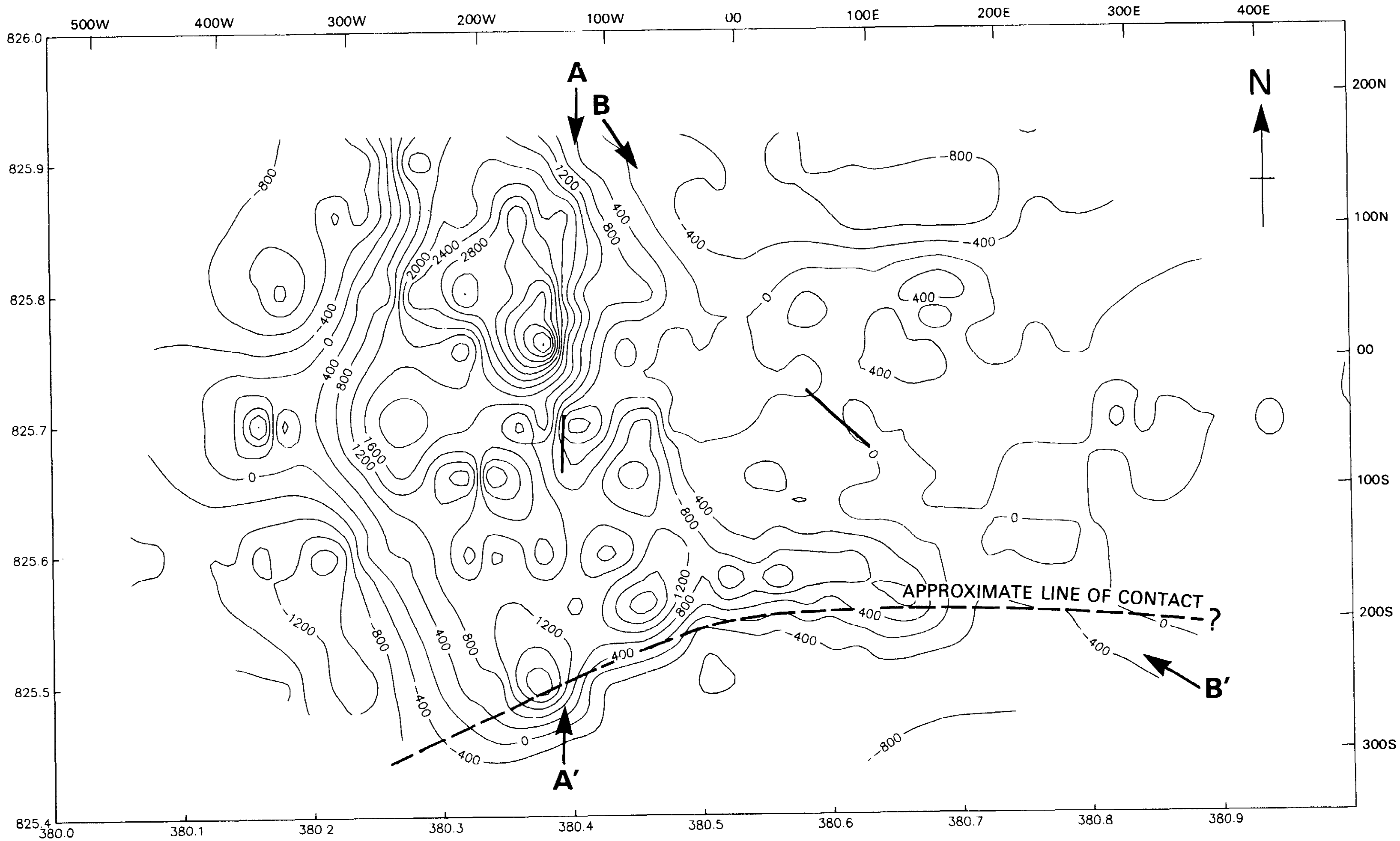

Figure 4 Contour map of total field magnetic data for the Barra area (datum 51000 nT)

The Cu levels reach a maximum of 142 ppm in a peridotite sample, with the olivine-rich cumulates averaging 66 ppm overall. One sample of sulphide-bearing gabbro was found to contain 122 ppm Cu. The maximum Ni concentration detected is only 731 ppm, with values normally between 300 and 500 ppm in the olivine-rich lithologies, falling to 100 - 200 ppm in the more evolved rock types. Cr shows the expected preferential concentration in the olivine-rich varieties with a mean value of 1900 ppm and a maximum of 2242 ppm. This contrasts clearly with the gabbros and the metasediment where values are less than 400 ppm. Similarly a clear distinction can be made between the olivine-rich lithologies and all others sampled by their very low concentrations of Ba and Zr.

