British Geological Survey

REGIONAL GEOPHYSICS RESEARCH GROUP

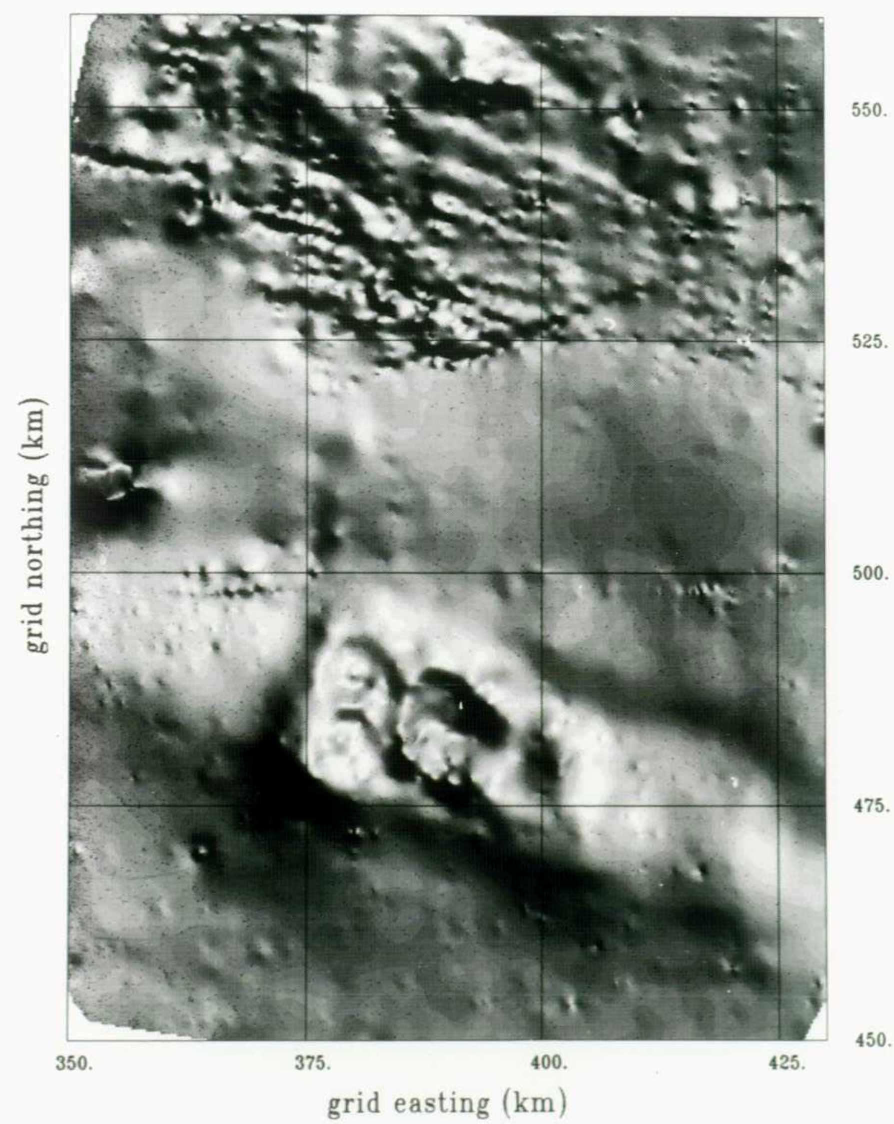
Technical Report WK/89/5

Regional Geophysics Series

The Digital Aeromagnetic Survey of the United Kingdom

I F Smith and C P Royles

BGS Aeromagnetic data for Pennines 0.25km grid



Natural
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TECHNICAL REPORT WK/89/5

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Cover photo
A pseudo-relief image of the aeromagnetic data for part of the Pennines, produced using COLMAP (C A Green)

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BRITISH GEOLOGICAL SURVEY

The full range of Survey publications is available through the Sales Desks at Keyworth and Murchison House, Edinburgh. Selected items can be bought at the BGS London Information Office, and orders are accepted here for all publications. The adjacent Geological Museum 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.

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1.1 The Aeromagnetic Survey of United Kingdom

Between 1955 and 1965 an airborne magnetic survey was conducted covering the land and parts of the sea areas of the United Kingdom. Different sections of the survey were conducted in different years by Hunting Geology and Geophysics Ltd. (variously Hunting Surveys Ltd. or Hunting Geophysics Ltd.) and Canadian Aeroservices Inc. as shown in Fig. 1. The survey was funded by the Department of Scientific and Industrial Research and, in Northern Ireland, by the Department of Commerce. For the first year of survey funds were also provided by the Nuffield Foundation.

The survey was overseen by the Geophysics Department of the (then) Geological Survey and Museum (subsequently Institute of Geological Sciences, subsequently British Geological Survey), in collaboration with the United Kingdom Atomic Energy Authority, Harwell, when local radiometric surveys were incorporated.

The data have been published at the following scales:

1. 1:1 584 000 Smoothed Aeromagnetic Map of Great Britain (Hall and Dagley, 1970);

2. 1:625 000 (10 mile to the inch) as two map sheets (Sheet 2, BGS 1965; Sheet 1, BGS 1967) to overlay the similar scale geological map;

3. a series of 1:250 000 scale Universal Transverse Mercator maps which cover the land and continental shelf areas (BGS 1:250 000 Aeromagnetic anomaly maps, Provisional Edition). These replace the 1:253 440 (4 miles to the inch) series which covered the land area with 16 maps based on the Ordnance Survey (OS) National Grid editions, although the Aeromagnetic Map of Northern Ireland is still available at that scale.

1.2 Technical specifications of survey

A series of contractors' reports provide specific details for each of the annual surveys and the main parameters for each survey are listed in Table 1. The following description provides an outline, although each survey may differ in detail.

The bulk of the survey was flown on a network of flight lines spaced at 2km, with tie lines usually at 10km. The orientation of the flight lines varied between annual surveys, either north-south or east-west, depending on the predominant geological strike, so as to optimise the resolution of the data. The flight lines were required not to deviate from the planned line by more than 1/4 mile (c. 400m) over land and 3/8 mile (c. 600m) over sea, for a distance of more than 5 miles (c. 8 km). Most of the country was covered at

