23.

COMPUTER COMPILATION AND INTERPRETATION OF GEOPHYSICAL DATA

Allan Spector
Allan Spector and Associates Ltd., Don Mills, Ontario

Wilf Parker
Dataplotting Services Inc., Don Mills, Ontario

Spector, Allan and Parker, Wilf, Computer compilation and interpretation of geophysical data; in Geophysics and Geochemistry in the Search for Metallic Ores; Peter J. Hood, editor; Geological Survey of Canada, Economic Geology Report 31, p. 527-544, 1979.

Abstract

This paper details the progress in the application of the digital computer to the compilation and the interpretation of geophysical data in the period 1967-1977. Probably the most dramatic feature of this period has been the dramatic drop in the cost of computers. Miniaturized electronics has reduced the cost and size of today's computers.

Much more accurate, versatile, and faster computer graphics devices have become available. The most important hard-copy devices are the large flatbed plotters, the fast drum plotters, and the electrostatic plotters. A colour plotter has become available and will be very useful for producing full colour geophysical and geological maps. Digitizers are larger and more accurate. Interactive computer terminals, connected to local or remote computers, allow fast editing and processing of data.

Semi-automatic computer compilation programs, using interactive terminals, permit the fast processing and plotting of large volumes of geophysical data. A good deal of this progress has been spurred by the development of reliable digital acquisition systems for airborne surveys, especially aeromagnetic, gamma ray spectrometer and electromagnetic (EM) surveys.

Not quite as dramatic, but surely significant advances have been made in the area of data analysis and interpretation. Several survey contractors have the software and hardware facilities to perform the following operations:

(a) Aeromagnetic data:

- *computation of synthetic anomalies for arbitrarily complex models and also interactive modelling,*
- *matched filtering, downward and upward continuation, vertical gradient, magnetic pole reduction, pseudo-gravity transformation facilitated by Fourier transform techniques and susceptibility mapping.*

(b) Gravity data: much more correlation and closer interaction with geological data plus iterative modelling for semi-automatic interpretation and various anomaly enhancement operations.

(c) Input electromagnetic data: conductivity-width and depth computation employing computer graphics facilities.

(d) Gamma ray spectrometer data: background definition, stripping, ratio computation and quantitative estimates of radioactive element composition.

Résumé

Le présent document fait état des progrès accomplis dans l'utilisation du calculateur numérique pour le rassemblement et l'interprétation des données géophysiques pour la période de 1967 à 1977. La caractéristique la plus étonnante de cette période a probablement été la chute dramatique du coût des ordinateurs. La miniaturisation des éléments a eu pour effet de réduire le coût et les dimensions des ordinateurs modernes.

On dispose maintenant d'appareils graphiques automatisés beaucoup plus précis, polyvalents et rapides. Les appareils d'impression les plus importants sont les gros traceurs à plat, les traceurs rapides à tambour et les traceurs électrostatiques. Il existe maintenant un traceur couleur: il sera très utile pour la production de cartes géologiques et géophysiques en couleur. Les convertisseurs analogiques/numériques sont plus gros et plus précis. Les terminaux de dialogue, reliés aux ordinateurs satellites et locaux, permettent le traitement et la correction rapides des données.

Les programmes de rassemblement semi-automatiques, utilisant des terminaux de dialogue, permettent le traitement et le tra^age rapides d'un grand nombre de données géophysiques. Une bonne partie de cette évolution a été motivé par la mise au point de systèmes efficaces de saisie numérique pour les levés aériens, principalement les levés aéromagnétiques, les levés électromagnétiques et les levés de spectromètre à rayons gamma.

Des progrès moins spectaculaires, mais tout aussi importants, ont été réalisés dans le domaine de l'analyse et de l'interprétation des données. Plusieurs arpenteurs privés possèdent les installations de matériel et de logiciel pouvant effectuer les travaux suivants:

(a) Données aéromagnétiques:

- *calcul des anomalies synthétiques pour les modèls arbitrairement complexes et aussi des modèles de dialogue,*
- *le filtrage assorti, la suite descendante et ascendante, le gradient vertical, la réduction du pôle magnégique, la transformation pseudo-gravité facilité par les techniques de transformation de Fourier et la cartographie de susceptibilité.*

(b) Données gravimétriques: relation et interaction plus serrées entre les données géologiques, en plus des modèles de dialogue pour l'interprétation semi-automatique et divers travaux de mise en valeur des anomalies.

(c) Données électromagnétiques en entrée: le calcul de la largeur et de la profondeur de conductivité au moyen des appareils graphiques d'ordinateur.

(d) Données de spectromètre à rayons gamma: la définition de la zone de fond, le stripage, le calcul des rapports et les évaluations quantitatives de la composition des éléments radioactifs.

INTRODUCTION

This paper describes the current state-of-the-art of computer application to both the compilation and the analysis of geophysical data intended for mining exploration. We have attempted to differentiate what is available on a commercial basis from that which is undergoing research and development. We shall be basically reviewing advances in computer hardware and software since 1967. Thus, this paper may be regarded as a sequel to a similar paper given by West et al. (1970) at the 1967 Niagara Falls conference. The reader is also directed to two other state-of-the-art papers on allied topics by Grant (1972) and by Reford (1976).

The authors would like to introduce themselves as a geophysicist and a geologist, who, over the last 10 years, have been specifically involved in the computer processing of geophysical data — on a contractual basis.

This paper is not intended as an exhaustive study of the subject but rather a bird's eye view dated 1977 over Toronto. Whereas in 1967 mining geophysicists were not really making great use of computers, in 1977 it is difficult to find a geophysicist who is not making use of, or is at least familiar with, data processing techniques. The electronic calculator, the programmable calculator, the minicomputer, and the microcomputer have all come into common usage during the past decade as a result of the miniaturization of electronic circuitry.

Four main areas are covered in this paper:

(1) digital acquisition,

(2) computer processing hardware, including terminals and plotting facilities,

(3) computer software, and

(4) anticipated future developments.

ADVANCES IN COMPUTER HARDWARE

Reliable Digital Acquisition

Probably the most significant improvement in the state-of-the-art since 1967 has been the development of reliable digital acquisition systems for airborne geophysical survey use. All major airborne survey contractors in Canada now have such systems. A minicomputer or microprocessor forms the nucleus of all the state-of-the-art systems. A stored computer program controls the acquisition of both digital and analogue data from the geophysical sensors. It also controls the formatting of the data onto magnetic tape and verifies that each tape record has been properly written on the tape.

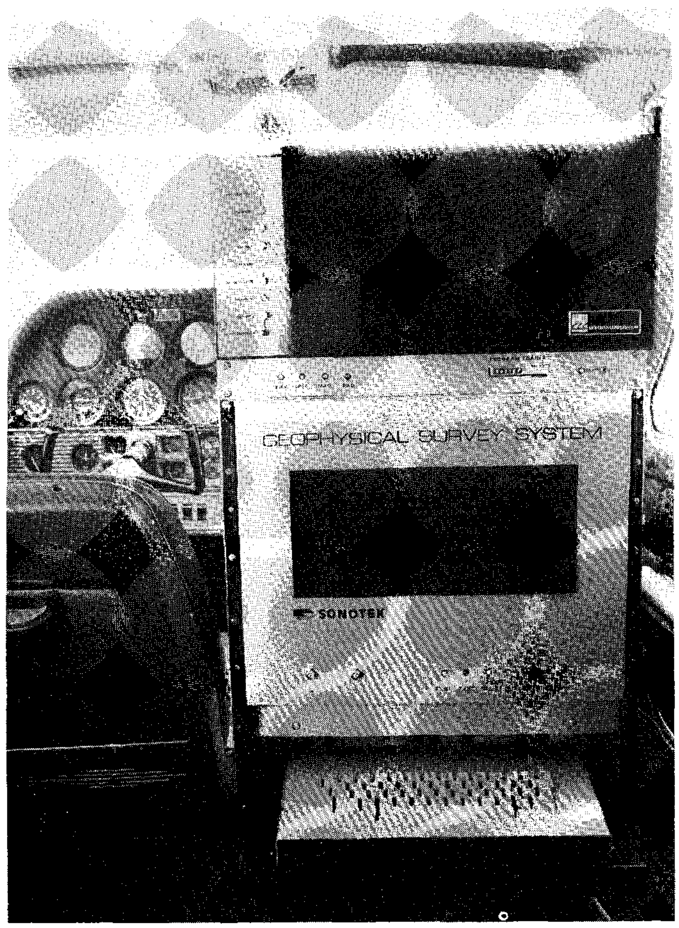

Figure 23.1. *Model IGSS Minicomputer-controlled digital acquisition system; Sonotek Ltd., Mississauga, Ontario. (GSC 203492-M)*

Each system may also contain a cathode ray tube (CRT) display, a keyboard and in some cases a low speed printer in addition to the ubiquitous analog chart recorder for display of the digital data.

The following North American companies have built state-of-the-art digital acquisition systems:

1) Applied Geophysics, Salt Lake City, Utah

2) Geometrics, Sunnyvale, California, U.S.A.

