# U. S. GEOLOGICAL SURVEY

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GEOPAC

by

Richard H. Godson
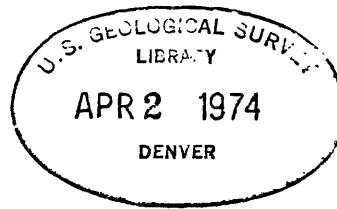
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ILLUSTRATIONS

PREFACE

The present result of combining several programs into one large overlay program would not have been possible without the previous work of many individuals in the U. S. Geological Survey and some outside the Survey. The Geopac system of programs was conceived and initiated by Gordon Andreasen of the Branch of Regional Geophysics a few years ago and he has been the prime mover behind the project. Walter Anderson, Dave Handwerker and Paul Zabel of the Computer Center Division were the persons mainly responsible for designing and coordinating the original programs in the system. Acknowledgement to several other people who wrote individual programs is given by citing their names with the subroutine titles under Contents. Recognition is also given herein to the authors of two subroutines that are not called directly but are an integral part of the package: PRPLOT (printer plot) by Peter Smidinger and CPLOT (printer contour) by Gary Selner.

As is necessary with a system such as this all programs were modified as to input and output and other modifications or additions were necessary sometimes to preserve the continuity of the program. However, in all cases an attempt was made to preserve the coding of the original author of the program. The original concept was to have two systems -- a two-dimensional and a three-dimensional system. This program combines both systems into one program and by doing this and using a catalogued procedure, Job Control Language cards are kept to a minimum and data sets can be passed quite easily between processing routines. The main reason for this approach was ease of use for the casual user.

All the subroutines are written in Fortran IV and compiled under the Fortan G compiler except for two small assembly language subroutines in the contouring subroutine. The program is now operational on an IBM 370/145 computer in Dhahran, Saudi Arabia with 140K bytes of main memory required, exclusive of the amount necessary for the various buffers. The three graphic subroutines are machine dependent as they are written for an EAI 430 plotter, but they can be quite easily changed to conform to other plotters.

The package consists of 24 subroutines that have been written up to the present time. It is anticipated that as new subroutines are written and suggestions and/or programs are certainly welcome, that the program will be updated from time to time.

R. H. Godson

Jeddah, Saudi Arabia
May, 1973

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Richard H. Godson

ABSTRACT

GEOPAC consists of a series of subroutines to primarily process potential-field geophysical data but other types of data can also be used with the program. The package contains routines to reduce, store, process and display information in two-dimensional or three-dimensional form. Input and output formats are standardized and temporary disk storage permits data sets to be processed by several subroutines in one job step. The subroutines are link-edited in an overlay mode to form one program and they can be executed by submitting a card containing the subroutine name in the input stream.

INTRODUCTION

GEOPAC is an acronym for geophysical package, a series of computer subroutines to process potential-field geophysical data. The present program was developed by combining several individual programs, written by many individuals, into one program in an overlay mode. This package contains subroutines that are called into memory from disk by a root program that is always resident in the computer. Only four Job Control cards are necessary for execution of this program.

The algorithms in the program reduce gravity and magnetic data, optionally store the data on permanent files for later retrieval, process the data by performing such transformations as upward continuation, digital filtering and surface fitting and then display results in graphic form on the printer and a plotter. Other types of data, for example, airborne radiation data, can also be processed by this program by preparing the data sets in the proper format in a previous job step. Explanation of the algorithms used and the necessary cards for execution are described under the individual subroutine sections.

Input may be profile data, random or gridded areal data. Random data may be gridded by subroutine GRID3D. The program will accept the input data from either the card reader, tape or disk, process and place the data sets on a temporary disk (Fortran reference number 11) in one of the two GEOPAC formats, depending on whether the data is in profile or gridded form. The subroutines that interpret the data place the output on temporary disk (Fortran reference number 15) in the same input format so that it can be reprocessed by any other appropriate subroutine. Since each of these subroutines automatically place output data at the start of the data set extent, any reprocessing should immediately follow the initial processing of data sets.

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The subroutines that optionally store data on permanent files, PROF2D, GRET3D and INPT3D have no provisions for updating, replacing or deleting data sets. If any of these operations are desired, a new data set name must be given to the data.

Each subroutine has certain built-in checks for the validity of information on the parameter cards and if an error is detected control is returned to the root program which prints an error message. However, execution continues by reading cards until a card with a subroutine name is encountered.

Several data sets can be processed with one call to a subroutine. This is made possible by the use of subroutine REREAD (transparent to the user), which is used throughout the program to control the flow of processing within a subroutine from one subroutine to another. REREAD is a routine that allows data that has been already read into an input buffer to be reread again with the same or different format without physical I/O.

The GEOPAC program was compiled in performance of the work agreement between the U. S. Geological Survey and the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia. The various subroutines were tested on the IBM 370/145 computer at the College of Petroleum and Minerals, Dhahran, Saudi Arabia, in 1972 and 1973.

PROGRAM STANDARDS

Certain standard specifications are used in order to keep the use of the package as simple as possible. The names of the subroutines associated with profile data have 2D (for two-dimensional) as the last two characters in the name, while areal data subroutine names end in the characters 3D. Also, the first four letters in each name are symbolic of the nature of the subroutine.

The maximum number of data values that can be processed with the 2D subroutines is 2000 per data set, except for subroutine TALW2D, where the maximum is 500. The maximum array size for the 3D subroutines is 64 by 64, with the exception of subroutine GRAV3D, which is 45 by 45 and subroutine PHYP3D, which is 32 by 32.

The index (1,1) of gridded data is the upper left corner of the grid. The first subscript refers to the row number while the second subscript is the column number. A row is considered a line that extends in an east-west or X direction and a column extends in a north-south or Y direction.

Disk input to all interpretative subroutines, that is, those routines not associated with data input or graphic output, is by the use of Fortran reference number 11 and output from those subroutines to temporary disk is by Fortran reference number 15. The format on both disks is the same.

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File 16 is used for a disk work area for subroutines CONT3D, MAGM3D, and MAGA3D. The plotter software uses file 9 for tape output while files 10, 12, and 14, are storage files for profile data, gravity data and gridded data, in that order. From the above it is seen that the program uses Fortran reference numbers 9 through 16, except for number 13, which is unused. Of course, all file designations can be overridden with appropriate Job Control Language statements to interface with a user's own files.

All interpretative subroutines with names ending in 2D will produce a printer plot of the processed data and those that end in 3D will automatically produce a printer contour map with 20 contour levels.

ABSTRACTS OF SUBROUTINES

PROF2D

This subroutine places data in profile form from either cards, tapes or disk to temporary disk in the format acceptable to the other two-dimensional subroutines of the GEOPAC program. Object-time formatting permits the input data to be in any format acceptable to the Fortran IV language. Options in the program allow for the preliminary operations of scaling, shifting, or detrending the data. Profiles may also be concatenated to combine several data sets as one and data sets may also be stored on a permanent file.

PRET2D

Profile data stored on a permanent file can be retrieved by this subroutine. The selected data sets are placed on temporary disk for input to other two-dimensional subroutines in the GEOPAC program. Optionally, the data set can be punched in any format specified by the user.

FILT2D

This subroutine computes weights for low-pass, high-pass and band-pass filters which are then applied to two-dimensional profile data. Weights are such that the phase shift is zero for all frequencies and a filter gain of unity from zero frequency to the ideal cutoff is obtained. Output will be some subset of the input data with certain frequencies removed.

CONT2D

Total intensity anomalies from data observed at equal intervals on a lower level are calculated by this subroutine. This method of upward continuation for profile data is based on the method of Henderson and Zietz (1949).

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TALW2D

This subroutine calculates the vertical component of gravitational attraction of two-dimensional bodies of arbitrary shape by approximating them to many sided polygons. The technique used is due to Talwani, Worzel and Landisman (1959).

MAGM2D

This subroutine computes theoretical magnetic anomalies for two-dimensional bodies magnetized in any specified direction. Vertical, horizontal, and total field anomalies are computed at a series of observation points equally spaced along a profile.

PLOT2D

This subroutine plots profile data on an EAI 430 plotter. Several profiles may be plotted together, the number depending on the height of the individual profiles.

INPT3D

This subroutine reads in gridded data from cards, tape or disk or retrieves the same type of data from a storage file and places it on temporary disk in GEOPAC format for entry to other three-dimensional subroutines. The input data can be in any format acceptable to the Fortran IV language or it may be unformatted if it is already in GEOPAC format. Optionally, the input data may be stored on a permanent file.

GRED3D

This gravity reduction subroutine computes the free-air and two simple Bouguer anomalies for stations located either within closed loops or on base to base traverses. Linear drift and tide corrections are applied to all stations. The reduced data after a polyconic projection are placed on a temporary disk for input to subroutine GRID3D and optionally punched on cards for storage by subroutine GRET3D.

GRET3D

Gravity data can be stored or retrieved by this subroutine. Data is stored by data sets but retrieval can be done by either data set identification or by specifying limits of latitude and longitude. A printer plot of station locations is always provided and also the data is always written on temporary disk for input to subroutine GRID3D.

GRID3D

This subroutine will compute grid intersection points over a defined region of any given dimension for irregularly spaced data. The random data values can come from the output of subroutines GRED3D or GRET3D or they can be on cards, tape or disk in any format acceptable to the Fortran IV language. The computed grid data is written

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out on temporary disk in GEOPAC format acceptable to other three-dimensional subroutines of the system.

FILT3D

This subroutine provides a method of wavelength filtering of map data. Regional, residual and band-pass filters of several different wavelengths can be applied. The filter coefficients were obtained from Zurflueh (1967).

FANF3D

This subroutine can be used to analyze data on a grid to determine anomaly lineation by means of fan-filtering techniques. The technique is used to separate anomalies that strike in a preferred azimuth range.

