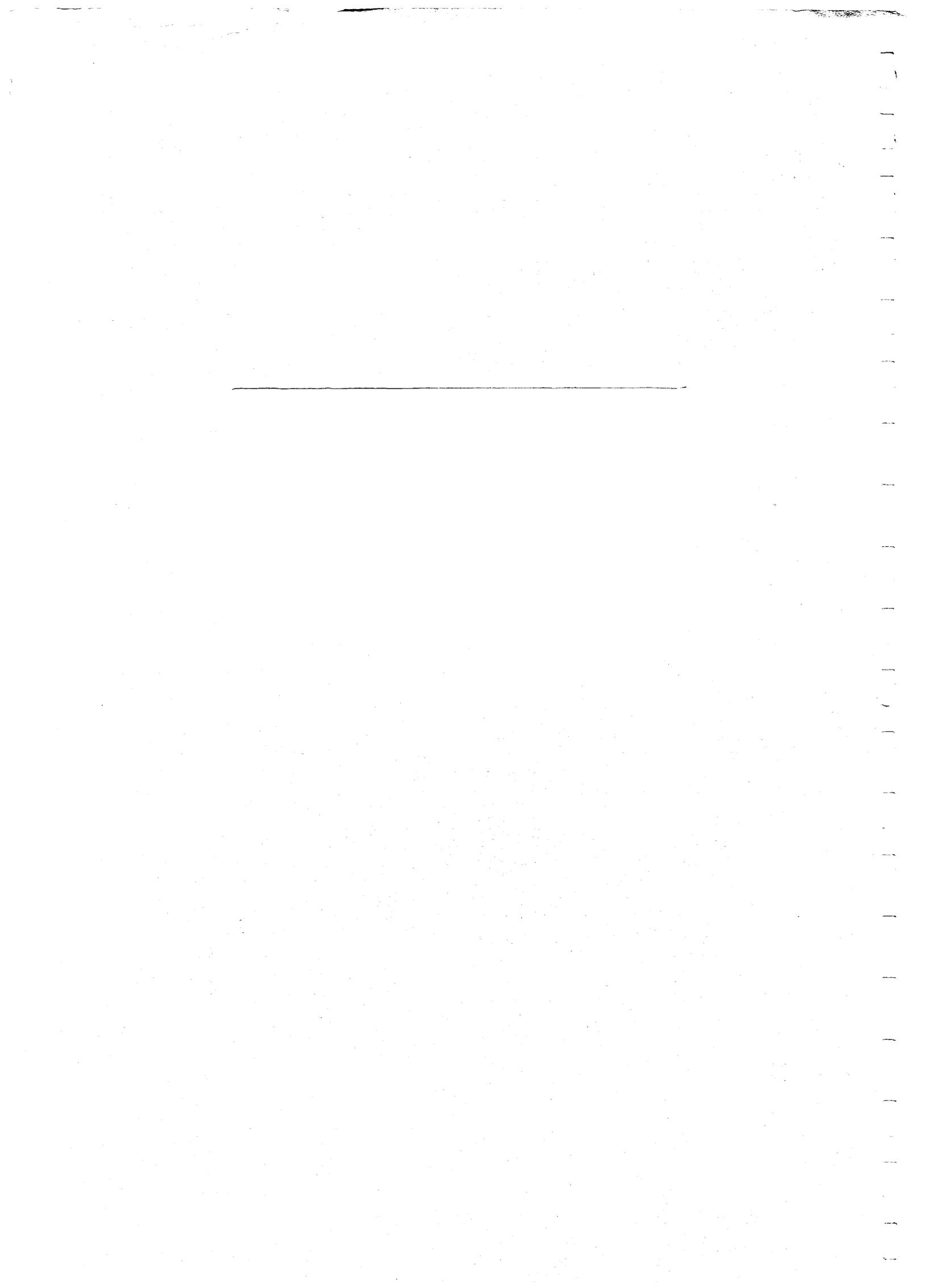


Natural Environment Research Council

Institute of Geological Sciences

# Mineral Reconnaissance Programme Report

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This report relates to work carried out by the Institute of Geological Sciences on behalf of the Department of Industry. The information contained herein must not be published without reference to the Director, Institute of Geological Sciences

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No. 31

**Geophysical investigations  
in the Closehouse-  
Lunedale area**



INSTITUTE OF GEOLOGICAL SCIENCES

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Closehouse-Lunedale area**

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## SUMMARY

The Lunedale Fault is a growth fault forming the northern edge of a deep Carboniferous sedimentary basin, the Stainmore Trough, which is a potential source of brines and in which thick limestones provide suitable host rocks for mineralisation in favourable structural traps.

The geology of the area therefore resembles that of areas containing some of the large Pb-Zn sulphide deposits in Ireland, and the presence of baryte in commercial quantities at Closehouse encourages the search for sulphides.

The Lundale Fault, including the area around Closehouse Mine, was investigated by an airborne geophysical survey consisting of magnetic, electromagnetic and radiometric recordings. The magnetic data are of unusual interest for exploration in this area because the Whin dolerite, occurring as sills and dykes, gives rise to pronounced magnetic features, of which some indicate previously unknown intrusions. The baryte deposit in the Closehouse Mine is closely related to the distribution and alteration of the Whin dykes, suggesting that a ground investigation of the aeromagnetic anomalies could be of value in further exploration. The electromagnetic maps do not indicate mineralisation of immediate interest and the amount of ground follow-up work was limited by access problems.

## INTRODUCTION

The Lune Forest lies in the heart of the northern Pennines just north of the B6276 road from Brough to Middleton-in-Teesdale. Most of the ground is peat-covered moorland, lying generally above 300 m OD and rising in the north-west to nearly 800 m on Mickle Fell. The moors are used for sheep-grazing and grouse-shooting and as collecting grounds for several large reservoirs. The sole industry is the working of baryte at Closehouse. The mine is approached by an unsurfaced road and rough tracks lead to other parts of the moors, but the terrain is rough and wide areas are inaccessible even to cross-country vehicles. Much of the land lies within the large Strathmore estate. The western part of the district is designated as a danger area in regard to the Ministry of Defence firing-range at Warcop.

## GEOLOGY

A recent re-survey of the district has produced a full geological account (Burgess and Holliday, 1979) of the 1:50 000 Brough-under-Stainmore sheet, accompanied by detailed 1:10 000 geological maps and the more generalised 1:25 000 Middleton-in-Teesdale map. During the present investigations, the geological lines were checked in places of particular interest but did not require modification. A detailed account of the Closehouse baryte deposit was published by Hill and Dunham (1968).

The Carboniferous succession of the district is shown on the maps and vertical section (Figs. 1 and 3). The oldest rocks were encountered in boreholes north of Closehouse mine but do not crop out locally. About 41 m of interbedded limestones, sandstones and shales were proved and are assigned to the Orton Group. The base of the Carboniferous sequence was not reached in these boreholes, but comparisons with the Teesdale and Cross Fell inliers suggest that Lower Palaeozoic rocks form a basement on the upthrow side of the Lunedale Fault close below the Orton Group.

The overlying Alston Group consists of marine limestones rhythmically alternating with clastic sediments of deltaic facies. In the lower part of the group carbonates predominate, but higher up terrigenous sediments are commoner and limestones comprise less than a third of the sequence. As shown on the vertical sections, local names are used for each of the thicker limestones. They are generally biomicrites and, in places, contain much bioclastic debris including broken brachiopods, corals, crinoids, foraminifera and bryozoa denoting accumulation in a high-energy environment in a shallow sea. The limestones usually have low inter-granular porosity due to extensive re-crystallisation of the carbonates. Each limestone is succeeded by mudstones, siltstones and then by sandstones. In turn, these are overlain by a seatearth and perhaps a thin coal. The entire rhythmic unit comprises a cyclothem of Yoredale type. The Namurian rocks overlying the Alston Group show similar rhythmic deposition but with a much higher proportion of clastic sediments.

The pattern of sedimentation in the district during Lower Carboniferous times was largely controlled by the distribution of blocks and basins (Fig. 2). Both the Alston and Askrigg blocks are underlain by Caledonian granites and subsided more slowly than the intervening Stainmore Trough. But throughout Dinantian times sedimentation largely kept pace with subsidence, so that the lithologies of the beds remained constant over wide areas but their thicknesses varied greatly. Many of the bounding structures to the basins are growth-faults. For example, across the Lunedale Fault, which marks the northern limit of the Stainmore Trough, the Dinantian sequence thickens from about 350 m

on the edge of the Alston Block to more than 800 m on the downthrow side.

There is a contrast between the folds and faults of the blocks and those of the basins. The rocks of the Alston Block dip very gently eastwards except near the main faults. These are characterised by brittle fracturing along reverse-faults in the basement rocks, overlain by plastic deformation in the Carboniferous cover. For example, the Burtreeford Disturbance (Fig. 3) is an east-facing, faulted monocline with a displacement of about 150 m. The Lunedale Fault is a similar structure with an overall downthrow to the south of 90 to 150 m. The Fault commonly consists of several sub-parallel fractures, with most of the throw taken up on the northernmost one and the intervening rocks dipping steeply towards it. A tight anticline lies just south of, and parallel to, the Lunedale Fault; its limbs dip steeply (40 to 80°) to the north and more gently (20°) southwards.

The Whin Sill, a quartz-dolerite sill of late Carboniferous age, is intruded into the flat-lying beds of the Alston Block. Near Closehouse, the sill is 30.5 m thick and lies just above the Smiddy Limestone. To the east of the Burtreeford Disturbance however, it is emplaced below the Scar Limestone. In general, the sill is bounded by the Lunedale Fault but in places it extends as a thin tongue of dolerite for a short distance to the south. Associated quartz-dolerite dykes are intruded along the Lunedale Fault in the Closehouse area and at the mine the baryte deposit partly replaces such a dyke, here about 20 m wide. Several thin dolerite dykes trend north-eastwards across Lunehead [e.g. 812 207] and presumably belong to the same intrusive suite.