Annual survey areas

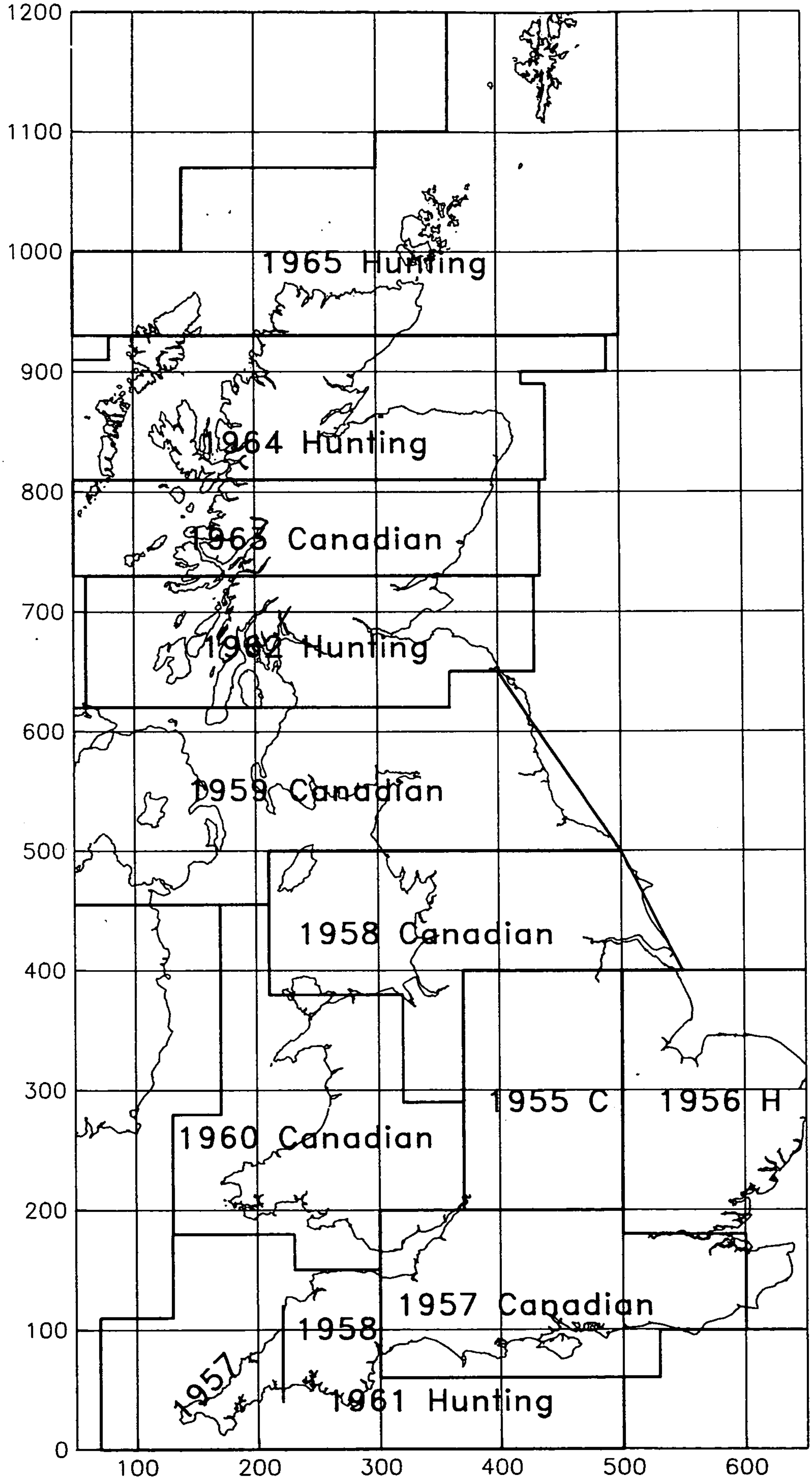

Figure 1 - Map showing annual survey areas with survey contractor

TABLE 1 - AEROMAGNETIC SURVEY OF GREAT BRITAIN : SURVEY PARAMETERS

SURVEY MODULE (1)	AREA OF SURVEY	REPORT (2)	FLYING HEIGHT (3)	FLIGHT LINE SPACING	TIE LINE SPACING	KM FLOWN
CS 1955	East Midlands	*	1000 ft MTC (N) 1800 ft Bar (S)	1 mile E/W	6 mile N/S	22,749
HG 1956	East Anglia & Kent	*	1500 ft Bar	2 km N/S	10 km E/W	22,944
CS 1957 A	Southern England		1800 ft Bar	2 km N/S	10 km E/W	24,223
HG 1957 B	Cornwall	*	500 ft MTC	400m N/S	Tie points & 3 tielines	7,432
CS 1958 A	Isle of Man to Humber		1000 ft MTC	2 km E/W	10 km N/S	23,408
HG 1958 B	Devon	*	500 ft MTC	400m N/S	Tie points & 3 tielines	20,663
CS 1959	Northern Ireland, Northern England & Southern Uplands		1000 ft MTC	2 km N/S	10 km E/W	39,810
CS 1962	Wales		1000 ft MTC	2 km N/S	10 km E/W	26,098
HG 1961	S W Approaches & South Coast	*	1000 ft MTC	2 km N/S	10 km E/W	24,654
HG 1962	Midland Valley of Scotland	*	1000 ft MTC	2 km E/W	10 km N/S	21,767
CS 1963	Sea of Hebrides & Grampians	*	1000 ft MTC	2 km E/W	10 km N/S	18,697
HG 1964	Hebrides to Moray Firth	*	1000 ft MTC	2 km E/W	10 km N/S	30,289
HG 1965	Lewis to Shetlands	*	1000 ft MTC	2 km E/W	10 km N/S	32,180

(1) Contractor abbreviation: CS: Canadian Aeroservices Inc., HG: Hunting Geophysics Ltd.
(2) * indicates that contractor's report is available
(3) MTC is Mean Terrain Clearance based on radio altimeter, bar indicates that barometric altimetry was used

a flight height of 1000 feet (305 m). Flight height tolerance was to be within 100 feet (c. 30m) of the specified height in most surveys, although 'drape' flying was permitted where the relief was severe, so that the flight height approximated a mean terrain clearance.

Total magnetic field fluxgate instruments were used, either as a 'stinger' in the aircraft tail, or as a 'bird' towed behind. The output was recorded as a trace onto continous chart paper, with step changes to accommodate values which were offscale. Positional information was derived from a navigation camera mounted vertically in the aircraft, which marked the paper record at every exposure. Over the sea, the Decca navigation system was used. Heights were determined using radio altimetry, except in early surveys, when aneroid instruments were used. Instrumental values were recorded photographically.

Continuously recording base-station fluxgate magnetometers were used to monitor magnetic storms, and sorties were reflown if there was significant magnetic interference.

1.3 Data reduction

The flight path over land was determined between fixed points identified at approximately 1 mile (c. 1580m) intervals on the OS maps, by reference to the navigation camera film. Intersections between flight and tie lines were also identified. Over the sea Decca fixes were determined on either side of flight line/tie line intersection and midway along flight lines between tie lines. These fiducial points were marked on worksheets (based on OS maps at the scale of 1:63 360, or 1:25 000 in parts of south-west England) and on the magnetometer records.

Closed loops between flight-lines and tie-lines with various dimensions were defined to identify closure errors and remove diurnal variation. The size of the loop was normally 10km square, in other words every 5th flight line and every tie line were used. Closure errors were minimised using a graphical least squares technique. Errors in the loops could be estimated from those flight lines which were not included in the analysis, and were generally less than 10 nT.

A standard linear regional field for the survey area was established at the begining of the project and is defined by:

$$[47033 + (2.1728 \times N) - (0.259 \times E)] \text{ nT}$$

This field was calculated for all the fiducial points, where N and E are the British National Grid kilometre northing and easting co-ordinates respectively for the point. The datum for each annual surveys was adjusted to previous adjacent surveys empirically, by overflying part of the previous area and determining the shift, which was then added to the regional field. From these data a linear regional field was drawn on each section of flight record between the fiducial points. To ensure all values were positive in an effort to reduce the possibility of errors, an arbitrary datum shift of 870nT was added. In some areas 2870nT was required to ensure this effect.

In the case of the 1955 survey an additional higher order regional field was applied, which is referred to as the Carnegie (or Smithsonian Institute) regional field.

Using a calibrated rule, 10 nT intercepts above the regional field and turning points were marked on the record. In areas of low magnetic relief 5nT intercepts were extracted, and in areas of high relief greater intercepts, which allowed the gradients to be satisfactorily represented, were chosen. These values were transferred to maps, assuming linearity between fiducial points. They were shown as ticks on one side of the trace of the flight line. Ticks on the other side of the trace were used to indicate turning points and intercepts at intervals of 50 or 100nT. The values associated with each point were marked as frequently as space allowed.

The data were contoured at 10nT intervals, with the prime contour being 870nT (or 2870nT locally) to return to the standard regional datum for UK. The results were fair drawn by the contractor, forming the primary results of the survey. In some cases both the data values and contours were plotted on one map sheet; in others they are on separate sheets.

1.4 Data archive

The following archive material is held by Regional Geophysics Research Group in Keyworth:

Field records:

1. Airborne magnetometer flight records
2. Base-station magnetic storm monitor records
3. Altimeter recordings
4. Radio navigation data
5. 35mm navigation film

Compilation data:

1. Plots of fiducial points on 1:63 360 scale OS maps
2. Contractors' reports and Certificate of Performance for each survey
3. Fair drawn worksheets on plastic film, showing intercept values and/or contour lines. The 1955 survey was drawn on paper.

The compilation of the Canadian Aerosurveys and the 1958 Hunting surveys were redrawn to a higher standard of cartography by OS.

2. DIGITISATION OF THE AEROMAGNETIC SURVEY OF UNITED KINGDOM

2.1. Introduction

Projects involving geophysical interpretation clearly benefit by the data being held in a digital form so that it may be manipulated, processed and plotted in a variety of ways. This is particularily true with regional potential field surveys such as aeromagnetic and gravity surveys, where the data may only be readily accessible in map form. Once the data are in digital form then the new range of interpretational power become available.

Some commissioned research projects needed digital aeromagnetic data for regional appraisals and also had staff-time which could be allocated to carrying out limited amounts of digitisation. When some areas had been converted to digital form, the value of doing so was recognised and small elements of temporary staff time was allocated from the Science Budget to carry out further work. This resulted in a significant area of England and Scotland being completed. At this stage Mobil North Sea Ltd., in addition to purchasing the existing data, provided a grant which enabled a temporary post to be funded for further digitisation. Subsequently, as part of a contract between BGS and NIREX a large tranch of data in northern Scotland was completed. The Geological Survey of Northern Ireland recommended that the Department of Economic Development should provided funds to allow the data covering the province to be digitised. Much interest was shown in the data by both commercial and academic geophysicists, which encouraged further committment of Science Budget funds to allow the completion of the exercise, and the continuation into the offshore areas.

2.2. Equipment used for digitisation

The bulk of digitisation has been carried out on a workstation based on an IBM-PC AT micro-computer. The computer is linked to a TDS HR-48 digitising tablet with a 4-button cursor and to a Cambridge Graphics Colour Monitor. The IBM-PC is equipped with an enhanced memory card and a graphics card for the monitor. An Epson FX-80 printer and an IBM 7273 6-pen plotter are available as optional output devices.

Processing of the data was carried out on the NERC VAX computer cluster and plots were generated on a Versatec plotter driven by the VAX.

Before the purchase of the digitising equipment and the availability of the VAX and its associated hardware, other systems based on a Ferranti CETEC table and GEC computer were used. No details of this now defunct system will be provided here.

2.3. Method adopted for digitisation

At the outset of the project of digitisation, it was recognised that a considerable amount of work could be saved if the processing of the raw aeromagnetic records could be eliminated, and the reduced data converted to digital form. This could be achieved by using the worksheets - on which the reduced values at 5 or 10 nT intercepts were plotted in their true positions - as the basic data from which the digitisation could proceed. There would be some loss of resolution because some high frequency components of the records would not be captured, but much of this part of the spectrum would have been lost in any case as a result of the flying height. An inspection of the records shows that most of the geophysical information has been resolved by the chosen intercepts, and instrumental noise is responsible for most of the high frequency content. In addition, it was recognised that the main application of the data would be in deriving interpolated grids of the magnetic field, which have a significantly lower resolution than the profile data themselves, in which case the high frequency content would not be important.

