Natural Environment Research Council

Institute of Geological Sciences

Mineral Reconnaissance Programme Report

A report prepared for the Department of Industry

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No. 24

Geophysical investigations along parts of the Dent and Augill Faults

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Geophysical investigations along parts of the Dent and Augill Faults

Geophysics

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Geology

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London   1978   *A report prepared for the Department of Industry*

Mineral Reconnaissance Programme Reports

1   The concealed granite roof in south-west Cornwall

2   Geochemical and geophysical investigations around Garras Mine, near Truro, Cornwall

3   Molybdenite mineralisation in Precambrian rocks near Lairg, Scotland

4   Investigation of copper mineralisation at Vidlin, Shetland

5   Preliminary mineral reconnaissance of Central Wales

6   Report on geophysical surveys at Struy, Inverness-shire

7   Investigation of tungsten and other mineralisation associated with the Skiddaw Granite near Carrock Mine, Cumbria

8   Investigation of stratiform sulphide mineralisation in parts of central Perthshire

9   Investigation of disseminated copper mineralisation near Kimelford, Argyllshire, Scotland

10   Geophysical surveys around Talnotry mine, Kirkcudbrightshire, Scotland

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ILLUSTRATIONS

Summary

The mineral investigations described in this report consisted of an airborne electromagnetic (AEM), radiometric and magnetic survey over selected parts of the Dent and Augill Faults, followed by ground studies of the most promising anomalies. The follow-up work consisted of electromagnetic surveys, using VLF, Turam and Slingram methods, and detailed geological mapping. A gravity survey was undertaken to provide Bouguer anomaly data typical of the margins of the Lower Carboniferous blocks in the northern Pennines.

The value of the airborne survey was limited by electricity power line interference in some parts of the area. Twelve AEM anomalies were investigated on the ground but five of these proved to be due to buried metal water pipes. Another five were associated with conductive shale or mudstone horizons in the Carboniferous sequence. The VLF and Turam methods produced anomalies at Kitchen Gill and Birkett Common which correlate with both faults and mudstone outcrops. In the former area the AEM anomalies are close to disused mine workings and may be due in part to mineralisation, but the targets were not sufficiently promising to justify boreholes. Anomalies at Long Rigg and Dowgill are thought to be due to conductive boulder clay.

The regional gravity survey indicated that the main faults are characterised by weak Bouguer anomaly highs. Other anomalies are not readily accounted for by the distribution of near-surface rocks and therefore probably reflect variations in the basement. Such changes may be generally useful in defining the boundaries of uplifted blocks of basement rocks.

Copies of the data and maps for the airborne and ground geophysical surveys are deposited with the Applied Geophysics Unit of IGS, London.

INTRODUCTION

The areas covered in the present investigation lie near the towns of Brough and Kirkby Stephen. They include parts of the Dent and Augill Faults, which form the western margins of the Askrigg and Alston Blocks respectively.

The higher ground is open moorland used for sheep-grazing and is difficult of access except to cross-country vehicles, but the lower ground is in agricultural use, generally as pasture, and is well served by roads and tracks.

The airborne electromagnetic (AEM) survey was restricted to the areas of known mineral veins (Fig. 1) along the Dent and Augill faults. No geochemical exploration was undertaken because of widespread contamination from the numerous mine dumps.

GEOLOGY

The northern part of the area shown in Fig. 1 was re-surveyed between 1958 and 1967 (Burgess and Holliday, in press) following the 19th-century primary survey. The southern part has not been completely re-surveyed, although parts of it were revised for the 1 inch to 1 mile scale geological map (Kirkby Stephen sheet 40) published in 1972 and detailed mapping of selected areas has formed part of the present investigations.

The area is mainly underlain by Carboniferous rocks (Fig. 2) and details of the successions are given in Figs. 2, 5 and 6. Permo-Triassic deposits are present to the west, just beyond the areas of detailed work (Fig. 2).

The oldest Carboniferous rocks exposed are the Orton Group, comprising marine limestones with sandstones and shales. The lower part of the overlying Alston Group consists of the massively bedded Great Scar Limestone, about 100 m thick. The succeeding beds comprise alternating limestones, mudstones, siltstones and sandstones deposited in a sequence of cyclothems. These are internally very variable and any one cyclothem is rarely fully developed.

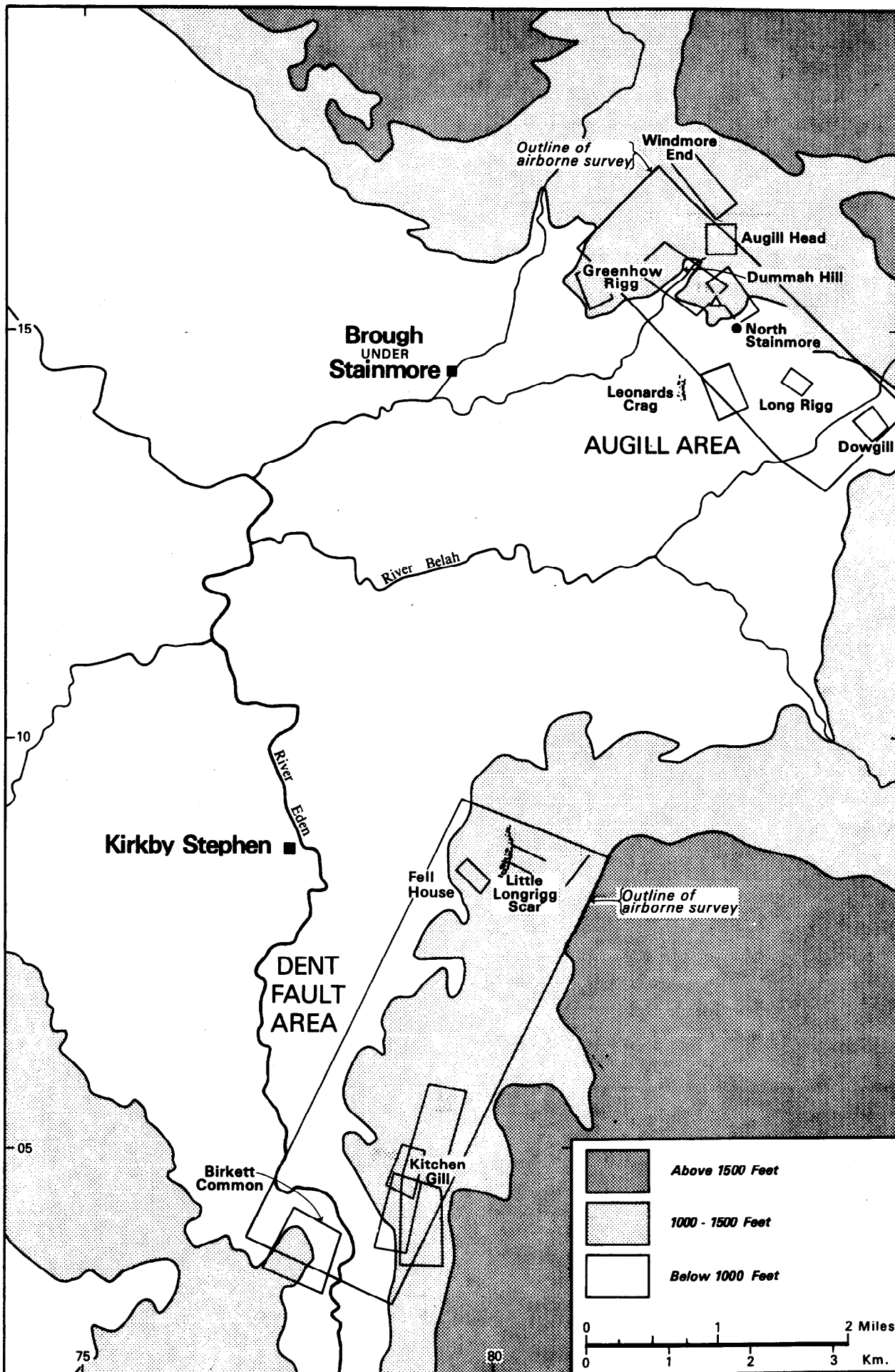Fig. 1. Locality map and topography of the Dent and Augill Faults area