During the main Devensian glaciation, a till-sheet was laid down by eastward-moving ice over the lower parts of the Closehouse area but it thins up-slope and is absent from the higher ground (Fig. 3). The till-sheet forms a smooth topography and consists largely of boulder clay with erratics of Carboniferous sandstone, limestone and Whin dolerite in a stiff, over-consolidated, grey clay. Excavations for the Lunedale reservoirs showed that the boulder clay locally contains lenses of sand and gravel within an overall thickness of more than 50 m, but near Closehouse it is likely to be less than 10 m thick. A minor, late-Devensian corrie-glaciation affected the southern slopes of Mickle Fell, and thick head deposits produced at this time cover most of the higher slopes around Closehouse. The head consists of angular sandstone blocks in a sandy clay matrix and results from solifluction downslope in periglacial conditions. Extensive cambering of many of the outcrops was also produced at this time.

## MINING

The Closehouse baryte deposit lies on the Lunedale Fault where a Whin dyke has been thoroughly carbonatised and then extensively converted to baryte. The orebody, dipping south at 50°, is up to 27 m wide over a strike length of 500 m and its extent downwards is unproven. That part of the orebody lying above the valley floor has now largely been extracted by opencast, but considerable proven reserves remain below this level. Further to the west, lenticular masses of baryte occur on the hanging wall of the Fault as exposed in Closehouse Hush [840 226]. To the east, thin veins of baryte and galena crop out along the Fault in Standards Hush [852 229] and are also present in small quantities along the parallel fault lying 100 to 200 m to the south. Throughout the Closehouse area, minor amounts of Pb and Zn are associated with the baryte deposits. These were sufficient to encourage the exploration of the area by hushing and driving levels from mediaeval times onwards, but commercial quantities of Pb and Zn have never been found in this area.

The Lunehead Mine [845 204], about 2 km south of

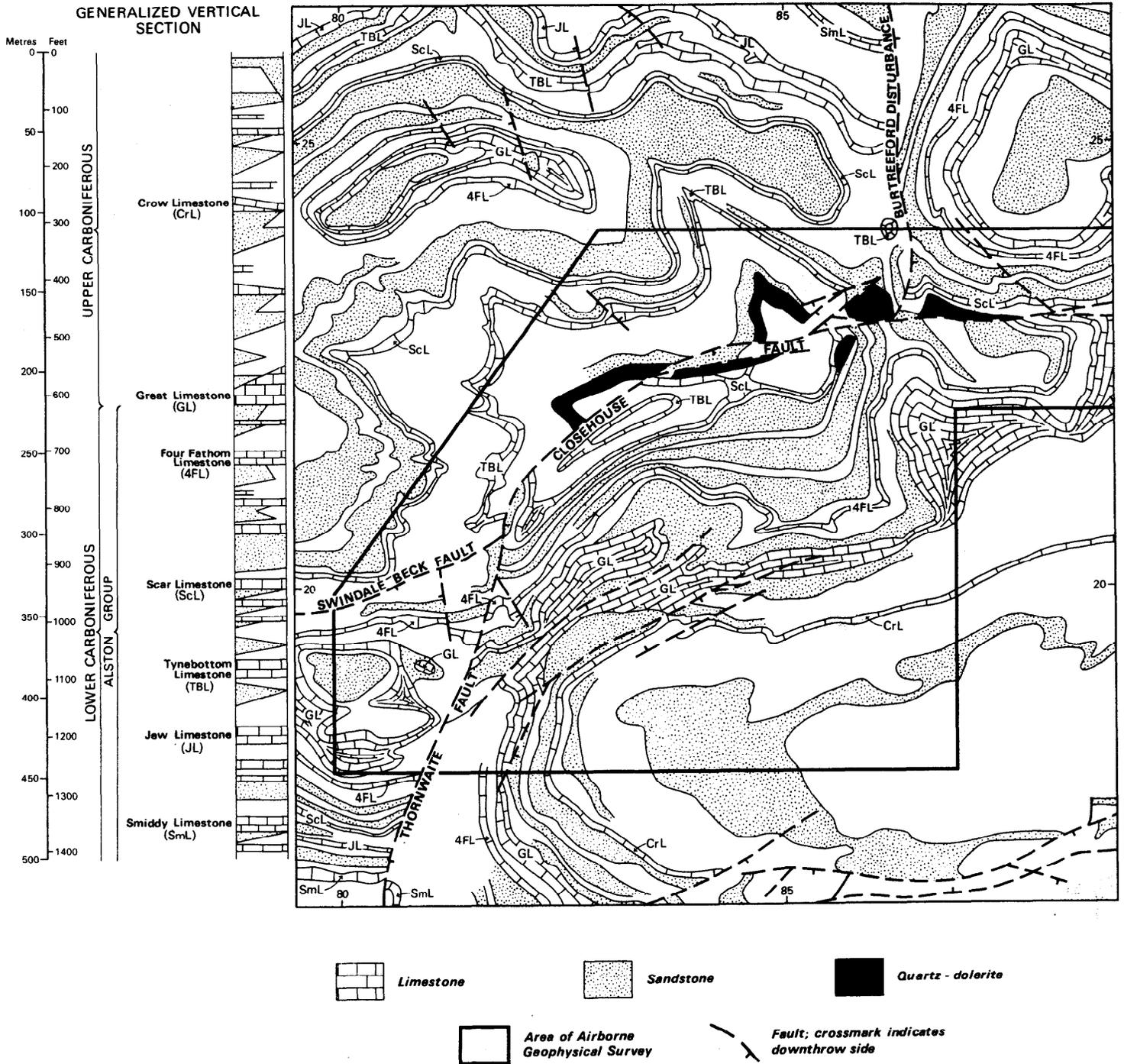


Fig. 1. Geological map and vertical section of the Carboniferous rocks of the Closehouse-Lunedale area