A computer file format was designed which defined for each intercept point the British National Grid easting and northing, the value of the point above the standard regional field for the UK, the flight line number, and the flight height. A separate index file listing each of the 522 maps covering the survey was created, thus making a suitable structure for the data.

The computer-aided design package AUTOCAD from Autodesk Inc. was used as the mechanism for capturing the analogue data. The use of a sophisticated package of this type has an element of redundant potential, but has immediate advantages as well. For example, co-ordinate values on the digitising tablet are automatically transposed to the co-ordinate system of the map; skewness in the mounting of the paper is not important; paper stretch is compensated. All of these are relatively trivial effects to remove by 'in-house' programs, but the cost of development was removed.

A small computer program called DIGIT was written in AUTOLISP (also from Autodesk Inc.) which could be called from within AUTOCAD, and which draws on the monitor screen a small cross with the associated value, but which also contains the constants for flight height and line number as invisible 'attributes'. In response to a series of prompts, the map was initialised in relation to the tablet, the flight line number and flight elevation were entered. The data for the flight line was entered by placing the cursor cross-hairs over the intercept point required and the cursor button pressed to run DIGIT, which prompted for the required value which was entered via the keyboard. This was repeated for the whole line, and the whole map, so that a 'drawing file' is produced. Any obvious errors could be corrected interactively.

When the map had been completed, the attributes of each cross were stripped out of the drawing file into a 'text' file in ASCII format so that all the necessary parameters were obtained.

The text file was transferred to the VAX computer. The first stage of checking the validity of the data was to identify any gross errors in the magnetic field values. No cost-effective means of checking this rigorously was devised but it was considered that the most likely errors would occur as a result of mis-typing digits, and these would tend to result in significantly different adjacent values. A short routine called CHECKMAG was written to test for differences of greater than the normal interval - namely 10nT - and identify each occurrence. This was then checked against the work sheet, so that when steep magnetic gradients caused greater intervals these cases could be eliminated. The data file was then corrected where errors had been created.

Next a plot of the position of the intercept points was produced for comparison with the worksheet and any missing points were identified. A contour plot using a interpolated grid size of 0.25km was generated to check against the hand-contoured version and any discrepancies were investigated. ollowing this the constant datum shift value was removed from the magnetic values.

At this stage the data was handed over to the supervisor who checked the files and plots for gross errors before entering the data into the databank. When the whole of a survey area was complete a plot of a large area, usually $100km^2$, was generated to identify duplication of points, gaps or mismatches, which were subsequently corrected.

This data forms the primary data-base and represents, within the reliability of the procedures adopted, an exact copy of the analogue worksheets in digital form, including data overlaps and man-made magnetic features (although in some cases the contractor had manually removed the latter). Errors made during the compilation stage, which had been identified during the digitisation had been removed. The Carnegie regional field applied to the 1955 survey data was also removed, by calculating the trend surface from a contour map of the regional field and applying the terms to the digital data.

3. THE ARCHIVE AND RETRIEVAL OF DIGITAL DATA

3.1. Data Organisation

The FORTRAN format used for the data is (i3,i7,1x,2f10.0,f7.0).

> Columns 1-3 contain the flight line code, where column 1 is the type of line: blank representing a normal flight line, 9 is a tie line, 8 is a closure line,5 shows a reflown or overlapping part; column 2-3 is the line number taken from the work sheet.
>
> Columns 4-9 gives the total magnetic field strength above the standard regional field (right justified).
>
> Columns 14-19 and columns 23-29 contain the British National Grid easting and northing respectively in metres.
>
> Columns 34-37 give nominal flight height in metres.

The data are held in files which have names with the structure AAnnXX .(DATA/LSB), where AA is either HG (Hunting Geology and Geophysics) or CA (Canadian Aeroservices Inc.), nn is the year of survey (55 to 65), XX is the worksheet number, and DATA or LSB is the extension to identify ASCII or binary files; for example: HG6206.DATA. The smaller sheets covering the detailed surveys in the south-west of England necessitate a modified system in which the second digit of the company code was replaced by the second digit of the alphabetic code for the 100 km BNG square (These were SS, ST, SW, SX and SY) so that a data file might be known for example as HX5809.DATA. A binary version of each of the 522 data files is held in a directory called DUA7:[K_IFS.DATABANK.AEROMAGNETIC.UKDATA], which occupy 25 210 blocks in total, as opposed to the 43 023 blocks which the ASCII version required (a block is 512 bytes). In the directory level above is an index file called UK_AMAG_INDEX.LIS which gives the filename, its limiting BNG co-ordinates, the range of flight-line and tie-line numbers, their spacing and orientation.

3.2. Data archive

Copies of the data are held in binary form (that is with a .LSB extension to the filename) permanently mounted on disk DUA7 on the VAX computer as described above. They were derived from the ASCII versions (with a .DATA filename extension) using a small utility program CON2BIN, the source of which is in directory [K_IFS.SOURCE.DATABANK.AEROMAG]. These files are accessed during the process of data retrieval. Copies of the files (with the full directory names) have been made using the ARCHIVE facility onto magnetic tape stored in the Keyworth computer room. They can be restored in the event of corruption or loss using the RETRIEVE command. The ARCHIVE facility has also been used to make copies of the ASCII files, which are required in the event of data errors being discovered.

A magnetic tape copy of each file in ASCII format has been made using the MTU (magnetic tape utility) routine (F.W.M Hopper, personal communication) onto tape A00337 which is held in the Keyworth secure tape store in the National Geosciences Data Centre. This tape is written at 6250 bpi, with 80 bytes per record, and 10 records per block. It contains a series of 523 unnamed files, the first of which is a copy of the index file, which gives the sequence of files on the tape.

Plots of the data points and contours for each of the 100 km^2 BNG squares have been generated at a scale of 1:125 000 and are stored in a map press in the RGRG data archive. A catalogue of the data points for each square has been compiled (Revell, 1988).

3.3. Data retrieval

A FORTRAN program called AMAG_EXTR has been developed to extract data from the aeromagnetic database, and the executable module is held in [K_IFS.DATABANK.PROGS] and the relevant source code is in directory [K_IFS.SOURCE.DATABANK.AEROMAG]. The program allows data to be extracted for a given area, for a specified flight line, a whole survey area or as individual worksheet files. The program may be run either directly or via a VMS command file [K_IFS]DATABANK.COM. Data are written onto temporary disk space, with a general filename MAGNETIC.DATA. A report file is generated which lists the number of points extracted, and the use of the data is logged into [K_IFS]DATALOG.LIS, with information on the VAX user identifier, the type of data accessed and the number of values extracted.

3.4 Data maintenance

The primary database will require periodic maintenance when errors require rectification. Errors could have occurred because data points have been missed, because the values were incorrectly read from the worksheets, or were incorrectly written onto the worksheets.

In this event the following procedure will be followed:

1. The source of the error will be traced back to the original data (either flight record or worksheet);

2. The appropriate ASCII file will be RETRIEVED from ARCHIVE (the full name is [K_IFS.DATABANK.AEROMAGNETIC]filename.DATA);

3. The necessary editing carried out using whatever method is appropriate;

4. Using CON2BIN, the file will be converted to binary and placed in directory [K_IFS.DATABANK.AEROMAGNETIC.UK_DATA] and the original version deleted;

5. Both new versions will be archived, ensuring that the binary file is kept by using the /RETAIN option. The old versions in ARCHIVE will be deleted.

It will be necessary every 3 months to print the log file [K_IFS]DATALOG.LIS and to delete its contents, because when it becomes large the process of updating is lengthy and data retrieval is slowed down.

4. ANALYSIS OF THE DIGITAL AEROMAGNETIC DATA

4.1. Approach to analysis

As an example of the validity of this exercise in data capture, some comparisons have been made over an area of the Pennines. In this area Hunting Geology and Geophysics Ltd. had digitised the whole analogue flight line records and this data was made available to BGS as a very large computer file with some 200 000 records. The two data sets can be compared in a number of ways: in the space domain (as plots of magnetic field strength against distance), in the frequency domain (which shows the significance of the component frequencies); in profile (showing the magnetic field variation against one dimension of distance), in map form, showing the variation against two dimensions of distance.

Each of these comparisons have particular advantages and allow different aspects of the data to be seen. For instance the spacially distributed data is best for comparing amplitudes and position of anomalies but is relatively insensitive to gradient or frequency variations. On the other hand frequency domain (either from autocorrelation functions or power spectra) provides no information of the form of the anomaly but the relative power of the component frequencies for each data set are readily compared.