CONT3D

This subroutine computes upward continuation, downward continuation, first derivative and second derivative of gridded data according to the method of Henderson (1960).

GRAD3D

Gradient values at each point on a specified grid are computed by this subroutine.

POLY3D

This subroutine fits, in the least-square sense, a surface to a set of data by means of orthogonal polynomials.

GRAV3D

This subroutine is designed to calculate a three-dimensional structural model directly from gravity anomaly data by means of the iterative method of Cordell and Henderson (1968). The source of the gravity anomaly is represented as a bundle of vertical prism elements - each prism element having a cross-sectional area equal to one grid square, uniform density, and a vertical position fixed with respect to a specified reference surface.

MAGM3D

This subroutine computes the exact values of the normalized magnetic field at a specified number of grid points on the observation plane above a three-dimensional body.

MAGA3D

This subroutine computes the anomalies caused by magnetic distributions of arbitrary shape in a three-dimensional modeling procedure. The total magnetic intensity at grid points in a north-

south vertical coordinate frame is calculated for bodies that can be in any form that can be described by plates or parallelepipeds.

MAGR3D

This subroutine carries out the "pseudogravity" transformation as used in potential-field geophysics, whereby a total magnetic intensity map is converted into a gravitational equivalent in terms of hypothetical physical properties. The procedure is based on convolution in the frequency domain, utilizing the Fast Fourier Transform.

PHYP3D

This subroutine implements a system of analysis of geophysical data by Cordell and Taylor (1971), based on Poisson's theorem relating gravitational and magnetic potentials due to a common homogeneous source. The program computes the total magnetization direction and the minimum of the Koenigsberger ratio Q, plus other related information, by utilizing the Fast Fourier Transform and a least-squares solution of a system of linear equations established in the frequency domain.

PLOT3D

This subroutine will produce a perspective drawing of gridded data on the EAI 430 plotter. The data can be viewed from any vertical and horizontal angle and the points can be drawn by straight line connections or connected as a histogram.

PRPL3D

Contour maps on line printer sheets can be produced from the output of this subroutine. Alphanumeric symbols are printed to represent the different contour levels. Input parameters allow the user to specify any plot scale, e.g., 1/250,000, a subset of the data, the minimum and maximum values to be contoured, the contour interval or the number of contour levels to be produced.

CTUR3D

This subroutine will contour a data set on an EAI 430 dataplotter using the Wolf Research contouring program. Several options are available to the user such as: grid and/or value overlays, contour suppression, rotation of plots, polar plots, contour enhancement and multiple plots.

PROF2D

by

Ralph N. Eicher and Wayne Buehrer

Description

This subroutine translates data in profile form from either cards, tape or disk to temporary disk in a format acceptable to other two-dimensional subroutines of the package. Object-time formatting allows the data to be in any acceptable format to the Fortran IV language. A profile represents a set of ordinate values measured at equal increments of distance along the abscissa. Incorporated into this program is a concatenate option which combines several profiles into one data set. The data may be scaled and/or shifted and/or detrended by means of three options (fig. 1). The scale and shift operations cause translation of the entire data set. The detrend option causes a rotation of the data set by removing a linear f (x) for which the (x,y) coordinates of two points must be furnished.

Each option operates upon the data produced by the previous option and when selected the following sequence takes place:

1) Concatenate
2) Scale
3) Shift
4) Detrend

1) Concatenate - causes several profiles to be combined by appending subsequent profiles to the end of preceding ones.

2) Scale - causes each value to be multiplied by the scale factor.

3) Shift - causes each value to be added by the shift value.

4) Detrend - provides for the removal of a specified linear trend from the data. The distance between consecutive Y_i^{11} values is Δx (a constant). Two points P_1 (x,y), P_2 (x,y) can be used to determine the slope and ordinates of the linear function. Then the distance between a point Y_i^{11} and a point P_i (x,y) on the straight line is formed by:

$$M = \frac{Y_2 - Y_1}{X_2 - X_1}$$

$$X_i = i\Delta x$$

$$Y_i = M(X_i - X_1) + Y_1, \quad i = 1,2,\ldots\ldots N$$

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and $Y_i^{1111} = Y_i^{11} - Y_i$

Y_i^{1111} is a distance parallel to the y-axis, not normal to the straight line.

Input

Card 1

Column	Format	Name	Description
1-4	A4	ID	Data set identification.
5-12	F8.4	DELX	The distance between data values. If left blank it is set to 1.0.
13	I1	OPTI	A one in this column initiates the detrend option.
16-23	F8.4	SCALE	A multiplicative scaling factor. If left blank no scale action is taken.
24-31	F8.4	SHIFT	A value to be added to each data point. If left blank no shift action is taken.
32-39	F8.4	X_1	Coordinate for $P_1(x,y)$.
40-47	F8.4	Y_1	Coordinate for $P_1(x,y)$.
48-55	F8.4	X_2	Coordinate for $P_2(x,y)$.
56-63	F8.4	Y_2	Coordinate for $P_2(x,y)$.
64-66	I3	ICNCT	Leave blank if data set consists of only one profile. To concatenate profiles place a 1 in the field for the first profile and a number between 2 and 8 for succeeding profiles, except for the last one when a 9 must be punched.

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Column	Format	Name	Description
68-69	I2	INPUT	Fortran input data set reference number. If blank it is set to 5 for the card reader.
73	I1	IOP	A one in this column will store the data set on tape.
75-80	A6	SNAME	The characters PROF2D must be punched.

Card 2

Column	Format	Name	Description
1-76	19A4	IFMT	The format of the data value cards that follow. For example: (10F7.0).
77-80	I4	N	The number of the data values in the profile.

The following cards are the data cards in the format described on Card 2. If profiles are concatenated, each profile will have a Card 1 and Card 2 followed by data cards.

Output

Prior to listing any output the program scales and shifts the data if these options are chosen. The first line of output lists the identifying parameters: ID, N, ITYPE, DELX, YMIN, YMAX, SCALE and SHIFT. The parameter ITYPE serves to identify whether or not the final data written on disk has been detrended, and at this point, it is given as 0. The following lines of output are the data values.

If the detrend option is exercised, the parameters ID, N, ITYPE, DELX, YMIN, and YMAX are printed. In this case ITYPE is assigned a value of 1,000. The detrended data values are then listed.

The data in its final status is then written on temporary disk in the standard two-dimensional format and if the option is chosen, the data is also placed on a permanent storage file (file 10). The ID for concatenated profiles is the identification of the last profile.
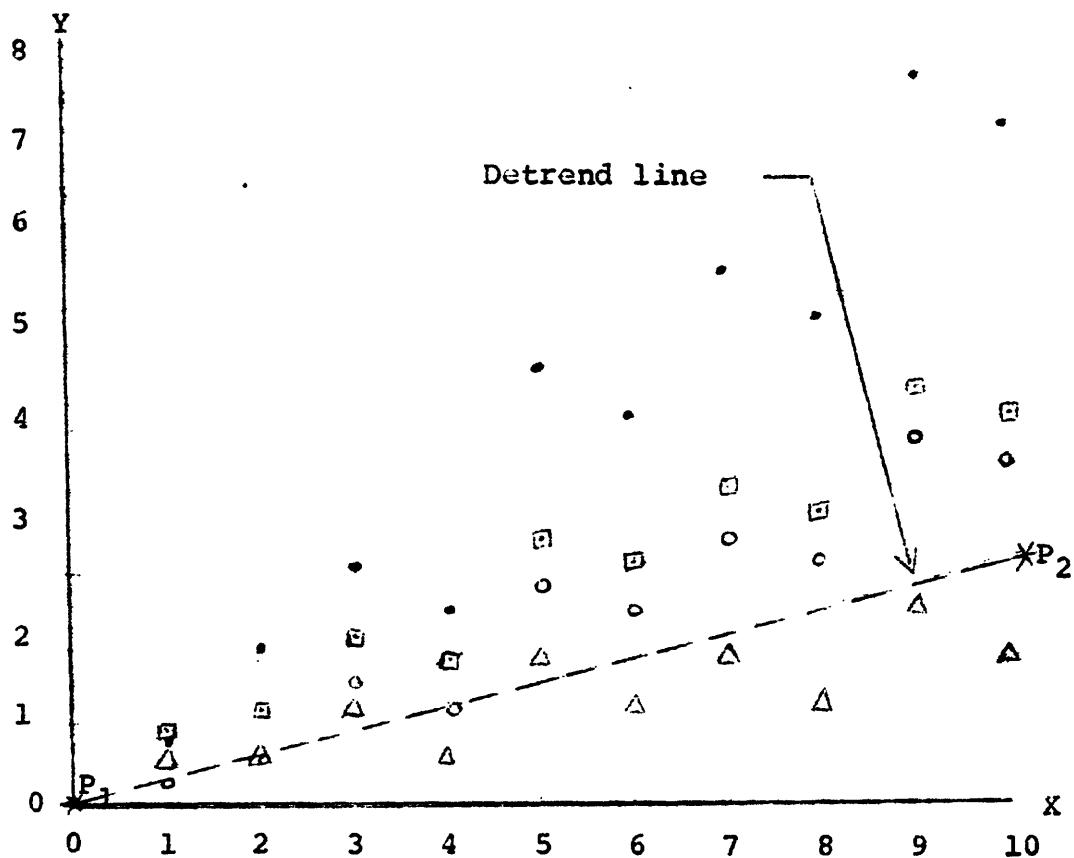
Figure 1. Plot of original data, scaled data, shifted data, and detrended data.

PRET2D

by

Richard H. Godson

Description

Profile data recorded on a permanent storage file can be retrieved by this subroutine. The storage file is searched serially until the data set ID on tape matches the specified ID on the parameter card. The data set is placed on temporary disk in the standard format and also listed on the printer. An option is provided to punch the data values in a format specified by the user.