Fig. 1. Locality map and topography of the Dent and Augill Faults area

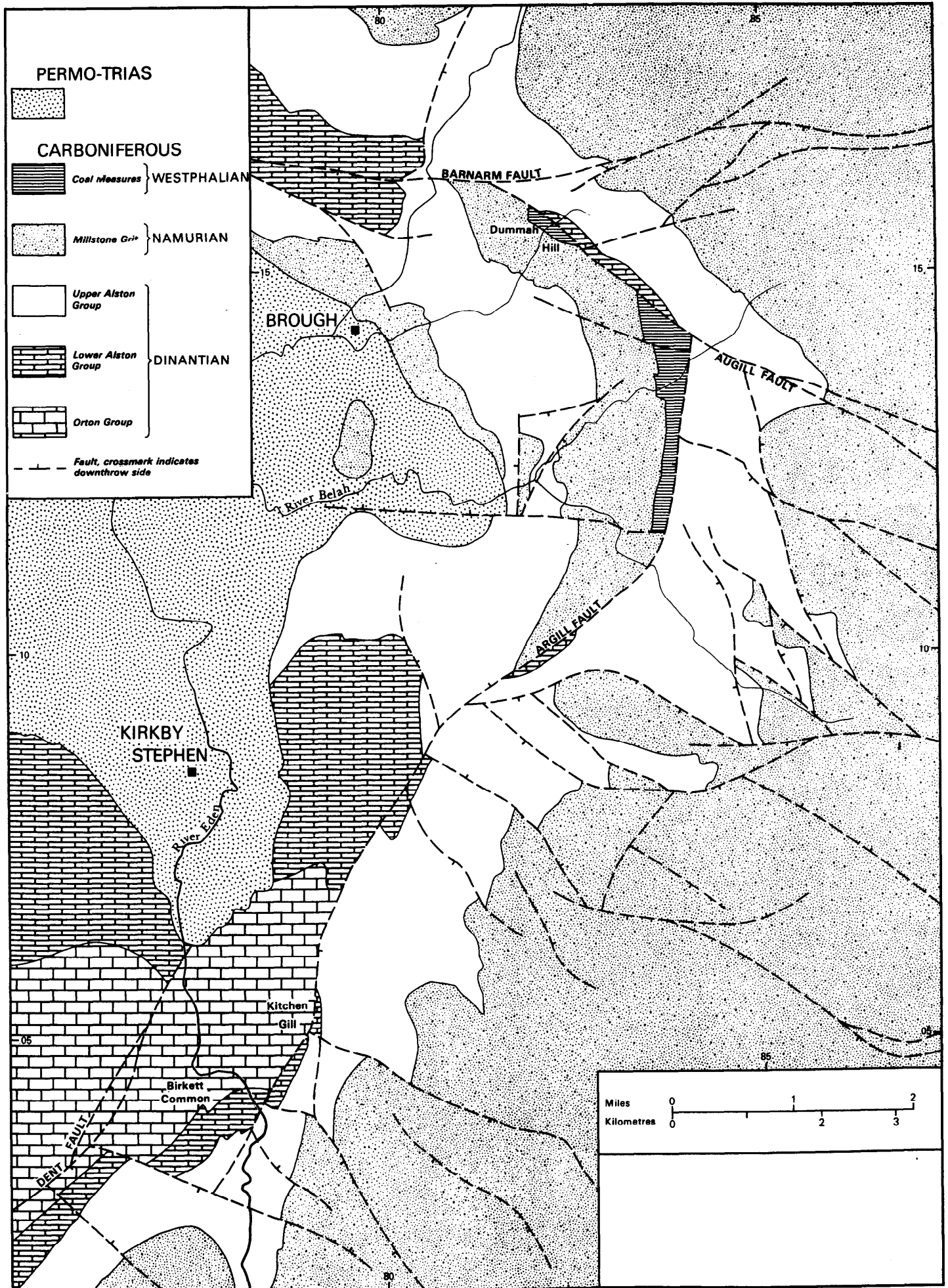Fig. 2a. Generalised geological map of the Dent and Augill Faults area.

Fig. 2b.   GENERALISED VERTICAL SECTION

MIDDLE COAL MEASURES

LOWER COAL MEASURES

CARBONIFEROUS

MILLSTONE GRIT

Peasah Wood Limestone

Upper Felltop Limestone

Upper Stonedale Limestone
Lower Stonedale Limestone
Crow Limestone (CrL)

CARBONIFEROUS

CARBONIFEROUS LIMESTONE SERIES

UPPER ALSTON GROUP

LOWER ALSTON GROUP

Little Limestone

Great Limestone (GL)

Iron Post Limestone
Four Fathom Limestone (4FL)

Three Yard Limestone (3YL)

Five Yard Limestone (5YL)

Scar Limestone (ScL)

Cockleshell Limestone

Single Post Limestone

Tynebottom Limestone

Jew Limestone (JL)

Lower Little Limestone (LltL)

Smiddy Limestone (SmL)

Robinson Limestone (RnL)

Great Scar Limestone (GScL)

Metres   Feet
0 — 0
          100
50   200
          300
100   400
150 — 500
          600
200   700
          800
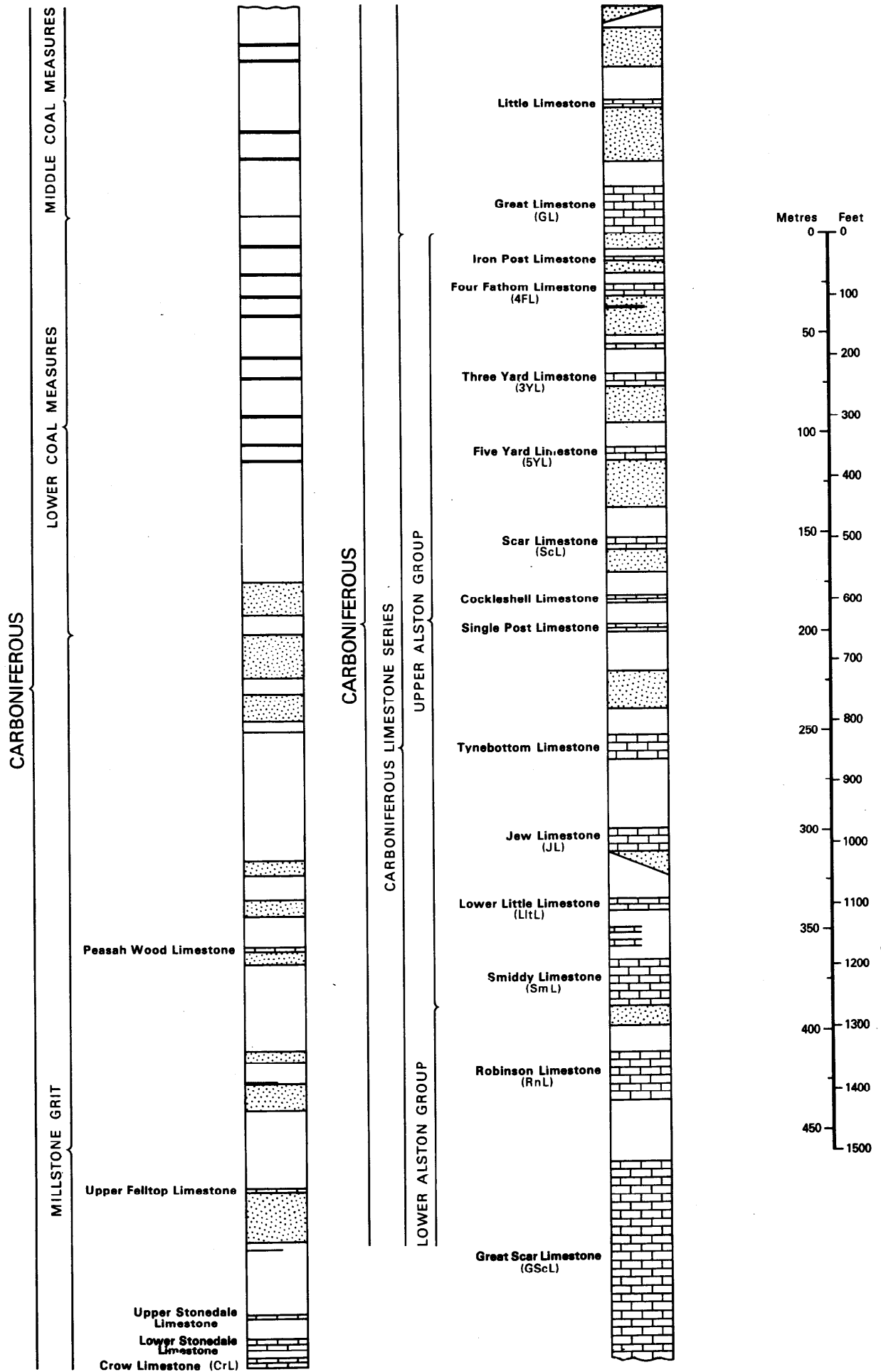250   900
300 — 1000
          1100
350   1200
400 — 1300
          1400
450   1500

Pale grey limestones predominate in the lower part of the sequence and darker limestones are more common higher in the group. Both types of limestone are biomicrites and are commonly pseudo-brecciated. On the Alston Block the group is about 300m thick, thickening to about 600m in the Stainmore Trough. On the Askrigg Block the group is generally about 400m thick, but it thickens to about 700m along the western margin.