4.2. Comparison of profile data

Fig. 2 shows a comparison between the BGS data and that digitised by Hunting of part of flight line 96 for of the 1958 survey. The Hunting data set has an interval between values of about 50m. A moderate amount of high frequency variation is apparent, especially in the smoother, flatter parts around 350km and 440km east. Comparison with the analogue record for the equivalent length of flight line is not easy because the scales are very different, but it appears that some spurious high frequency noise with an amplitude of up to 2nT has been introduced during the following and digitising of the analogue trace, and the contractor's report recognises a noise envelope of +/- 2nT in the analogue data. The BGS digital data for the same section of flight line is spaced at 10nT *vertical* interval. In general the comparison is good, although several points should be noted.

1. the resolution of points of inflexion is not as good on the BGS data, so that minor features may not be represented. However, the detail transferred from the flight record to the worksheets varies from survey to survey, and in some areas features may be better defined. The shape of the turning points is different, tending to be sharper and less closely defined on the BGS data.

2. Some errors are noted in the displacement of the minor peak at 385km and in the truncation of the peak at 405km, the former because a single point was misplaced, the latter because one was omitted. Errors of this nature might have been trapped during the checking of the data, but in areas of steep magnetic relief the detail might tend to obscure them. Clearly the likelyhood of this occurring is random.

3. The noise level in the BGS data has been suppressed compared to the Hunting data because of the lower definition: the BGS data consists of 97 values; the Hunting data 1937 values.

Uniformly spaced interpolated data sets were generated with a bicubic spline method using the computer program LVL2LVL (J.P. Williamson, personal communication). The resolution afforded by the BGS data was significantly better at 500m than 1km, and noticeably better at 200m than at 500m. There was no benefit in interpolating to 100m, even over the turning points. 200m thus probably represents the limiting resolution of the data and further interpolation will lead to data redundancy.

Fig.3 shows the comparison between the two sets interpolated to 200m, and as can be seen all the major features are represented. The amplitudes of the turning points are reduced in the BGS data, although they are very similar in shape. The minor inflections are not fully defined.

A comparison has been made using power density spectral plots (power spectra) using the computer program PROFILE (C.A. Green, personal communication), using the Hanning window to reduce edge effects, a size correction with a half width of 0.1 km and smoothed to reduce the noise levels. This is shown in Fig. 4. For low wavenumbers (long wavelength) between 0.2 and 2 (wavelengths of 30 and 3 km), the comparison is good. For the higher wavenumbers from 2.5 to 15.7 (2.5 to 0.4 km wavelengths) the data, although there is overall

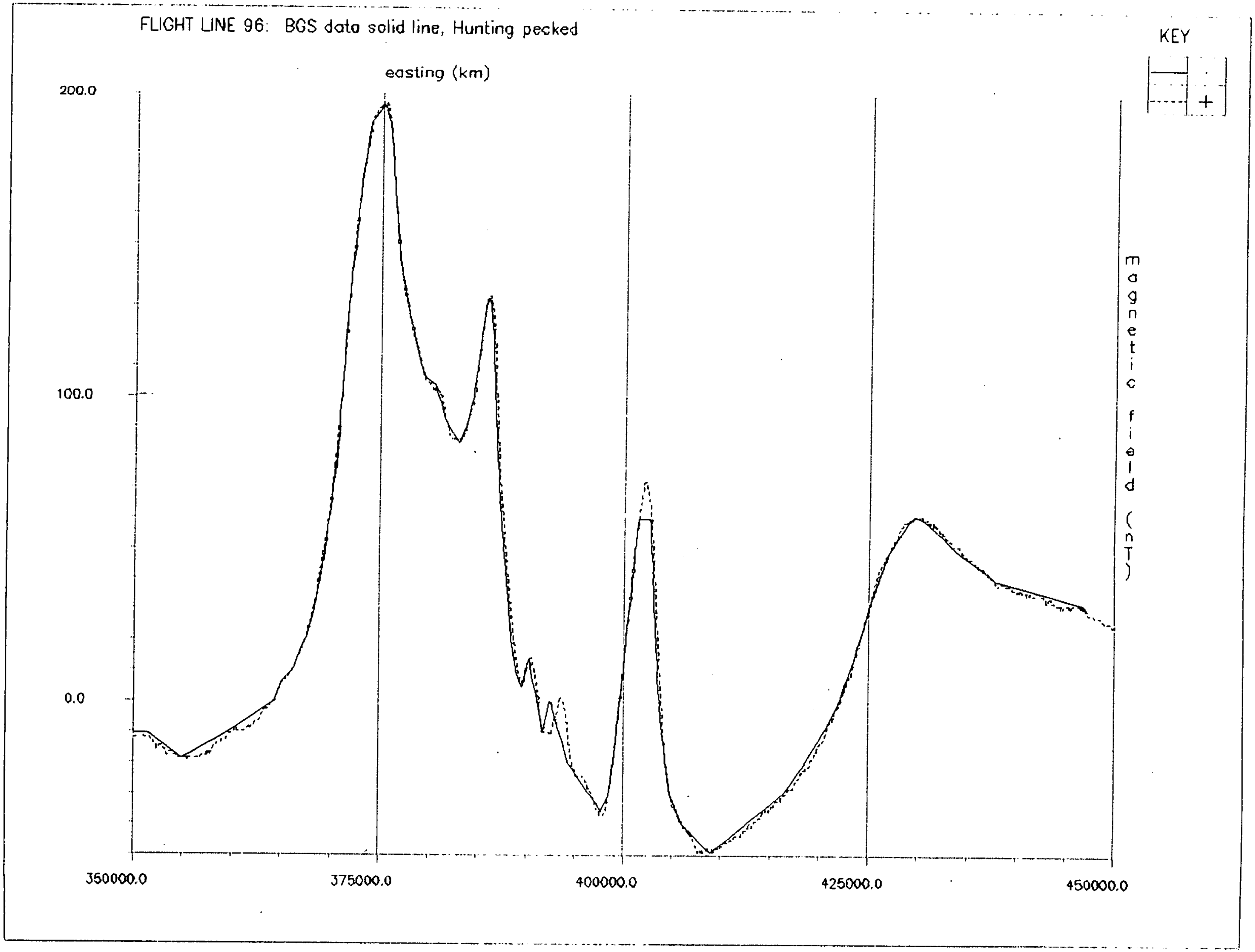

Figure 2 - Comparison of raw BGS and Hunting ditital data for a flight record.

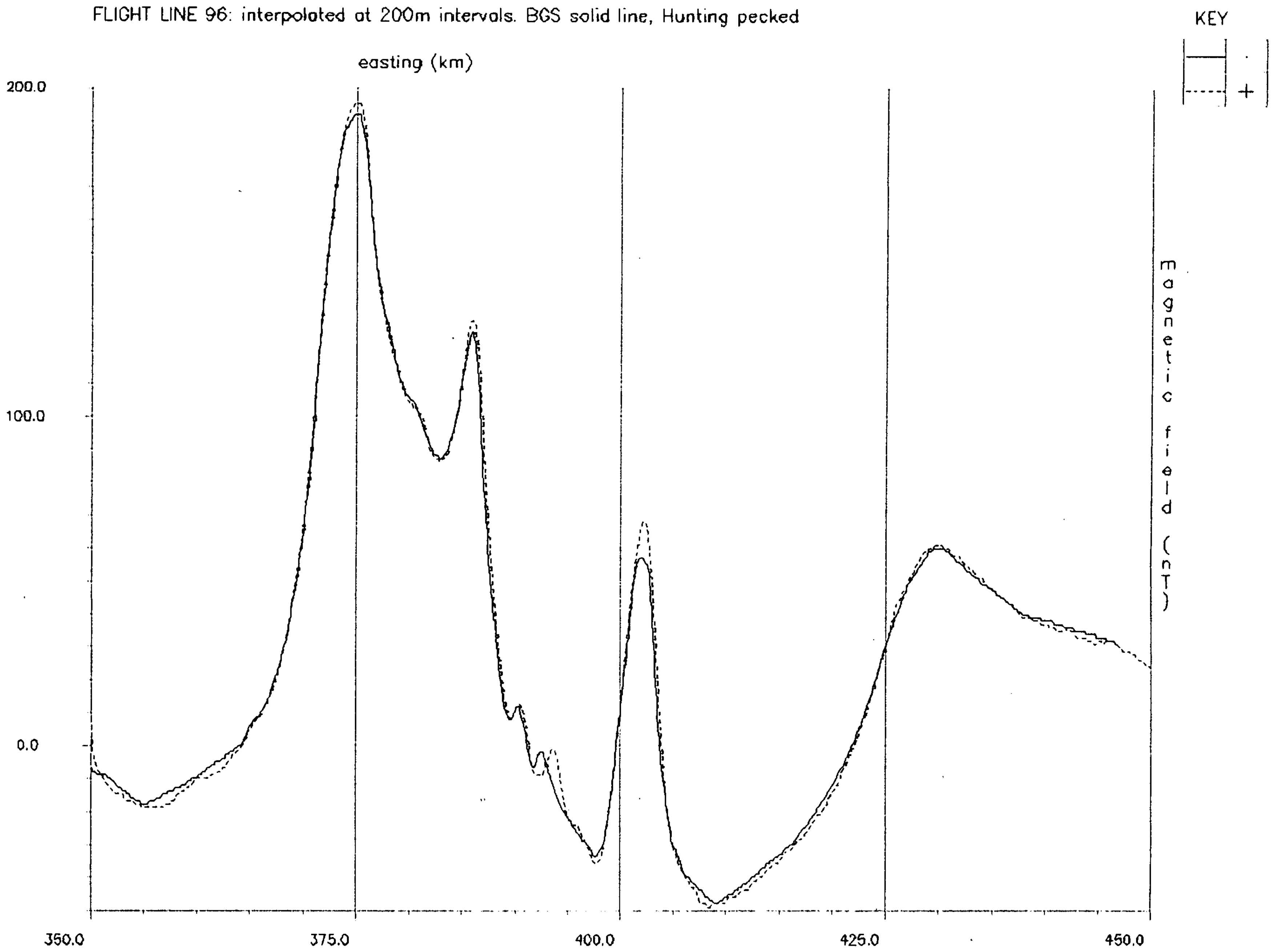

Figure 3 - Comparison of BGS and Hunting data for a flight record interpolated to a
a uniform spacing of 0.2km.