Input

One card is required for this subroutine in the following format:

Column	Format	Name	Description
1-4	AF	ID	Data set identification.
6-37	8A4	IFMT	Format of punched card output of data values.
40	I1	JOP	Leave blank if no card output. A one in this column will punch data values.
75-80	A6	SNAME	The characters PRET2D must be punched.

Output

The data set parameter and data values are listed on the printer and also placed on temporary disk in the standard format. If the punch option is taken, the first card will contain the ID and delta X value and the remaining cards will have the data values in a user-specified format.

FILT2D

by

Dave Handwerker and Ralph N. Eicher

Description

Weights for either high-pass or band-pass filters may be based on weights for appropriate low-pass filters. The weights for a low-pass filter are calculated using a given h which is a variable

parameter permitting variations in the slope of sine termination and r_c' the normalized cutoff frequency. The number of weights calculated is always odd and the values are symmetrical about the central weight. Weights are such that the phase shift is zero for all frequencies and a filter gain of unity from zero frequency to the ideal cutoff is obtained. (If both h and r_c are zero, an odd number of equal weights summing to unity is obtained, which is the moving average case.)

If the number of weights is 2N+1, the output will never include smoothed values for any of the first N or last N points. If the given values are spaced at intervals of ΔX, the transformed values may be computed at some multiple of ΔX.

As an option the frequency-response function R as a function of r, the normalized frequency ratio, may be computed for certain values of r between 0 and 0.5.

For a low-pass filter involving 2N+1 discrete weights W_{-N}, W_{-N+1}, ... W_{-1}, W_0, W_1, ... W_{N-1}, W_N the quantities L_k (k=0,1, ... N) are computed as follows:

$$L_0 = 2(r_c + h)$$

$$L_k = \left[\frac{\cos 2\pi k h}{1 - 16h^2k^2}\right] \cdot \left[\frac{\sin 2\pi k(r_c + h)}{\pi k}\right] , \quad (k = 1, \ldots N)$$

Here r_c is the normalized cutoff frequency for the ideal filter and h is a variable parameter which permits variation in the slope of the sine termination and is effective in diminishing the oscillations beyond the first zero crossing of the frequency-response function. Note that considering the first factor of L_k, a continuous function of h, its value is $\pi/4$ when the denominator vanishes, i.e. when hk = 1/4.

Then $W_k = L_k + \dfrac{\Delta}{2N+1}$, (k=0,1, ... N)

where $\Delta = 1 - \left[L_0 + 2 \sum\limits_{k=1}^{N} L_k\right]$

furthermore $W_{-k} = W_k$ for k=1, ... N

For a high-pass filter with 2N+1 discrete weights and parameters r_c and h the weights are readily computed in terms of those of the corresponding low-pass filter.

$W_0' = 1 - W_0$

$W_k' = W_k$ (K=1, ... N)

For a band-pass filter with $2N_1+1$ weights W_k for the lower cutoff and $2N_2+1$ weights W_k' at the higher cutoff

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$$W_k'' = W_k' - W_k \; , \; k = 1, \; \ldots, \; N = \max(N_1, N_2)$$

where the W_k' and W_k are computed for high-pass and low-pass filters with parameters r_c', h' and $r_c h$ respectively, and if N_1 and N_2 weights W_k and W_k' have indices beyond N_1 or N_2 respectively they are set at zero.

The frequency response function R for a given normalized frequency ratio, r, is given by

$$R(r) = W_0 + 2 \sum_{k=1}^{N} W_k \cos(2\pi k r)$$

r is the ratio f/fs where f is the frequency in cycles per unit independent variable and fs the sampling rate.

The smoothed value for the ith data point is found from

$$Y_i = \sum_{k=-N}^{N} Y_i + k W_k$$

thus involving 2N+1 given y values, as well as 2N+1 weights, with $W_{-k} = W_k$ for high and band-pass filters as well as for low-pass filters.

Input

One parameter card is required to compute one set of weights for either a low-pass, high-pass or band-pass filter. The layout for such a card is as follows:

Columns	Format	Name	Description
1-4	A4	ID	Data set identification.
16-20	I5	I1	The first point (between 1 and NY) for which a smooth value is desired.
21-25	I5	I2	The last point for which a smooth value is desired.
26-27	I2	IDEL	The ratio of the X interval on the output to that on the input. If given as less than 1, it is set to 1.
28-30	F3.3	CUT(1)	The first normalized cutoff frequency.

Column	Format	Name	Description
31-33	F3.3	H(1)	The first variable parameter h.
34-36	I3	N(1)	The total number of weights 2N(1) + 1 to be used in connection with CUT(1) and H(1) $0 \leq N(1) \leq 300$.
37-39	F3.3	CUT(2)	Second normalized cutoff frequency. Not needed except for band-pass filter when it should exceed CUT(1).
40-42	F3.3	H(2)	Second variable parameter. Not needed except for band-pass filter.
43-45	I3	N(2)	The number of weights 2N(2)+1 for the higher normalized frequency. $1 < N(2) \leq 300$. Not needed except for band-pass filter.
46-49	I4	ITOUT	The type of filtering desired. If the digit in column 46 is 2 or less, a low-pass filter is called for; if equal to 3 a band-pass filter is called for; while if this digit is 4 or more, a high-pass filter is called for. The last three digits (columns 47-49) may be used to identify different filters used for the same data set.
50	I1	IRSP	If not zero (or blank) a frequency response curve is not computed.
51	I1	IPRN	If not zero (or blank) smoothed values will not be written on the printer.

Column	Format	Name	Description
52-61	E10.0	XMAX	The maximum value of the X axis on the plot of the data. The maximum input data point is used if these columns are left blank.
62-71	E10.0	XMIN	The minimum value of the X axis on the plot of the data. The minimum input data point is used if these columns are left blank.
72	I1	NPLOTS	The number of the plots of the filtered data desired. If blank it is set to one.
75-80	A6	SNAME	The characters FILT2D must be punched.

If any of the following: $H(1)$, $H(2)$, $CUT(1)$, $CUT(2)$, $N(1)$, or $N(2)$ are given as non-positive the corresponding value is set to zero. If I1 is less than N+1, it is set equal to N+1. If I2 is either less than or equal to I1 or else greater than NY-N, it is reset to NY-N.

Output

The weights W_o, W_1, -----, W_n will be printed out, after being computed, 10 values on a line.

If IRSP is zero, responses R for normalized frequencies r are printed out for r = .001 to .050 in steps of .001; for r from .052 to .100 in steps of .002; for r from .105 to .200 in steps of .005; and for r from .210 to .500 in steps of .010.

If IPRN is different from zero the filtered values are printed.

The filtered values are written on temporary disk in the standard format and also plotted on the printer. The variable ITYPE that is written on disk may vary from ITOUT on the parameter card as follows: the first digit of ITOUT on output will always be 2 for low-pass filters and always 4 on high-pass filters. Also, if ITYPE is equal to ITOUT, then the last three digits of the input ITOUT are increased by 1 for the output ITOUT.

CONT2D

by

Dave Handwerker, Gordon Andreasen and Paul Zabel

Description

A data set profile is read from an input file and then it is continued upward the number of units specified by an input parameter. The parameter NK specifies the number of coefficients $K(I,H)$, (actually $2(NK)-1$ coefficient values because they are symmetric about the middle point), to be used in obtaining upward continued values, where $I = 1,2,...,NK$ and H is the height to which the data is to be continued. The data points are $Y(J)$, $J = 1,2,...,NY$, where NY is the total number of points observed at an equal interval DELX.

$$K(I,H) = \frac{DELX*H*1/\pi}{(H^2+X^2)} \quad \text{where } X = (I-1)DELX, \quad I = 1,2,...,NK.$$

At a point J and a height H, the upward continued value $Z(J)$ is found by the following equation:

$$Z(J) = \sum_{I=J1}^{I=J2} Y(I) . K(L,H) \quad \text{where } L = |I-J| + 1,$$

$J1 = $ maximum $(1,J-NK+1)$, and $J2 = $ minimum $(J+NK-1,NY)$.

J may be any value from 1 to NY. The interval for J's may be from 1 to 99 (which implies that the X-interval may be from DELX to 99 DELX on the output). To avoid undesirable end effects, the user should choose I1 (minimum J) as greater than or equal to NK and I2 (maximum J) as less than or equal to NY - NK + 1.

Input

One parameter card with the following format is necessary for each continuation.

Columns	Format	Name	Description
1-4	A4	ID	Data set identification.
14-18	I5	I1	The first point on the profile for which upward computations are to be made.
19-23	I5	I2	The last point on the input profile for which upward computations are to be made.

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Column	Format	Name	Description
24-25	I2	IDEL	The multiple of the input interval DELX to be used for output $(1 \leq DELX \leq 99)$.
26-28	I3	NK	The number of the coefficients to be used in obtaining upward continued values.
29-36	F8.0	H	The height to which the data values are to be continued $(H > 0)$.
37	I1	IPRN	If a 1 is punched in this column, the upward continued values will not be printed out. Leave blank if they are to be printed.
38-42	F5.0	XMAX	The maximum value of the X axis on the plot of the data. The maximum input data point is used if these columns are left blank.
43-47	F5.0	XMIN	The minimum value of the X axis on the plot of the data. The minimum input data point is used if these columns are left blank.
75-80	A6	SNAME	The characters CONT2D must be punched.

The following default options take place if the indicated parameters are left blank. If I1 is less than 1 or greater than the number of points it is set to 1 and in the same way I2 is set to the number of points. If H is non-positive, it is set to 1.0.

Output

The output will include the input parameters, the computed data values with maximum and minimum and a printer plot of both input and output profiles. The upward continued values will be written on temporary disk in the standard format.