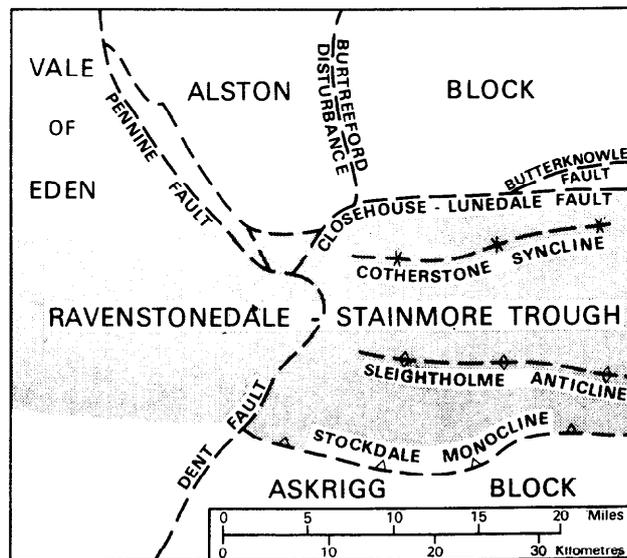
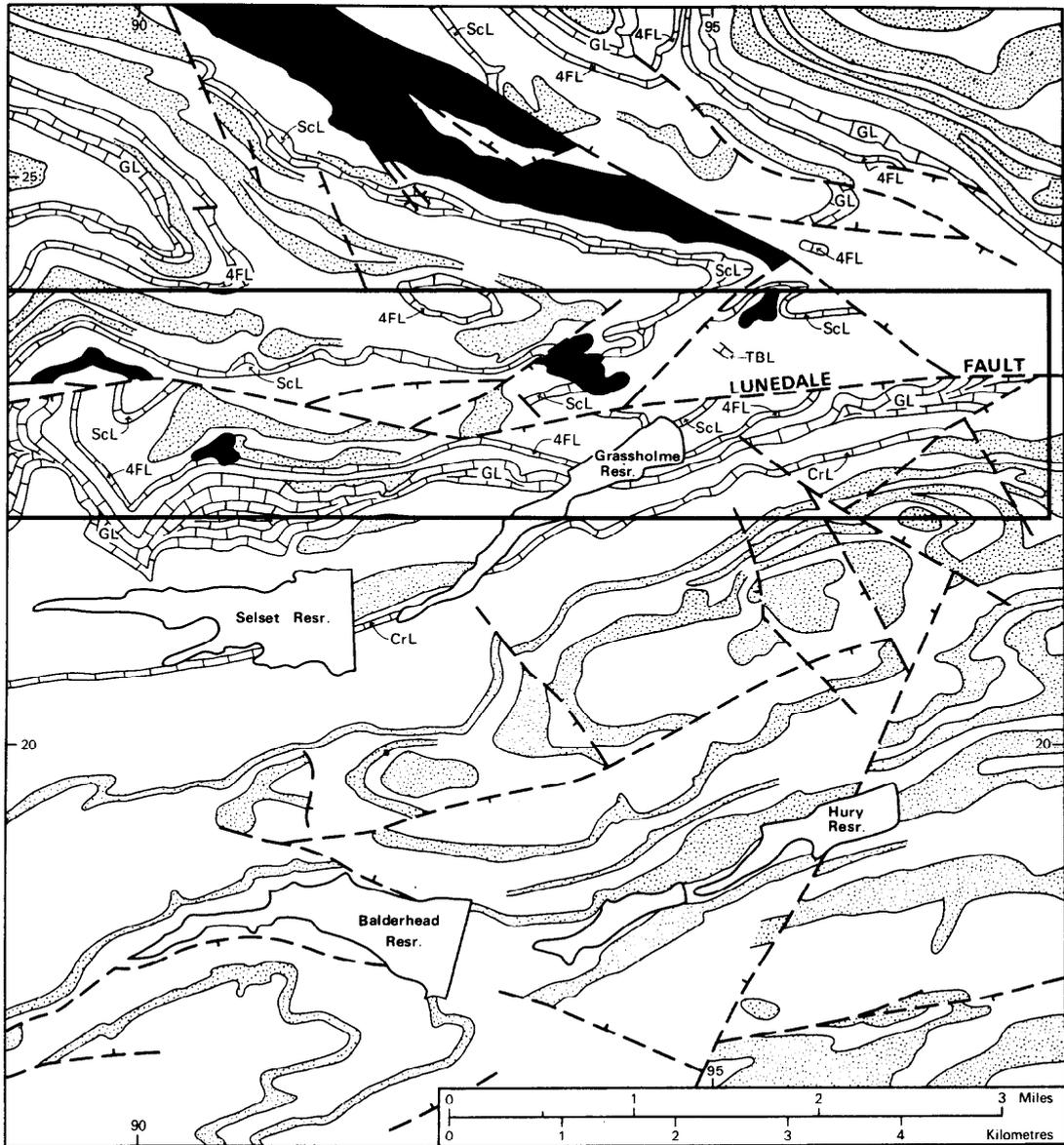
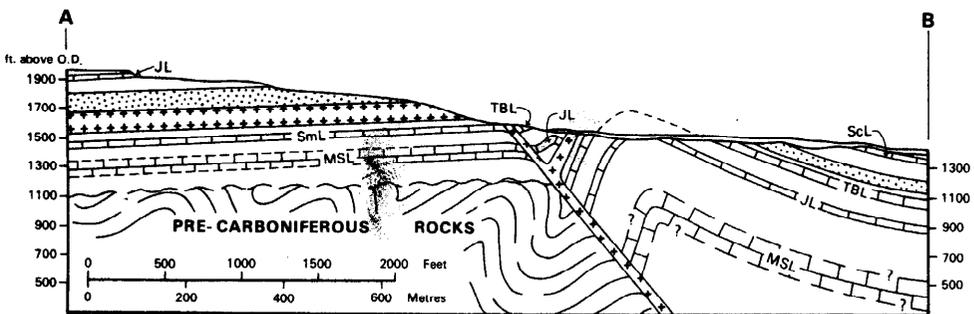
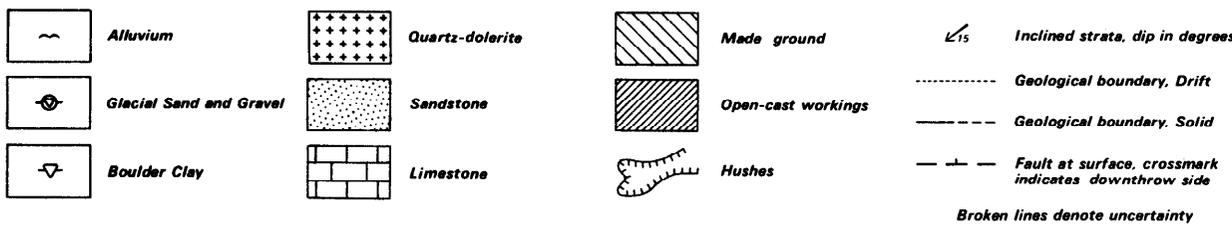
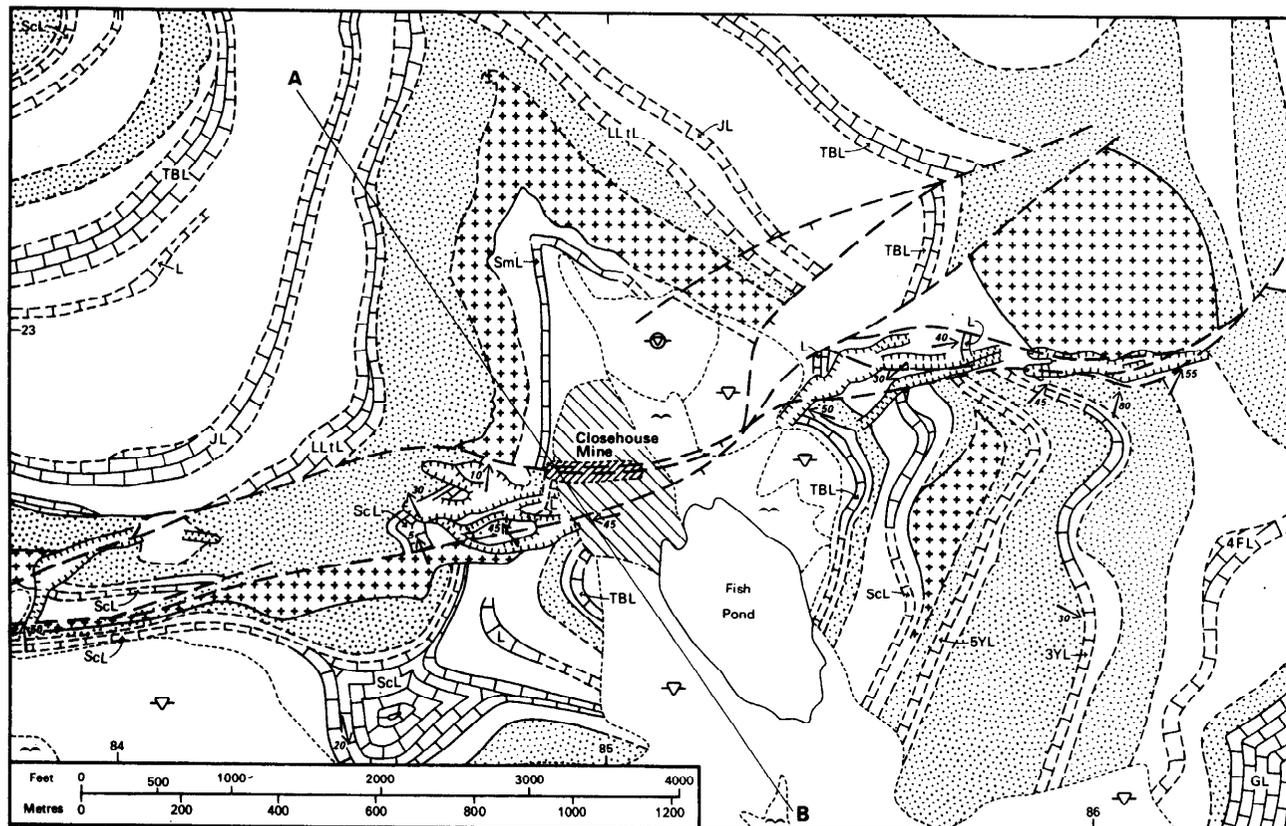


Fig. 2. Major structures and Carboniferous block-basin relationships



GENERALIZED VERTICAL SECTION  
north of Lunedale Fault

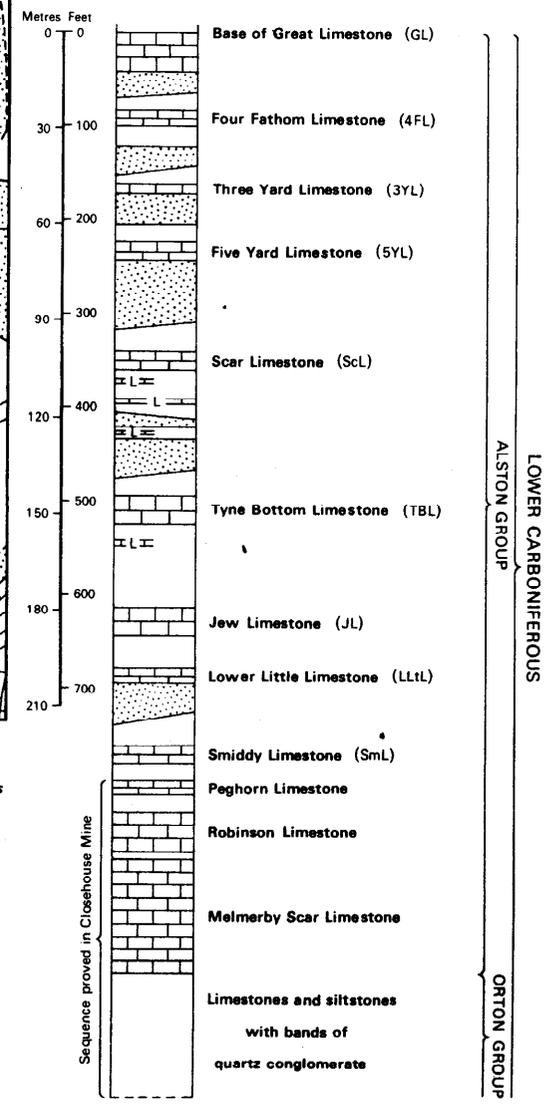


Fig. 3. Geology around Closehouse Mine

Closehouse, was worked as a Pb mine in ancient times and latterly for baryte. It is situated on a gentle anticline, with limbs dipping at less than 10°, within the Stainmore Trough. The oreshoots are veins in the Great Limestone and contain baryte with subsidiary galena and witherite.

#### MINERAL POTENTIAL

The mineral prospects of the Closehouse area are encouraging because of some analogies which can be drawn between this area and those containing some of the large Pb-Zn sulphide deposits in Ireland. The Irish occurrences are commonly situated on the margins of Lower Carboniferous sedimentary basins and generally occur near the base of the local carbonate succession. The sulphides in some cases appear to have been syngenetic with the host sediments, whilst elsewhere they were derived from hot chloride-rich brines. The latter were probably formation waters, heated by burial in the deeper parts of the basin and expelled towards the margins by fluid pressures. Traps for the brines were commonly provided by carbonate host-rocks, capped by Carboniferous mudstones or faulted against tight rocks in the Lower Palaeozoic basement. Basin margins, defined by growth faults active during sedimentation, seem to have been particularly favourable localities for Irish-style mineralisation. Furthermore, where the Irish deposits show zoning between metallic sulphides and massive baryte, the latter tends to be peripheral to the Pb and Zn.