The base of the Namurian is taken on palaeontological grounds at the base of the Great Limestone, although this is the last limestone in the succession with characteristics similar to those of the Alston Group. The other Namurian limestones are muddy, often siliceous and thinner. The Namurian sequence is cyclic with alternations of mudstones, siltstones and sandstones which vary laterally.

Coal Measures of Westphalian age are exposed in the Stainmore outlier where over 300m of strata dip steeply and are much faulted against the Augill and Argill faults (Owens and Burgess, 1965).

The main structure of the area consists of the Alston Block in the north and the Askrigg Block to the south, separated by the Stainmore Trough. The southern part of the Vale of Eden Syncline lies west of the faults bounding these blocks. Movements on the boundary faults were complex, with the initial movements taking place in end-Silurian times. During the Armorican earth movements, compressional forces produced an easterly-facing monocline along these fault-lines which was succeeded by westerly down-faulting under later tensional movements. Similar tensional forces during the Alpine earth movements also produced westerly down-throws of between 300 and 500m in the northern part of the area. These various stresses and associated movements produced steeply dipping or overturned strata, together with a belt of tight folds along the major faults (Burgess and Holliday, in press). Between Brough and the area north of Kirkby Stephen, where the Dent and Augill Faults meet, the local structural pattern is even more complex.

FORMER MINING

Veins were mined in the area as early as the beginning of the 19th century, if not earlier, but production was small compared with that of other mines in the Pennines and by the 1880s the local industry was in rapid decline. The mines produced mostly lead with a small amount of zinc. Several mines produced barytes but copper was rarely present and then only in very small quantities. Generally in the Pennines the principal ore-bearing horizons are the Great Limestone and the highest limestones of the Alston Group. In the present area, however, mining was confined to the Lower Alston Group, particularly the Great Scar and Robinson Limestones adjacent to the Argill and Augill Faults. Mineralisation generally took the form of both veins and flats associated with shearing on these faults and developed in the broken ground of the adjacent country rocks.

The Augill mine [823 155] produced galena and barytes from ankeritised Great Scar Limestone. This deposit is unusual for the area, being a low-grade disseminated orebody. Both surface and underground working were carried out but the extent of the mine and the tonnage extracted are unknown (Burgess and Holliday, in press). Cabbish Mine [841 160] produced galena and barytes, mainly from the Great Limestone, with minor amounts from adjacent sandstones and shales. The workings are fairly extensive and the deposit was not exhausted when the mine closed in 1920 (Wilson and others,1922). East of Kirby Stephen [797 075 and 802 080] and at Great Bell [787 046], galena, barytes and fluorspar were obtained, at times in appreciable quantities, from the Great Scar Limestone. At the workings east of Kirby Stephen, small shows of copper were found during the early mining operations.

MINERAL POTENTIAL

The geology of the Dent-Augill area suggests certain similarities to the geological setting of the Irish base-metal deposits. The Irish deposits occur in carbonate rocks, generally of Courceyan age, lying near the base of a thick Lower Carboniferous succession and commonly faulted against Lower Palaeozoic rocks. The origin of the Irish deposits is not fully understood, the ores having characteristics of both syngenetic mineralisation and epigenetic mineralisation from brines (Evans, 1976; Skevington, 1971). In both Ireland and the Pennines, mineralisation is associated with rigid blocks and sedimentary basins separated by major faults, which in some cases were growth-faults during Lower Carboniferous sedimentation. In the Dent-Augill area, there are two lines of this type bounding the eastward-trending Stainmore Trough - the Lunedale Fault and the Stockdale Monocline (Cornwell and Wadge, in preparation Fig. 2). Analogy with Ireland suggests that the lowest carbonates in the sequence are favourable horizons for mineralisation, but these beds are generally covered by younger rocks and are accessible only where brought to the surface by the Dent and Augill Faults. The potential for mineralisation seems greatest, therefore, where these faults intersect the margins of the Stainmore Trough.

The mainly limestone succession in the Lower Alston Group seems the most promising host-rock for sulphide mineralisation and the mudstones higher in the group provide potential cap rocks. Thus zones of mineralisation may be expected over a range of depths at times too great for location by surface mapping or geochemical sampling. In addition, it is possible that the known mineralisation along the Dent and Augill Faults was formed by upward leakage from deeper mineralisation. Much of the present work was aimed at locating near-surface occurrences so that these could be tested at greater depths for larger deposits.

REGIONAL GRAVITY SURVEYS

The Dent and Augill Faults area was included in routine regional gravity surveys carried out by the Applied Geophysics Unit and the general results were published on a 1:250,000 scale Bouguer anomaly map (Institute of Geological Sciences, 1977 - 1:250,000 Bouguer Gravity Anomaly Map. Lake District, Sheet 54° N - 04°W). The Bouguer anomaly map of the Alston Block was described by Bott and Masson Smith (1957), who included some of the few published interpretations of Bouguer anomalies associated with block margins. They pointed out that the decrease in Bouguer anomaly values across the Stublick Fault and the Ninety Fathom Dyke, forming the northern margin of the Alston Block, could be due to thickening of the Lower Carboniferous sediments into the Northumberland Trough. Similarly they described a decrease in Bouguer anomaly values across the Lunedale Fault, at the southern edge of the Alston Block, and ascribed this to thickening of the Lower Carboniferous rocks in the Stainmore Trough.

Since the station density of the original survey of the Dent-Augill Faults area was inadequate to define the anomalies associated with the main structural features, additional gravity observations were made. It was not possible to establish new stations in the large tracts of moorland lacking elevation control and, in the north-west, on the Warcop firing range, but 249 stations were occupied, giving an average cover of 1 station per km^{2}.

After standard corrections, the data were plotted as Bouguer anomalies (Fig. 3). A uniform density of 2.70 g cm^{-3} was assumed for the Bouguer correction, so that anomalies over rocks of markedly different density (e.g. Permo-Triassic at 2.40 g cm^{-3}) are distorted and may correlate with topography. Individual profiles were selected (Fig. 4) over anomalies of interest and reduced to an arbitrary datum level using densities appropriate to the underlying beds, whose thicknesses were estimated from the geological maps.