TALW2D

by

Paul Zabel

Description

The program will compute the vertical gravitational attraction at any point where X and Z coordinates are given specifically or it will compute the value along a profile where the first and last X-coordinates, delta X, and a constant Z-coordinate are given. The gravity values will be plotted on the printer either on a page size plot or a varying size plot by running the X-axis down the page. The calculated gravitational attraction may also be incremented by any constant desired. The program also contains an option which allows the problem to be defined in terms of miles, kilofeet, or kilometers.

If desired, an observed profile may be read from disk for comparison with the calculated profile.

Definition of terms

(1) Field points are the points at which the gravitational attraction of each body is calculated. The origin of the coordinate system (with X-axis horizontal and Z-axis positive downwards) may be at any point ($-9999.999 <$ X-coordinates <9999.999). The coordinates of the field points are determined with respect to the origin.

(2) Body points beginning with the first polygon that approximates the cross section of a two-dimensional body, arbitrarily assign the value 1 to any of the vertices. Assign the values 2, 3, 4... N in clockwise order to the other vertices, ending at the first point vertex. The first vertex thus has two values assigned to it, 1 and N. Thus if the body has N geometric points it will have N+1 body points.

General formula

The irregular cross section of the two-dimensional body is first represented by an irregular polygon. This is the only approximation involved in this method. It will be recognized that the approximation can be improved merely be increasing the number of sides of the polygon.
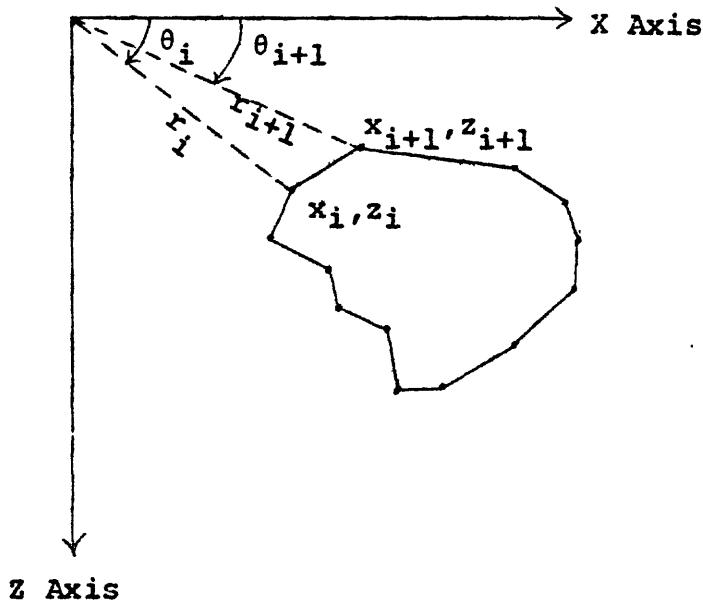
Figure 2. Cross section of a polygonal two-dimensional body.

This expression for the attraction of a two-dimensional body with the cross section of a polygon has been obtained in terms of the coordinates of the vertices of the polygon by Talwani et al. (1959). The expression given below has been slightly rearranged to make programming easier for a computer. If x_i, z_i, and x_{i+1}, z_{i+1} are the cartesian coordinates of successive vertices (in clockwise order), the vertical component of the gravitational attraction of the n sided polygon evaluated at the origin is given by

$$ KS \sum_{i=1}^{N} \frac{x_i z_{i+1} - z_i x_{i+1}}{(x_{i+1}-x_i)^2 + (z_{i+1}-z_i)^2} \left[(x_{i+1}-x_i)(\theta_i - \theta_{i+1}) + 1/2 (z_{i+1}-z_i) \log \frac{r_{i+1}}{r_i} \right] $$

where

$$ r_i^2 = x_i^2 + z_i^2 $$

$$ r_{i+1}^2 = x_{i+1}^2 + z_{i+1}^2 $$

$$ \theta_i = \arctan \frac{z_i}{x_i} $$

$$ \theta_{i+1} = \arctan \frac{z_{i+1}}{x_{i+1}} $$

S = density contrast

K = constant; 13.34 if units in kilometers, 4.065 if units in kilofeet and 21.46 if units in miles.

Most arc tan subroutines yield a + answer when dealing with a + argument and a − answer when dealing with a − argument. To get the correct value of $\theta_i - \theta_{i+1}$ the following procedure is used:

If x_i is −, z_i is −, $\theta_i = \arc\tan \dfrac{z_i}{x_i} - \pi$

If x_i is −, z_i is 0 or +, $\theta_i = \arc\tan \dfrac{z_i}{x_i} + \pi$

If x_i is +, z_i is +, − or 0, $\theta_i = \arc\tan \dfrac{z_i}{x_i}$

If x_i is 0, z_i is −, $\theta_i = -\dfrac{\pi}{2}$

If x_i is 0, z_i is 0, $\theta_i = 0$

If x_i is 0, z_i is +, $\theta_i = \dfrac{\pi}{2}$

Similarly θ_{i+1} is evaluated.

The difference $\theta_i - \theta_{i+1}$ is taken in the following manner. If it is more negative than $-\pi$, 2π is added to it. If it is greater than $+\pi$, 2π is subtracted from it. This yields the proper value $\theta_i - \theta_{i+1}$ to be used in the above formula.

Input

Several parameter cards are needed to execute this subroutine.

Card 1

Columns	Format	Name	Description
1-4	A4	ID	Data set identification.
25-34	F10.0	XMAX	Maximum X coordinate to be used in plotting.
35-44	F10.0	XMIN	Minimum X coordinate to be used in plotting.
45-54	F10.0	YMAX	Maximum Y coordinate to be used in plotting.
55-64	F10.0	YMIN	Minimum Y coordinate to be used in plotting.

If the four preceding parameters are left blank the maximum and minimum of the points to be plotted will be used.

Column	Format	Name	Description
65-66	I2	NL	The number of vertical grid lines in the graph image of the long plot.
67-68	I2	NS	The number of the printer spaces plus one between the vertical grid lines. The value of S in the following equation must never exceed 6,000. $$S = ((NL * 10) * (NS * 10)+1))+3$$
69	I1	COL69	A "1" indicates that the long plot is wanted. If left blank the standard page size plot is desired.
70	I1	COL70	A "1" indicates that no observed profile is to be read in. If left blank an observed profile is read in from the disk.
71	I1	IPR	A "1" will print individual attractions. If left blank no printing of individual attractions.
75-80	A6	SNAME	The characters TALW2D must be punched.

Card 2

1-80	20A4	IDEN	Any alphnumeric information to identify the problem.

Card 3

1-5	I5	L	Total number of bodies.
6-10	I5	M	The number of field points in the problem; used in conjunction with Card 4b. If Card 4A is used these columns must contain five 9's.

Column	Format	Name	Description
11-20	F10.1	CONS	A constant in milligals which will be added to the sum of the attractions of all the bodies.
21-25	I5	J	This is non-zero if another problem follows. The subroutine will start again with card 2.
26-30	I5	JSS	If this variable is greater than zero the contribution of the line integral of each side of the polygonal shaped body is printed in tabular form.
31-35	I5	JJ1	In addition to the table attractions of all the bodies plus a given constant, one can also obtain a table of attractions of the first body plus a constant, the sum of the attractions of the first two bodies plus a constant and so on up to the total attraction table which is always printed. This variable is equal to the number of bodies to be summed, which are summed in the order they are read in.
36	I1	PUN	If PUN is non-zero the X-coordinate and the vertical gravitational attractions are punched on cards in 2F10.5 format, one field point per card.

Column	Format	Name	Description
37-48	3A4	UNITS, UNITS2, U3	The problem may be defined in terms of MILES, KILOFEET, or KILOMETERS, which may be punched, starting in col. 37. If left blank the program assumes kilometers.

Card 4A

Used when field points are not read in.

Column	Format	Name	Description
1-7	F7.0	FF	First X-coordinate of a profile of field points at which the vertical gravitational attraction is to be calculated.
8-14	F7.0	FL	The last X-coordinate of the above profile.
15-21	F7.0	DF	The number of units between the points in the profile.
22-28	F7.0	FZZ	This is the Z-coordinate for all the field points in the profile.

Card 4b

Used when field points are read in.

Column	Format	Name	Description
1-64	8F8.3	FX,FZ	FX is the X-coordinate and FZ the Z-coordinate of field points. They are punched four points to a card. The Z-axis is positive downward. Usually the X-axis is chosen as the plane for the field points, but if you wish to have field points vary in the Z direction (to represent topography for instance) remember points above the X-axis have a negative Z-coordinate. Note: The maximum number of field points per problem is 500.

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Column	Format	Name	Description
1-5	I5	LNO	This is the number of the body. The number of the last body must be equal to the value of L on Card 3,
6-10	I5	N	This is the number of vertices in the body plus one.
11-20	F10.5	RHO	This is the density in gm/cc of the body. Usually the surrounding material is assigned a density of 0.0 and a density contrast is used for the body.

Card 6

1-64	8F8.3	X,Z	These are body point cards punched four to a card in the same manner as Card 4b. There may be up to 500 body points for each body. The first vertex punched may be anywhere on the body. The rest of the vertices must be entered in order around the body in a clockwise direction and the first vertex must be punched as the last vertex. This is the reason N on card 5 is equal to the number of vertices plus one.

The following deck setup is the order of data cards for a problem where Card 4a is used to define the field points and there are three bodies.

1. Card 1
2. Card 2
3. Card 3
4. Card 4a
5. Card 5

6. Card (s) 6 (1st body)
7. Card 5 (2nd body)
8. Card (s) 6 (2nd body)
9. Card 5 (3rd body)
10. Card (s) 6 (3rd body).

Any additional problems would follow.

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Output

The printer output is generally self-explanatory. The vertical component of gravitational attraction and the vertical component plus a constant factor are printed in the tables. Additional tabular output is optional (see variables JSS and JJ1 on Card 3). The calculated and the observed profile if one exists are plotted on the line printer either on a page size plot or an extended plot with the X-axis running down the page.

Optional card output may be obtained (see parameter PUN on Card 3).