The trace element compositions for the Barra rocks are, with the notable exceptions of Ni and Cu, comparable to those reported for ultramafic rocks in the Huntly area by Fletcher (1989) and by Gunn et al. (1990). The Ni and Cu concentrations present in the Barra peridotites are, however, markedly lower than those from the undeformed olivine-rich cumulates from the Huntly intrusion which average around 1200 ppm and 230 ppm respectively. The deformed and altered ultramafic intrusive rocks from the Upper Deveron valley near Huntly compare closely with similar types present in the Boganclough intrusion and in the tectonised pods from the western part of Insch. These types average around 2500 ppm Ni and only 1 - 2 ppm Cu, in marked contrast to the undeformed lithologies present at Barra.

The precious metal concentrations determined in the Barra rocks are uniformly low, with maxima of 6 ppb Pt, 4 ppb Pd, 2 ppb Rh and 3 ppb Au.

Overburden geochemistry

In 1982 a programme (Phase 1) of basal overburden sampling was conducted to investigate the Cu-Ni anomalies defined by Noranda at Barra East. A total of 37 samples where collected from sites spaced at 25 m intervals along east-west traverses 100 m apart (Figure 5). The mean depth of these samples was 2.2 m, with a range of 0.9 - 4.1 m.

A conventional hand augered mineral soil sample was also collected at each site from depths in the range 0.3 - 1 m. Chemical analysis indicated that these samples were derived from mixed sources and that, in accordance with Noranda's findings, were not suitable for mapping of bedrock geochemistry. This technique was therefore not employed in Phase 2 and the results are not discussed in this publication.

Phase 2 Cobra sampling was conducted over a 2 week period in 1989 to extend and infill the earlier coverage. During Phase 2 the ground magnetic survey described above, conducted in tandem with Cobra sampling, helped to elucidate potential target zones. One hundred basal overburden samples were collected during this phase of work (Figure 5).

Summary statistics for the 137 basal overburden samples collected in the 2 phases of investigation are presented in Table 1.

The peridotite outcrop shows characteristically high levels of Cr, Fe, Ni, Co and Cu and is low in Ca. Strong positive correlations (Spearman rank correlation coefficients 0.47-0.91) between these elements are significant at the 99% confidence level and indicate a primary lithological control.