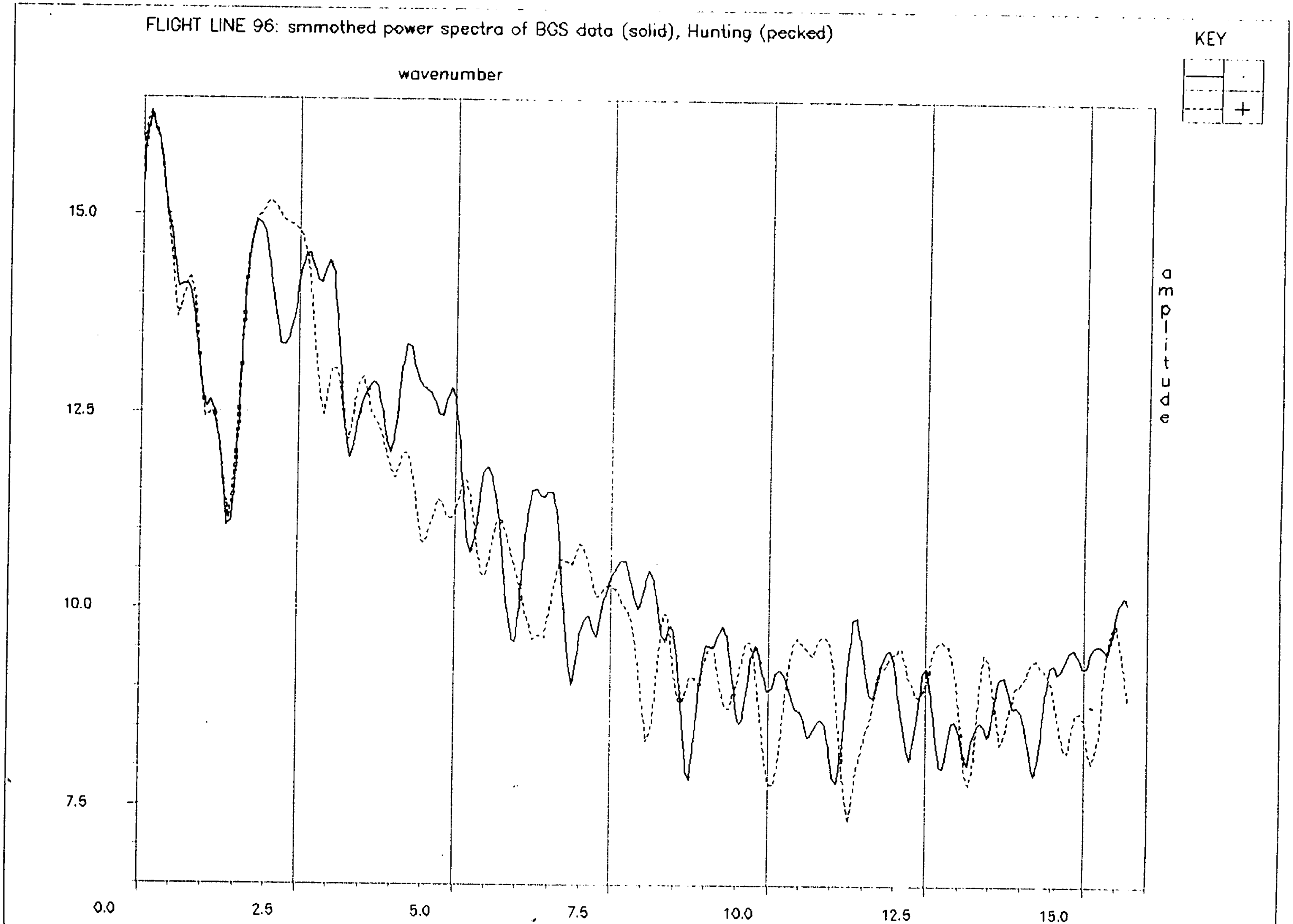

Figure 4 – Comparison of powe density spectra of a flight record for the BGS and Hunting data.

similarity, the spectrum has a different pattern. The wavenumber of 15.7 represents the Nyquist frequency of 0.4 km (twice the sample interval, beyond which data aliasing for the profile data would occur, so that the analysis would be meaningless.

4.3 Comparison of map data

Sets of both data for the area were converted into the United States Geological Survey (USGS) two-dimensional 'standard grid' using the EASYGRID computer routine (J.P. Williamson, personal communication). The USGS standard grid is a regular interpolated data set with a self-describing format, which is used for many data-processing and manipulation programs in use in RGRG. The dimension of the grid was 0.25 km in this case.

Plots of the two data sets have been obtained using the program COLMAP (C.A. Green, personal communication), which provides pseudo-relief images by 'illuminating' the grids with a light source from a specified position. In both cases the illumination was from the north-east at an azimuth of 45°. The images are powerful indications of local gradients, especially those with a north-west to south-east trend.

The first impression of the Hunting data (Fig. 5) is of the mis-ties of parts of certain flight lines, giving prominent north-south and east-west discontinuities. Such features are not prominent on the BGS data (Fig. 6), apart from the flight line along 498 km north. There is a weaker orthogonal texture associated with the Hunting data, which does not appear on the BGS data, and which probably results from incomplete adjustment of the data. On the BGS data are a number of localised features which do not appear on the Hunting data, which are probably discrete errors in data capture, and which will be corrected as they are discovered. Examples are at kilometre grid references 365 473 and 419 470. The geologically significant features appear to be resolved in a very similar way, although certain local features may be slightly enhanced in one or other of the images. Only careful study and detailed adjustment and correction of the data sets will clarify which of the two is superior.

Figs. 7 and 8 show two-dimensional power spectral density plots of the same two data sets produced using FORTRAN program ASPEC2D and presented using COLMAP, both written by C.A. Green (personal communication). The two data sets show a similar overall pattern, although the Hunting data presents a noisier aspect, with increased amplitudes at normalised wavenumbers of 0.2 and 0.5.

4.4 Discussion

Most of the use of the digital data is to produce equally spaced data along profiles or on grids. This involves an averaging process, with the loss of some detail along the flight lines in order to obtain an uniform spacing, and to avoid introducing large amounts of imaginary data normal to the flight direction and involving heavy consumption of computational time. The minimum spacing between digital points is about 100m, so this defines the absolute minimum of resolution, and the average spacing must be around 0.5 km. A grid