The calculated profile is written out on temporary disk in the standard format.

MAGM2D

by

William B. Joyner and Gordon Andreasen

Description

A profile is calculated over a number of bodies which must be polygons in cross section. The bodies are described by specifying the coordinates of the polygons' vertices, as illustrated in Figure 3. Up to 300 bodies may be included, and the direction of magnetization may be chosen independently in each. The total number of points used to describe all of the bodies must not exceed 999. A body may extend to infinity in one direction, as illustrated by body number 2 in Figure 3, but in that case the lines bounding the portion that extends to infinity must be parallel.

The first point on the computed profile will be located where the horizontal coordinate X equals zero. Subsequent points will be computed at a specified interval DX. The total number of points computed, NLIM, may not exceed 2,000. The bodies may extend beyond the limits of the profile at either end.

If desired, an observed profile may be read from disk for comparison with the calculated profile. Both will be plotted on a page size plot or a long plot. Any units (miles, feet, kilometers, etc.) may be used for horizontal and vertical distance, as long as the same units are used consistently throughout.

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Card 1

Column	Format	Name	Description
1-4	A4	IDN	Data set identification.
65-66	I2	NL	The number of vertical grid lines in the graph image of the long plot.
67-68	I2	NS	The number of printer spaces plus one between the vertical grid lines of the long plot. Note: the value of S in the following equation must never exceed 6,000. $$S = ((NL*10)+1) * ((NS*10)+1)+3$$
69	I1	COL69	A "1" in this column indicates the data is to be plotted on a long plot where the X-axis (distance) extends down the page. If left blank a standard size plot will be produced and cols. 65-68 may also be left blank.
70	I1	COL70	A "1" must be punched in this column if no observed profile is to be read in.
75-80	A6	SNAME	The characters MAGM2D must be punched.

Card 2

Column	Format	Name	Description
1	I1	ID	A "1" must be punched in this column.
2-65	16A4	ALPHM	Any alphanumeric identification data to be printed out.

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Card 3

Columns	Format	Name	Description
1	I1	ID	A "2" must be punched in this column.
2-4	I3	NB	The number of bodies ($1 \leq NB \leq 300$).
5-10	F6.0	T	The total field of the earth in gammas.
11-15	F5.1	FINC	The inclination of the field in degrees.
16-20	F5.1	STRK	The angle in degrees between the magnetic north and the direction of the right end of the profile.
21-24	I4	NLIM	The total number of points in the computed profile.
25-34	E10.0	DX	The horizontal distance between points on the computed profile.
35	I1	NEL	The number of elevations for which profiles are to be computed ($1 \leq NEL \leq 9$).
36	I1	IOP	When IOP=1 the vertical magnetic field anomalies will be plotted, or if IOP=2 the horizontal field, or if IOP=3 the total magnetic field.
37-45	E9.0	XMAX	The maximum value of the X-axis on the plot of the profile.
46-54	E9.0	XMIN	The minimum value of the X-axis on the plot of the profile.
55-62	E8.0	YMAX	The maximum value (in gammas) of the Y-axis on the plot of the profiles.
63-70	E8.0	YMIN	The minimum value (in gammas) of the Y-axis on the plot of the profiles. If the last four parameters are left blank the program will use the maximum and minimum values of the data.

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Column	Format	Name	Description
71-72	I2	NPLOTS	The number of the times each plot is to be printed ($1 \leq$ NPLOTS ≤ 99).

Card 4 (Body Card)

Column	Format	Name	Description
1	I1	ID	A "3" must be punched in this column.
2-4	I3	NBC	The body number. The bodies must be numbered in sequence beginning with one, and the body cards must be in order in the input deck.
5-7	I3	NP	The number of points to describe the body. The total number of points used in describing all the bodies must not exceed 999, and if a point is shared by more than one body it must be counted for each body.
8-14	F7.5	FMAG	The intensity of the magnetization of the body in emu. For example if T=54,000 and K=.001, then FMAG=.001 x .54000 = .00054.
15-19	F5.1	RINC	The inclination of the magnetization vector in degrees.
20-24	F5.1	STRR	The angle in degrees between the horizontal projection of the magnetization vector and the direction of the right end of the profile. Note: Since the component of magnetization perpendicular to the plane of the profile has

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Column	Format	Name	Description
			no effect on the computation, it is permissible to set FMAG equal to the intensity of the component of the magnetization vector in the plane of the section. In that case RINC should be set equal to the apparent inclination in the plane of the section and STRR should be set equal to 0 or 180, whichever is appropriate. This method of specifying the magnetization vector will be more convenient in some cases.
25	I1	INF	This variable is zero if the body is a closed polygon cross section. The variable is one if the body extends to infinity. The body may extend to infinity in only one direction, and the lines that bound the portion of the body that extends to infinity must be parallel.
26-30	F5.1	PHI	The dip in degrees of the portion of the body that extends to infinity. It is measured clockwise from the positive X-axis (which is the right end of the profile). If the body is closed the program ignores PHI.

Point Cards

On the point cards are listed the horizontal and vertical coordinates of the points defining the polygonal body. The points must be listed in sequence proceeding clockwise around the body. If the body is closed it does not matter which point is taken first, but if the body extends to infinity, the list of the points must begin and end with points adjacent to the portion of the body which extends to infinity, as illustrated in Figure 3.

The horizontal and vertical coordinates are X and D, respectively. The point X=0 is the point where the program begins computing the profile, but the X values of the points defining the body may be either positive or negative. Depth, D, is measured positive downward from the chosen reference elevation. The D values of the points defining the body may also be either positive (below the reference level) or negative (above the level). However, all the points of the body must lie below the lowest level on which a profile is to be computed.

Column	Format	Name	Description
1	I1	ID	A "4" must be punched in this col.
2-4	I3	NBCQ	The number of the body to which the points belong. This number must correspond to NBC on the preceding body card.
5-7	I3	NQC	The number of the point card. The set of point cards for each body card must be numbered in sequence from one, and the cards must be in order.
8-17	E10.0	XC	The X value for the first point.
18-27	E10.0	DC	The D value for the first point.
28-37	E10.0	XC	The X value for the second point.
38-47	E10.0	DC	The D value for the second point.
48-57	E10.0	XC	The X value for the third point.
58-67	E10.0	DC	The D value for the third point.

Additional point cards may be added as needed as long as the total number of points for all of the bodies does not exceed 999.

30
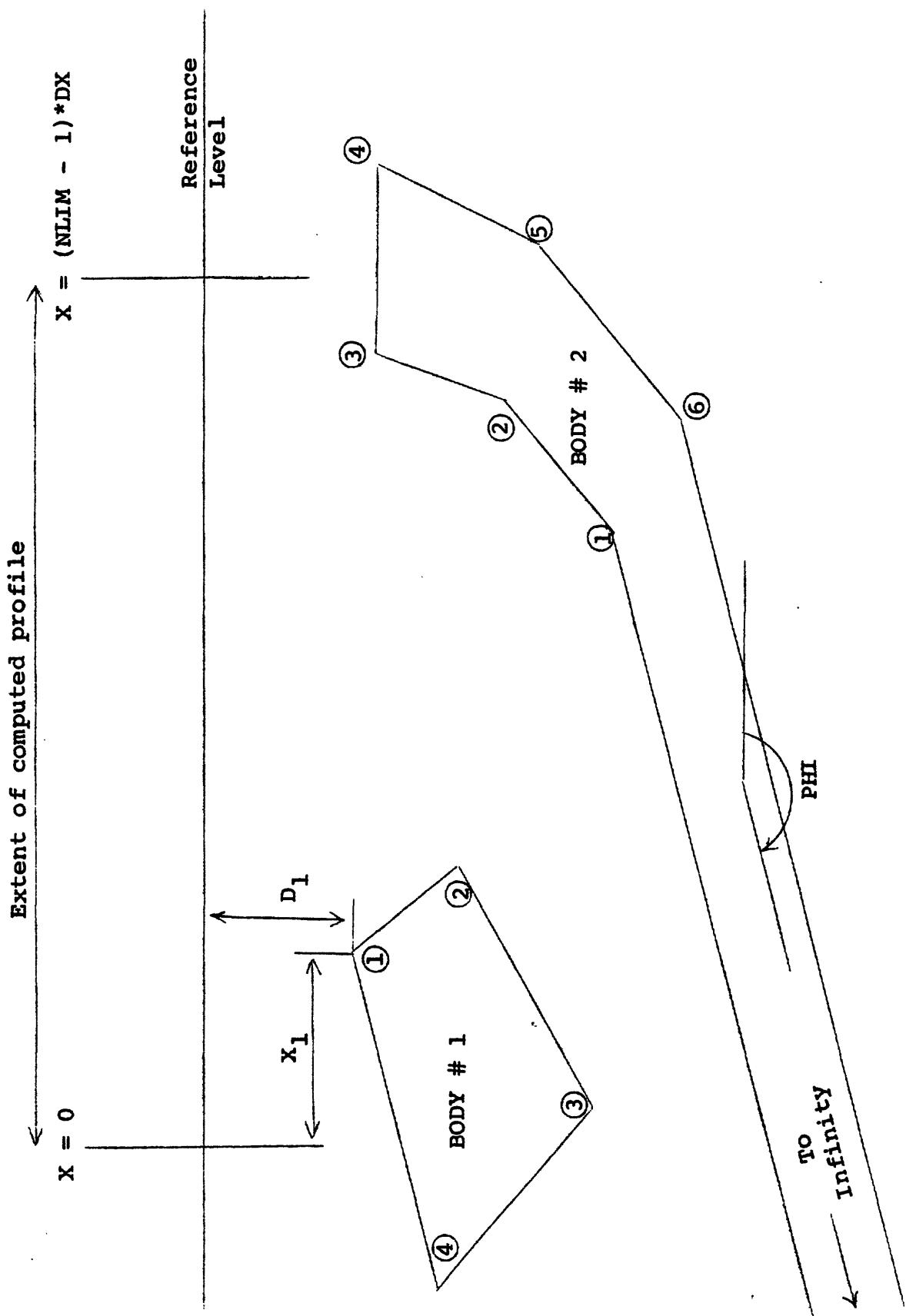
Figure 3. Computed profile extent and two-dimensional polygonal cross sectional bodies

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Elevation Cards

The elevation cards specify the elevation at which the theoretical profile is computed. If profiles at more than one elevation are desired, there must be an elevation card for each profile. At least one elevation card must always be supplied (see NEL on parameter card 3).