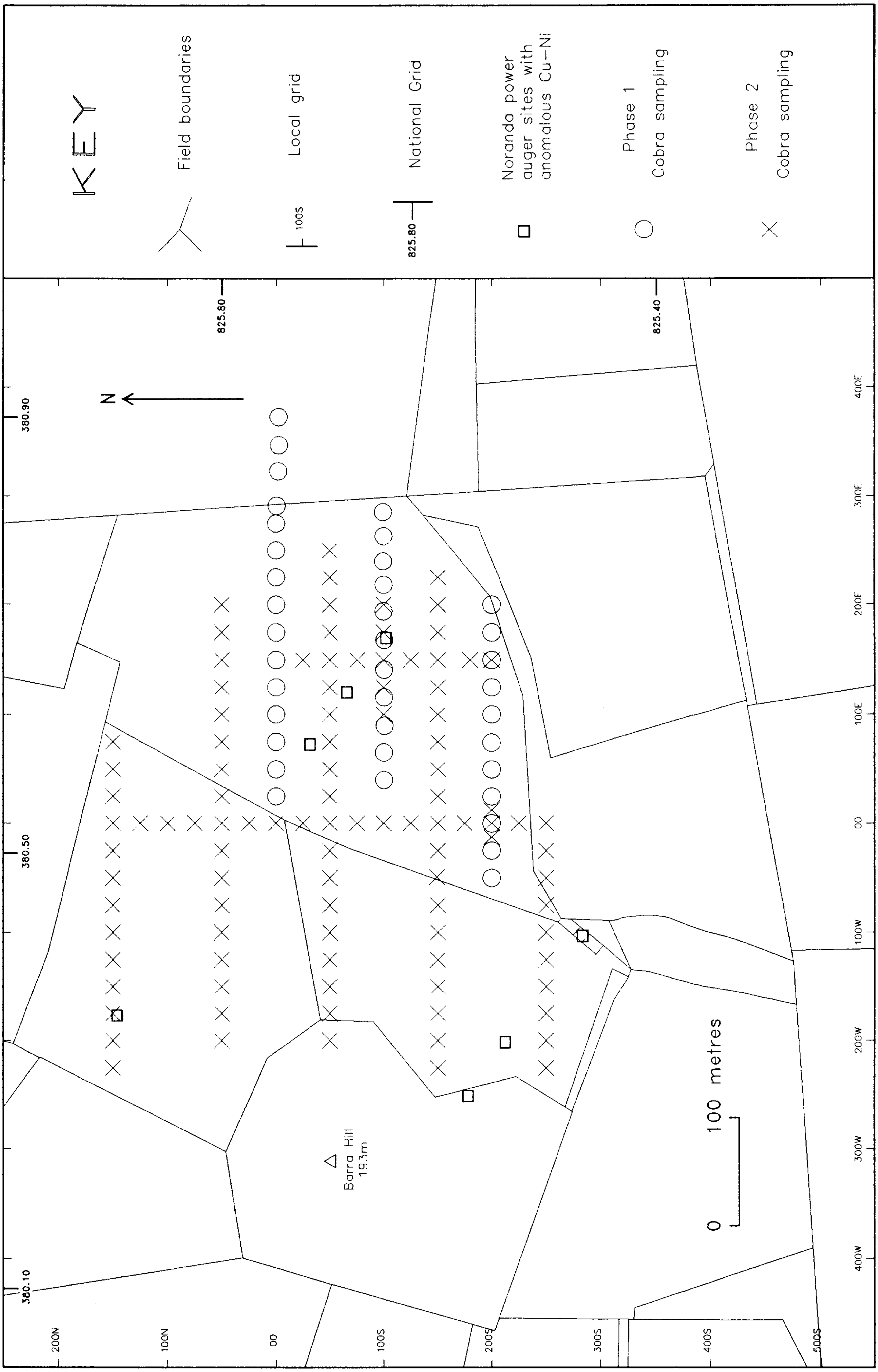

Figure 5 Location of Noranda Cu-Ni anomalies and overburden sites from Phases 1 and 2

To the east of line 50W, while some samples have the characteristic peridotite signature, others are distinctly different. Locally enhanced levels of Ca and V are coincident and may indicate that gabbroic lithologies are present. The pattern for Zr is also irregular, and in places similar to Ba, suggesting the possible incorporation of metasedimentary material in the samples.

Table 1 Summary statistics for basal overburden samples

Element	No Samples	Mean	Standard Deviation	Minimum	Maximum
Pt (ppb)	100	1.7	1.05	1	6
Pd (ppb)	100	2.3	0.75	2	6
Rh (ppb)	100	2.0	0.14	2	3
Au (ppb)	100	2.5	1.6	1	12
Si (ppm)	37	232883	32238	202631	320782
Al (ppm)	37	59994	32985	9839	160710
Ti (ppm)	137	3027	2091	530	8633
Fe (ppm)	137	101114	29581	17500	167800
Mg (ppm)	37	89833	61010	6513	223750
Ca (ppm)	137	14255	11399	900	48743
Mn (ppm)	137	1620	572	155	3096
As (ppm)	137	3	8	0	88
Cr (ppm)	137	1243	796	10	2869
Co (ppm)	137	127	58	3	234
Cu (ppm)	137	253	254	12	1668
Ba (ppm)	100	127	116	37	628
Ni (ppm)	137	807	531	34	3023
S (ppm)	37	222	173	68	919
V (ppm)	137	83	40	14	191
Zr (ppm)	137	67	63	7	373
Zn (ppm)	137	79	20	32	215
Cu/Ni	137	0.35	0.38	0.06	3.39

Overburden chemistry confirms the boundary of the intrusion as delineated by the magnetic data in the southern part of the survey area. Along sections of lines 200S and 250S, the presence of metasediments is indicated by high Ba, Zr and Ti concentrations, accompanied by low Ni, Cr, Co and Cu.