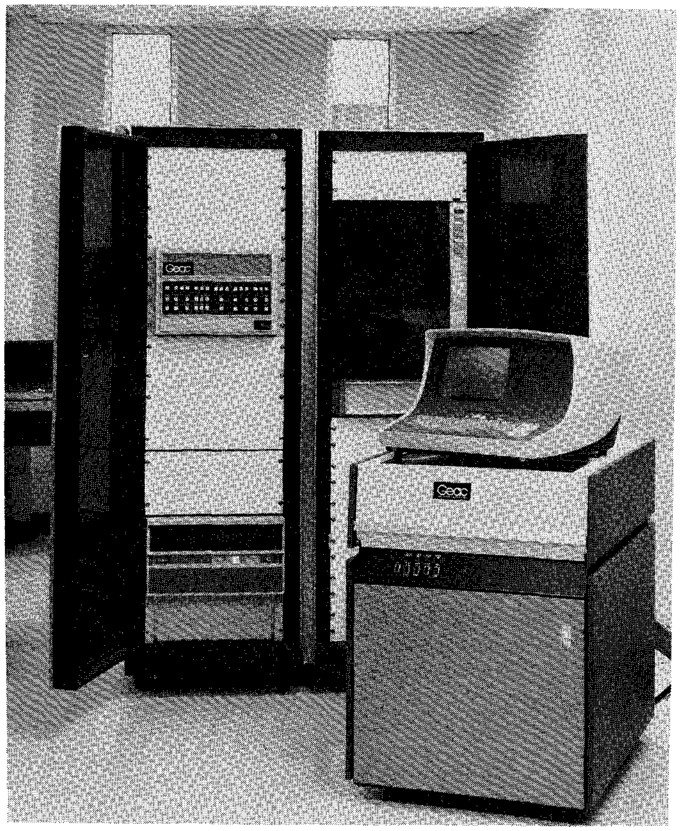

Figure 23.2. *Geac Minicomputer system; Dataplotting Services Inc., Don Mills, Ontario. (GSC 203492-N)*

3) Geoterrex, Ottawa, Canada
4) Kenting, Ottawa, Canada
5) McPhar Instruments, Toronto, Canada
6) Sander Geophysics, Kanata, Ontario
7) Sonotek, Mississauga, Ontario, Canada.

This list gives an indication of the number of systems available in North America; other systems have been fabricated in Europe and elsewhere. Figure 23.1 shows a digital acquisition system, manufactured by Sonotek, installed in a single engine light aircraft. Sonotek has stated that the system is so reliable and easy to operate that it has been flown without an instrument operator with the pilot and copilot/navigator alone in the survey aircraft.

The Minicomputer

Today's minicomputer systems are similar in capability to the large 1967 systems, such as the IBM 7094 and the Univac 1108 computers, at about one-tenth of the purchase price. A typical minicomputer system presently costs about $150 000 U.S. Some of the more popular systems are manufactured by Digital Equipment Corp., Data General, and Hewlett Packard. There are many other reputable manufacturers and a user should select the system most suited to his needs and his budget.

Both batch mode and interactive mode are important on any system. In batch mode, a job is submitted to the computer and the user waits for the job to be completed and examines the results. In interactive mode a job is submitted to the computer and intermediate results are usually displayed on a terminal; the computer may request data or instructions from the user in order to continue with the computations.

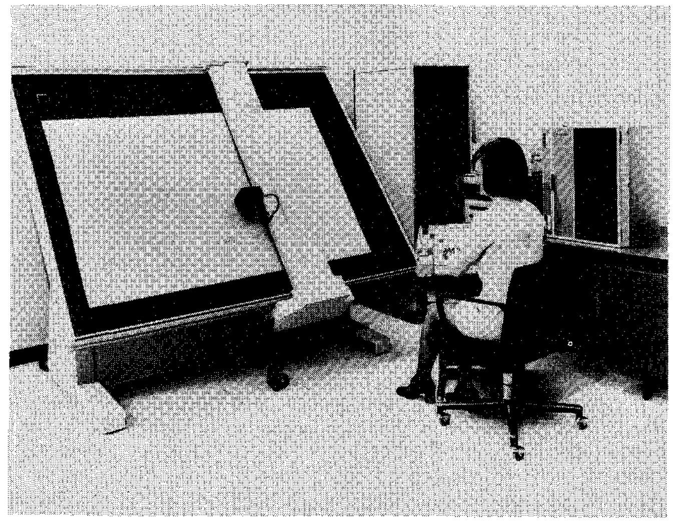

Figure 23.3. *Gerber Model 22 Flatbed Plotter; Dataplotting Services Inc., Don Mills, Ontario. (GSC-203492-P)*

Figure 23.2 shows a minicomputer system which consists of the following components: a central processing unit (CPU) with 64K (K=1024) bytes of memory, a 9-track magnetic tape drive, a 60 million character disk drive, a 300 line per minute printer, a 300 card per minute card reader, and 3 CRT terminals.

Interactive Graphics Terminals

The most popular interactive graphics terminals are made by Tektronics. These terminals are usually connected to a computer system so that graphics data such as curves, profiles, and contours can be displayed on a CRT. The functions that a user is allowed to perform at the graphics terminal are totally dependent upon the program in the computer system that controls the terminal.

Plotting Devices

In 1967, the drum plotter was the only commonly-available plotting device. By 1977, the drum plotter was still greatly utilized but its speed and quality were vastly improved. Flatbed plotters and electrostatic plotters have now come into general use. A colour plotter has just become commercially available.

The drum plotter remains the most popular plotting device because of its cost and ease of operation. Plots can be created that are up to 36 inches (91.4 cm) in width and up to 120 feet (36.6 m) in length. Plot width and length varies from model to model. From one to four ballpoint or ink pens are used simultaneously to create the plot.

The flatbed plotter is more expensive and more difficult to operate than the drum plotter but it can produce a much higher quality plot. Ink on mylar plots can be of drafting quality. The largest flatbed plotter in general use can produce drawings up to 4 feet by 7 feet (1.2 x 2.1 m). Larger flatbed plotters are used for aircraft and ship design.

The electrostatic plotter, available in widths up to 72 inches (182.9 cm), can produce a plot several times faster than a drum or flatbed plotter but the quality is not as good. The resolution is 0.005 inch (0.013 cm) (200 dots/inch) compared to an increment size of 0.0002 inch (0.0005 cm) for a flatbed plotter. Figure 23.3 shows a Gerber Model 22 flatbed plotter.

ADVANCES IN COMPILATION SOFTWARE

Lower cost computer time, interactive terminals, and better quality plotters have encouraged a great deal of development in programming for the purposes of data compilation and data analysis. The Geological Survey of Canada specifications for airborne gamma ray spectrometer and magnetometer data have also required that survey contractors in Canada become very computer conscious.

Most computer groups or computer departments involved in the processing of geophysical data have developed their own computer programs and subroutines. The methods can vary widely from group to group and are dependent on such things as the type of computer used, the type of data being processed, and the preferences of the individuals involved. The most important advances have been made in gridding and contouring programs (Walters, 1969; Crain, 1970; Crain, 1972; Wren, 1975). In 1967, contour maps were plotted on drum plotters, with a coarse grid size, and were often not considered to be a final product. Today, greatly improved software and better quality plotters have permitted the production of high quality final contour maps.

The cost of computer compilation is generally less than the cost of manual compilation but the great advantage of computer compilation is its speed. Large volumes of data can be processed many times faster by computer than by manual methods.

EXAMPLES OF SOFTWARE APPLICATION

Aeromagnetic Survey Compilation

The key to processing large volumes of digital data is the early detection of errors. The detection process starts with the digital recording system in the aircraft and continues in the data processing centre. The data processing centre must be capable of quickly performing editing operations. This is best accomplished using an interactive terminal to view the data and enter any corrections.

The following operations, involved in the compilation of a typical aeromagnetic survey for mining exploration, demonstrate the extent to which computer graphics are utilized.

(a) Digital Data: The digitally-recorded survey data are copied from magnetic tape to a computer disk file. The data are reformatted into a format which is readily usable by the computer. Any "bad" data are displayed on a CRT terminal and are corrected by compilation personnel.

(b) Flight Path Position Data: The flight line is digitized from the base map and entered into the computer. A computer program calculates the average speed of the survey aircraft between the picked points and plots these speeds in the form of a bar chart so that inconsistencies are easily recognized. This is generally referred to as a "speed check".

(c) Rough Contour Maps: Several preliminary or rough contour maps are drawn to establish whether errors may be detected in the contoured data, e.g. herringbone patterns indicate poor levelling.

This is an iterative process of finding errors, correcting the data and plotting another contour map. From three to six "rough" contour maps may be necessary to complete the editing operation.

(d) Final Contour Map: The final contour map, such as the one shown in Figure 23.4, is plotted with black ink on a stable base material. A flatbed plotter generally gives the best quality and accuracy. Flight lines and fiducial locations may be plotted onto the contour plot or onto a separate overlay. In order to achieve a high quality final map it is necessary to use a small grid size (0.25 cm or smaller) which accurately represents the original data and to use a contouring method which gives an accurate and visually pleasing presentation of the data. Holroyd (1974) has described the computer-oriented aeromagnetic data compilation system developed at the Geological Survey of Canada.

Aeromagnetic Interpretation

Since 1967, a much wider acceptance of the computer and computer graphics (Smith et al., 1972) in the interpretation of geophysical data has occurred. Firstly, the availability of the data in digital form has allowed the interpreter a great deal more freedom to assess the data, particularly in profile form at whatever scale he chooses. To some interpreters, a surprising amount of useful information can be gleaned from profiles e.g., the two-gamma faults discussed by Friedberg (1976). In 1967, computer-plotted profiles of aeromagnetic data were the normal product of high sensitivity surveys for petroleum exploration, because only in these surveys was the higher cost of digital acquisition really accepted.

Figure 23.5 shows the advantages gained by digitally recording the output from the magnetometer in the aircraft with the magnetometer on the ground serving as a diurnal monitor; namely

1) compensation for diurnal variation,
2) altitude correction, and
3) rectification to constant horizontal scale.