Fig. 3. Bouguer anomaly map with contours at 1 mGal (= 10 gravity units) intervals.
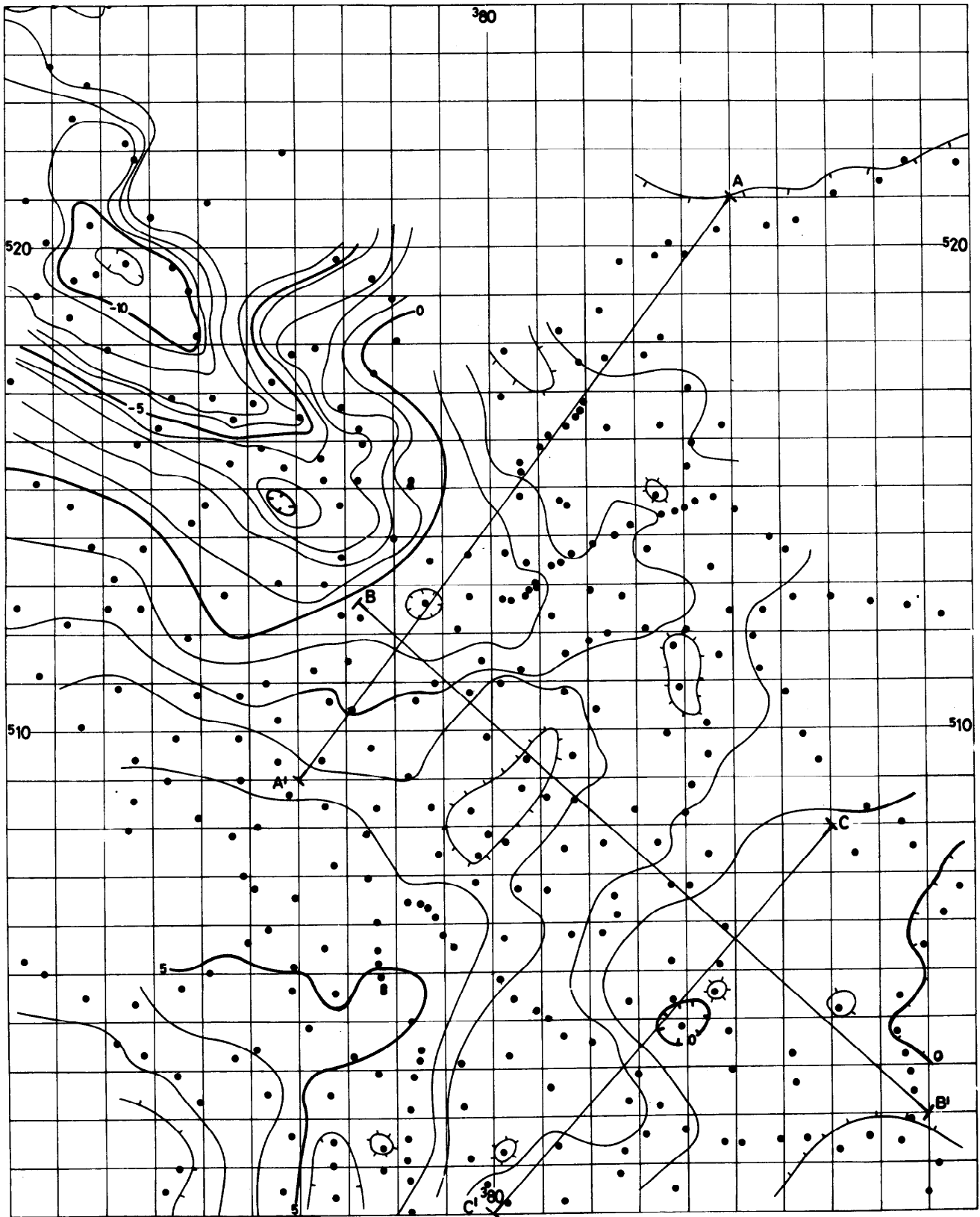
Contours at 1 mGal intervals

A———A' Profile

0 _____ 5 km

N

• Gravity Station

The most pronounced Bouguer anomaly in the area is the elongated low in the north-west part of Fig. 3 ⌈725 197⌉ produced by low-density Permo-Triassic rocks. The Bouguer anomaly values rise away from this low to culminate in a belt of maximum values extending from the south-west corner of the map towards a point near ⌊83 13⌋ where it changes direction by about 90° and strikes towards the north-west. Further east the values decrease north-eastwards towards the Alston Block and south-eastwards towards the Askrigg Block, both blocks being underlain by granite cores in the basement rocks. Bouguer anomaly highs over Carboniferous rocks can be due to either an increased amount of higher density horizons (i.e. limestones) in the underlying Lower Carboniferous sequence or a rise in the elevation of higher density pre-Carboniferous basement rocks. Lower Bouguer anomaly values would be expected over Carboniferous rocks where the sequence contains appreciable thicknesses of sandstones or shales, although the Bouguer correction can be adjusted for this if details of the succession above sea level are sufficiently well known.

In the south-western part of Fig. 3, the Bouguer anomaly values rise towards the exposed Silurian rocks (mainly slates and grits) of Ravenstonedale Common. The values decrease eastwards across the line of the Dent and Argill Faults and gradually drop as the thickness of the Carboniferous succession increases.

Fig. 4B is a profile through the northern extension of the broad high in the south-west corner of the area and shows the peak corresponding with the local high at ⌈803 083⌉ in Fig. 3. The effect of the lower density Namurian sediments has been included in the Bouguer correction for this profile and the fact that there is still an eastward decrease of values indicates more deep-seated density variations. The values also decrease towards the Permo-Trias basin to the north-west in Fig. 4B, but the absence of any pronounced local

Fig. 4. Bouguer anomaly profiles, topographical sections and geology along
three traverses shown on Fig. 3.

SURFACE GEOLOGY

T PERMO-TRIAS
N NAMURIAN
D DINANTIAN
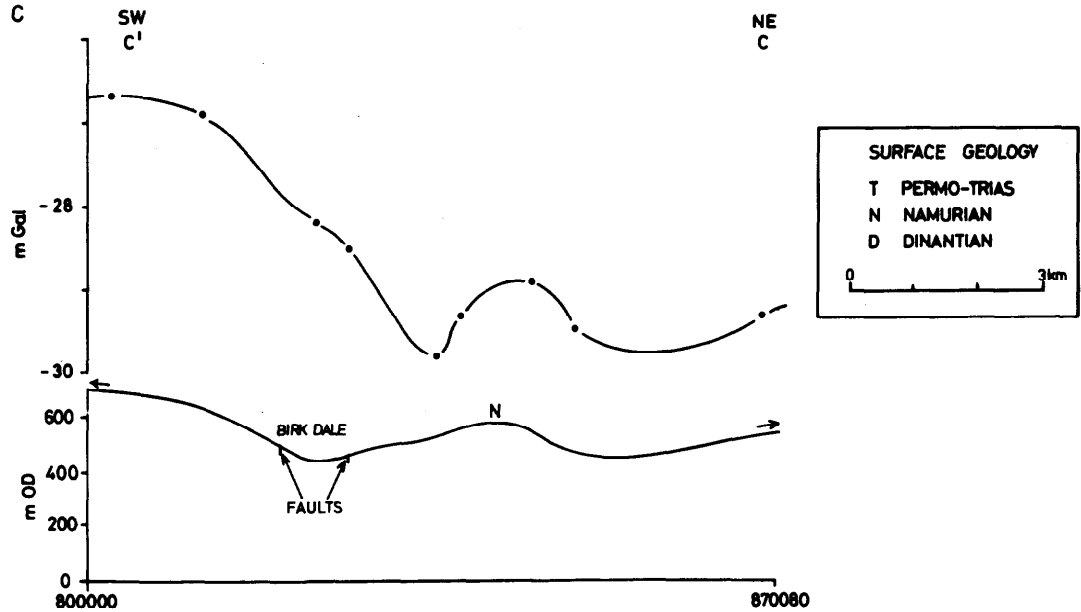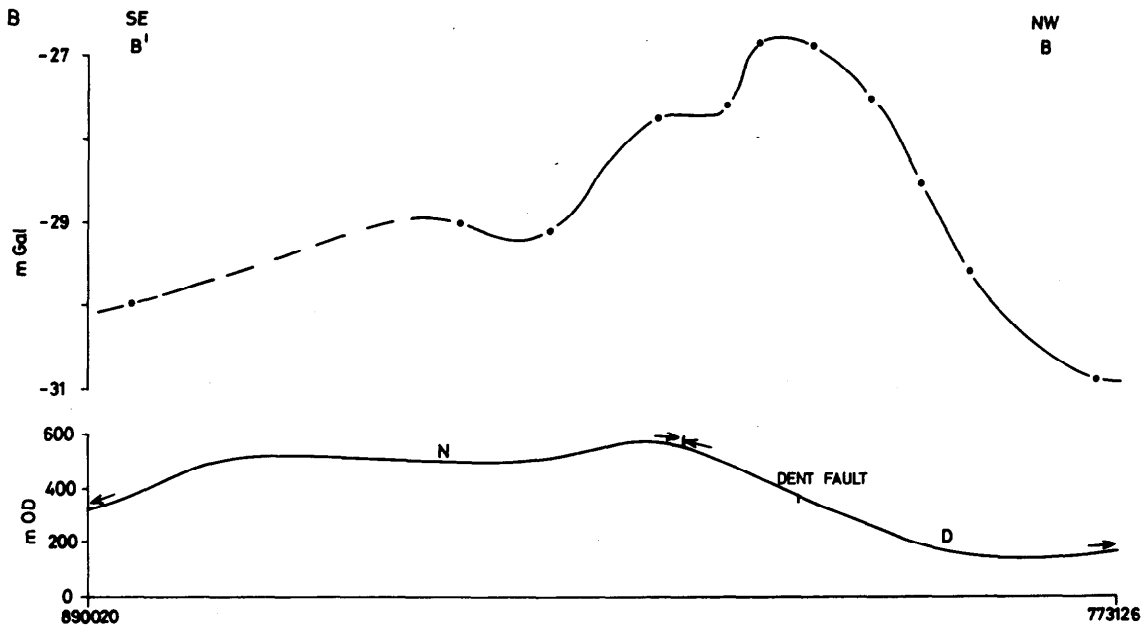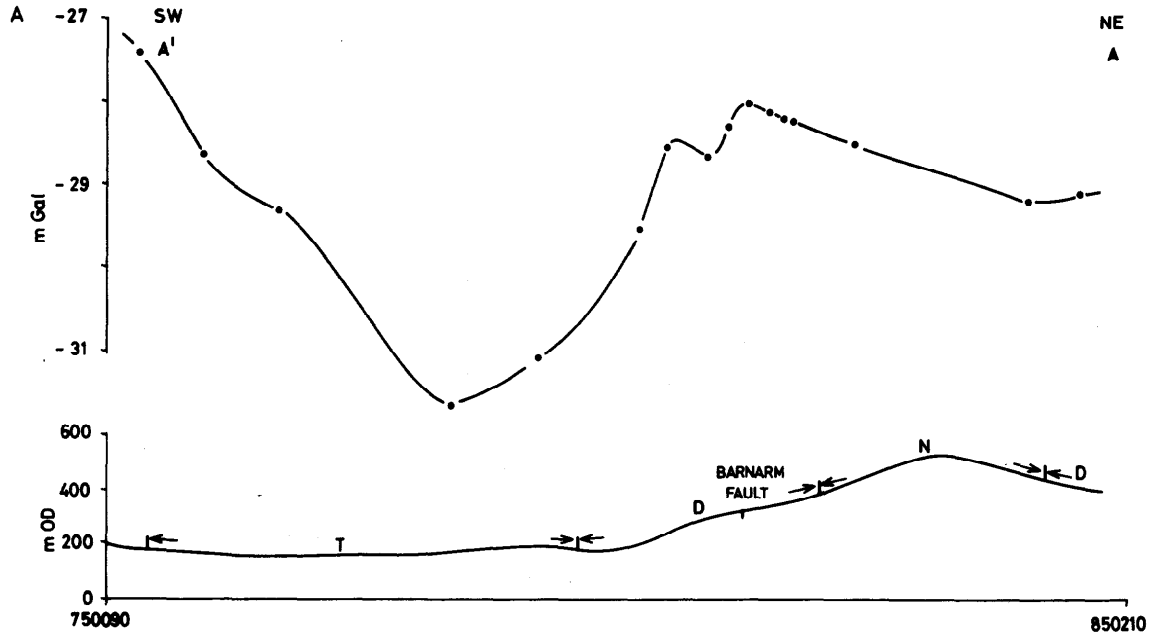
Bouguer anomaly west of Kirkby Stephen (Fig. 3) is due to the thin