Enhanced Cu levels, markedly in excess of the concentrations found in the exposed peridotite bedrock, occur sporadically throughout the survey area (Figure 6), with 19 values above 500 ppm.

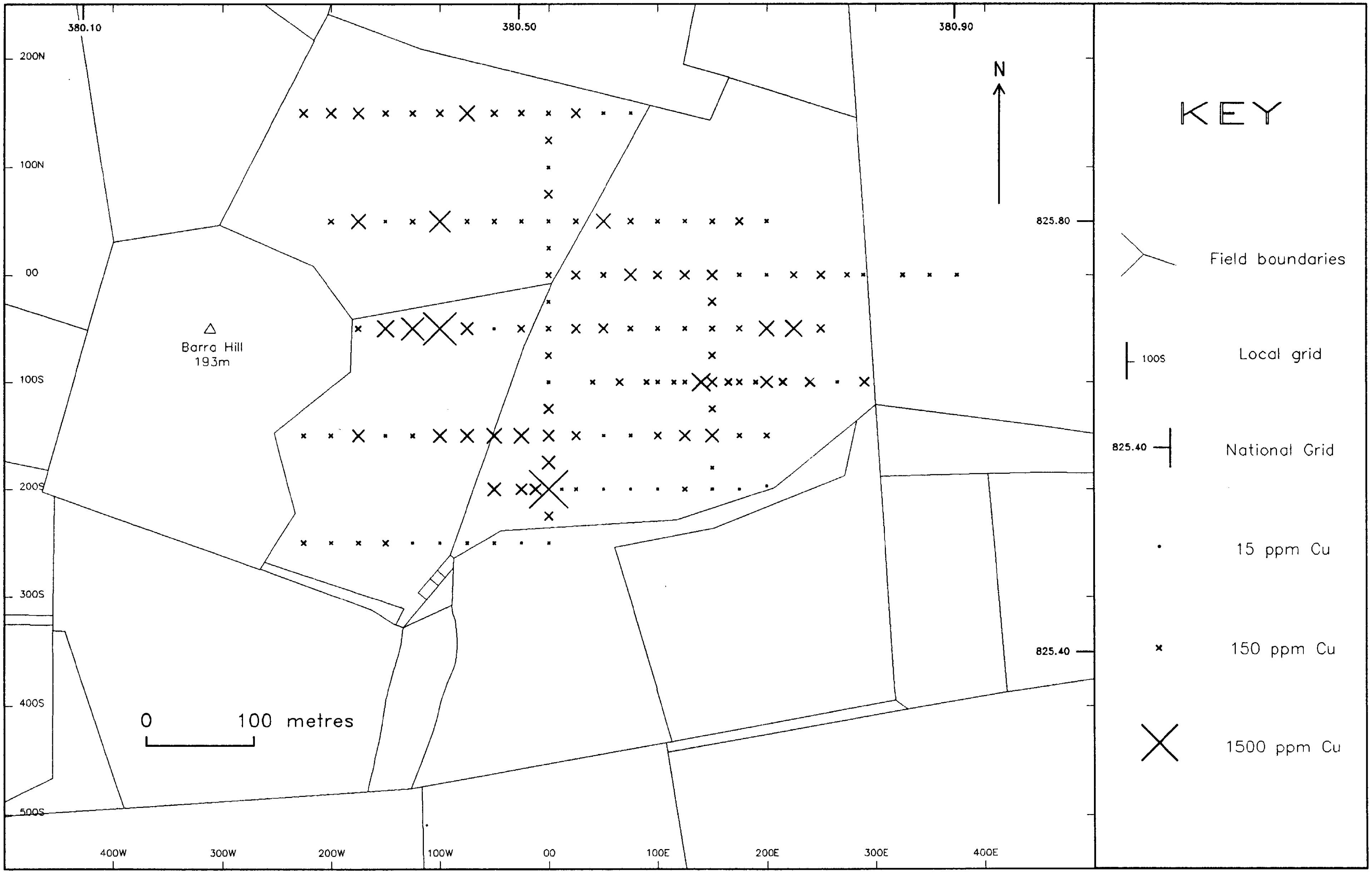

Figure 6 Distribution of Cu in basal overburden samples

Ni has a generally similar distribution pattern to Cu, with a mean value of 806 ppm and a maximum of 3023 ppm Ni. However, a separate population of samples showing relative enrichment in Cu is indicated in the Cu - Ni scatter-plot (Figure 7).