Other operations carried out to aid in the analysis of aeromagnetic profiles include various kinds of filtering (especially to remove high frequency noise) and the production of vertical/horizontal derivatives to help differentiate overlapping anomalies.

Model curves are generated by the computer on a routine basis to assist the analyst in the identification of anomalies, the location of contacts, the computation of depth to magnetic basement, and to give various other forms of information. Figure 23.6 shows an example of magnetic anomalies computed over a prism model for various combinations of prism width and strike length. Model curves of this nature help familiarize the analyst with anomaly characteristics at a particular magnetic latitude.

Automatic Aeromagnetic Profile Interpretation

Major development work in the field of automatic anomaly analysis was carried out just prior to 1967 by a research group associated with Aero Service of Philadelphia. The technique that they developed was called Werner Deconvolution (Hartman et al., 1971). In the deconvolution technique, anomalies were first resolved and then both prismatic and laminar models were used to determine depth, horizontal position, dip and magnetization of the causative source. Figure 23.7 shows an example of its application, taken from a 1977 Aero Service brochure. This profile illustrates how the following major geological features are discerned;

(A) major vertical contact,

(B) vertical dyke,

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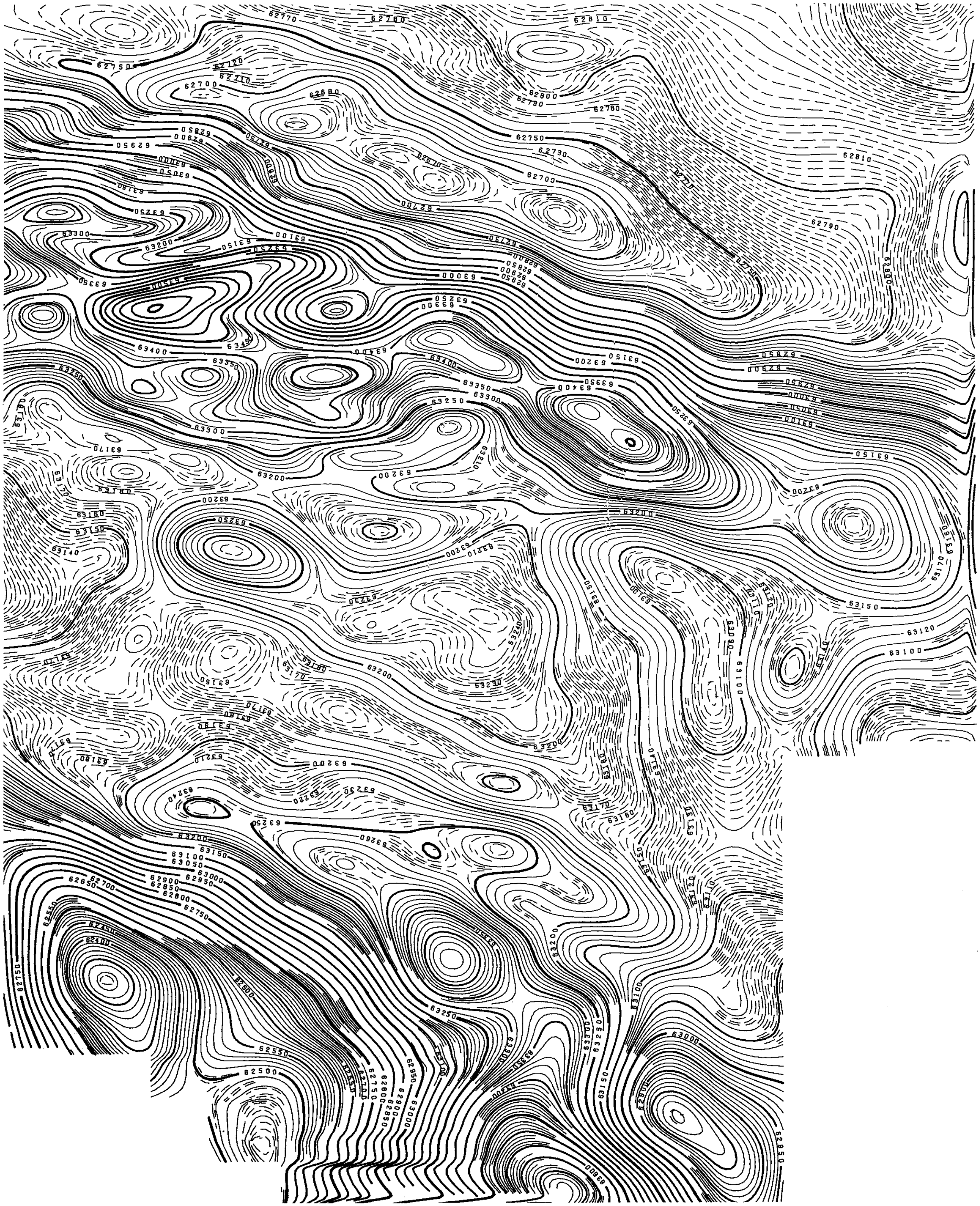

Figure 23.4. *A typical aeromagnetic contour map; Dataplotting Services Inc., Don Mills, Ontario.*

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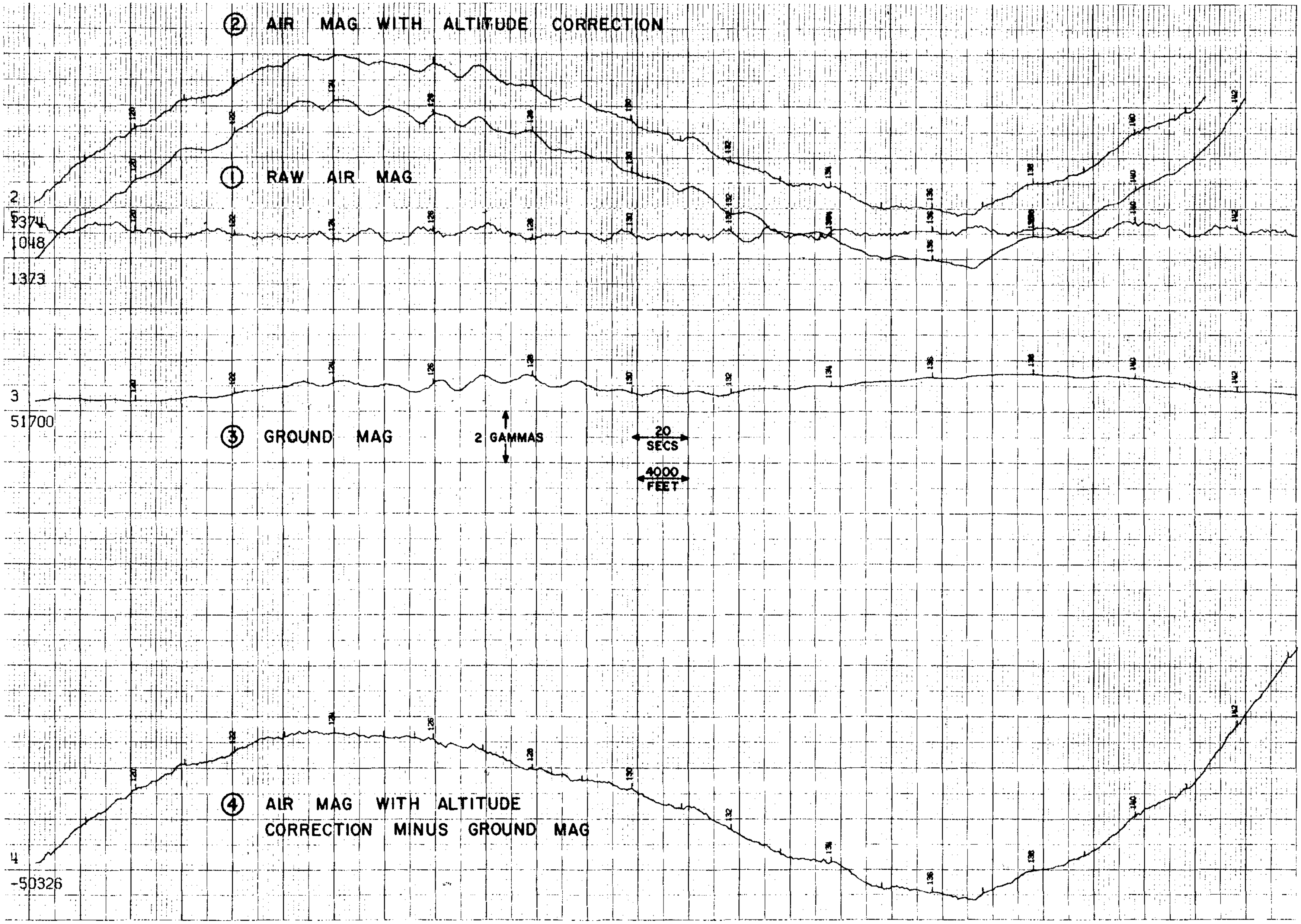

Figure 23.5. *Correction of aeromagnetic data for diurnal and altitude variation; Geoterrex Ltd., Ottawa.*