Several important characteristics of the Irish occurrences are also present in the Closehouse area. The Stainmore Trough is a deep Lower Carboniferous sedimentary basin probably exceeding 2 km at its maximum depth below present ground level. The basal succession contains thick mudstones, and probably evaporites in the lowest parts of the sequence, so the basin is likely to have been a prolific source of brines. Movement of the brines was probably easiest through the limestones which are also likely to have been good host-rocks where the brines could encounter a source of sulphur. The occurrence of the baryte-galena veins at Lunehead Mine of a shallow structural trap in the Great Limestone appears to show that this process has operated in the area.

In predicting likely occurrences of this type of mineralisation it is important to locate effective traps for migrating brines, and in this respect two particular aspects of the Closehouse area are promising. Firstly, the anticline south of the Lunedale Fault brings the lowest and thickest carbonate (the Melmerby Scar Limestone) in the sequence to within about 100 m of the surface. The formation is at least 35 m thick and is potentially a good host-rock, situated in a favourable structural trap. Secondly, the Lower Palaeozoic rocks on the upthrow side of the Lunedale Fault might have provided a tight barrier against which migrating brines were trapped in the fault plane. This appears to have been the process for the emplacement of the baryte deposit and it seems reasonable to suppose that metallic sulphide ores were formed beneath it.

#### AIRBORNE SURVEYS

An aerial reconnaissance geophysical survey using helicopter-borne equipment was flown, under contract, by Hunting Geology and Geophysics Ltd, between July 1 and 3, 1973. The north-south flight lines were 200 m apart and, together with east to west tie lines, totalled 333 line km. The helicopter carried a magnetometer, and electromagnetic (EM) and radiometric equipment. The area covered by the airborne survey is defined by the following National Grid references: [3800 5190, 3870 5190, 3870 5220, 3980 5220, 3980 5240, 3830 5240 and 3800 5210]. Information on the instrumentation, map presentation and flight records is included in a separate report (Burley and others, 1978). The original flight records and copies of the 1:10 560 scale magnetic and EM maps for Lunedale are deposited

with the Applied Geophysics Unit of IGS.

The radiometric profiles were examined briefly but show only increases of up to 200 cps in the total count above a background value of about 230 cps. Some of these higher values occur over the opencast workings ('hushes') around Closehouse Mine and others appear to be associated with shale horizons in the Lower Carboniferous sequence. Other anomalies occur over the Great Scar Limestone forming the hill at [825 201] and over the River Lune where a thin overburden may provide an explanation.

#### Electromagnetic (EM) surveys

A simplified and reduced version of the original 1:10 560 EM contoured maps is shown in Fig. 4 with contours of the in-phase component at 25 ppm intervals. The most prominent features occur in the eastern part of this map (Fig. 4) and consist of:

- A — a continuous elongated negative anomaly, which exceeds 200 ppm in the in-phase component and is due to a power line.
  - B — a narrow, sharply defined anomaly of 100-300 ppm in the in-phase component (and a smaller anomaly in the out-of-phase component) coinciding with a water-main pipe leading from Grassholme reservoir.
- Other anomalies tend to be less well-defined, but the following can be recognised in Fig. 4.:
- C — a strong anomaly observed on two flight lines only and suspected to be of instrumental origin.
  - D & E anomalies (e.g. Fig. 10) usually restricted to one flight-line but together forming an area of possible interest. In the area of D the flight-lines run parallel to the geological strike.
  - F — an east to west zone along the southern margin of the area.

Values of the out-of-phase component were not contoured but these data were used to compile anomaly ratio maps. The out-of-phase component is typically more variable than the in-phase component since it responds to poorer conductors such as conductive overburden or some shale horizons. In the Lunedale area sections of profile show almost continuous anomalies in the out-of-phase component and these can be combined to form the anomalous zones indicated in Fig. 6.

#### Magnetic surveys

The aeromagnetic map of the Lunedale survey area is dominated by a belt of strong anomalies (Fig. 5) characterised by an almost continuous series of troughs compared with the undisturbed background field to the south. The negative anomalies are flanked by positive peaks usually with much lower amplitudes. The anomalies are strong (up to 500 gamma) with steep gradients and are associated with the dolerite of the Whin Sill and Whin dykes (Figs. 1 and 2).

Hallimond and Butler (1949) carried out magnetic surveys over the Whin Sill in the vicinity of the Closehouse Mine [850 228] and concluded that the magnetic anomalies could only be explained if the sill were assumed to have a strong near horizontal remanent magnetisation in a direction opposite to that induced by the present geomagnetic field (i.e. 'reversed' magnetisation).

Palaeomagnetic investigations on the Whin Sill by Creer and others (1959) and subsequently by Storetvedt and Gidskehaug (1969) confirmed that the igneous rock has a 'reversed' direction of magnetisation, almost opposite in declination to the present geomagnetic field and with a small upward inclination. Using susceptibility data provided by Creer and others (1959) for five sites, the total magnetisation (the resultant of the remanent magnetisation plus the magnetisation induced in a field 0.5 oersted) of the Whin Sill has been calculated (Table 1). It is

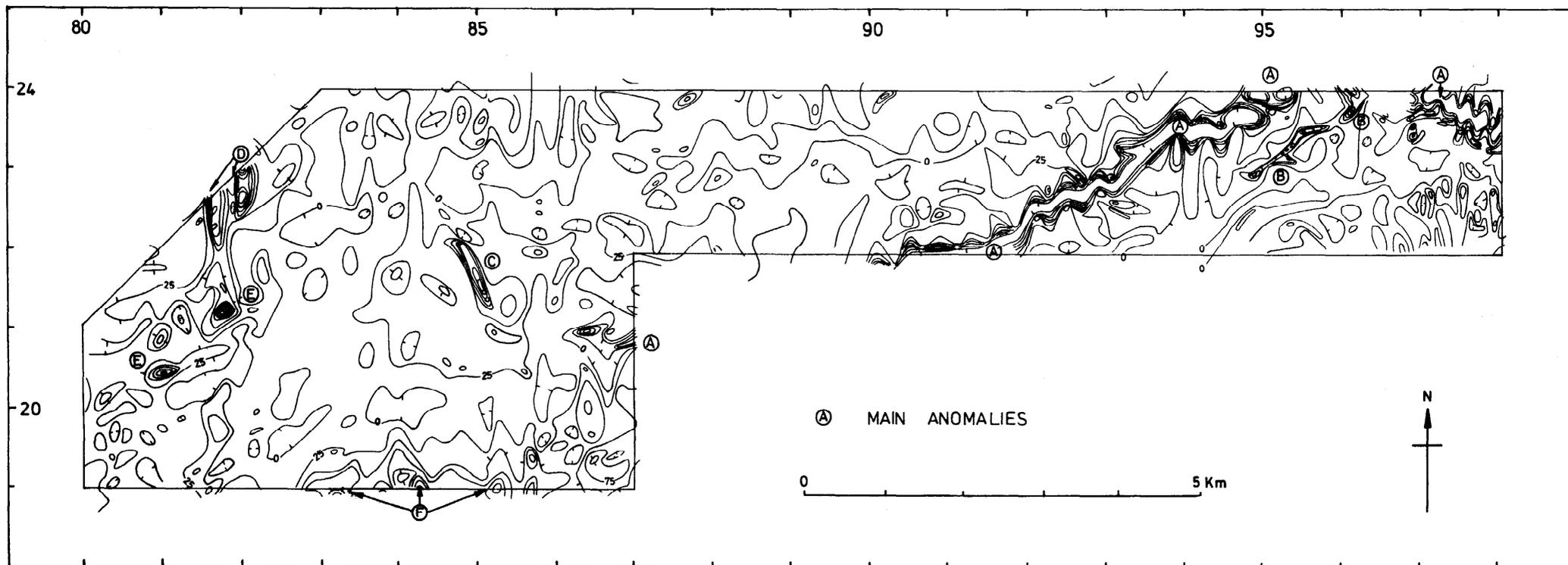


Fig. 4. Electromagnetic map of the Lunedale area with contours of the in-phase component at 25 ppm intervals. Anomalies indicated are referred to in the text. The outline of the airborne survey area is also shown