Permo-Trias sequence in this area.

One feature which interrupts the general anomaly pattern in the

south-eastern part of the area is shown in profile form in Fig. 4C. A

3 mGal northward decrease in values occurs near the faults in Birk Dale

[830 024] but there is no obvious explanation for its existence in the

surface geology, since the observed throw of the faults here is only about

80 m. It is likely, therefore, that the Bouguer anomaly map is showing

the gravity effect of a change in basement lithology.

The Bouguer anomaly contours in the southern part of the map tend to

run parallel with the NNE-striking Dent Fault but north of National Grid

line 513N they swing round to the north-west, parallel with the Augill Fault.

Local highs at [840 110] and [834 150] lie on the upthrow sides of the

Argill and Augill Faults and are due perhaps to the local uplift of basement

rocks along these structures. The high shown in profile AA^1 (Fig. 4A)

straddles the Barnarm Fault which lies at an angle of about 45° to the profile.

The south-western part of this profile crosses Triassic rocks which are

largely responsible for the Bouguer anomaly low hereabouts. The high in

AA^1 (Fig. 4A) can be regarded as a 'residual' feature at the margin of this

broad low.

The Bouguer anomaly map of the area generally shows a pattern conforming

with the known major structures of the area or related deeper basement

features, although the effect of topographic variation must be considered

when interpretations are made. The significance of features such as that seen

in Fig. 4A cannot be assessed without further information. Although not of

more than general application to mineral exploration in the Dent-Augill area,

the Bouguer anomaly data obtained, particularly the presence of local highs

along the main faults, suggest that the method might be of use where block

margins are less well defined at the surface.

AIRBORNE GEOPHYSICAL SURVEYS

The two airborne surveys across parts of the Dent and Augill Faults are small in area (6 km^2 and 12 km^2 respectively) and cover ground occupied by scattered farm buildings, roads and power lines. The exact areas covered by the airborne survey were defined by the following full National Grid references:

Dent   379.6E 509.4N, 381.5E 508.6N, 378.8E 503.1N and 377.0E 504.0N.

Augill   384.0E 513.0N, 385.0E 514.0N, 382.0E 517.0N and 381.0E 516.0N

Electromagnetic (AEM), magnetic and radiometric data were recorded at nominal heights of 100 ft. (30m), 150 ft. (46m) and 200 ft. (61m), respectively, and the first two sets of data were compiled into maps at a scale of 1:10,560. Copies of these maps, together with the original flight records, are deposited with the Applied Geophysics Unit of IGS. Further details of instrumentation and procedure are given by Burley and others (1978).

Flight lines were aligned north-east to south-west in the Augill Fault area and east to west in the Dent Fault area, all at 100 m intervals. Locations of the survey areas are shown in Fig. 1, together with the locations of the ground follow-up surveys.

The AEM maps of both the Dent and the Augill Fault areas fail to show any overall recognisable contour pattern, the in-phase variation typically being about 50 ppm. One of the few places where a pattern extends over more than two flight lines is in the western corner of the Augill area, where a broad zone of in-phase anomalies of 25-50 ppm continues for about 1 km. Although this zone can be reasonably explained by thick Namurian shales on the downthrow side of the Augill Fault, it is not clear why the zone does not continue further to the south-east. Stronger linear anomalies do occur (250 ppm) and are particularly noticeable in the Augill Fault area, but these are due to overhead power lines. The anomalies for ground follow-up were largely selected by examining individual flight-line records and priority was given to large in-phase to out-of-phase ratio anomalies on more than one flight line. Several of the

in-phase anomalies subsequently turned out to be due to buried metal water pipes.

Variations in background levels of 100 to 200 cps can be detected in the total count radiometric profiles for both areas but tend to be more pronounced in the Dent Fault area. Most of the higher values occur along the line of the Dent Fault and probably originate in shale horizons immediately above the Great Scar Limestone, the fault being parallel to the strike of the sediments in this area. A few patchy radiometric anomalies occur over the main outcrop of the Great Scar Limestone west of the Dent and Argill Faults but to the east the radiometric values are particularly low where Namurian sandstones are covered by thick drift. There are a few anomalies over the Augill Fault but the highest readings mark the outcrop of the shales above the Four Fathom Limestone (Fig. 5).