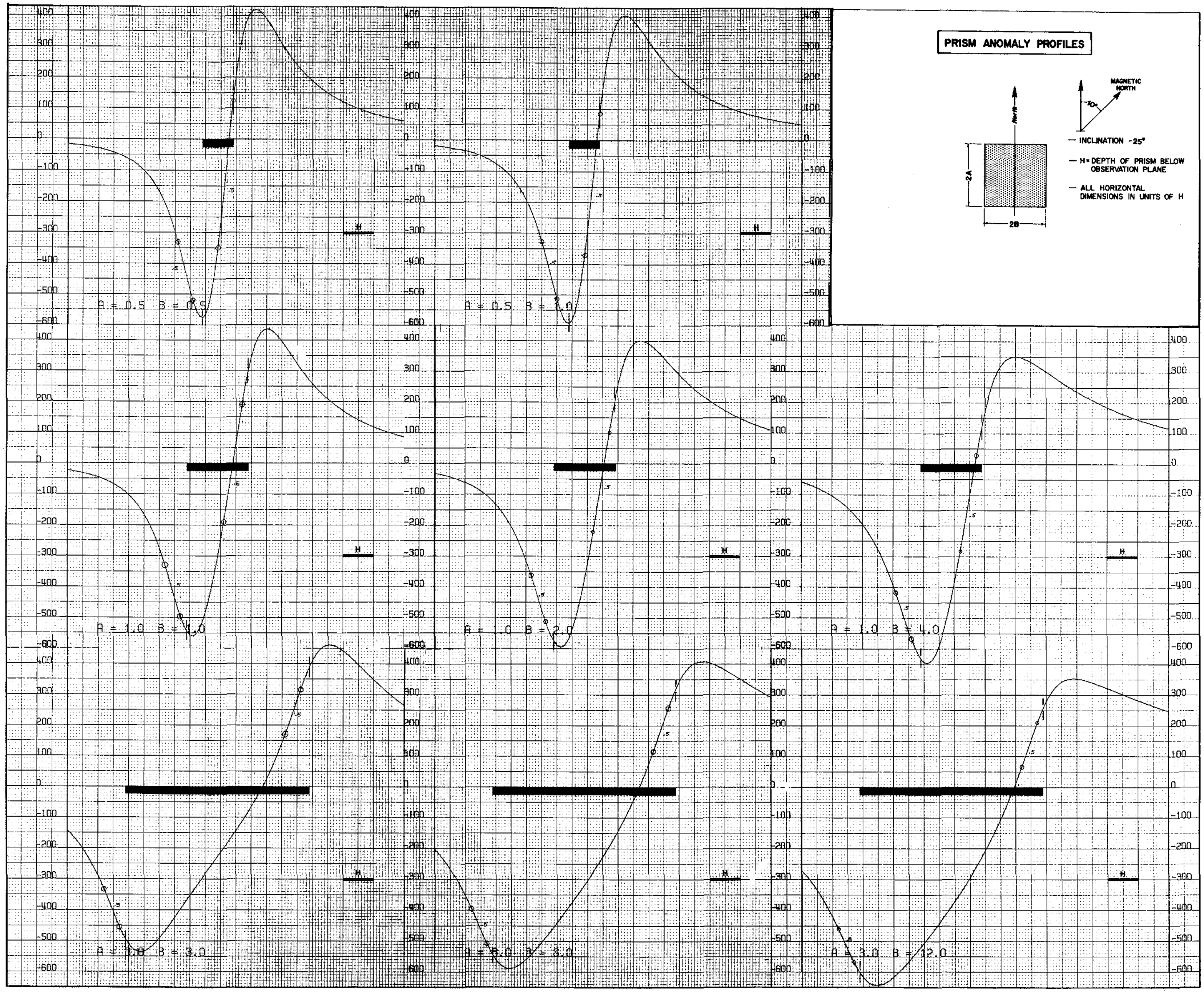

Figure 23.6. *Synthetic magnetic profiles over a vertical prism model at latitude 25°S for various geometries.*

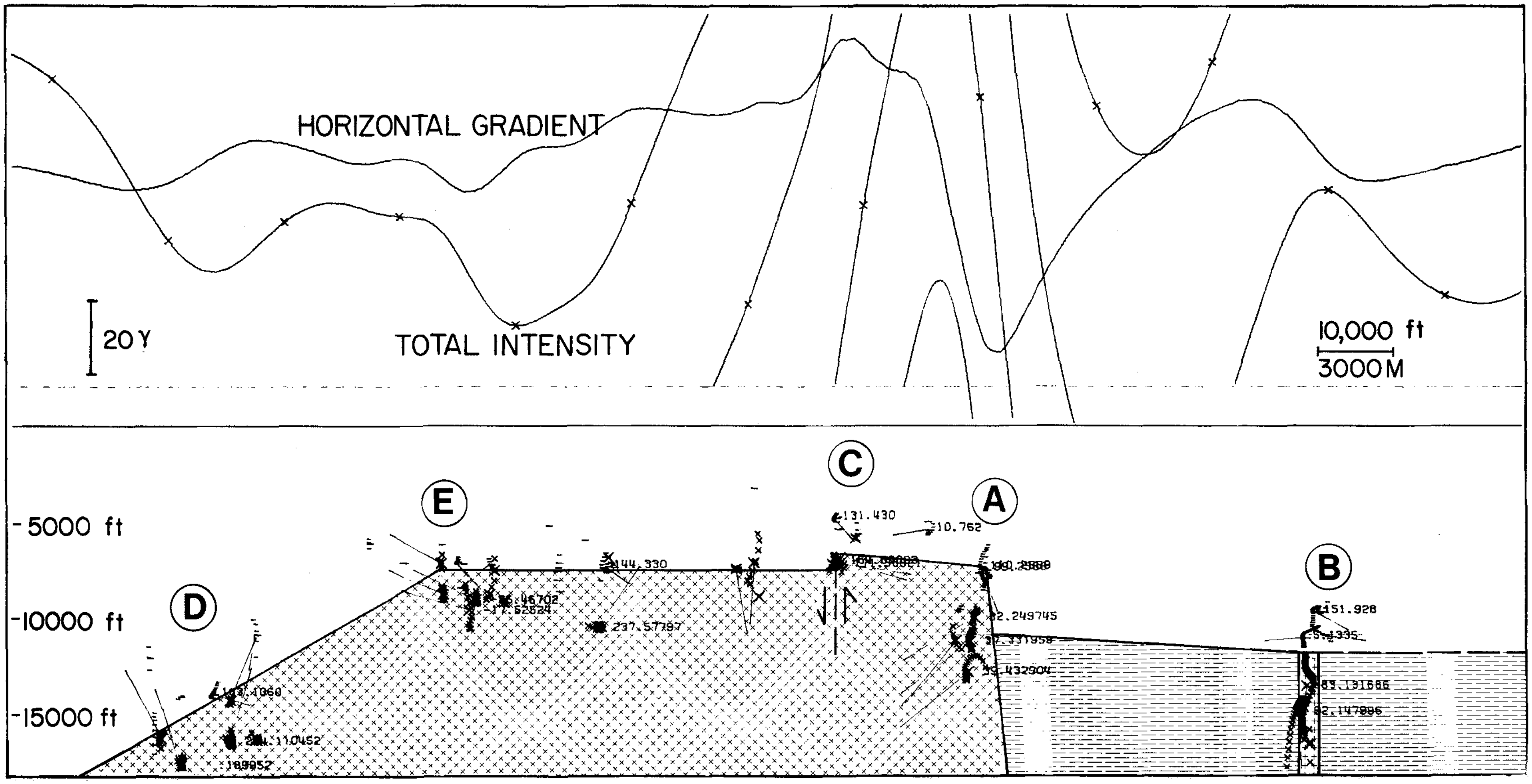

Figure 23.7. *Automatic aeromagnetic interpretation by Werner Deconvolution, Aero Service Corp., Houston.*

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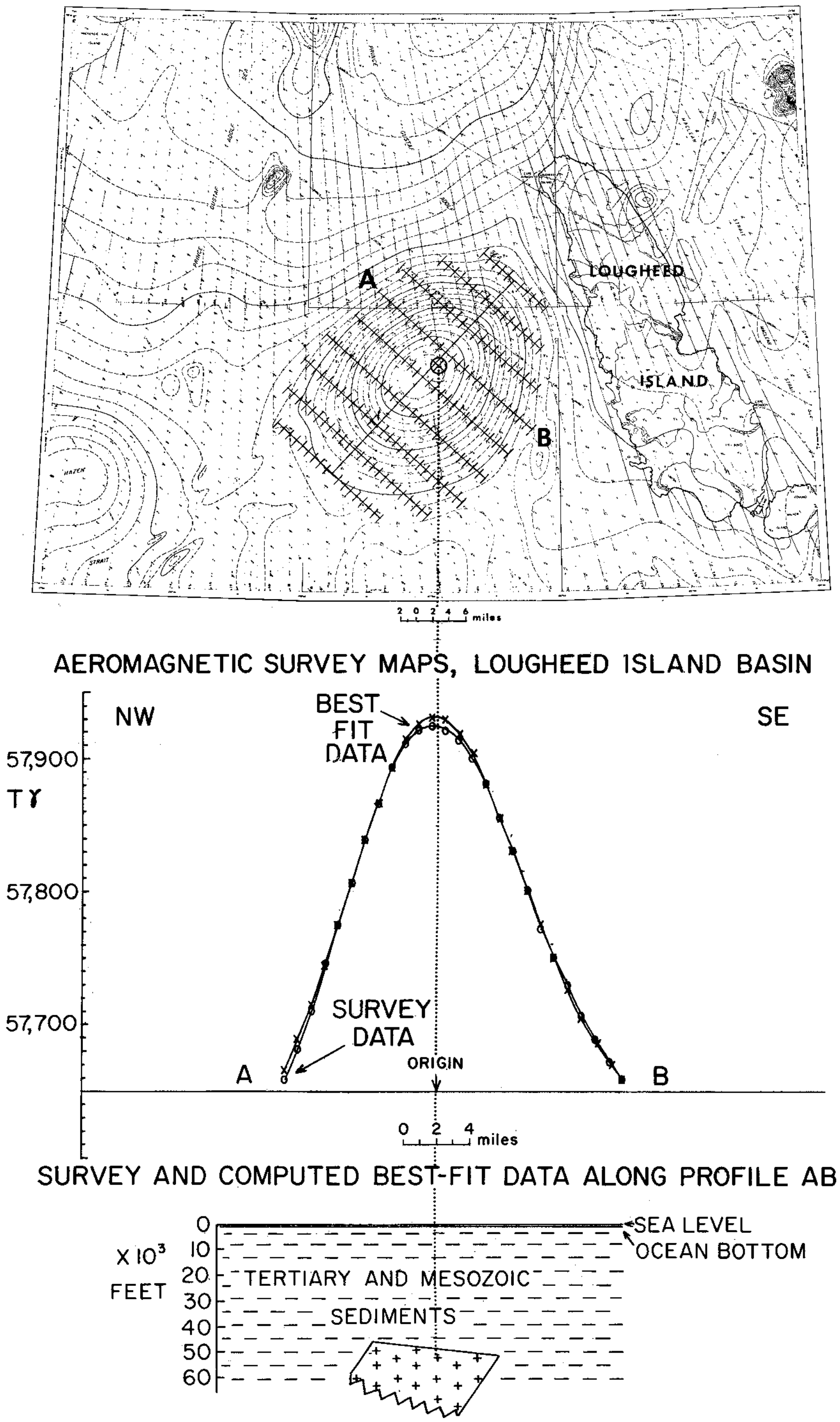