Column	Format	Name	Description
1	I1	ID	A "5" must be punched in this col.
2-5	A4	IDN	Alphanumeric identification used to identify profiles written on the output file. IDN must not be blank and a different IDN must be used for each elevation.
8-17	E10.0	E	The elevation at which a profile is to be computed, measured positive upward froi the reference level. The elevation must be such that it lies above the highest point of the bodies.

Output

The output is generally self explanatory. The input parameters are printed in table form followed by lists containing the X coordinates and the vertical, horizontal and total field anomalies at each coordinate IOP on parameter card 3 allows the user to choose the kind of anomaly he wants plotted and the COL69 parameter on card 1 determines the type of printer plot. The output profiles are written out on temporary disk with ITYPE = 6,000 + IOP * 100.

PLOT2D

by

Richard H. Godson

Description

This subroutine will plot profiles on an offline EAI 430 flatbed plotter. More than one profile can be plotted per call to this sub-routine as they are plotted one above the other with an inch interval

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until there is no more space available in the Y direction (30 inches).
The program automatically labels the X and Y axis with appropriate
values, depending on the magnitude of the data.

Input

One card is required for each profile.

Column	Format	Name	Description
1-4	A4	ID	Data set identification.
6-29	24A1	TITLE	Any alphanumeric information which will be plotted below the profile.
30-37	8A1	VTYPE	The units of the data, which will be plotted on the vertical scale. (i.e. gammas, milligals).
38-47	F10.0	YSCALE	Data values per inch on the vertical scale. If left blank the height of the plot is set to 1/3 the width and YSCALE computed accordingly.
48-57	F10.0	XSCALE	The number of ground inches per plot inch. If left blank it is set to 24,000.
58-67	F10.0	XLNGTH	The length of the profile on the ground If it is left blank the length is obtained from disk by the formula $(N-1)$ *DELX, where N is the number of points and DELX is the interval between points Caution: Unless DELX is explicitly specified when the data is placed on disk by subroutine PROF2D, it is set to 1.0.

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Columns	Format	Name	Description
69-72	A4	TYPE	The units of XLNGTH. It is either FEET, MILE, KILO, METR, or INCH. If left blank it is set to FEET.
75-80	A6	SNAME	The characters PLOT2D must be punched.

Note: the maximum length of any profile is 35 inches. On the vertical scale, the minimum and maximum values are rounded down and up, respectively, to the nearest 10th, 100th or 1000th values, whichever is appropriate.

Output

The generated plots are written on a 9-track unlabelled magnetic tape. Profiles are plotted one above the other with a one-inch interval between them. Each profile is labelled on the X and Y axis with appropriate values and the title, horizontal scale and profile identification plotted beneath each one.

The input parameters are printed along with a message saying 'End of plot of profile number n' after every profile, where n equals the number of the plot.

INPT3D

by

Richard H. Godson

Description

This is an interface subroutine that will either read in gridded data from cards, tape or disk or retrieve data from a storage file and place it out on temporary disk for input to other GEOPAC subroutines. An option is provided to store the data on permanent file in GEOPAC format. Data values are read in one row at a time starting with the upper left corner of the grid. Object time formatting allows the user to specify the format of his data when the input is on either cards, tape or disk. Unformatted data can also be read in from tape or disk provided that it is in GEOPAC format.

The maximum size of the input data matrix is 110 rows and 210 columns but the maximum size of the matrix that is placed on temporary disk or on a storage file is 64 rows by 64 columns. A provision is made on the input parameter card to specify a subset of a matrix, if desired.

Input

The required parameter card has the following format:

Column	Format	Name	Description
1-4	A4	ID	Data set identification.
6-10	I5	INPUT	The input data set reference number. The numbers 9 through 16 should not be used as the GEOPAC program reserves these for other uses. If left blank it is set to 5 for the card reader. When retrieval is requested, this variable is not used.
11-15	I5	NROW	The number of rows in the input matrix. It is not used when data sets are unformatted or retrieved.
16-20	I5	NCOL	The number of the columns in the input matrix. It is not used when data sets are unformatted or retrieved.
21-23	I3	IMIN	Beginning row number of a subset of the input data matrix.
24-26	I3	IMAX	Ending row number of the subset.
27-29	I3	JMIN	Beginning column number of the subset.
30-32	I3	JMAX	Ending column number of the subset. The above four variables are left blank if the entire matrix is desired.
33-34	I2	IJ	Row increment of a subset.
35-36	I2	JI	Column increment of a subset. The above two variables are set to 1 if left blank.

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Column	Format	Name	Description
37-68	8A4	INFMT	The input format of the data matrix. Leave blank for unformatted data sets or when retrieval is requested.
69	I1	IPRT	A number other than zero is punched if the data values are not to be printed; otherwise leave blank for printing.
70	I1	ISTR	A number other than zero is punched if the data set is to be stored on a permanent file (file 14); otherwise leave blank.
71	I1	IRETR	A number other than zero is punched if the data set is to be retrieved from a permanent file (file 14); otherwise leave blank.
75-80	A6	SNAME	The characters INPT3D must be punched.

Output

The values from the input parameter card are printed along with the data values if they are requested. The data is placed on temporary disk, file 11, in GEOPAC format and if the option is taken it is also placed on storage file 14 in the same format.

If several data sets are to be processed in one job, they should all be placed on disk with one call to subroutine INPT3D. This is because the data is written at the beginning of the disk extent with each subroutine call.

GRED3D

by

Richard H. Godson, Gordon Andreasen and Paul Zabel

Description

This gravity reduction subroutine computes the free-air and two simple Bouguer anomalies for stations that are located either within closed loops or on a base to base traverse where the gravity value

is known at the initial and ending station. An infinite number of
loops or traverses within one data set as well as any number of data
sets may be processed at one time. The only restriction is that the
number of stations per data set may not exceed 500. Input data may
be meter readings or computed gravity values in milligals.

The first Bouguer anomaly is based on a density of 2.67 while the
second uses a density provided by the user on one of the parameter
cards. Linear drift and tide corrections are applied to all stations
when the gravity values are determined from the meter readings. A
Block Data control section now contains tables for converting meter
readings to milligals for three La Coste meters (numbers G50, G62, and
G138) now in use in Saudi Arabia.

Theoretical gravity is based on the formula:

$$978049.0* (1.0+.0052884* \sin \emptyset^2 - .0000059* \sin 2 \emptyset^2); \text{ where}$$
$$\emptyset = .000004841368* \text{ latitude in seconds.}$$

The free-air anomaly is obtained by the following formula:
Observed gravity - theroretical gravity + ((.09411549 - .000137789 *
$\sin \emptyset^2$) * ELEV) - .0000000067 * $ELEV^2$; where ELEV is elevation of the
station in feet.

The Bouguer anomaly equation is as follows: Free-air anomaly -
.012774 * density * ELEV.

A polyconic projection to obtain map X and Y coordinates is
computed for each station. These values plus the three anomaly values
of each station are placed on disk for input to the gridding subroutine
GRID3D. Station data may optionally be punched on cards for storage
by subroutine GRET3D.

Input

Data input to this subroutine is by card only. The first card
of a data set is an identification card:

Column	Format	Name	Description
1-20	5A4	JD	Data set identification.
25-28	I4	CMD	Degrees of the central meridian of the data set.
29-30	F2.0	CMM	Minutes of the central meridian of the data set. The above two parameters are used for the polyconic projection.

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Columns	Format	Name	Description
32-39	F8.2	BVL	The gravity base value in milligals used for this data set (e.g., Jeddah airport value).
40	I1	OPT	A one in this column will punch the station data for subsequent storage.
50	I1	IOPT	If the gravity values of the stations have already been computed and these are used as input, punch a 1 in this column. Otherwise the subroutine will assume that meter readings will be the input.
75-80	A6	SNAME	The characters GRED3D must be punched in these columns.

The beginning of each loop or station to station traverse must begin with a parameter card:

Columns	Format	Name	Description
34-40	F7.3	BMR	Meter reading of the initial station of the loop or station traverse. Not necessary if observed gravity values are read in.
41-48	F8.2	GBV	The observed gravity in milligals of the initial station.
49-51	F3.2	D2	Density value for the second Bouguer anomaly computed; if blank, it is set to 2.50.

Columns	Format	Name	Description
52-57	F6.5	TMF	La Coste meter multiplication factor; if blank, it is set to 1.0.
58-61	A4	MN	The meter number. It is either G50, G62 or G138 and it must start in column 58.

The station cards have the following format:

Columns	Format	Name	Description
1-16	4A4	IST	Station identification.
17-18	I2	IDA	Day.
19-20	I2	IM	Month.
21-24	I4	IY	Year.
25-26	I2	IT	Time in hours, corrected to Greenwich.
27-28	I2	ITM	Time in minutes.
29-35	F7.3	MROG	Meter reading. The number on the first station must match the number on the parameter card.
36-38	I3	LATD	Degrees of latitude.
39-42	F4.2	LATM	Minutes of latitude.
43-46	I4	LONGD	Degrees of longitude.
47-50	F4.2	LONGM	Minutes of longitude.
52-59	F8.3	ELEV	Elevation in meters.
60	Al	ELEVA	Elevation accuracy code. Not used at present time.
61-68	F8.2	COG	Observed gravity value in milligals. Used if IOPT=1 on the first identification card; otherwise leave blank.