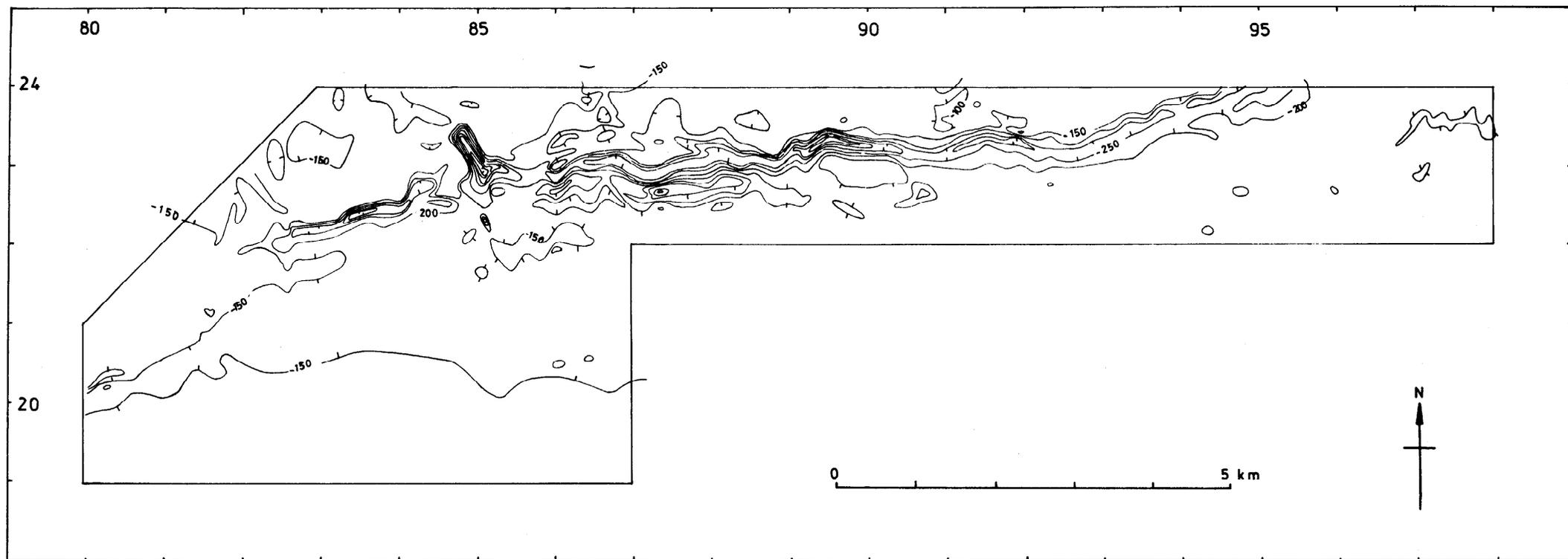


Fig. 5. Total magnetic field map with contours at 50 gammas (= 50 nt) intervals

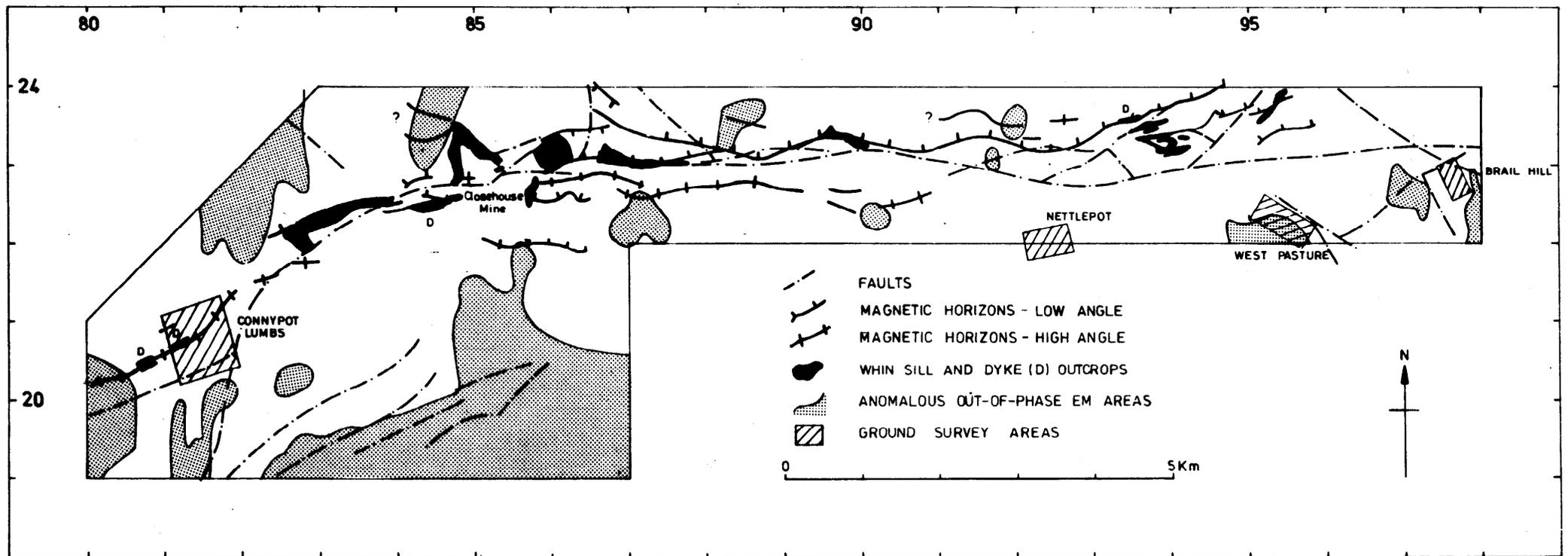


Fig. 6. Map of the Lunedale area showing ground survey areas, location of magnetic horizons, based on provisional interpretations, outcrops of dolerite intrusions, and zones of anomalous out-of-phase component values.

Table 1. Remanent and total magnetisation of five sites in the Great Whin Sill (from Creer and others, 1959)

Site No.	Direction		Remanent magnetisation			Total magnetisation		
	D°	I°	Intensity x 10 <sup>-3</sup> emu	Susceptibility x 10 <sup>-3</sup> emu	Q	D°	I°	Intensity x 10 <sup>-3</sup> emu
7	183	-1	1.99	2.25	1.77	186	+30	1.84
10	171	-14	3.10	2.16	2.87	169	+5	2.60
12	190	-20	4.00	2.31	3.45	192	-6	3.54
15	196	-19	2.86	1.64	3.49	199	-5	2.45
24	177	-10	2.02	1.56	2.59	178	+12	1.76
	Mean		2.79	1.98	2.82	185	+4	2.31

D° — declination in degrees. I° — inclination, negative upwards. Q is the ratio of the remanent to the induced magnetisation.

almost horizontal and produces magnetic anomaly forms very different from those due to induced magnetisation alone.

Fig. 7 illustrates the types of anomalies produced along north to south profiles by various two-dimensional models with a Whin-Sill-type magnetisation. Fig. 7 A-E are for sheet-like bodies with different dips with additional models (2 and 3) in Fig. 7E illustrating the effect of an inclined upper surface (at 45° and 10° to the horizontal). Model F represents a horizontal faulted block of dolerite and G shows the result of a combination of a vertical dyke and a horizontal sill. The curve for this model is very similar to that for a sheet inclined at 45° (D) but separating the two parts of the model (G2) produces a curve with a central positive peak flanked by two negative anomalies. In all these examples it has been assumed that remanent magnetisation was acquired with the magnetic bodies in the positions shown — any significant post-magnetisation movement of the intrusions would produce a total magnetisation different from that in Table 1 and consequently alter the shape of the anomalies in Fig. 7.

The main magnetic anomaly in Fig. 5 typically has a large negative section with a smaller positive section to the north. In parts of the area this anomaly is uncomplicated by other features and can be accurately reproduced by the curve for a single 'sheet-like' body similar to Fig. 7E. This low angle of dip is consistent with the fact that the Whin Sill is intruded along the almost horizontal bedding of the Lower Carboniferous rocks. The topography usually intersects the horizontal sill at low angles so that the curve 3 (Fig. 7E) is probably the most realistic representation of the observed curve. This model agrees with the magnetic profiles for the eastern part of the anomaly (90.5 E - 95.0 E) for the section between 82.5 E and 84.3 E. In a few places a second minor negative anomaly suggests the presence of a minor intrusion (Fig. 8D). Between 84.3 E and 90.5 E the anomalies are more variable, consisting either of a positive anomaly to the south of the main negative or several anomaly peaks (Fig. 8, A and B) as well as the simple negative anomaly. In profiles such as Fig. 8A the combination of positive and negative peaks is the opposite to that expected from a single vertical sheet, magnetised horizontally, and requires an interpretation using more complicated models, perhaps consisting of near-horizontal sills (giving the double negative anomalies) and a steeply dipping sheet (causing the positive anomaly c.f. Fig. 7C). Alternatively the multiple sheet model may not be applicable at all and the presence of exposures of the Whin Sill up to 500 m wide

suggests that anomalies similar to Fig. 7F can occur (such as at 86 E). The position of the Whin Sill appears to be controlled by both the faulting and the stratification of the sediments, so the irregular nature of the magnetic anomalies is not unexpected in the area where the Lunedale Fault intersects the north-trending Burtreeford Disturbance. The complicated nature of the anomalies and the similarity of profiles G1 and D (Fig. 7) make it difficult to show how the dykes and sills are related but their close proximity suggests that dykes and sills are directly connected at depth. In this respect it is relevant that positive anomalies are most pronounced on the south side of the main negative between 86.0 E and 88.3 E and again between 89.5 E and 90.3 E. These are sections where the sill edge is at, or close to, the Lunedale Fault and major vertical dykes might be expected.

In the north-west of the area, irregular, low amplitude anomalies north of the main anomaly zone suggest that the underlying Whin Sill is disturbed by faulting or horizon changes. Towards the south-west the anomaly pattern is clearer and a single weak anomaly corresponds with the outcrops of several small dolerite dykes. South of the main belt of anomalies the magnetic field is undisturbed and igneous rock seems to be completely absent.

In the extreme east of the area small positive magnetic anomalies near Mickleton and an isolated anomaly at the Banklands Quarry [970 229] are probably caused by man-made objects.

A provisional interpretation of the magnetic anomalies is summarised in Fig. 6. The observed magnetic profiles were compared with model curves and the southern edge of the Sill located with respect to the anomaly peak. There is a good correspondence with outcrops, although the greater resolving power of ground magnetic surveys would be needed to interpret anomalies due to complicated structures as around 85 E to 87 E, or small intrusions such as the dykes at 81 E. The map shows the sill to be a continuous intrusion with its southern margin coinciding with the Lunedale Fault between 84 E and 94 E but further east the margin seems to follow one of its northern branches. Near Greengate [934 234] the main anomaly coincides with outcrops of thin sills but the extensive exposures to the south, including those at Lunedale Quarries [954 239], are indicated only by small irregular anomalies. The course of the southern margin of the sill west of its last outcrop at 82.5 E is not clear on the magnetic map. It may thin gradually in that direction and it