Figure 23.8. *Least-squares fit of model to aeromagnetic data (from McGrath and Hood, 1973).*

(C) fault of small throw, and

(D) and (E) reversely magnetized zones.

However, a great deal of effort is still required to synthesize all of this output information to interpret basement configuration. A similar automated interpretation technique has been developed recently by Compagnie Generale de Geophysique of Paris and is offered by Geoterrex of Ottawa. Compu-Depth is another computer-oriented interpretation technique offered by Geometrics of California (O'Brien, 1971), which maps basement depth and structure by utilizing Fourier and Hilbert transformations. A semi-automatic method of magnetic curve fitting has been developed by McGrath and Hood (1973) in which a wide range of geological features may be synthesized using combinations of the thin plate model. Using an iterative procedure, the computer program achieves a best least-squares fit, as is shown in Figure 23.8.

Some of the major obstacles in the application of the various methods listed above are described as follows:

(1) the data must be carefully edited in advance;

(2) there is a problem in defining background or regional levels;

(3) two-dimensional causative bodies are often assumed;

(4) a very high degree of manual interaction is often required to synthesize the results into plausible geology; and

(5) the high cost of computer processing versus manual or graphical methods must be considered.

Aeromagnetic Map Analysis

In the last 10 years, there has been a very strong swing toward the computer processing of airborne geophysical data, particularly aeromagnetic data. Today, there are few geophysical contractors that do not have access to packaged programming to do a wide range of analytical operations, including the computation of complex model anomalies. Particular emphasis, however, has been placed on the application of Fourier transformation for purposes of analysis of the data in the frequency domain and especially to perform linear filtering. Because of this heavy emphasis, this paper elaborates on the subject of spectrum analysis, matched filtering and the various other linear filtering operations that are possible through Fourier transformation and are only feasible techniques if the computer is utilized in carrying them out.

Spectrum Analysis and Matched Filtering

Matched filtering of aeromagnetic maps has been found to be particularly useful in areas of volcanic cover e.g., the southwestern U.S.A. to obtain the following information:

(a) identification of buried intrusives, as well as regional structure concealed by the volcanic cover, and

(b) variations in the thickness of the volcanic cover, i.e., where it is excessively thick.

Matched filtering is based on an analysis of the computed energy spectrum of an aeromagnetic map. From spectrum analysis, a picture of the physical make-up of the data is gained. In the spectrum, contributions in the magnetic data from the following sources can be distinguished:

(a) shallow or near-surface features,

(b) regional lithologic and structural features, or

(c) deep-seated features.

Contents

ENERGY SPECTRUM ANALYSIS

1. Compute Fourier Transform

$$\Delta\bar{T}(f_x, f_y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \Delta T(x,y) \cdot H(x,y) \cdot e^{-2\pi i(f_x \cdot x + f_y \cdot y)}\, dx\, dy$$

where $H(x,y) = \frac{1}{4}\left(1 + \cos\frac{2\pi x}{L_x}\right) \cdot \left(1 + \cos\frac{2\pi y}{L_y}\right)$ "Data Window"

2. Compute Energy Spectrum and Radial Component

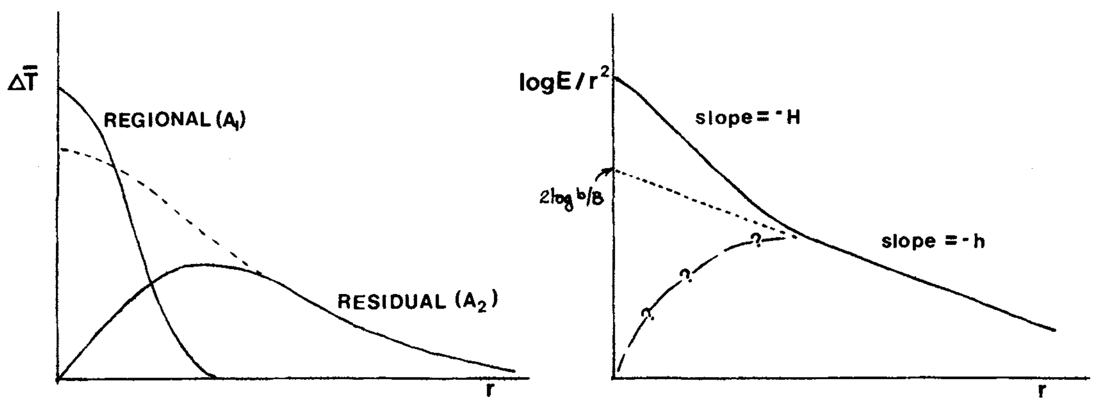
$$E(f_x, f_y) = |\Delta\bar{T}|^2$$

$$E(r) = \frac{1}{2\pi}\int_0^{2\pi} E\, d\theta$$

where $\theta = \tan^{-1}(f_x/f_y)$ "azimuth"

$r = 2\pi\sqrt{f_x^2 + f_y^2}$ "radial frequency"

3. Analysis



$$\Delta\bar{T}(r) = A_1(r) + A_2(r)$$

$$\therefore E(r) = (A_1(r) + A_2(r))^2$$

Approximations $A_1 \simeq Be^{-Hr}$

$A_2 \simeq be^{-hr}$

$$\therefore E(r) = \left(Be^{-Hr}\left(1 + \frac{b}{B}e^{(H-h)r}\right)\right)^2$$

$$E(r) = A_1^2 \cdot 1/W^2$$

$\therefore$ set Filter Transfer Function $W(r) = 1/\left(1 + \frac{b}{B}e^{(H-h)r}\right)$

Figure 23.9. *Energy spectrum analysis and design of a matched filter.*

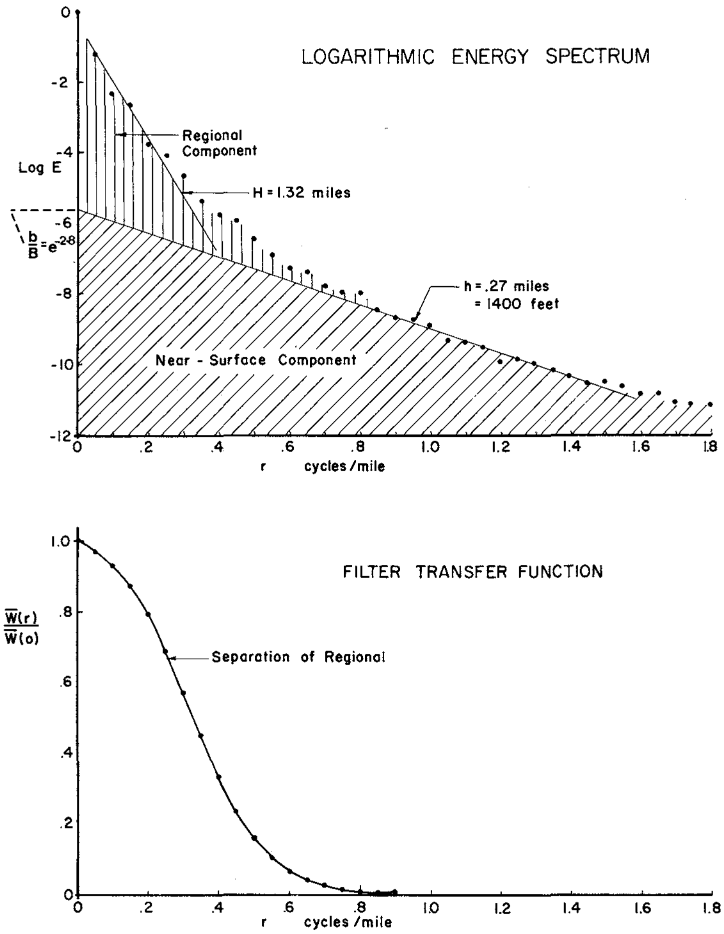


Figure 23.10. *An example of a logarithmic energy spectrum and a corresponding filter transfer function.*

Figure 23.9 describes some of the computational steps involved:

- computing an estimate of the Fourier Transform or "Complex Spectrum" after first multiplying the data by a "Data Window" to avoid distortion in the spectrum caused by abrupt edge effects;
- taking the modulus of the Complex Spectrum to obtain the Energy Spectrum; and
- averaging the Energy Spectrum with respect to azimuth on the frequency plane in order to view the drop-off of the logarithmic spectrum with radial frequency.