DETAILED GEOLOGICAL AND GROUND GEOPHYSICAL SURVEYS

The AEM flight records and 1:10,560 scale maps were examined and anomalies selected for ground follow-up surveys on the basis of amplitude, particularly of the in-phase component, and location. Anomalies due to man-made sources (power-lines, buildings and pipes) were ignored as far as possible although the recognition of buried conductors, such as pipes, is often difficult. The areas covered by ground surveys are shown in Fig. 1 and listed in Table 1. The main follow-up method used was Turam, with a straight cable grounded at the ends and 15 or 30 m staff separation although Very Low Frequency (VLF) and Slingram EM methods were used in places. The stratigraphical horizons referred to in the following descriptions of individual surveys are shown in Figs. 2b,5 and 6.
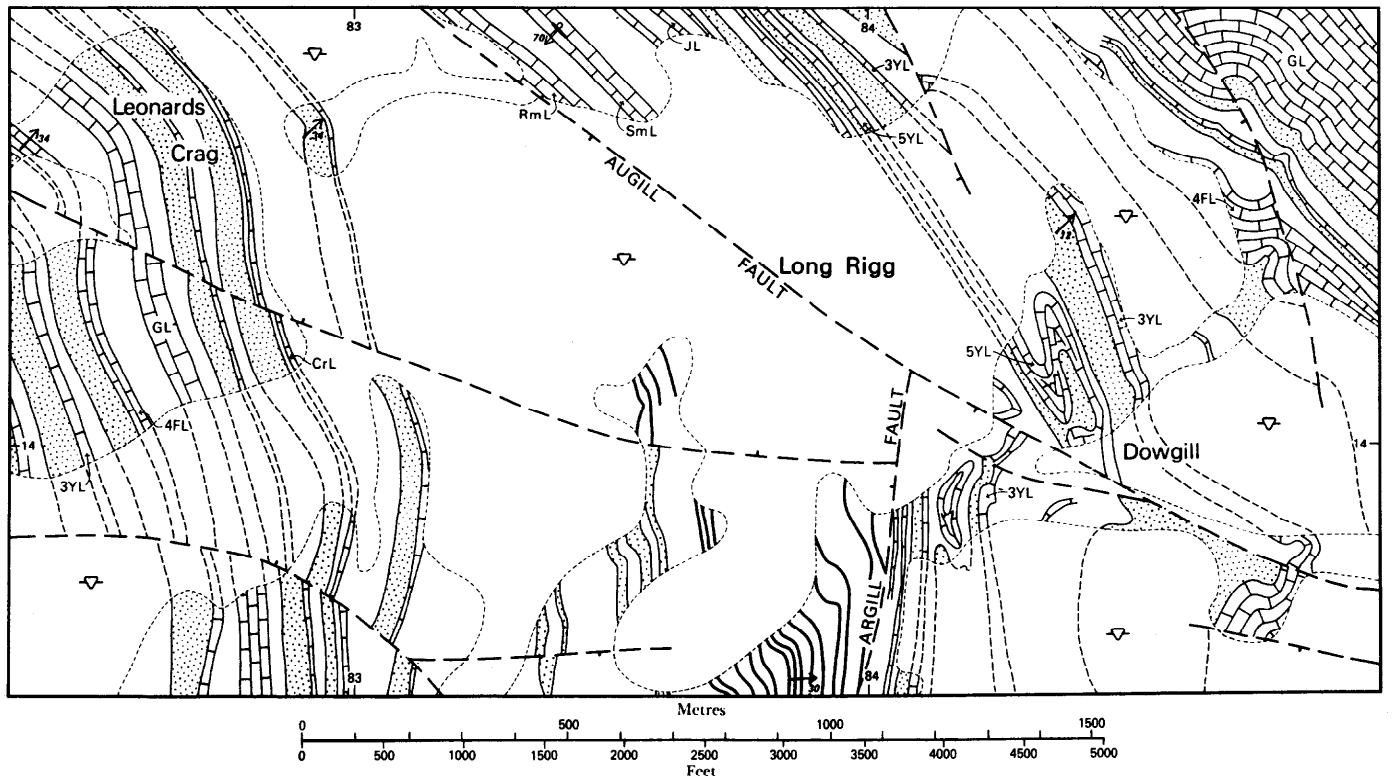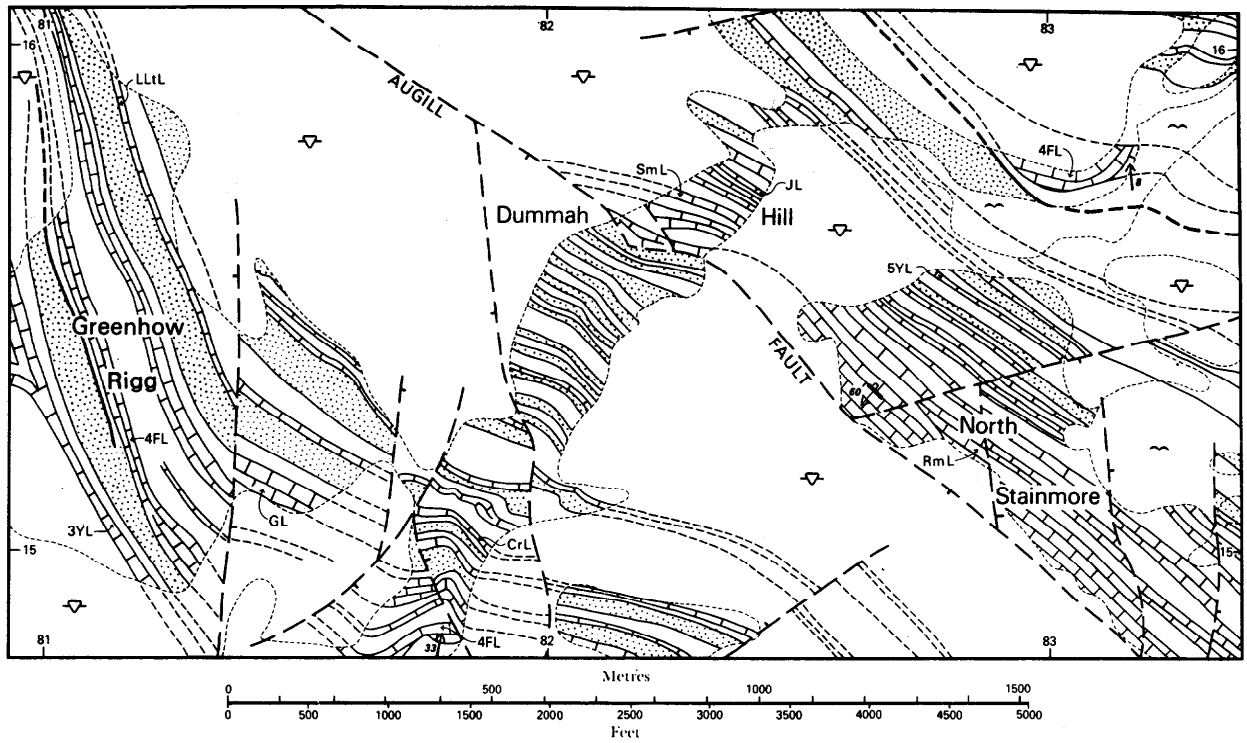
Windmore End

The area is underlain by alternating limestones, mudstones and sandstones of the Upper Alston Group and lower Namurian sequences. AEM anomalies occur at

	AREA		GEOPHYSICAL DATA		ORIGIN OF ANOMALIES
Name	OS map		Method	Line km	
AUGILL FAULT					
Windmore End	81 NW		Turam	2.4	Pipe + stratigraphic conductor
Augill Head	81 NW		"	1.7	Pipe
Dummah Hill	81 NW		" + VLF	3.2 + 0.8	Mudstone
North Stainmore	81 NW		"	1.9	Pipes
Greenhow Rigg	81 SW		"	1.8	Mudstone
Leonards Crag	81 SW		"	2.2	Shale + pipe
Long Rigg	81 SW		VLF	1.0	Boulder Clay
Dowgill	81 SW		VLF	1.0	Boulder Clay
DENT FAULT					
Little Longrigg Scar	80 NW		VLF	1.0	Shale
Fell House	70 NE		VLF	0.5	Pipe
Birkett Common	70 SE		VLF + Slingram	3.0 + 1.5	Fault + shale
Kitchen Gill	70 NE, SE		Turam + Slingram	15.2 + 0.5	Faults, possibly mineralised
			+ VLF	+ 1.5	+ shales

Table 1.   Detailed geophysical survey areas.

Fig. 5. Detailed geology of part of the Augill Fault.

Metres

Feet

Metres

Feet

INDEX AND EXPLANATION

Limestone	Alluvium	Inclined strata, dip in degrees
Mudstone	Boulder Clay	Overturned strata, dip in degrees
Sandstone		

---------- Geological boundary, Drift

------ Geological boundary, Solid.

--⊥-- Fault at surface, crossmark indicates downthrow side

--- Coal - crop

Broken lines denote uncertainty.

the extreme ends of the flight lines and a Turam ground follow-up survey located one strong anomaly, caused by a buried pipe, and several weak anomalies at the south end of the area. The latter anomalies follow the base of the Great Limestone and their configuration suggests that they are not caused by mineralisation.

Augill Head

The area lies immediately to the south of Windmore End and the Turam results are dominated by very strong anomalies, again due to a buried metal pipe.

Dummah Hill

The area is cut by the deep gorge of Augill Beck, which exposes a succession of the lower part of the Lower Alston Group thrown against Lower Coal Measures by the Augill Fault. Near-vertical limestones close to the fault have been worked for lead in the past.

Scattered AEM anomalies of up to 70 ppm of the normal field were investigated on the ground with the Turam and VLF methods. A series of weak Turam anomalies (reduced ratio (RR) 1.14, phase difference (PD) -9.5°) coincides with mudstones containing the Swinstone Bottom Marine Band. The Augill Fault is possibly reflected by weak anomalies (RR 1.17, PD -4.0°) on two lines. The VLF method also responded to conductive stratigraphic horizons.

North Stainmore

Results of a Turam survey to the immediate south of Dummah Hill were dominated by large, sharp anomalies caused by buried metal pipes.