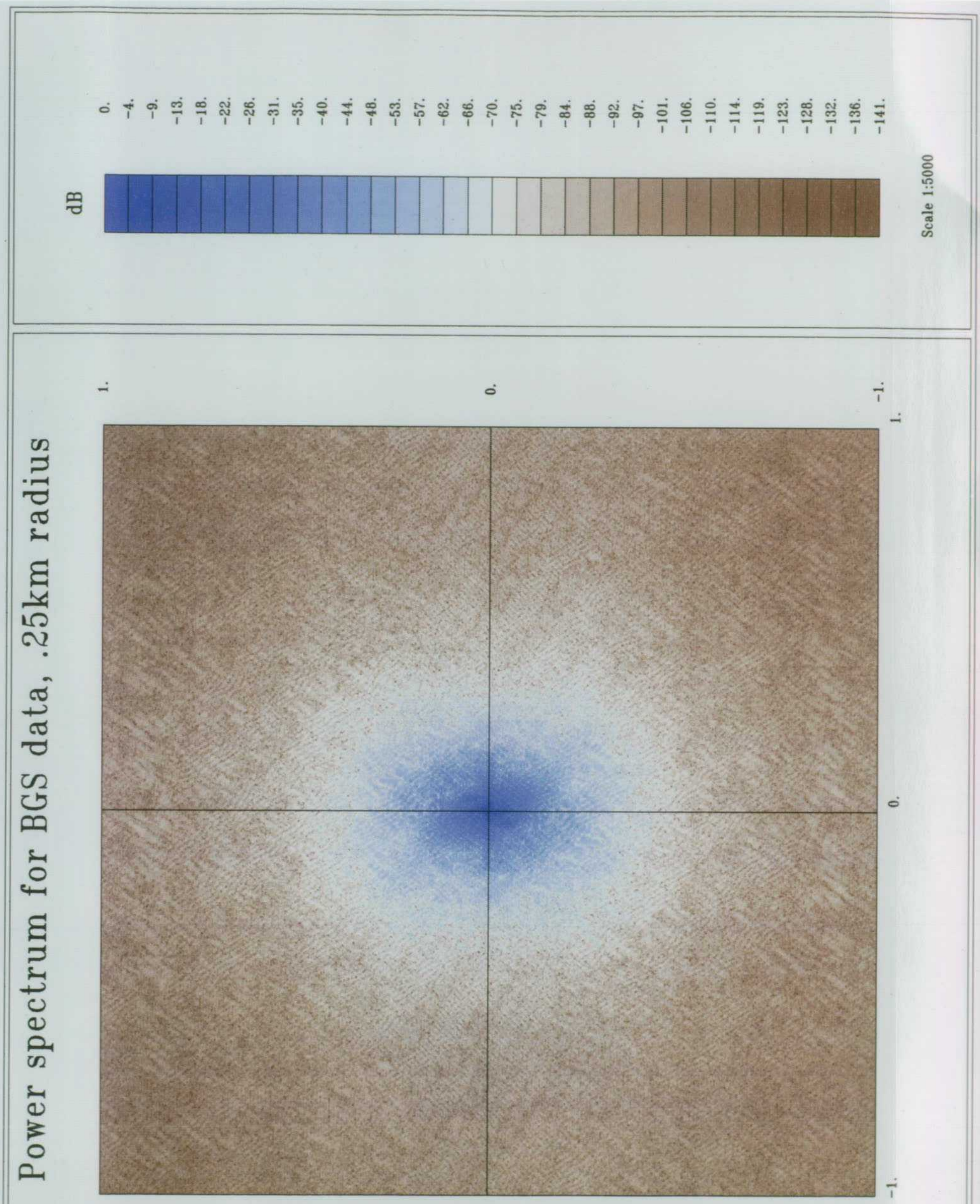

Figure 7 - 2-D Power spectral density plot of the BGS data for part of the Pennines

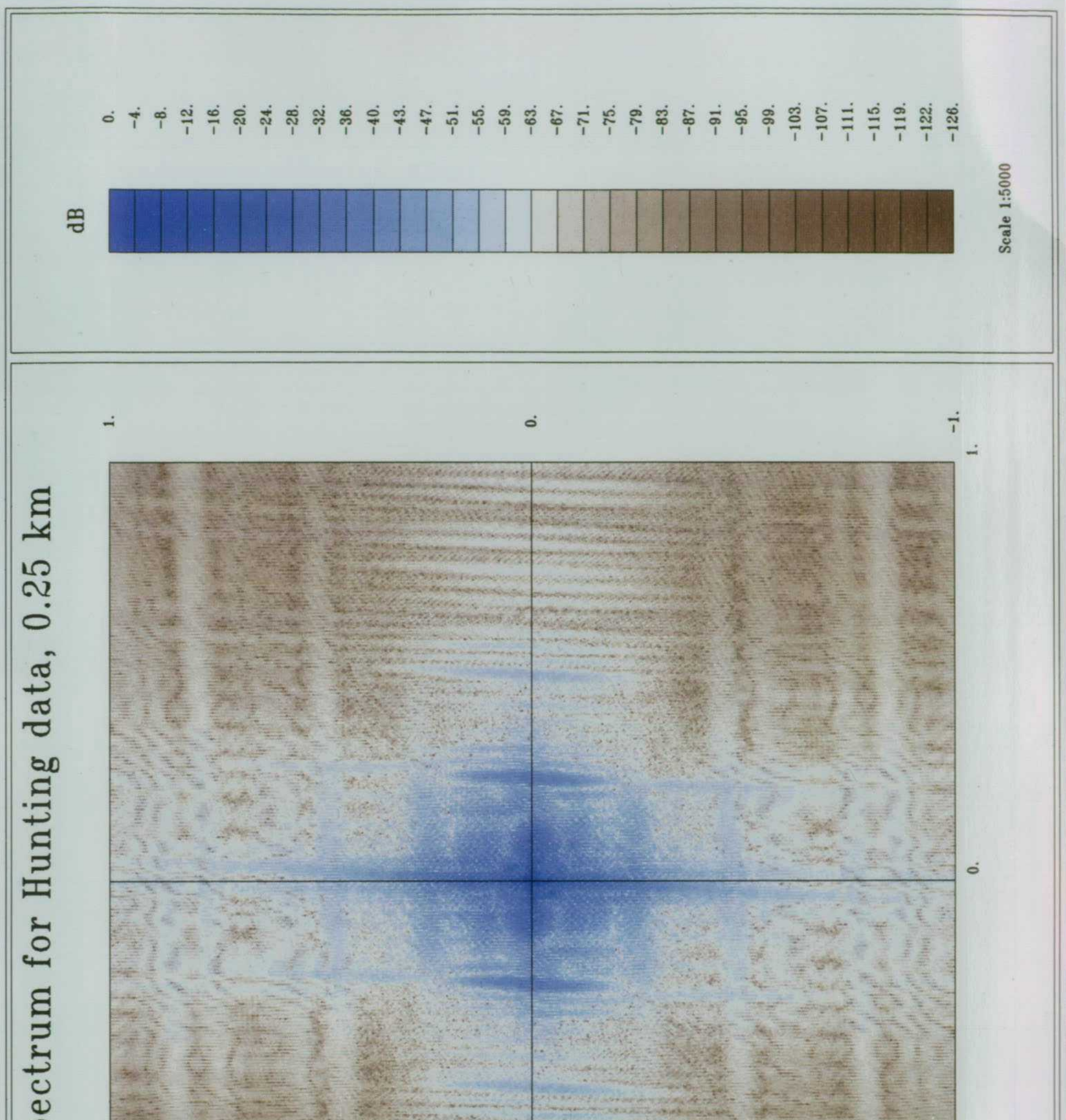

Figure 8 - 2-D Power spectral density plot of Hunting data for part of the Pennines