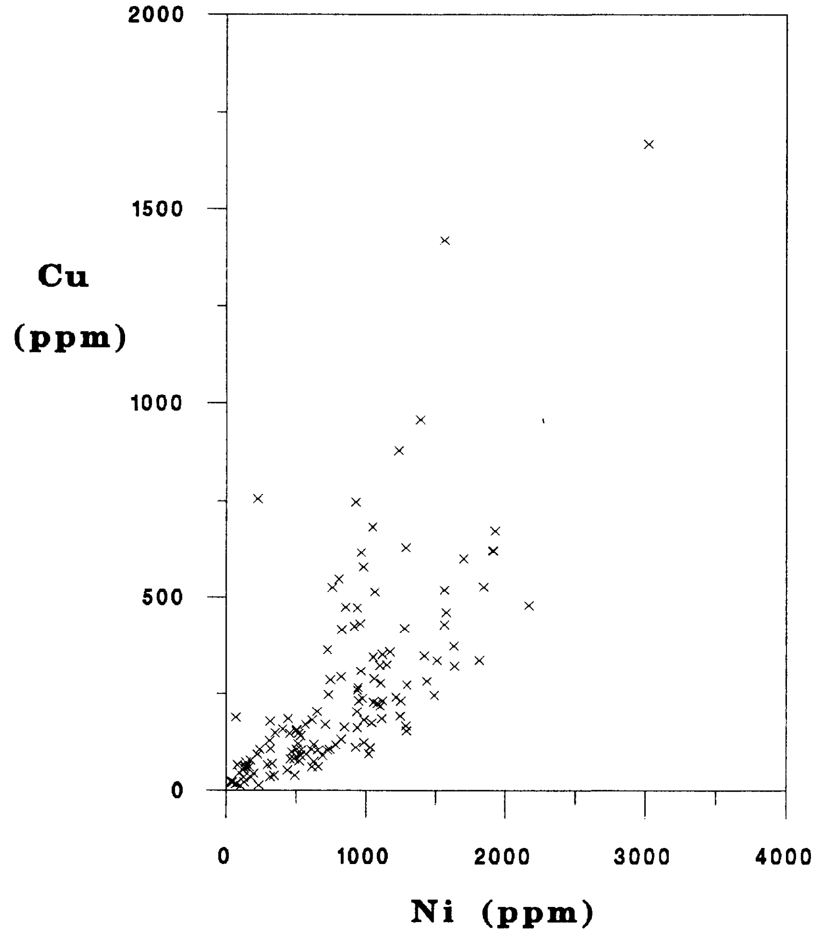

Figure 7 Relationship between Cu and Ni in basal overburden samples

At one site in the south of the survey area (00 200S), a Phase 2 sample recorded the highest As value (88 ppm), coinciding with high Cu (747 ppm), and relatively high Cu/Ni ratio. This sample was from a previously sampled site, where values of 35 ppm As and 1668 ppm Cu respectively were reported in Phase 1. Samples from 2 adjacent sites were found to contain the next highest reported As levels in the survey area, 35 and 16 ppm. These sites lie close to the inferred boundary between ultrabasics and metasediments and may indicate hydrothermal enrichment of these elements along the structural contact zone at the southern margin of the intrusion.

Other high Cu values are sporadically distributed throughout the survey area. Their distribution may be related to structural features indicated by the magnetic data. In particular, elevated levels are present on 3 traverses (50S, 50N and 150N) at the eastern edge of the main peridotite body which runs nearly north-south between lines 75 and 100W (A - A' in Figure 4). This pattern may represent concentration of Cu along a fault, but could also indicate a primary stratiform enrichment as the layering also trends in this direction. Cu/Ni values in this linear belt are also generally slightly enhanced, but the 2 highest values are found outside this zone.

The highest Cu/Ni value (3.38) is derived from a site located within the north-west-trending magnetic discontinuity running from around 250E 200S (B - B' in Figure 4). This zone is also marked by sporadic Cu enrichment at 4 more sites along its length. These features may indicate the presence of sporadic Cu-bearing sulphide mineralisation developed along this structure.