In Step 3, spectrum analysis is done. Based on the appearance of the spectrum, i.e., changes in the slope of the spectrum curve, the spectrum is divided into two components:

(a) shallow origin or Near-Surface Component; the slope of high frequency part of the curve gives us the average depth to magnetic sources: h

(b) the Regional Component which dominates the low frequency or the long wavelength part of the spectrum.

The complex spectrum may be approximated as

$$\Delta\bar{T}(r) = A_1(r) + A_2(r)$$

with the following approximations:

$$A_1(r) = Be^{-Hr} \quad \text{(Regional Component)}$$

$$A_2(r) = be^{-hr} \quad \text{(Near-Surface Component)}$$

so that

$$E(r) = (Be^{-Hr}(1 + \frac{b}{B}e^{(H-h)r}))^2$$

$$= (A_1 \cdot (W)^{-1})^2$$

$$= ((\text{Regional Component})\cdot(\text{Filter Transfer Function})^{-1})^2$$

Matched filtering consists of multiplying the Fourier Transform of an aeromagnetic map by the Transfer Function W in order to separate out the Regional Component. The parameters for definition of W; H, h and b/B, are determined directly from a graphical analysis of the energy spectrum curve, i.e., its logarithmic, radial component.

It is implicit in the preceding discussion that the slopes of each of the two parts of the spectrum curve are due to differences in depth between (a) the Near-Surface Sources and (b) the Regional Sources. Actually, the slope of the spectral curve, to a large extent, is decided by the size or cross-section of the causative sources; the larger the source the more long wavelength spectral composition and therefore, the greater the slope of the spectral curve.

According to Spector (1968), a correction can be applied to the spectral curve to correct for the size effect, if some measure of average body size can be made.

For the limited purposes of the analysis, it is preferable to lump the depth and size effects together, i.e., to treat the slope as indicating an apparent depth, H, which we understand, is in excess of the true average depth to the deeper magnetic basement. Figure 23.10 shows an actual example of a computed energy spectrum and the corresponding filter transfer function.

Figure 23.11 shows a comparison between the original aeromagnetic map and the filtered result, the Regional Component. The major feature in the filtered map is a large granitic intrusive.

Other Forms of Linear Filtering

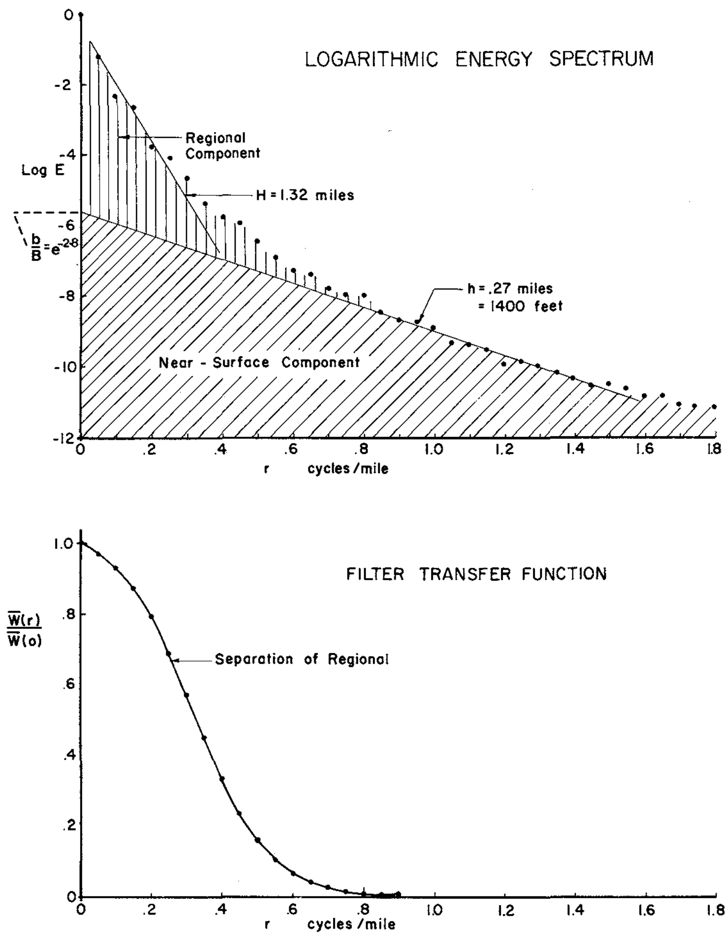
Figure 23.12 shows how matched filtering is just one of several types of linear filter operators that can be effectively used through Fourier transformation as follows:

1) downward/upward continuation,

2) magnetic pole reduction,

3) pseudo-gravity transformation (see Fig. 23.13).

In addition, susceptibility mapping, a computer processing service offered by Paterson, Grant and Watson Ltd. of Toronto, has been applied rather extensively. An example is shown in Figure 23.14. The upper part of the figure is part of an aeromagnetic map published by the Geological Survey of Canada; the contour interval is 10 gammas. The lower part is the corresponding susceptibility contour map; contour interval is 0.5×10^{-3} e.m.u. A similar process described as "Magnetization Mapping" is offered by Geometrics of California.



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2) magnetic pole reduction,

3) pseudo-gravity transformation (see Fig. 23.13).

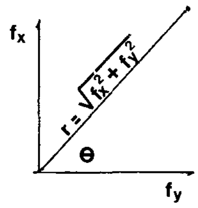
In addition, susceptibility mapping, a computer processing service offered by Paterson, Grant and Watson Ltd. of Toronto, has been applied rather extensively. An example is shown in Figure 23.14. The upper part of the figure is part of an aeromagnetic map published by the Geological Survey of Canada; the contour interval is 10 gammas. The lower part is the corresponding susceptibility contour map; contour interval is 0.5×10^{-3} e.m.u. A similar process described as "Magnetization Mapping" is offered by Geometrics of California.

Contents

DECONVOLUTION OF AEROMAGNETIC DATA

1. Compute Fourier Transform:

$$\Delta\overline{T}(f_x, f_y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \Delta T(x,y)\cdot e^{-2\pi i(f_x\cdot x + f_y\cdot y)}dx\, dy$$



2. Apply Filter Transfer Function (W)

$$\boxed{\Delta\overline{T}_F = \Delta\overline{T}\cdot W}$$

where

$$W_{MF} = \left\{1 + \frac{b}{B}e^{(H-h)r}\right\}^{-1}$$ Matched Filtering

$$W_{DC} = e^{Zr}$$ Downward Continuation

$$W_{MP} = \{\sin I_E + i\cos I_E\cdot\sin(D_E+\theta)\}^{-2}$$ Magnetic Pole Reduction

$$W_{PG} = \frac{G}{4T_o}\left(\frac{\Delta\rho}{\Delta k}\right)\frac{e^{\Delta hr}}{r}\cdot W_{MP}$$ Pseudo Gravity Transformation

where

$\frac{b}{B}$, H, h: matched filter parameters from energy spectrum analysis,

Z: the depth of continuation,

I_E, D_E: inclination and declination of the earth's magnetic field,

G: Universal Gravitational Constant

T_o: Geomagnetic Field Intensity

Δk: average susceptibility contrast

$\Delta\rho$: average density contrast

Δh: mean separation between aeromagnetic survey altitude and gravity survey elevation.

3. Compute Inverse Fourier Transform:

$$\Delta T_F(x,y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \Delta\overline{T}(f_x, f_y)\cdot W\cdot e^{2\pi i(f_x\cdot x + f_y\cdot y)}\, df_x\, df_y$$

Figure 23.12. *Deconvolution of aeromagnetic data; various types of linear filtering.*

Computer Processing of Airborne Electromagnetic (AEM) Data

Compilation of Input EM Data

The Input EM method was developed by Barringer Research of Toronto and is in extensive use. Two survey contractors are licensed to fly Input: Questor Surveys of Toronto and Geoterrex of Ottawa. The Input data collected by Questor are processed in the following manner: (1) the data are copied from the digitally recorded data tape to a computer disk file, (2) the data are then displayed on a graphics terminal and an operator flags EM anomalies and associated magnetic highs, and (3) a computer program calculates the value of the conductivity-thickness product from the anomaly and plots a map of the anomalies. The use of the computer/plotter combination allows the processing of large volumes of data in a much shorter period of time than by manual methods. The cost is also less for large volumes of data, than by manual methods.

Compilation of Dighem Data

The Dighem EM system was developed by Barringer Research of Toronto and is flown by Dighem Ltd. of Toronto (Fraser, 1972). The data are processed by computer and a stacked profile plot is produced for each line of data. All recorded data as well as several computer calculated profiles are plotted. The calculated profiles show anomaly enhancement and the suppression of surface conductivity. An example of a Dighem profile over the Montcalm orebody in Quebec is shown in Figure 23.15.