Greenhow Rigg

In this area the sediments occur at a similar stratigraphic position to those at Windmore End and dip steeply to the east-north-east. AEM anomalies occurred at the ends of the flight records, and ground surveys indicated two weak, but apparently continuous, conductors following the geological strike.

Fig. 6. Detailed geology of part of the Dent Fault.

Metres

Feet

INDEX AND EXPLANATION

| ~ Alluvium | ▽ Boulder Clay | 22 Inclined strata, dip in degrees | ✗ Fault at surface, crossmark indicates downthrow side | Hushes |
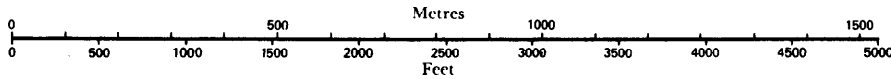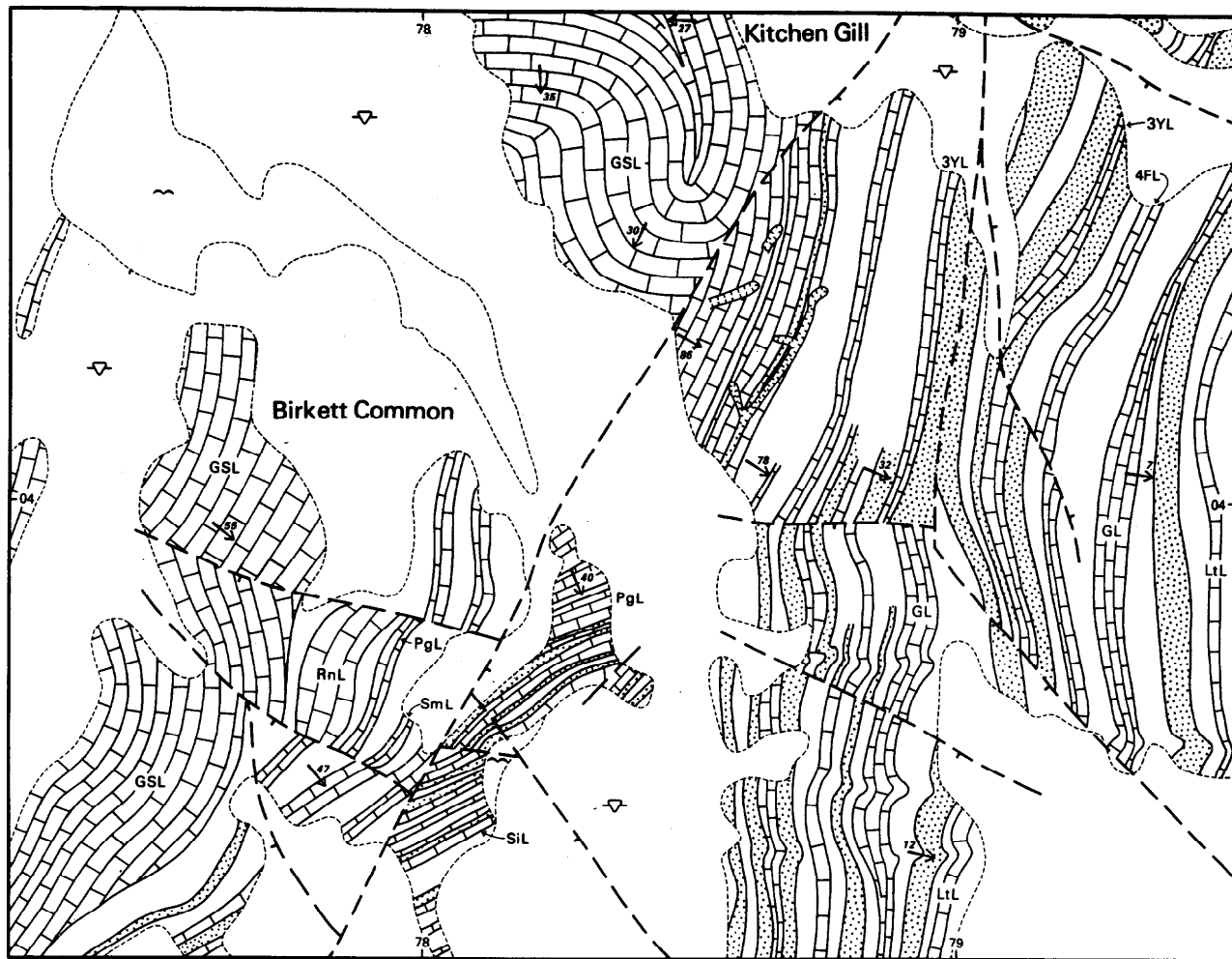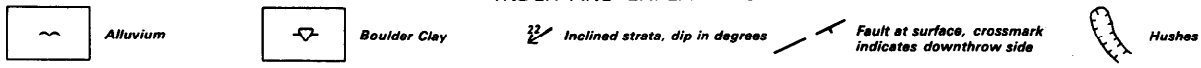
GENERALIZED VERTICAL SECTION

Feet Metres

CARBONIFEROUS

MILLSTONE GRIT SERIES

CARBONIFEROUS LIMESTONE SERIES

UPPER ALSTON GROUP

Little Limestone (LtL)

Great Limestone (GL)

Four Fathom Limestone (4FL)

Three Yard Limestone (3YL)

CARBONIFEROUS

CARBONIFEROUS LIMESTONE SERIES

UPPER ALSTON GROUP

LOWER ALSTON GROUP

Simonstone Limestone (SiL)

Smiddy Limestone (SmL)

Peghorn Limestone (PgL)

Robinson Limestone (RnL)

Great Scar Limestone (GSL)

One coincides with a mudstone underlying the Great Limestone and the other marks the outcrop of a mudstone above the Lower Little Limestone.

Leonards Crag

Anomalies due to a buried pipe are clearly indicated over a distance of 200 m at the northern end of the area and are distinguishable from weaker anomalies to the east. These weak anomalies coincide with lower Namurian shales.

Long Rigg

An isolated AEM anomaly marks the position of the Augill Fault beneath a large drumlin. The anomaly was investigated with the VLF method. Broad VLF anomalies coincide with the maximum AEM anomaly and are typical of thick conductive overburden.

Dowgill

The area is underlain by rocks of the Upper Alston Group. The Augill Fault has a down-throw of 40 to 60 m to the south-west and its trace coincides with several small (25 ppm) AEM anomalies. VLF investigations of these anomalies were restricted by crops and topography; however, only one weak anomaly was located over thickening drift on the east side of the fault.

Little Longrigg Scar

The Argill Fault crosses the area and causes local steepening of beds belonging to the Lower Alston Group. AEM anomalies of up to 75 ppm were investigated on the ground with the VLF method which revealed strong anomalies coincident with shales lying between the Robinson and Smiddy Limestone.

Fell House

A reconnaissance VLF traverse over an isolated AEM anomaly identified a buried metal pipe.