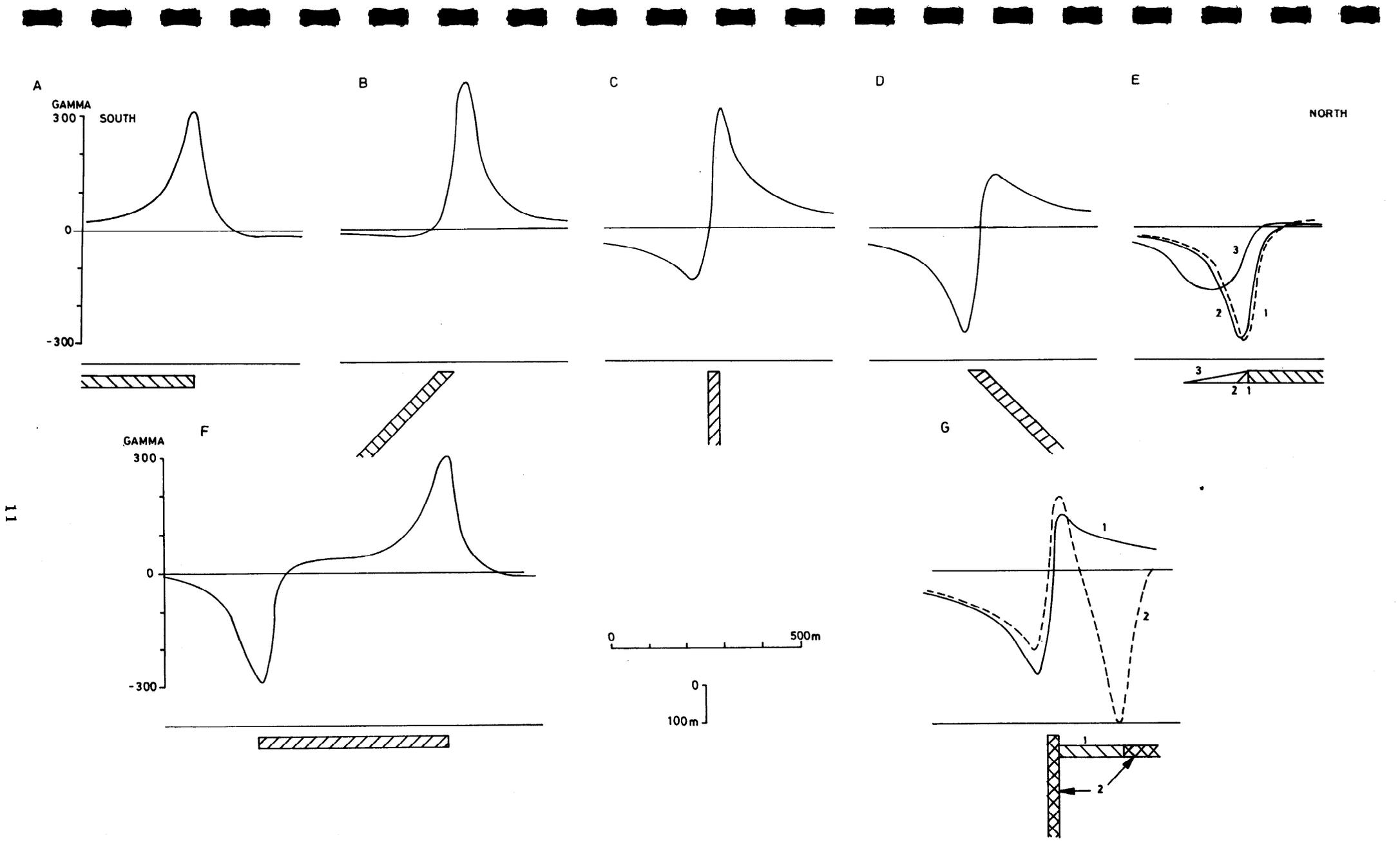


Fig. 7. Theoretical magnetic curves for the sheet-like models shown with different dips and a magnetisation similar to that of the Whin Sill. (1 gamma = 1 nT)

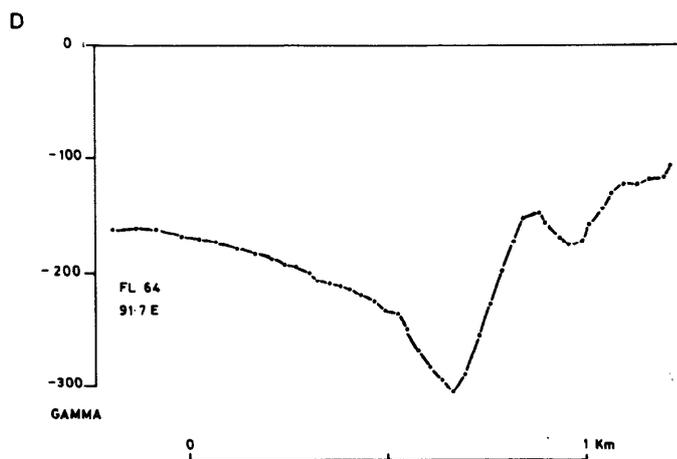
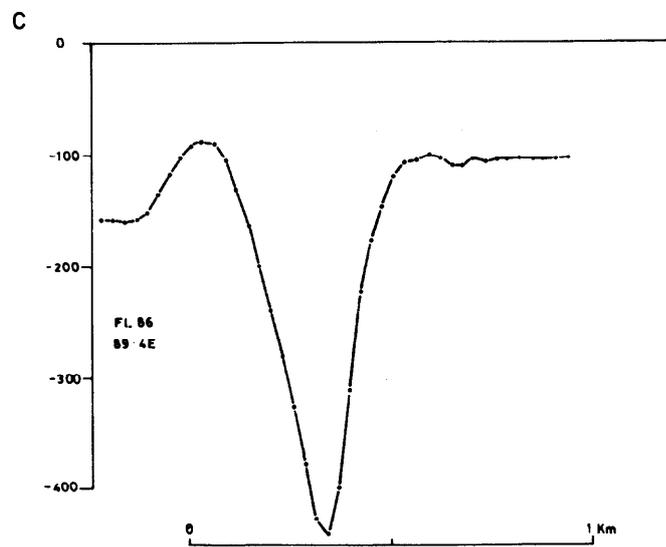
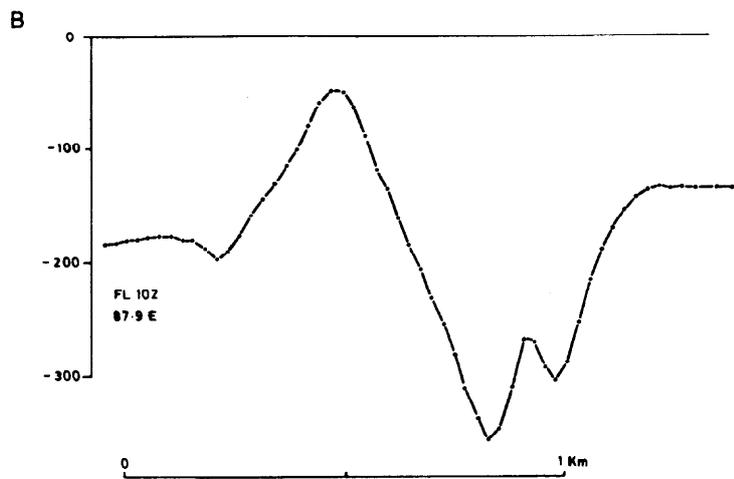
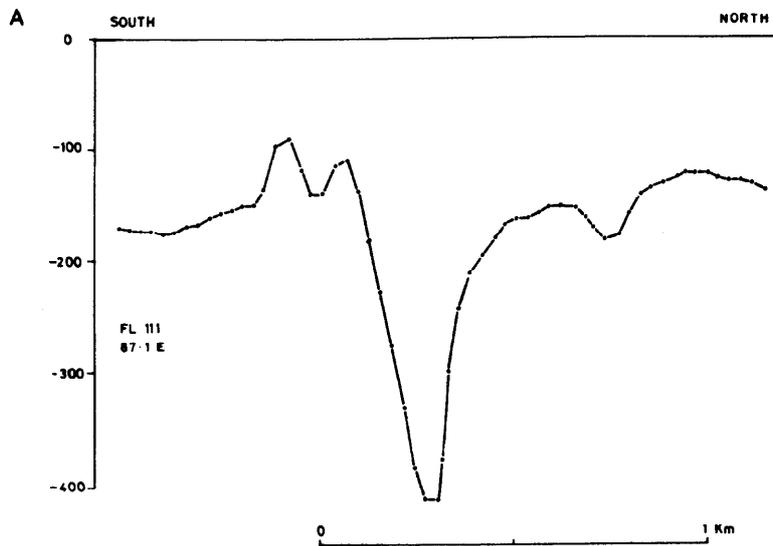


Fig. 8. Magnetic profiles for flight lines at A-87.1E, B-87.9E, C-89.4E and D-91.7E

seems unlikely that it extends southwards beyond 22 N.

#### Magnetic anomalies around Closehouse Mine

Baryte is the principal mineral worked in Closehouse Mine (Hill and Dunham, 1968). It replaces a Whin dyke, intruded along the Lunedale Fault, and adjacent rocks in both the hanging and foot walls. The mineralisation occupies fractures in the Whin dyke, in adjacent limestones and even occurs in argillaceous rocks in the No. 3 deposit (Hill and Dunham, 1968), but in all cases the major fracture of the Lunedale Fault appears to have been the main channel for the mineralising fluids. These fluids profoundly affected the chemical composition of the dolerite, converting it to 'White Whin'. One result of this has been to alter titanomagnetites to 'leucoxene' (Hill and Dunham, 1968), suggesting that altered dolerite is non-magnetic.

The No. 1 deposit at Closehouse consists of the heavily altered and mineralised Whin dyke, about 16 m wide and dipping southwards at 45° to 52°. Westwards the dolerite is altered but less mineralised; baryte reappears still further to the west in the No. 2 deposit. A second dolerite dyke, the South Dyke, occurs about 100 m to the south of the main deposit but is not mineralised, although flanked by lenses of barytes.

The main features of the magnetic data collected during the 1973 airborne survey are shown in Fig. 9 for the area around the Closehouse Mine. In this simplified map, contours at 50-gamma intervals only are shown, although the 1:10 560 maps available on open file are contoured at 10-gamma intervals. The main anomalies have been numbered 1 to 13, starting in the west. Feature 1 is a typical sill-edge anomaly (cf Fig. 7A) but this bifurcates eastwards and there are clearly two sill anomalies at about 84.4 E. Anomaly 2 indicates the concealed edge of the main sill where it has been truncated by the North Fault, and anomaly 3 coincides with the exposed patch of sill along the South Fault. Eastwards, where the sill is replaced by a Whin dyke [848 226], anomaly 3 terminates at about 84.7 E. and is replaced by a small positive anomaly (not shown in Fig. 9) marking the dyke along the South Fault.