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Columns	Format	Name	Description
70-78	F8.2	GBV2	Used only in base to base traverses. In those cases, the last station card (base) has the observed gravity value in milligals in these columns.
79	I1	IK	Leave blank unless it is the last station card of a <u>data set</u>, in which case a '9' must be punched in this column.
80	I1	IJ	The last station card of a closed loop must have a '9' in this column and the ending base station card of a base to base traverse must have a '8' in this column.

Note: If IOPT=1 on the first identification card (observed gravity values are read from the station cards), then the time, date and meter readings are omitted from the station cards. Also, the minus sign for longitude is not punched.

Output

Input data obtained from each station card, X-Y coordinates, the tide correction, the observed gravity, the free-air and the two simple Bouguer anomalies are printed in tabular form.

A station location printer plot is provided for each data set, along with a set of anomaly statistics that contain the maximum and minimum values of the X and Y coordinates, the three anomalies and the latitude and longitude.

The X and Y coordinates and the three anomaly values of each station are automatically put on disk for input to the gridding subroutine GRID3D.

If the option is taken the station data is punched on cards in the proper format for storage by subroutine GRET3D. This format is described under INPUT in the forementioned subroutine.

GRET3D

by

Richard H. Godson

Description

This subroutine can either store or retrieve gravity data. Data is stored on file 12 by data sets from punched card output of sub- routine GRED3D. A maximum of 1000 stations per data set can be stored. Retrieval from this file can be obtained by data set iden- tification or by latitude and longitude parameters. For retrieval by data set identification the file is searched until a match is made between the name on the input parameter card and the name on the storage file. When retrieval is by latitude and longitude, a parameter card containing the east and west longitude and the north and south latitude of the area requested is supplied. In this case, the entire file is read and those stations falling within the specified area are retrieved.

Only storage or only retrieval can be accomplished with one call to this subroutine. If both are required in the same job, then separate calls to the subroutine must be made.

Input

For storage of data the following cards are necessary:

Card 1

Columns	Format	Name	Description
50	I1	ISTR	Punch a non zero number in this column.
75-80	A6	SNAME	The characters GRET3D must be punched in these columns.

Card 2

Columns	Format	Name	Description
1-20	5A4	ID	Data set identification.
21-30	I10	N	The number of stations in the data set to be stored. It can not exceed 1000.

Station cards. Each station consists of two cards:

Station card 1

Columns	Format	Name	Description
1-16	4A4	IST	Station identification.
17-18	I2	IDA	Day.
19-20	I2	IM	Month.
21-24	I4	IY	Year.
25-26	I2	IT	Time in hours, corrected to Greenwich.
27-28	I2	ITM	Time in minutes.
29-31	I3	LATD	Degrees of latitude.
32-36	F5.2	LATM	Minutes of latitude.
37-40	I4	LONGD	Degrees of longitude.
41-45	F5.2	LONGM	Minutes of longitude.
46-54	F9.3	ELEV	Elevation in meters.
55	A1	ELEVA	Elevation accuracy code. Not used at the present time.
56-59	A4	MN	Meter number.
60-68	F9.2	GBV	The gravity base value in milligals used for this data set (e.g., Jeddah airport value). It would be the same value on all station cards of a data set.
77-80	A4	JST	The first four characters of the station identification (columns 1-4).

Station card 2

Columns	Format	Name	Description
1-8	F8.2	SBA	Simple Bouguer anomaly in milligals calculated with a density of 2.67.

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Columns	Format	Name	Description
9-17	F9.2	COG	Computed observed gravity in milligals.
18-25	F8.3	TC	Terrain correction in milligals.
26-33	F8.2	CBA	Complete Bouguer anomaly in milligals calculated with a density of 2.67.
77-80	A4	KST	The first four characters of the station identification. It must match the characters punched in the same columns of station card one.

Note: The terrain correction and complete Bouguer anomaly values are zero at the present time due to the lack of good elevation control.

For retrieval of data one card is required. It can be in one of two formats. The format for retrieval by data set identification is as follows:

Columns	Format	Name	Description
1-20	5A4	ID	Data set identification.
40	I1	OP	Punch a '1' in this column if punched card output is desired; otherwise leave blank.
75-80	A6	SNAME	The characters GRET3D must be punched in these columns.

The format for retrieval by latitude and longitude is:

Columns	Format	Name	Description
1-2	I2	NLATD	Degrees of north latitude.
3-7	F5.0	NLATM	Minutes of north latitude.
8-9	I2	SLATD	Degrees of south latitude.
10-14	F5.0	SLATM	Minutes of south latitude.

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Columns	Format	Name	Description
21-23	I3	WLONGD	Degrees of west longitude.
24-28	F5.0	WLONGM	Minutes of west longitude.
29-31	I3	ELONGD	Degrees of east longitude.
32-36	F5.0	ELONGM	Minutes of east longitude.
40	I1	OP	Punch a '1' in this column if punched card output is desired; otherwise leave blank.
75-80	A6	SNAME	The characters GRET3D must be punched in these columns.

Note: The minus sign for longitude is not punched.

Output

Station data is always printed in tabular form whether the data is being stored or retrieved. In addition, a station location printer plot is always provided.

The program automatically computes the central meridian from the longitude limits of the data and converts geodetic positions to X and Y coordinates. The X and Y coordinates and the simple and complete Bouguer anomaly values are always placed on disk for input to the gridding subroutine GRID3D. When retrieval is by latitude and longitude, retrieval may transcend several data sets, so it is necessary to place a unique identification on disk in case the data is to be used by subroutine GRID3D. The characters RETR followed by 16 blanks is the data set identification in this case.

When data is being retrieved, an option is provided to punch out the data on cards.

GRID3D

by

Paul Zabel

Description

This subroutine is used to calculate values on grid intersection points over an area where random values are located. Input can come from the output of subroutines GRED3D and GRET3D or it can be on

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cards, tape or disk. The selected grid dimensions (see parameter card input) are defined as: XMIN, XMAX, YMIN, YMAX, M (no. rows), N (no. columns). The conditions on these parameters are simply:

$$XMIN < XMAX; \quad YMIN < YMAX; \quad i < M \le 64; \quad i < N \le 64.$$

The spacing between grid points is computed from:

$$DELX = \frac{XMAX - XMIN}{N - 1}$$

$$DELY = \frac{YMAX - YMIN}{M - 1}$$

The grid generation process is a multi-pass method utilizing a general weighted average approach. The algorithm is briefly described as follows:

Step 1. Initialize array storage

$$W_{ij} = 0 \quad \text{and}$$
$$WZ_{ij} = 0 \quad \text{for}$$

$$i=1, 2, \ldots, M+2 \; ; \; j=1, 2, \ldots, N+2.$$

Step 2. Form weight functions and weighted sums for each random data point X_k, Y_k, Z_k

$(k=1, \ldots, P)$, provided X_k, Y_k satisfy

the relations

$$XMIN - DELX \le X_k < XMAX + DELX$$

$$YMIN - DELY \le Y_k < YMAX + DELY$$

(If either of these relations are not satisfied, the point is ignored and the next point (k=k+1) is tested.)

The weight functions for the neighbouring grid points (p=1,2,3,4) to X_k, Y_k are $W_p = 1/d_p^2$, where d_p is the distance from (X_k, Y_k) to the p-th grid point. If $d_p = 0$, then the program sets $W_p = -1$ to "flag" a point exactly on a grid intersection (i.e., the weighted average is bypassed and the given Z_k value is used whenever $d_p = 0$.)

For any $W_p \neq -1$ the corresponding p-th sums are accumulated as:

p	Weight sum	Weight product sum
1	$W_{ij} = W_{ij} + W_1$	$WZ_{ij} = WZ_{ij} + W_1 \times Z_k$
2	$W_{ij+1} = W_{ij+1} + W_2$	$WZ_{ij+1} = WZ_{ij+1} + W_2 \times Z_k$
3	$W_{i+1j} = W_{i+1j} + W_3$	$WZ_{i+1j} = WZ_{i+1j} + W_3 \times Z_k$
4	$W_{i+1j+1} = W_{i+1j+1} + W_4$	$WZ_{i+1j+1} = WZ_{i+1j+1} + W_4 \times Z_k$

The grid indices (i,j) are the upper left corner of the grid box containing the point $(X_k Y_k Z_k)$ as illustrated:
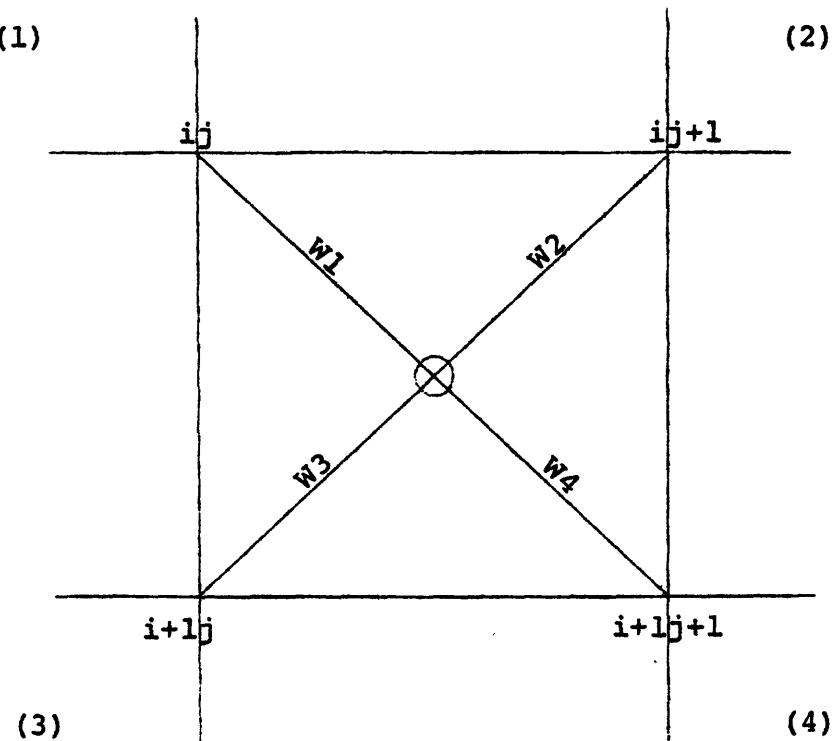
Figure 4. Indices of a grid box

Step 3. Compute weighted averages for all points with:

$$W_{ij} > 0 \ (i=1,\ldots,M+2; \ j=1,\ldots,N+2):$$

$$WZ_{ij} = \frac{WZ_{ij}}{W_{ij}} \qquad \text{(stored in } WZ_{ij})$$

If $W_{ij} = 0$ then the grid point is termed "missing" and is flagged with $WZ_{ij} = 10^{10}$.