The Computer Processing of Gamma ray Spectrometer Data

The computer processing of gamma ray spectrometer data has undergone important developments during the past decade which are likely to continue for many more years. Larger crystal sizes and improved technology has resulted in more reliable data and computer processing techniques have improved the presentation of the data, either in the form of contour maps or stacked profiles. The recording of "full spectrum" data, up to 1024 channels, is one of the latest survey developments to become commercially available.

The computer processing operations for the compilation of gamma ray spectrometer data consist of the following steps:

(a) determination and subtraction of background radiation levels,

(b) correction of the data for variations in survey altitude, and

(c) corrections for Compton scattering.

These operations were described in detail by Grasty (1972).

Due to the presence of a fairly large component noise it is often desirable to filter the data prior to contouring. Total count and uranium contour maps are normally produced, while thorium, potassium, and the ratio maps (U/Th, U/K, Th/K) are produced selectively. Perhaps the most useful presentation is the stacked profile. This is a separate data plot for each flight line and usually nine parameters are displayed: Total Count U, Th, K, U/Th, U/K, Th/K, altimeter, and magnetometer. Figure 23.16 is an example of such a plot.

Processing of Ground Geophysical Data

Gravity Data

There has been a continued shift towards utilization of computer processing of gravity data for two main reasons:

(a) to reduce the time and cost of data reduction, and

(b) to increase the ability to distinguish what is significant in the measurements.

Low cost, portable desktop programmable computers have become an essential requirement to perform preliminary data reduction after each day's survey production. An example of a field minicomputer is the Hewlett-Packard Model 9820A which has a memory capacity of 1477 words. Gravity in measurements can be stored on a cassette tape.

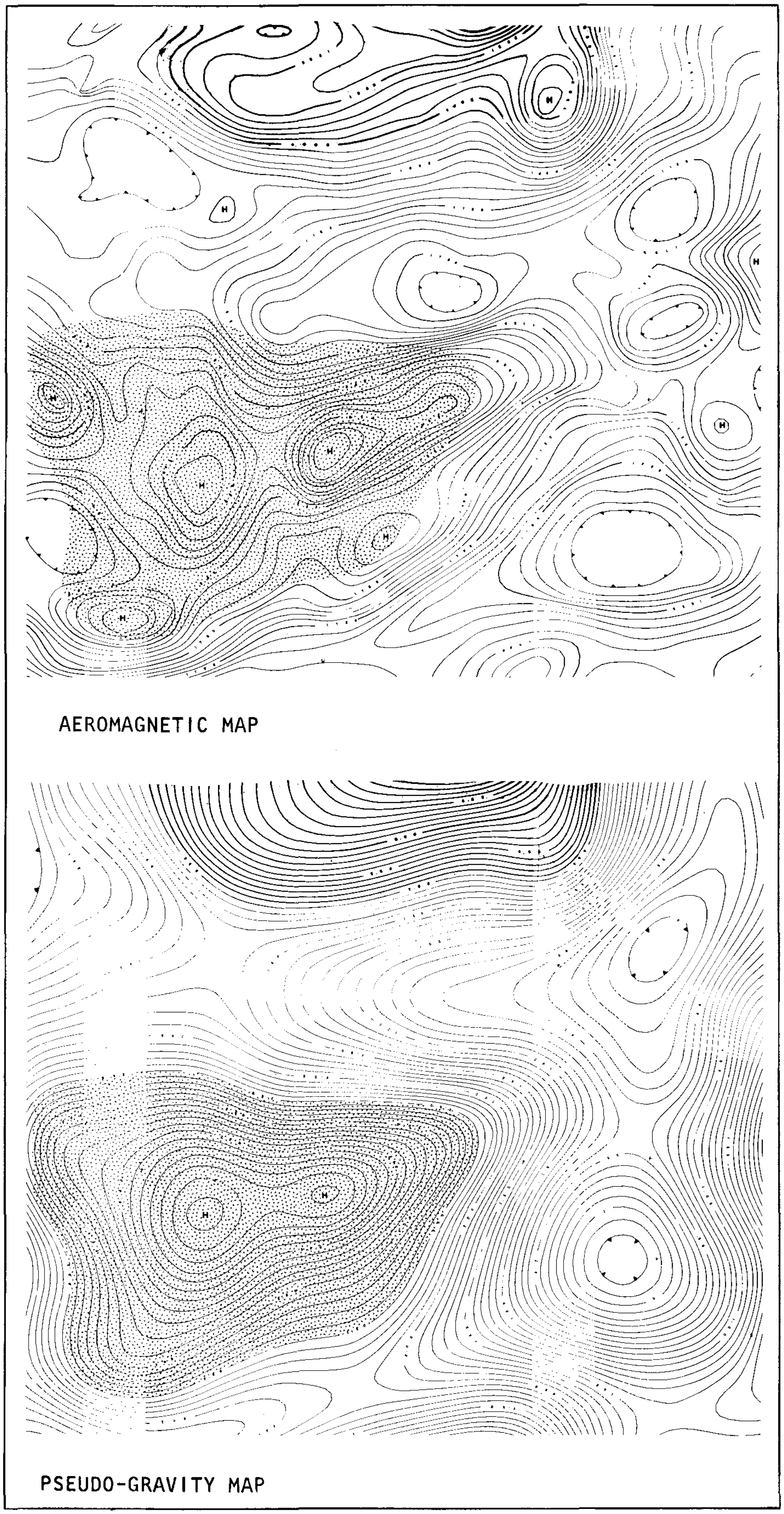


Figure 23.13. *An example of pseudo-gravity transformation.*

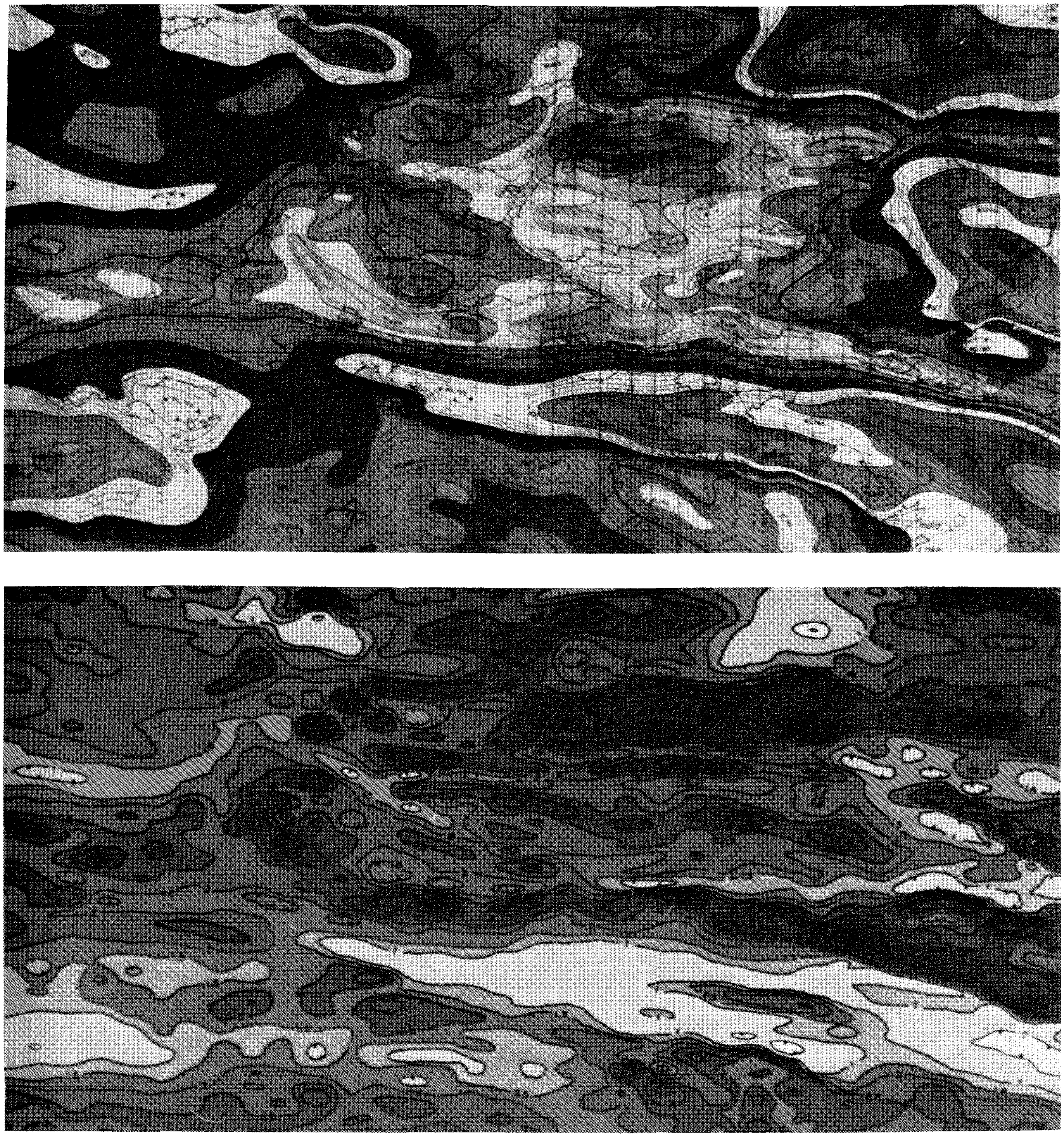


Figure 23.14. *An example of susceptibility mapping; Paterson, Grant and Watson Ltd., Toronto. (GSC 203492-O)*

Terrain correction programs have been developed by a number of contractors and government agencies, e.g. Stacey and Stephens (1970). There are many types of gridding and contouring packages available which are particularly suited for gravity data, e.g., Hessing et al. (1972). Linear filtering through Fourier transformation has been introduced gradually to attack the fundamental problem of regional/residual separation, in place of the older trend-fitting approaches. Grant (1972) has given an excellent discussion of this problem.