The north-south striking segment of Whin Sill north-west of Closehouse Mine coincides with the direction of the flight lines, making interpretation difficult, and the significance of positive anomaly 4 is not clear. One possibility is that part of the anomaly is related to anomaly 5 and that the sill in this area is not so extensive as shown on the geological map. Anomaly 5 however is clearly related to the patch of Whin Sill cropping out about 0.5 km north of the mine, although the strike of the anomaly differs slightly from the trend of the outcrop (Fig. 3). The sudden terminations of anomaly 5 suggest the possible presence of unmapped faults. Anomaly 5 extends north-westwards as a weak anomaly which indicates that the concealed sill in this area is down-faulted or changes stratigraphical horizon. Anomaly 6 is an eastward extension of anomaly 5 apparently due to a previously unknown patch of Whin Sill at depth.

Although feature 7 is small in area, this positive anomaly is significant as it appears to mark a magnetic dyke-like feature along the fault. Feature 8 is a large-amplitude positive anomaly recorded on one flight line only and may be due to a small intrusion of Whin dolerite. It could be related to the source of feature 9 which is an elongated anomaly with a maximum amplitude of only about 100 gamma. For most of its strike length the anomaly is positive, favouring a dyke-like origin, but near its eastern end its form is more like that of a sill.

In the north-eastern corner of the map, anomalies 10 to 13 all appear to be truncated along a line trending NNE to SSW. This passes through the outcrop of the Whin Sill [857 226] and

could be a fault (Fig. 9) although the geological evidence does not support this interpretation. To the west of this line the magnetic anomalies are weak, suggesting that the dolerite bodies are reduced in size or have been altered. The presence of anomaly 10 near the northern edge of an outcrop of Whin Sill is consistent with the geological evidence for a faulted boundary (cf Fig. 7F) which seems to continue for a considerable distance to the east. The negative anomaly 12 is complementary to 10 and marks the southern edge of the sill. The positive anomaly 11, also over the outcrop of the Whin Sill, is however not so obviously explicable and could be due to a flexure or fault in the sill or an underlying dyke.

Features 13 and 14 are adjacent and vary in their relative amplitudes, making interpretation difficult. It seems possible that a dyke, representing the westward end of the feature shown in Fig. 6, and/or a sill could be present. The anomalies seem comparable with Fig. 7, G2.

Around the Closehouse Mine the magnetic data reveal a complicated and variable character for the Whin intrusions and seem to require modifications of the geological structure within areas where the Whin intrusions can be seen at the surface and also indicate several completely new intrusions, notably along the southern edge of the area shown in Fig. 9. A great deal of information is available from the magnetic data but detailed ground surveys and complete interpretations of the numerous examples of adjoining anomalies would be necessary before the intrusions could be accurately located on the ground. The absence of strong anomalies over the dykes in the immediate vicinity of Closehouse Mine could be due to the alteration of normally magnetic dolerite into White Whin, which in turn suggests a means by which altered dolerite could be recognised in further exploration work.

#### GROUND SURVEYS

Detailed ground geophysical surveys were made at sites selected on the basis of both the results of the airborne EM survey and geological knowledge of the area. The location and orientation of the ground surveys were planned to cover interesting EM features and measurements were made usually with the Turam method, although Slingram and VLF methods were sometimes used as alternatives. Within the Lunedale area ground surveying over all the interesting targets was not possible due to access restrictions and a complete assessment of the area is therefore not possible at present.

The results of the ground surveys are listed in Table 2 and the locations of the areas are shown in Fig. 6. In Table 2 the totals of line kilometres covered on the ground are listed together with an indication of the amplitude of the EM anomaly observed on the airborne survey.

#### Connypot Lumbs

The group of AEM anomalies in the south-west corner of the survey area (E, Fig. 4) occur over low lying ground in the valleys of the Connypot and Lune Head Becks. The anomaly at [810 214] was selected for further investigation and five parallel traverses were covered with Slingram. The results show little variation, with a maximum range of 10% in both the in-phase and the out-of-phase component values measured, although there is a tendency for a larger separation of the components to the north. No clear indication corresponding with the AEM anomaly was discovered (Fig. 10).

A single magnetometer traverse produced an anomaly of about 230 gammas coincident with a narrow dyke of Whin dolerite.

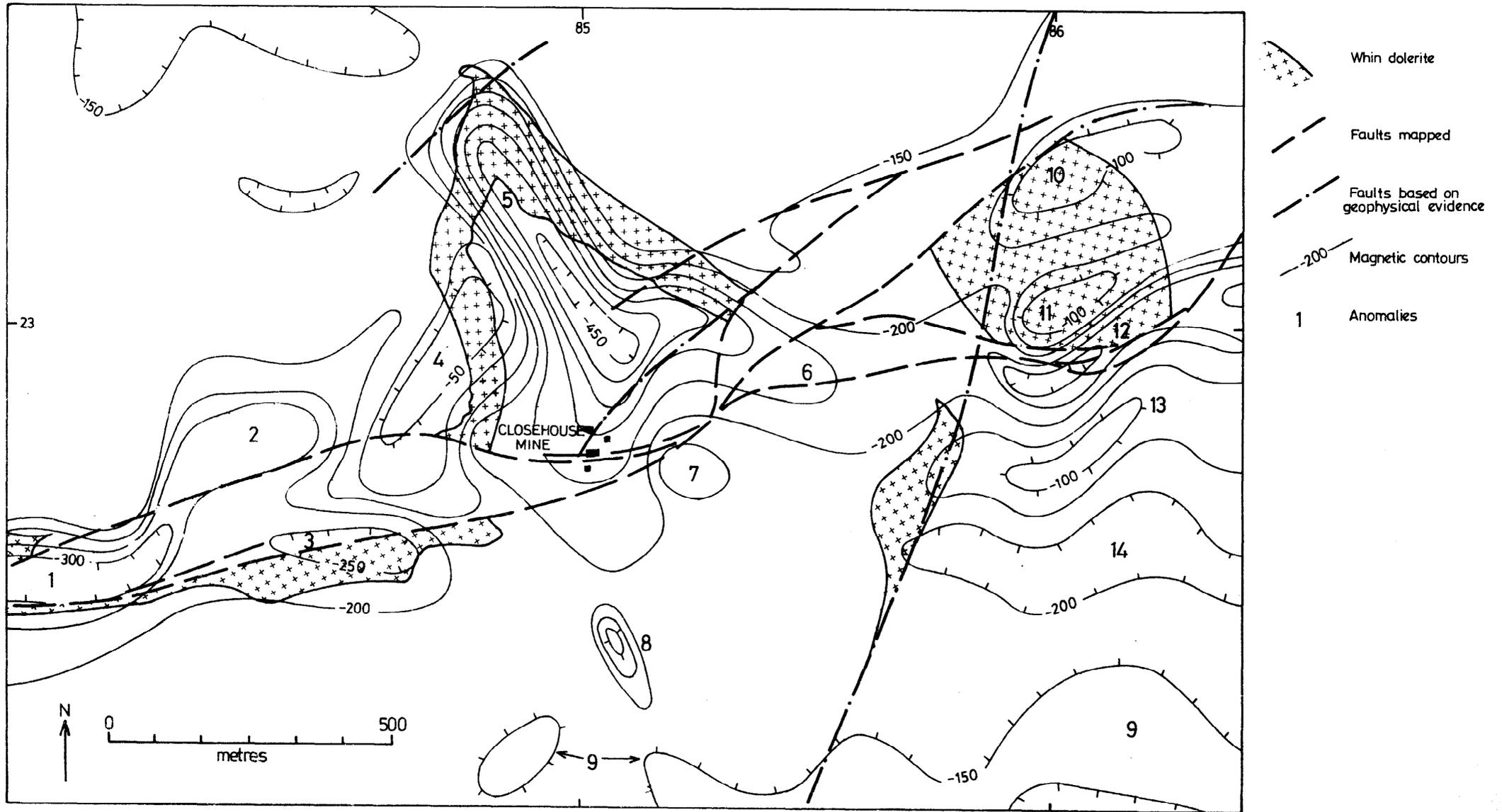


Fig. 9. Magnetic anomalies and outcrops of the Whin Sill around Closehouse Mine. Contours at 50 gamma (= 50 nT) intervals