A second very high Cu/Ni value is found at a site near the margin of the intrusion at 150W 250S. This sample, however, has very low Cr, Fe, V and Co concentrations, with attendant enhanced Zr and Ba, and is clearly from a sedimentary source. The Cu concentration (188 ppm) is, however, at least 3 times greater than in any of the other sediment-derived samples, and may relate to hydrothermal Cu enrichment along the structurally-controlled southern margin of the intrusion.

A small number of samples collected during Phase 1 and all those from Phase 2 were analysed for the Pt, Pd, Rh and Au. The maximum reported values were 6 ppb Pt, 6 ppb Pd, 3 ppb Rh and 12 ppb Au, with most values being below the detection limit of the analytical method employed. It is significant to note, however, that the highest gold value is derived from the same site as the maximum As at 00 200S.

DISCUSSION AND CONCLUSIONS

Fletcher (1989) and Fletcher and Rice (1989) reported precious metal data for drillcore from the EVL Cu-Ni exploration programme conducted in the Huntly - Knock area of west Aberdeenshire. The highest Pt+Pd values of 700 ppb were found in massive and sub-massive Cu-Ni ores located in a complex, sheared marginal zone on the south east flank of the Knock intrusion. The base metal sulphide mineralisation is regarded as essentially of magmatic origin, although locally modified by deformation and hydrothermal alteration. The PGE distribution is considered to be largely related to these hydrothermal processes. They concluded that potential exists in similar structural settings for PGE enrichments, possibly of greater magnitude, associated with the other basic intrusions of the region.

The existence of major shear zones marginal to and within the Insch intrusion, recognised by Ashcroft and Munro (1978) and Gallagher (1983), suggested that these structures were favourable for the occurrence of base-metal sulphide mineralisation of this type, possibly with attendant enrichment of PGE. Attention has therefore been focused in this study on the Hill of Barra area where Lower Zone cumulates occupy a disrupted belt in contact with Dalradian metasediments.

The results of this survey indicate the presence of limited Cu-Ni mineralisation, with probable structural control, at or close to the southern sheared margin of the intrusion. Coincident enrichment in As and Au has also been noted at one site. Other structures delineated by the ground magnetic survey have also been shown to contain enhanced Cu and Cu/Ni values which may be indicative of hydrothermal base-metal mineralisation. Rice (1975) reported soil data for Cu and Ni from EVL investigations in the Arthrath area, a largely unexposed eastern extension of the

Arnage intrusion in eastern Aberdeenshire. He suggested that Ni levels of 250 ppm in B horizon soils were significant, but also noted that the soil chemistry did not always reflect bedrock mineralisation. The best intersections of mineralised bedrock, containing up to 10 % of base metal sulphides, were found in boreholes sited on the basis of coincident IP, magnetic and soil anomalies. The Cu-Ni levels revealed at Barra by Noranda and in the present study may therefore be of significance, especially if they are accompanied by chargeability/resistivity anomalies.

The olivine-rich cumulates exposed at Barra contain lower whole rock levels of Ni and Cu than comparable lithologies in the Huntly intrusion. They are also conspicuously lacking in base-metal sulphides which are widely disseminated in similar rock types from Huntly. This contrast may be explained in terms of the role of sulphur saturation in controlling the chemistry of the products derived from the magma chamber. When a magma becomes sulphur saturated chalcophile elements, such as Cu, Ni and the PGE, are strongly partitioned into an immiscible sulphide liquid. If this liquid segregates from the magma, minerals subsequently crystallising are depleted in these elements. It is possible therefore that the Barra peridotites were derived from a magma from which sulphide had already segregated. The timing of the sulphur saturation event and the location of any sulphide accumulations are not known. It is possible, however, in view of the marked depletion relative to the levels observed in Huntly, that the exposed Barra peridotites were formed in close proximity to a zone of sulphide segregation. The east side of the Hill of Barra was identified on geological grounds as the base of a block of olivine-rich cumulates (Ashcroft and Munro, 1978) and is therefore regarded as a potential site for a sulphide accumulation resulting from such processes. The overburden chemistry supports this contention, indicating a north-trending zone of Cu enrichment along the line of the observed magnetic discontinuity which marks the eastern boundary of the peridotite. In contrast, at West Huntly, there was continued and repeated sulphur saturation during formation of the layered cumulates. As a result no massive sulphide segregations were produced and PGE levels were continuously depleted.