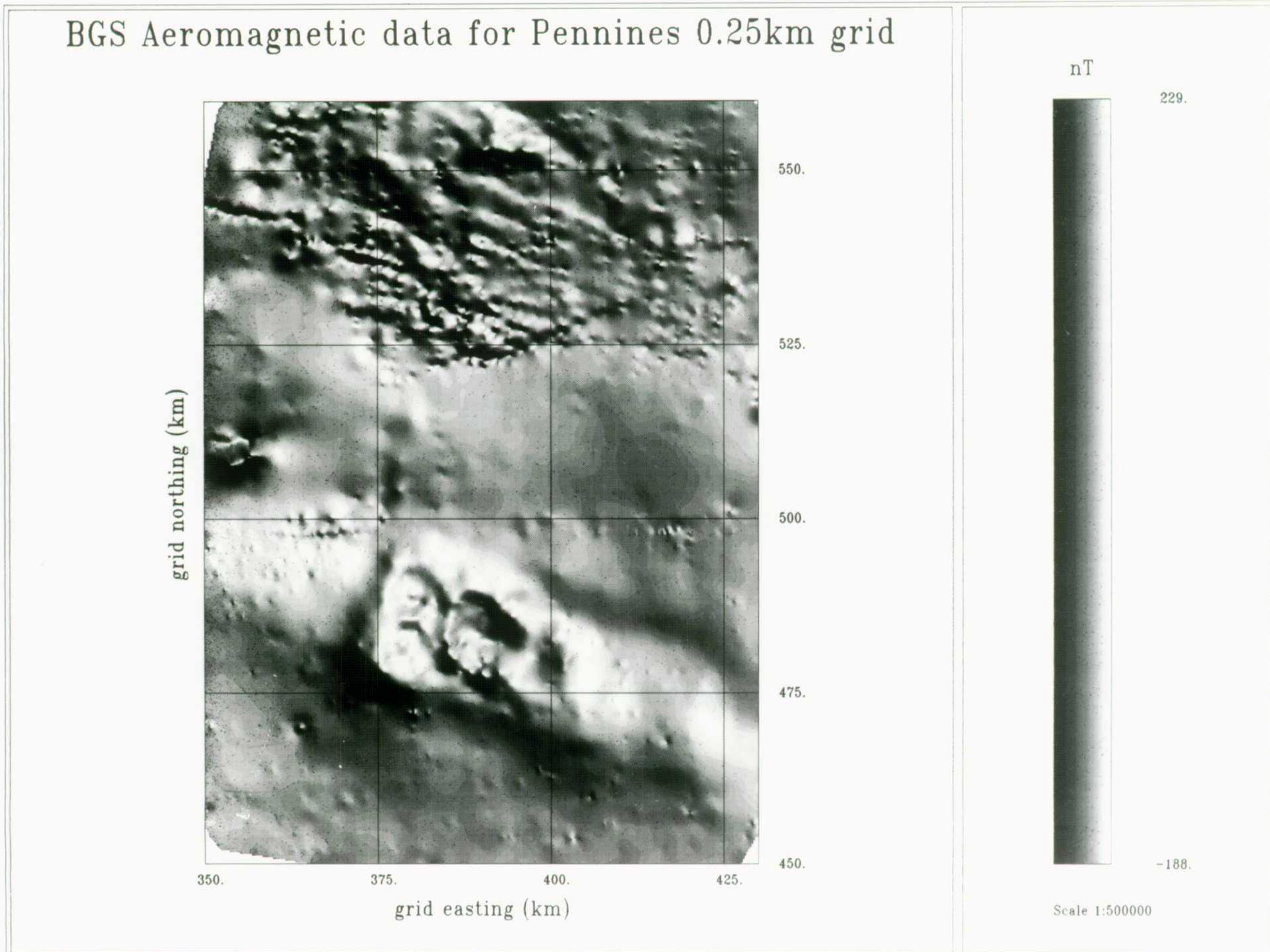

Figure 5 - Pseudo-relief plot of the BGS data for part of the Pennines

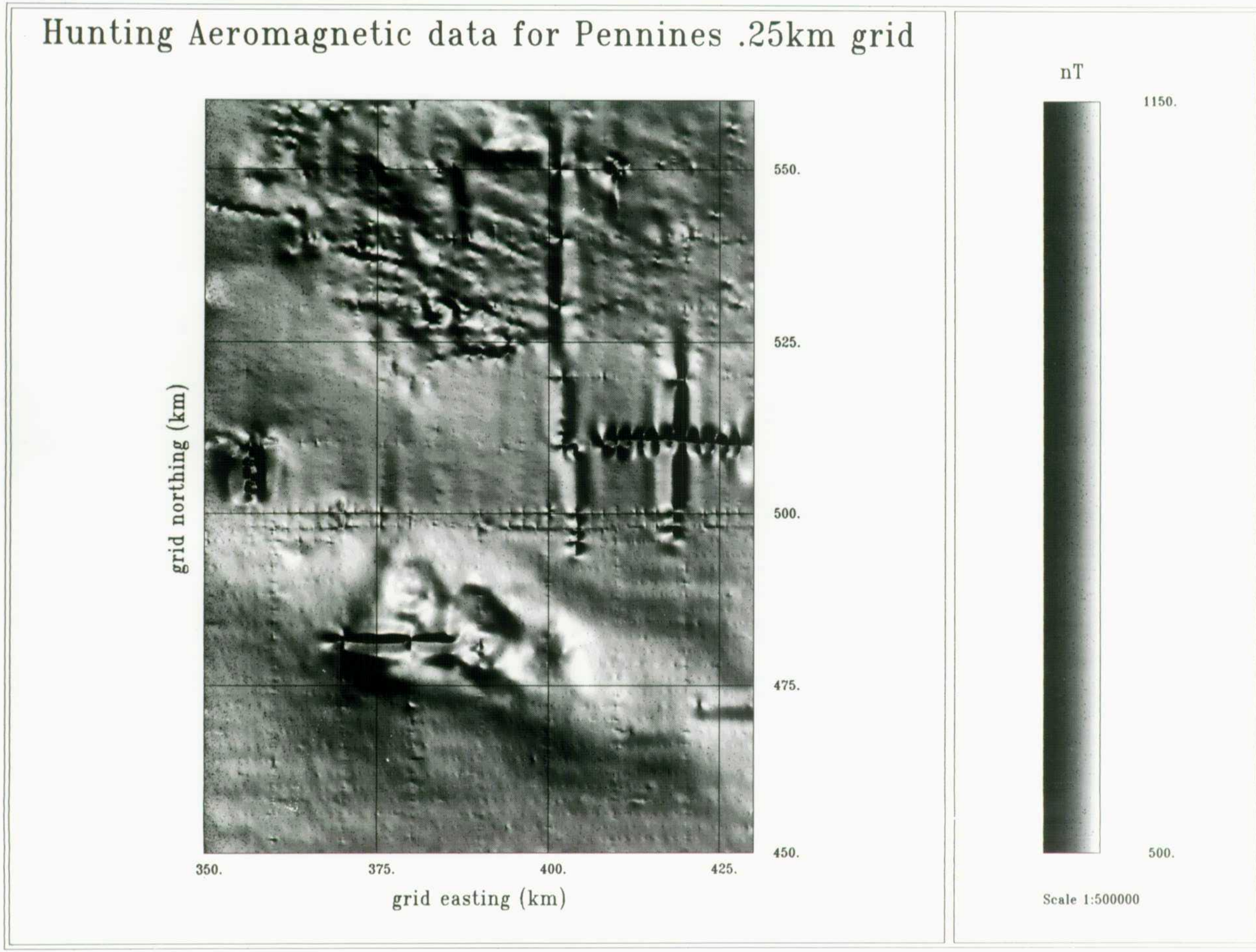

Figure 6 - Pseudo-relief plot of Hunting data for part of the Pennines

spacing of 0.5 km perhaps represents an optimum of data resolution and file-size, although 0.25 km might be appropriate in some cases. In the areas covered by the detailed South-West England surveys, a grid size of 0.1 km may be justifiable. Along the flight profiles a data point spacing of 0.2 km is suggested as being optimal in most cases.

In certain parts there are small overlaps of successive annual surveys. Where a mismatch in datum level occurs this can lead to a obtrusive dimpled effect, especially on the pseudo-relief plots produced by COLMAP (C.A. Green, personal communication). This may result from any of three main causes:

1. a shift in datum level resulting from different flight heights. The geomagnetic gradient is 21 nT/km in UK, and a maximum difference between adjacent surveys of about 5 nT is possible;

2. secular variation for the period of 1955 to 1965 varied between 4 nT and 37 nT per year. There could well have been a datum shift of several nanotesla during the course of a survey lasting several months;

3. the shape of an anomaly will change in response to distance from the magnetic body, because higher frequency components of the anomaly decrease with elevation. Thus surveys at different heights will produce different shaped anomalies over the same body.

The effects of 1 and 2 will tend to be removed by the connections between surveys carried out by the contractor, who adjusted their survey levels on an empirical basis by comparison of overlaps. This may not have been easy to do in some cases and minor errors may have occurred. With a detailed inspection some fine adjustment of the datum of adjacent surveys, perhaps coupled with elimination of overlapping data should alleviate this problem. The effect of continuation as described in 3 probably does not have a significant influence on this effect, because anomalies resulting from near-surface bodies which will be most affected by upward continuation are likely to be rather complex in any case and 'dimpling' may not be apparent.

In many parts of a heavily populated country there are significant magnetic anomalies resulting from steel in constructions such as factories, ships and towns: so-called cultural noise. In some cases the contractors smoothed out these anomalies out at the data reduction stage, so that response does not appear on the worksheets and has not been included in the digital data. However, the policy adopted for the digitisation was to include all the anomalies which appeared on the worksheets, even though they might have been identified as having a specific man-made cause. Thus there is a certain inconsistency in the appearance in the digital data set of cultural noise.

Despite the current (1989) discussions to carry out a high-resolution multi-component airborne survey for the UK, it is likely to be some time before a complete data set will become available which will make this data-set redundant. This data has become available at a most appropriate time to allow full use of the modern computing environment which is provided for BGS, and to service a wide range of contracts which BGS has undertaken. The limitations of the data quality and density are apparent, but the effort in creating this data-set is now very well-justified.

There is clearly a case for editing the primary data files to remove errors which come to light during the use of the data. There is equally a case for producing a definitive data set which removes inconsistencies in datum levels and overlaps, and which refers the data to the International Geomagnetic Reference Field (IGRF), so that adjacent surveys will be compatible. Most use will be made of the data in interpolated form, so it may be appropriate to consider the production of a grid file or set of grid files for discrete areas, which has sufficient resolution to satisfy the users' requirements, and which would be generally accessed. An assessment of this will be made in due course, in consultation with users of the data.

5. Acknowledgements

The bulk of the routine digitisation of this data has been generated by a small army of assistants. They have consistently maintained a high standard of concentration, accuracy and productivity, often with poor quality data and confusing detail. Their ability to carry out this apparently endless exercise for long periods is only really obvious when the data-set is used, but the considerable interest that it and its geological interpretations have aroused is justification for their efforts. They are Richard Crosby, David Drury, Alistair Gibberd, Tim Green, David Lewis, Grant McDougall, John Pantlin, Giles Revell, Suzanne Self and Paul Vickers. The others who have contributed small sets of data are also acknowledged.