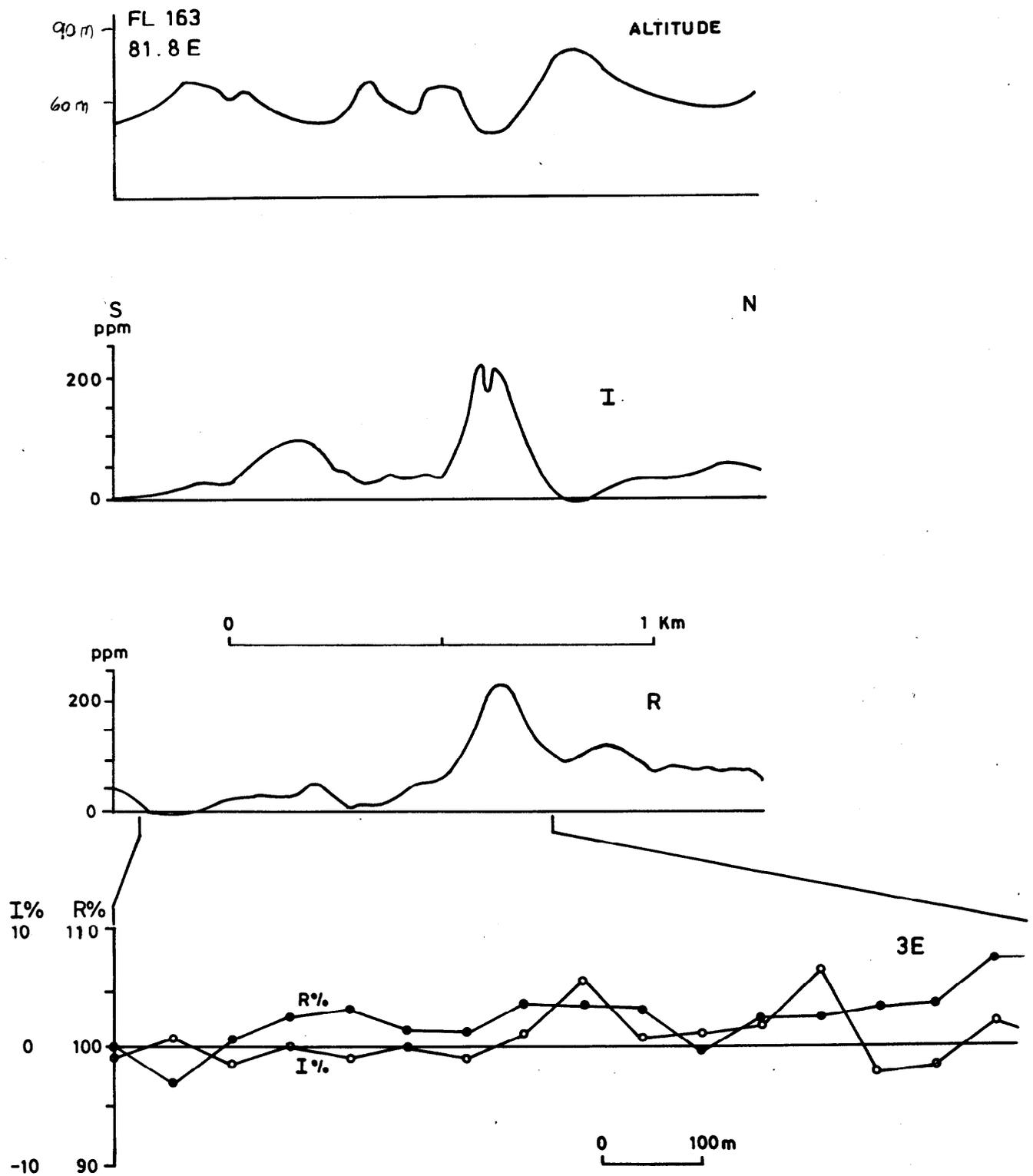


Fig. 10. (A) altimeter, (B) EM (out-of-phase component) and (C) EM (in-phase-component) records for flight line 163 and (D) ground Slingram results for part of line. Note apparent correlation between altitude and EM anomalies

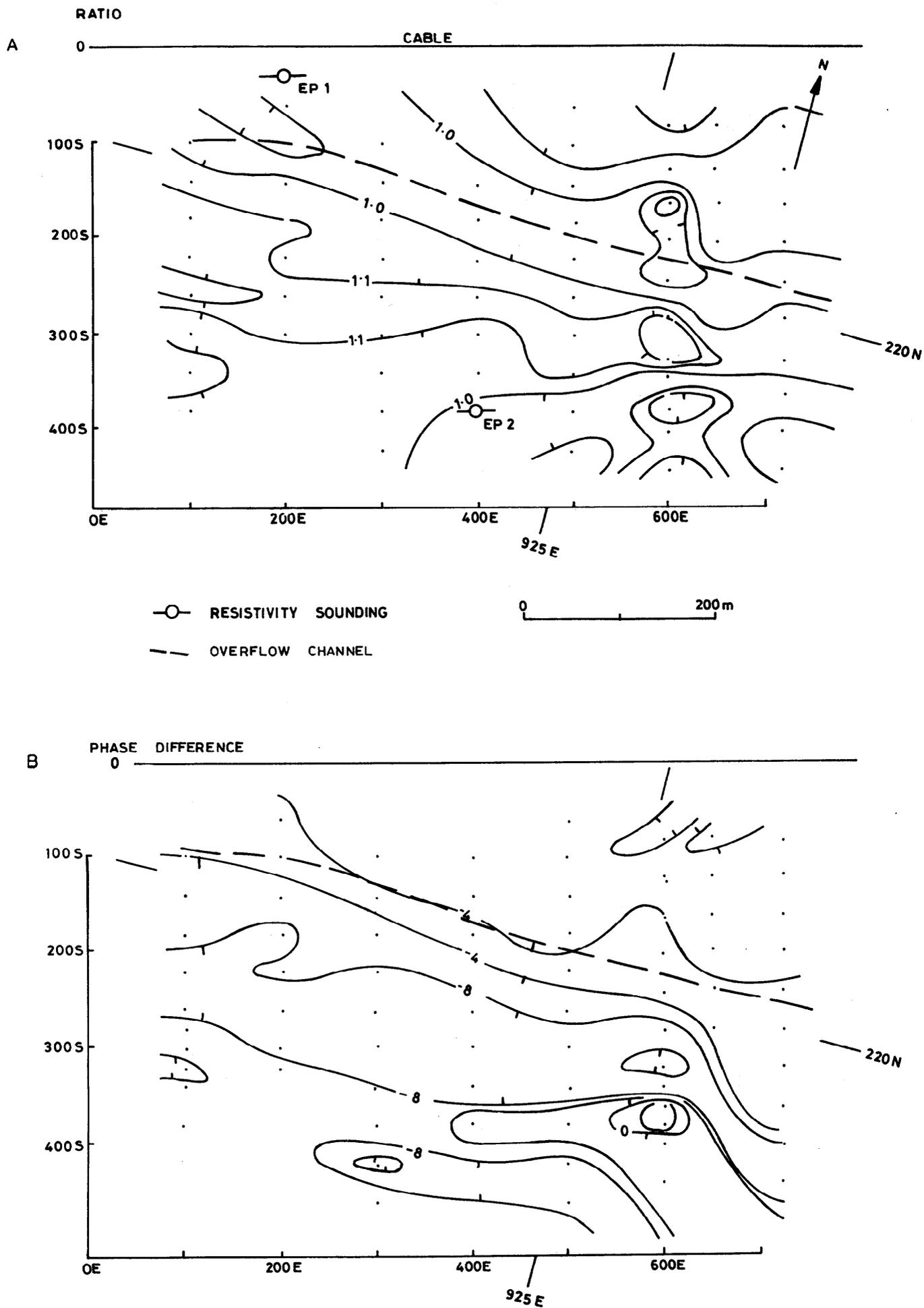


Fig. 11. Turam map of the Nettlepot area with (A) contours at 0.1 intervals for reduced ratio and (B) contours  $4^\circ$  intervals for phase difference

Table 2. Summary of detailed ground surveys in the Lunedale area

NAME	AREA		GEOPHYSICAL DATA			REMARKS
	1:10 560 MAP	METHOD	LENGTH OF LINE (in km)	AIRBORNE EM ANOMALY (ppm)		
				In-phase	Out-of-phase	
Connypot Lumbs	NY 82 SW	Slingram	4.8	60	200	No significant EM anomaly
		Magnetics	1.0			
Nettlepot	NY 92 SW	Turam	2.6	50	160	Buried pipe responsible for main AEM Anomaly
West Pasture	NY 92 SE	Turam	2.4	85	260	No significant EM anomaly
Bail Hill	NY 92 SE	Slingram	1.4	95	10	Artificial conductors

#### Nettlepot

The Turam survey at Nettlepot covered a less well-defined AEM anomaly than at Connypot Lumbs. On traverse 600E strong EM anomalies were recorded over a pipe which runs parallel with the line and is responsible for the main AEM anomaly, but for the remainder of the area only comparatively small variations were recorded. The variations can however be contoured (Fig. 11) in a manner which suggests some relationship with the strike of the strata with possibly an additional feature due to a glacial channel.

Two depth soundings (Fig. 11, EP1 and EP2) were made, using resistivity equipment to examine the range of bedrock resistivities within the area. Interpretations of these soundings gave the following results:

Layer	Depth (metres)	EP1		EP2	
		Resistivity (ohm metres)	Depth	Resistivity	Depth
Layer 1		530		92	
Layer 2	0.5	53	1.6	9	
Layer 3	1.1	1590	4.0	30	
Layer 4	5.4	180	4.7	92	

Although the upper layers (probably drift and weathered bedrock) differ considerably, the difference between the respective fourth layers cannot be considered diagnostic in terms of bedrock classification.

#### West Pasture

Irregular AEM anomalies in the area combined with a number of potentially mineralised faults warranted a ground survey at West Pasture (Fig. 6). The Turam survey, however, revealed no distinct anomalies, the variation over the area being small (7° phase difference and 0.15 reduced ratio maximum).

#### Bail Hill

Trial EM surveys using Slingram equipment revealed several man-made sources of anomalies and the work was discontinued.

#### CONCLUSIONS

The airborne survey produced extensive EM and magnetic data along the Lunedale Fault. There are numerous EM anomalies, mostly in the out-of-phase data, and, although some of these are due to power-lines or pipelines, the majority are as yet uninvestigated. Ground follow-up of 2 strong airborne EM anomalies failed to locate ground anomalies of comparable intensity and it may be that, in these cases at least, the airborne work has emphasised weak conductors of no economic significance. Two other anomalies examined on the ground proved to be due to artificial conductors. Further ground surveys of the remaining airborne EM anomalies would be desirable.

The airborne magnetometer results reveal strong anomalies, usually with negative peaks, over the edges of the Whin Sill and over Whin dykes. These enable the outcrops of the Sill to be extended beneath shallow cover and also suggest that in places the edge of the Sill is associated with more Whin dykes than appear at crop.

It was initially intended that the geophysical work described in this report should be accompanied by geochemical sampling and that the main new indications of mineral deposits be tested by scout drilling. However, before that programme could be undertaken, renewed mining company interest and curtailed access to the ground precluded further work by the Institute. The mineral potential of the area therefore remains largely untested.

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