PGE levels at Barra are uniformly low with no enrichment comparable to that found at Knock. Nevertheless the potential remains elsewhere for more significant structurally-controlled base-metal enrichment with associated elevated PGE and Au concentrations. The tectonised pods of ultramafic rocks which are found along the margins of the Insch intrusion further to the west remain attractive targets. The hypothesis regarding a potential site for magmatic sulphide accumulation on the east side of the Hill of Barra could be tested by means of additional ground geophysical surveys (VLF and IP) and drilling of angled boreholes. The tectonic disruption of the Insch Lower Zone rocks may however preclude the identification of zones of sulphide segregation based on this geological model.

The surveys described in this report provide useful information regarding the geology of this part of the Insch intrusion. The integrated use of geochemistry and geophysics allows delineation of the southern boundary of the intrusion and confirms the extent of the peridotite in the survey area. Hitherto unrecognised structural complexity is indicated in the eastern part of the survey area and probably indicates the tectonic juxtaposition of basic rocks and metasediments with the peridotite. Ground magnetic data and basal overburden geochemistry, in combination with lithological observations made on the Cobra samples in the field, produced a broadly coherent picture of the geology of the survey area. The magnetic data is particularly effective at delineating geological contacts and linear structures which may be faults or shear zones. These techniques are recommended for use in detailed mapping and prospect evaluation in similar terrain elsewhere in the Grampian region.

ACKNOWLEDGEMENTS

The cooperation of the landowners in the area covered by this report is gratefully acknowledged, in particular Major Q H R Irvine of Straloch, Newmachar and Mr G Stephen of Conglass, Inverurie. The authors are indebted to various BGS colleagues and Dr T A Fletcher (formerly of Aberdeen University) for discussion and suggestions relating to the content of this report. K E Rollin provided the magnetic contour plot and commented on its interpretation. Assistance on certain diagrams was given by the Drawing Office at Keyworth under the supervision of R J Parnaby.

REFERENCES

ASHCROFT, W A and MUNRO, M. 1978. The structure of the eastern part of the Insch Mafic Intrusion, Aberdeenshire. *Scottish Journal of Geology*, Vol. 14, 55-79.

CLARKE, P D, and WADSWORTH, W J. 1970. The Insch layered intrusion. *Scottish Journal of Geology*, Vol. 6, 7-25.

FLETCHER, T A. 1989. The geology, mineralisation (Ni, Cu, PGE) and isotope systematics of Caledonian mafic intrusions near Huntly, N.E. Scotland. PhD thesis, University of Aberdeen.

FLETCHER, T A and RICE, C M. 1989. Geology, mineralisation (Ni-Cu) and precious - metal geochemistry of Caledonian mafic and ultramafic intrusions near Huntly, northeast Scotland. *Transactions of the Institution of Mining and Metallurgy (Section B: Applied Earth Science)*, Vol. 98, September - December 1989.

GALLAGHER, J W. 1983. The northeast Grampian Highlands: an investigation based on new geophysical and geological data. PhD thesis, University of Aberdeen.

GUNN, A G, STYLES, M T, STEPHENSON, D, SHAW, M H and ROLLIN, K E. 1990. Platinum-group elements in ultramafic rocks of the Upper Deveron Valley, near Huntly, Aberdeenshire. *British Geological Survey Technical Report WF/90/9 [BGS Mineral Reconnaissance Programme Report 115]*.

MUNRO, M. 1986. Mylonite zones in the Insch 'Younger Basic' Mass. *Scottish Journal of Geology*, Vol.22, 132-136.

NORANDA-KERR LTD. 1973. Unpublished reports of Noranda-Kerr Ltd. to Department of Trade and Industry under the Mineral Exploration and Investments Grants Act - now on Open File.

RICE, R. 1975. Geochemical exploration in an area of glacial overburden at Arthrath, Aberdeenshire. In *Prospecting in areas of glaciated terrain 1975*. JONES M J (editor) (London: IMM), 82-6.