Birkett Common

Nearly the full thickness of the Great Scar Limestone is well exposed on Birkett Common. Thickly bedded limestones are interbedded with thin mudstones
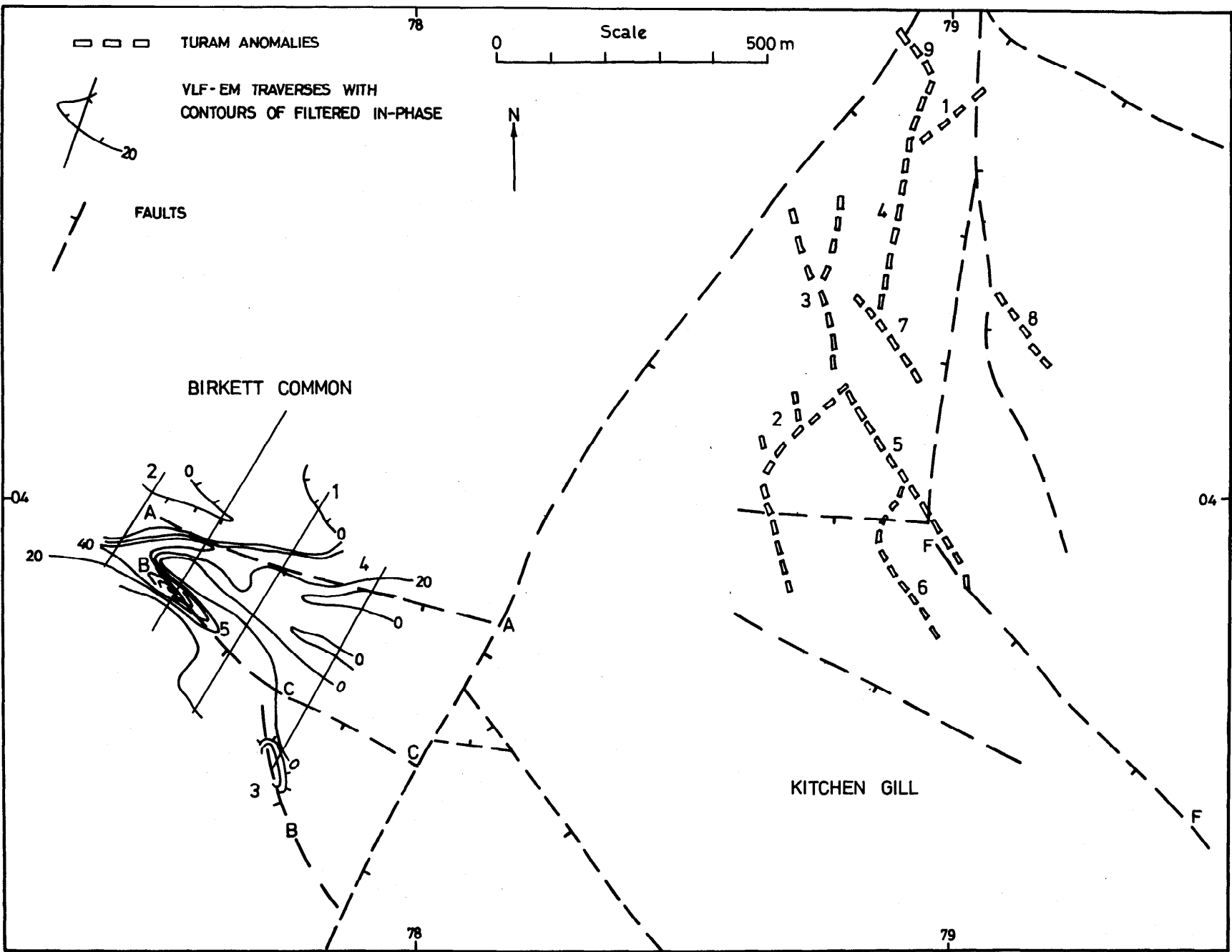
Fig. 7. Results of detailed geophysical surveys south of Kirkby Stephen and near the main faults.

TURAM ANOMALIES

VLF-EM TRAVERSES WITH
CONTOURS OF FILTERED IN-PHASE

FAULTS

BIRKETT COMMON

KITCHEN GILL

and minor sandstones. In places they are marked by closely-spaced jointing and evidence of movement along bedding planes commonly associated with secondary calcite veins. The rocks between the Great Scar Limestone and the Lower Little Limestone also crop out. Much of the lower ground is covered by boulder clay, but it is not very thick and the rocks are exposed in the adjacent river bed. The beds dip steadily to the south-east or east at 30° to 60°. The area is traversed by a number of faults, trending north-west to south-east.

A scatter of small AEM anomalies (25 ppm) occurring over Birkett Common was investigated on the ground with VLF and Slingram methods. The VLF results are ambiguous; anomalies coincide with two faults (A-A and B-B on Fig. 7), but maximum filtered values also occur at drift/limestone interfaces e.g. anomalies 1, 2, 3 and 4, Fig. 7. Fault C-C, which is a continuation of the western part of B-B, is not indicated by VLF. The strongest VLF anomaly (5 on Fig. 7) coincides with the westernmost mapped part of B-B. However the in-phase and out-of-phase profiles have the same sign, a feature which has been shown elsewhere in the Pennines to characterise the edges of some shale outcrops. Slingram anomalies found to be coincident with the VLF anomalies were very weak (in-phase <10%, out-of-phase zero to -5%). It is considered that the EM anomalies are caused by either stratigraphical conductors or fault crush material; no metallic conductors are indicated and no economic significance is attached to these anomalies.

Kitchen Gill

The area is composed of rocks lying between the Great Scar Limestone and the Little Limestone (Fig. 6). The lowest beds here are the upper parts of the Great Scar Limestone, consisting of grey, fine to medium-grained, thickly bedded carbonates, about 100 m thick. Thin shales above the Great Scar Limestone are overlain by 50 m of grey, fine to medium-grained limestones, marked by thin bands and lenses of chert and minor recrystallisation close to the Argill Fault. The overlying beds are less well-exposed up the hillside to

the east. Close to the Argill Fault, dips are near-vertical, but they decrease rapidly eastwards to the low inclinations typical of the Askrigg block. There is little superficial cover. There are minor old workings on lead veins [785 044].

Small AEM anomalies were investigated on the ground with the Turam method using a straight 1.6-km cable. The northern part of the area was undisturbed but a significant anomaly (RR 1.22, PD -14°) to the south-west was investigated further with a second cable layout. Anomalies discovered in this area were weaker but linear trends were established and confirmed by two subsequent surveys. Fig. 7 shows a plot of major anomalies established by the ground survey, together with mapped faults. Two main anomaly trends are indicated, a weaker north to south direction parallel with the geological strike (1, 2, 3, and 4, Fig. 7) and a south-easterly direction (5, 6, 7, 8, and 9) parallel with one of the fault trends. The former anomalies are considered to be caused by weakly conductive lithologies such as mudstones, notably those below the Three Yard Limestone. No surface indications of mineralisation were found within the anomalous horizons.

The strongest anomaly located in the survey (number 5 in Fig. 7) has a maximum reduced ratio of 1.60 and phase difference of -13.5° at 660 Hz. The profile of the anomaly was compared with model curves presented by Bosschart (1966), the closest fit being the curve for a steep, thin conductor dipping slightly to the east. The resistivity/thickness ratios, estimated from the complex components of the secondary field, are of the order of 10, indicating a moderately good conductor. The depth to the top of the conductor appears to be 30 to 40 m. Anomaly 5 marks a possible north-west continuation of fault F-F on Fig. 7 but has possibly been accentuated by the grounding position of the cable near the fault. The south-east continuation of the anomaly is much weaker and is not quite coincident at surface with the mapped position of the

fault, but the interpreted dip and depth of the anomalous body indicate that the fault is conductive at depth. Anomalies 6, 7, 8 and 9 are weaker (maximum RR 1.30, PD -11°) and may mark the position of unmapped fractures. It is evident from Fig. 7 that not all mapped fractures produce a Turam response and if some of the anomalies are caused by metallic minerals, the distribution of the mineralisation is sporadic and of no great lateral extent.

Slingram traverses across anomaly 5 produced only very weak anomalies of the order 7% (in-phase), 10% (out-of-phase) and it is obvious that the ground penetration of this method is less than that with Turam. A VLF survey revealed strong shale-type anomalies (in-phase 60%, out-of-phase 9%) over Turam anomalies 3 and 4 and only a weak anomaly over Turam anomaly 5.

The results of ground surveys at Kitchen Gill are therefore not considered to indicate extensive mineralisation either near the surface or at depth. Much of the EM response is due to conductive shale horizons, the remainder of the anomalies being attributed to fractures, beneath drift, which may carry some metallic mineralisation.

CONCLUSIONS

Airborne geophysical surveys were carried out over parts of the Dent and Augill Faults and magnetic, EM and radiometric data recorded along 211 km of traverses. The EM data were affected in many places by power lines but twelve anomalies were selected for more detailed investigations by geological and geophysical observations on the ground. Five of these anomalies proved to be due to buried pipes but ground surveys over another three showed that the shale members of the cyclic Carboniferous sedimentary sequence are commonly conductive, although of no economic mineralisation significance. Conductive overburden was responsible for two anomalies and at another two sites the anomalies appear to be due to faults.

The most promising area for investigation on the ground appeared to be around the old mine workings at Kitchen Gill where Turam surveys identified anomalies due to shale horizons and previously unmapped faults. The faults could contain mineralisation in veins but as these are likely to be of limited extent no further work was justified.

Geochemical prospecting could not be justified because of contamination from the old workings.

The airborne magnetic surveys detected no anomalies and the radiometric data showed small variations related only to lithological changes in the bedrock.

A trial regional gravity survey showed small Bouguer anomalies to be associated with the Dent and Augill Faults. A more detailed investigation, including drilling, would be needed, however, for the results to be fully assessed or used to guide exploration at deeper structural levels.

No further work is envisaged in the area in this programme, although exploration for possible mineral deposits at depth in this apparently favourable geological environment would be worthwhile in the future with the further developments of detection and interpretation techniques.

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