Iterative model-fitting interpretation programs are widely used, particularly for problems that can be solved using a single density interface, e.g., the thickness of a buried salt mass, whose upper or lower surface is known in advance.

Contents

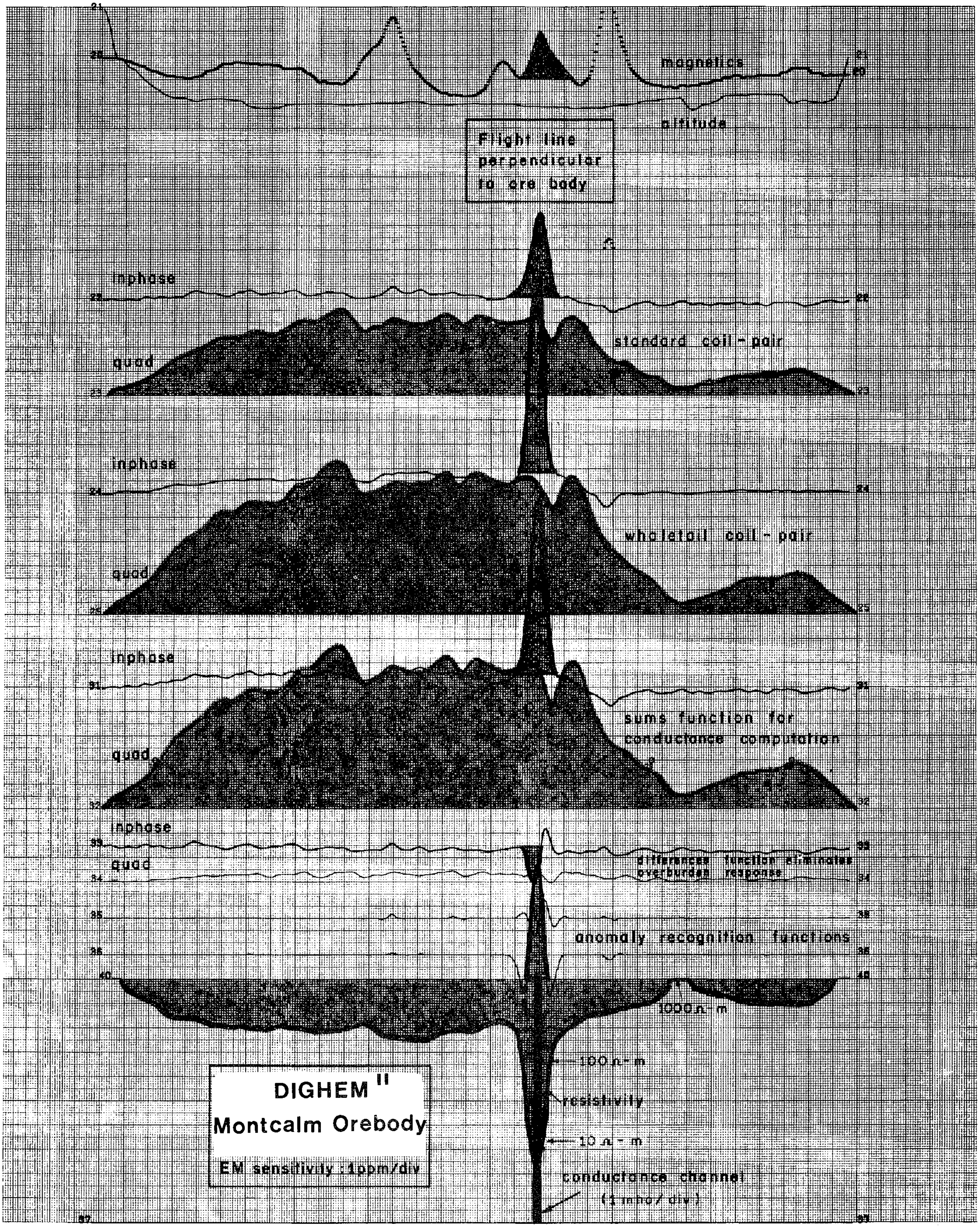


Figure 23.15. *Dighem II computer processed data over the Montcalm Deposit; Montcalm Township, Ontario, Dighem Ltd., Toronto.*

Contents

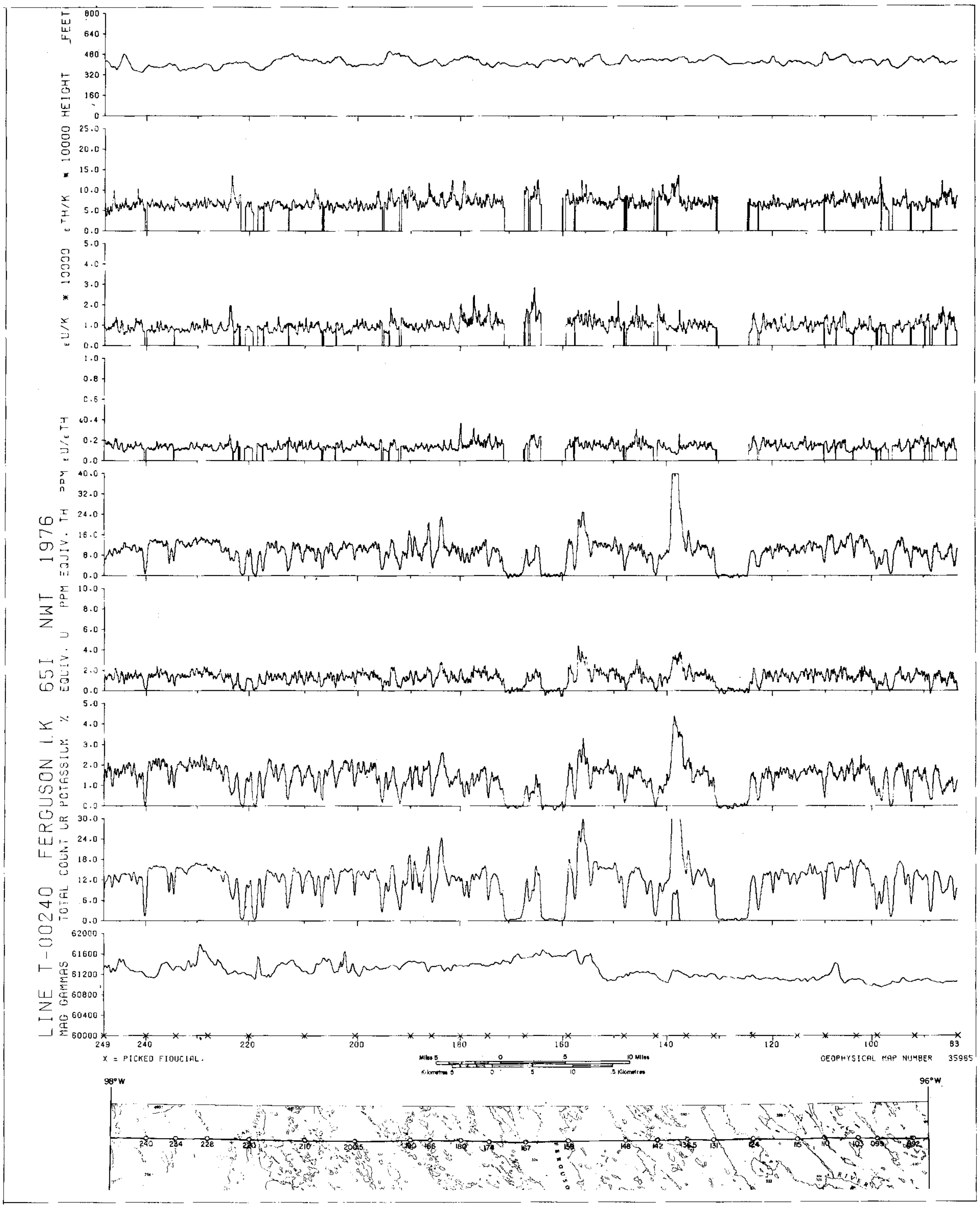


Figure 23.16. *Stacked profile representation of spectrometer survey data; Dataplotting Services Inc., Don Mills, Ontario.*

Magnetometer and Electromagnetic Data

Computer compilation of ground magnetometer and electromagnetic data is becoming quite common. With regard to VLF electromagnetic surveying, computer processing is useful for the compilation of such data because of the need for filtering (smoothing) and for computing the horizontal derivative of the in-phase component.

FUTURE TRENDS

Increased Computer Utilization

If the present trend to lower prices of computer hardware is maintained, we can expect an even greater percentage of geophysicists to acquire either digital computers or computer services. Specifically, interactive graphics displays will become more and more commonplace as an ideal tool both for the initial screening of survey data and subsequent analysis including semi-automatic anomaly interpretation.

The Man/Computer Interface

Computer languages will continue to become more powerful and easier to use and computer operating systems and user programs will allow a greater usage of interactive terminals by the geophysicist. The computer is a powerful tool for the geophysicist and easier usage will expand its utilization.

Software Development

With multi-sensor surveys involving, in the case of gamma ray spectrometer data, simultaneous measurement of 512 or 1024 channels of data, there is a major demand for more comprehensive data analysis programming, e.g., the anomaly picker devised by Dighem (see Figure 23.15). Pattern recognition algorithms are currently the subject of much research, particularly the identification of soil and rock types from gamma ray spectrometer data.

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