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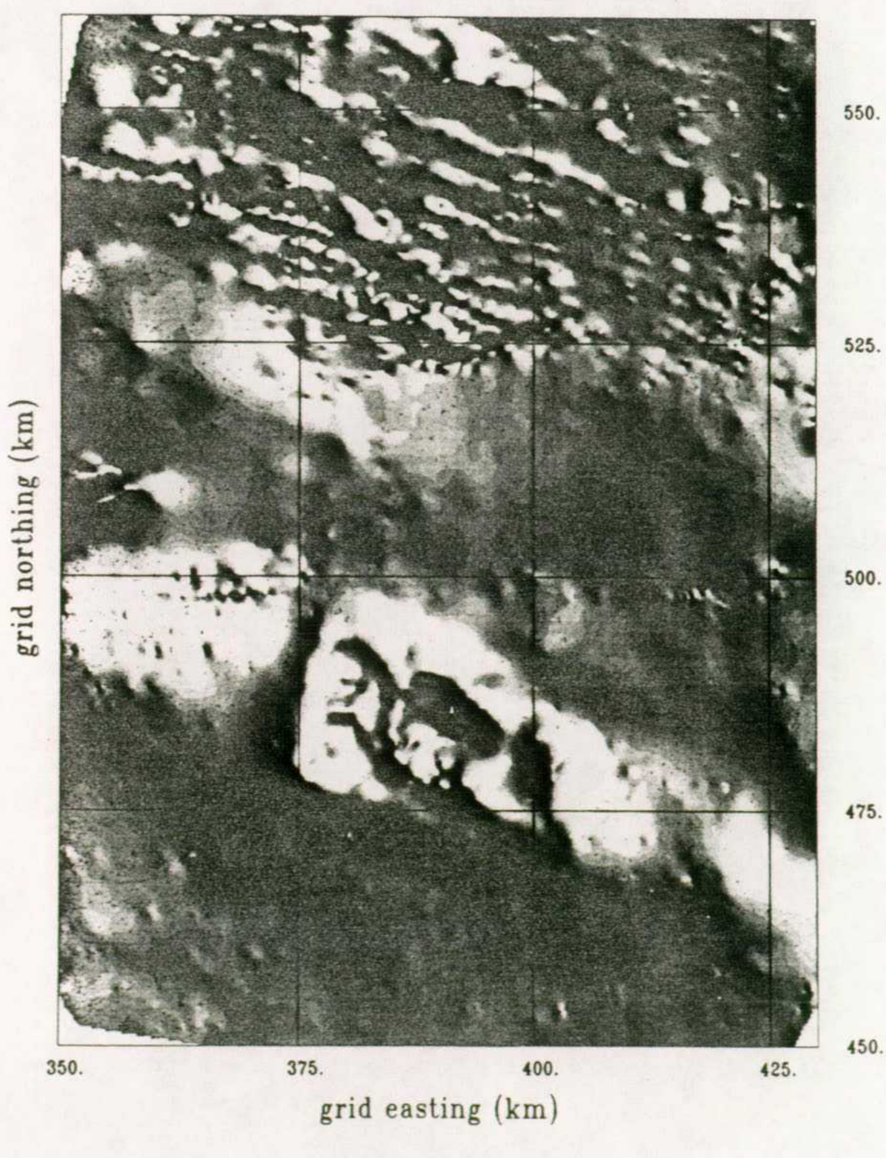
BGS Aeromagnetic data for Pennines 0.25km grid



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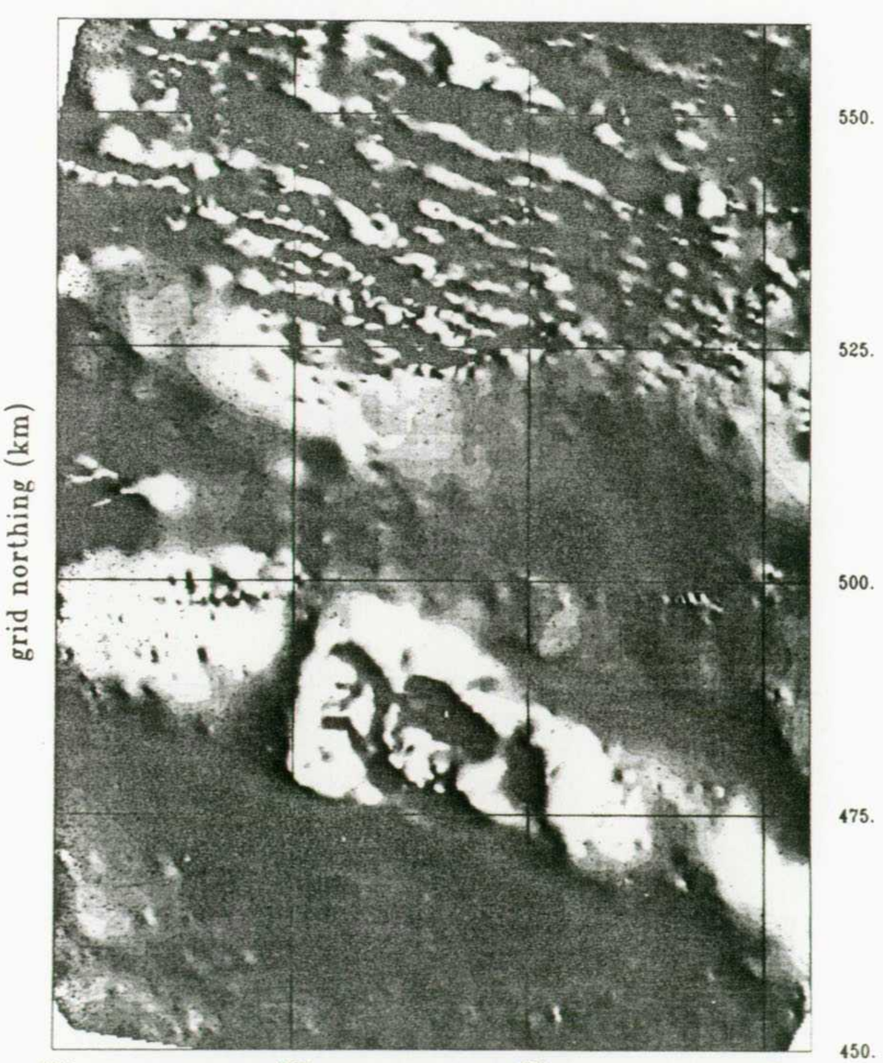

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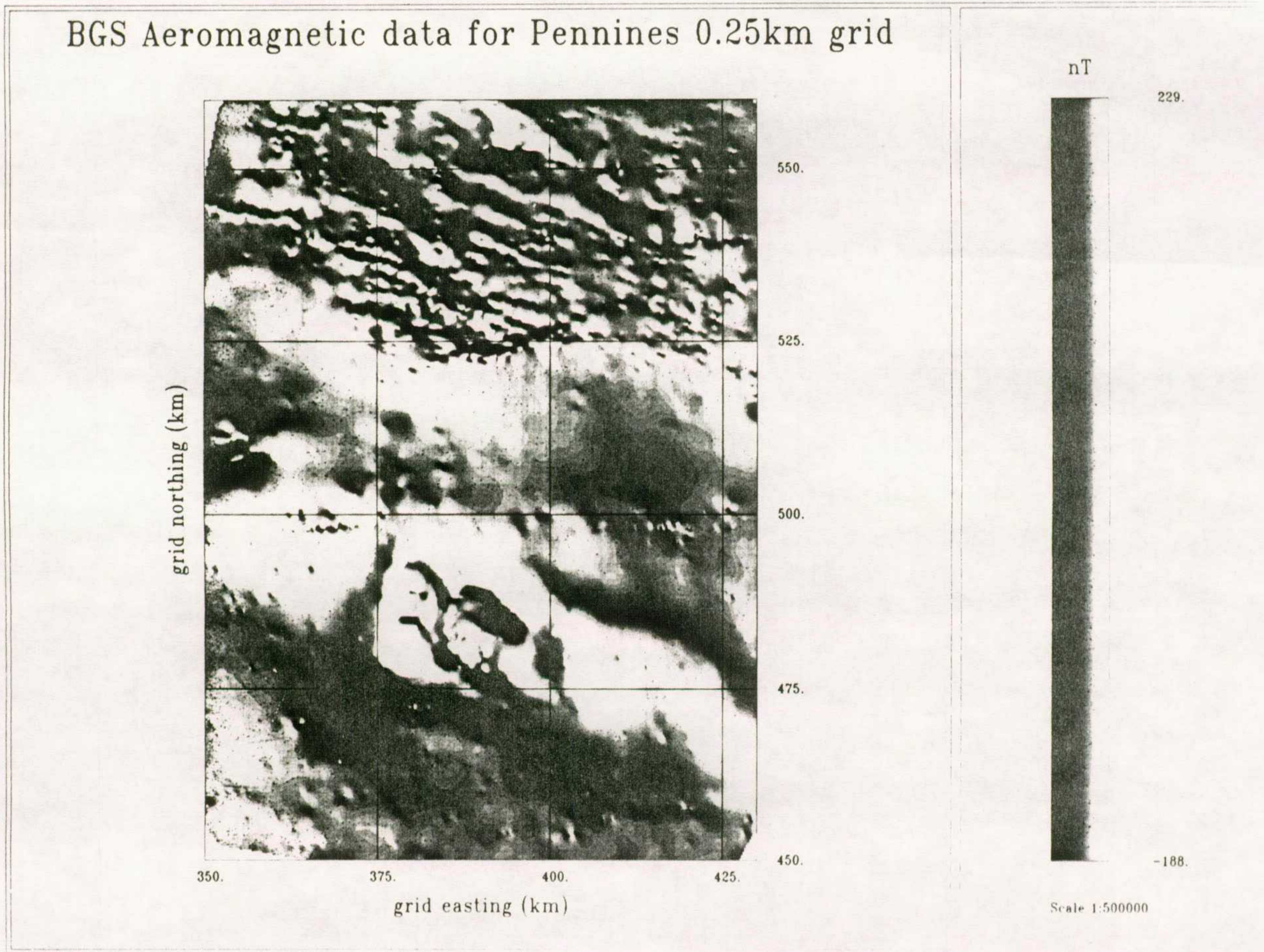

Figure 5 - Pseudo-relief plot of the BGS data for part of the Pennines