Step 4. The entire matrix WZ_{ij} $(i=2,3,\ldots,M+1; \ j=2,3,\ldots N+1)$ is scanned for any missing points. If none are missing, then the grid generation process is completed. If any missing points are found, then Step 5 is performed.

Step 5. At each missing point $(WZ_{ij} = 10^{10})$ a "k-th local grid model" is positioned with its center on the missing point (see illustration below). We set k=1 for the first pass through this step, and k is incremented by 1 for each successive pass (step 4 is repeated after step 5). The local grid model uses all possible values immediately surrounding the missing point and within the grid model and boundary of the matrix WZ_{ij}. A weighted average is found within the grid similar to that outlined in steps 2-3.

The "k-th local grid model" is illustrated as:
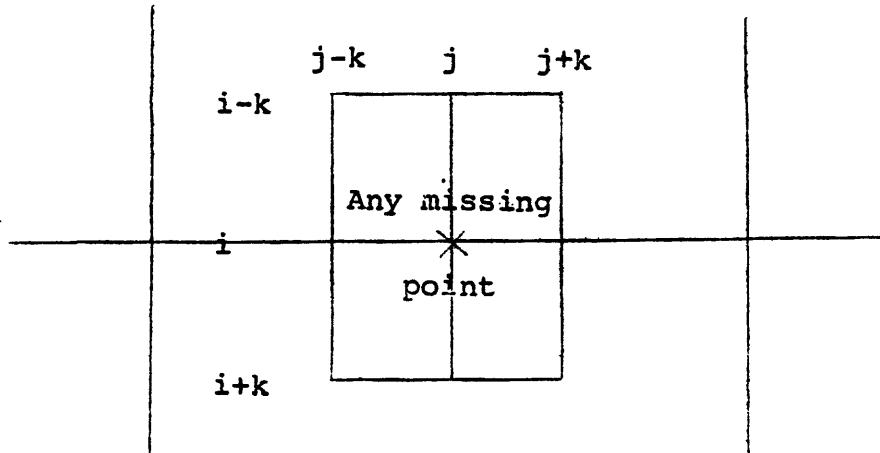
Figure 5. "K-th local grid model"

Step 4 is now repeated until all missing points are found via step 5.

Input

One parameter card is required regardless of the source of the input. If input is not from subroutine GRED3D or GRET3D, then one additional parameter card must be supplied.

Columns	Format	Name	Description
1-20	5A4	ID	Data set identification. This must correspond to the ID from subroutine GRED3D or GRET3D if the input is from either of these routines. See subroutine GRET3D for special case of retrieval by latitude and longitude. If input is from another source, any characters can be used. The first four characters will become the ID of this data set for input to the other subroutines in GEOPAC.
21-25	I5	IZI	This will either be a 1, 2, or 3 if input comes from GRED3D or a 1 or 2 if input comes from GRET3D. Otherwise it can be left blank. A '1' will grid the simple Bouguer anomaly values calculated with a density of 2.67. A '2' will grid the simple Bouguer anomaly values calculated with a density of 2.50 if the input is from GRED3D. A '2' will grid the complete Bouguer anomaly if the input is from GRET3D. A '3' will grid the free-air anomaly calculated in GRED3D.

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Columns	Format	Name	Description
26-30	I5	M	The number of rows for the generated grid. It cannot be more than 64.
31-35	I5	N	The number of columns for the generated grid. It cannot be more than 64.
36-39	A4	INPUT	The letters GRAV must be punched if input comes from subroutine GRED3D or GRET3D. Otherwise it is left blank.
40-71	8A4	IFMT	Used only if input is from other than subroutines GRED3D or GRET3D. The format of the data source which contains the X and Y coordinates and Z values of the random points. Only one location is permitted for each record (card).
72-73	I2	INNUM	Used only if input is from other than subroutines GRED3D or GRET3D. It is the input data set reference number. If left blank, it is set to 5 for the card reader.
74	I1	IPRT	A '1' is punched if the gridded values are to be printed; otherwise leave blank for no printing.
75-80	A6	SNAME	The letters GRID3D must be punched.

If the input is from other than the output of subroutine GRED3D or GRET3D, the following parameter card must be supplied.

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Columns	Format	Name	Description
1-5	I5	NP	Number of random data points to be gridded.
6-15	F10.0	XMAX	The maximum value of the X coordinate to be used in generating the grid.
16-25	F10.0	XMIN	The minimum value of the X coordinate to be used in generating the grid.
26-35	F10.0	YMAX	The maximum value of the Y coordinate to be used in generating the grid.
36-45	F10.0	YMIN	The minimum value of the Y coordinate to be used in generating the grid.

If the random values are on cards they would follow in the format specified on the first parameter card.

Output

The gridded data values are placed on the temporary disk (reference number 11) in GEOPAC format for input to the other sub-routines. The output ID is the first four characters of the input ID. In addition, a printer contour map is automatically supplied. Optionally, the gridded data values are printed (see parameter IPRT on Card 1).

FILT3D

by

Richard H. Godson and Gordon Andreasen

Description

This subroutine provides a method of wavelength filtering of gridded data, which can separate anomalies of different wavelengths. It is used to emphasize certain features on a map, to eliminate noise by using a small wavelength filter and in some cases to separate geophysical anomalies according to depth of source. Several different wavelengths can be applied; see Zurflueh (1967) for a complete description of the theory and practical examples.

Two sets of filter coefficients (Zurflueh, 1967) are provided in this program; 21.3 grid unit coefficients and 16 grid unit coefficients, both of which have steep cutoffs, approximating a step function as closely as possible. All the filters are symmetrical about the centerpoint and, therefore, introduce no phase shift.

The filters are described in terms of grid units; for example a 16 grid unit filter means that all wavelengths less than 16 grid units will be filtered. The wavelengths that are passed depend on the actual distance between the grid units. For instance, a 16 grid unit filter on data that has a grid interval of 1 kilometer will pass different wavelengths than a 16 grid unit filter that has a grid interval of 1 mile.

The two basic filter coefficient sets mentioned above can be used to obtain other filters by using every second, every fourth, etc., point and renormalizing the resulting coefficient set so that the sum of the coefficients is approximately 1. Filters with the following grid unit sizes are available in this subroutine: 21.3, 16, 10.5, 8, 5.7, 4, and 2.7.

The selected filter coefficients are convolved with the gridded data values and as with all convolution processes filtered data is lost on the edges of the data. The "edge effect" is quite severe with large grid unit filters and this subroutine attempts to partially overcome this problem by multiplying the convolved data at the edges by a ratio which depends on the number of missing values.

The filtered data is subtracted from the original data and so with one execution both regional and residual filtered values are obtained. Optional output will display values of the total grid or just that part which has been completely filtered.

Input

One parameter card is necessary for this subroutine.

Columns	Format	Name	Description
1-4	A4	ID	Data set identification.
6-10	F5.0	ADCON	An optional constant that will be added to all the input data.
11-15	F5.0	GUNIT	This is the grid units of the regional filter. Wavelengths less than this value will be rejected. One of the following values must be used: 21.3, 16, 10.5, 8, 5.7, 4 or 2.7.

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Columns	Format	Name	Description
20	I1	IFG	A '1' in this column will add a constant (ADCON) to the input data. If not wanted, leave blank.
25	I1	IPRIN	A '1' must be punched if printing of the input and filtered data values is wanted; otherwise leave blank.
30	I1	IEDGE	If a '1' is punched in this column only that part of the grid that has been completely filtered will be displayed; otherwise the whole grid is displayed.
75-80	A6	SNAME	The characters FILT3D must be punched.

Output

Printed output will depend on the variables IPRIN and IEDGE mentioned above under INPUT. A printer contour will always be displayed for both the regional and residual filters.

If IEDGE is set to 1 only the completely filtered values will be contoured. This option is recommended, otherwise the contour lines will tend to be concentrated on the edges of the map. The following numbers show the limits of the output grid for each filter when IEDGE = 1.

Filter unit	21.3	16	10.5	8	5.7	4	2.7
Beginning row number	18	14	10	8	6	5	4
Ending row number = number of rows minus	17	13	9	7	5	4	3

The above numbers refer only to rows but columns would be the same. As an example, with a 8 grid filter acting on a 50 row x 40 column array. The output grid would consist of rows 8 through 43 and columns 8 through 33.

The regional and residual values are also placed on temporary disk. The ID for the residual is the last three characters of the input data set identification (ID) followed by a blank.

FANF3D

by

Edwin S. Robinson and Richard H. Godson

Description

This subroutine is used to separate anomalies that strike in a preferred azimuth range. The technique used is called fan-filtering and was originally used to process seismic data. The grid values of a fan-filter having 2m rows and 2n+1 columns are computed from the following expression which was modified from the equation of Embree and others (1963) by substituting X and Y co-ordinates for the t and x coordinates applied to seismic data:

$$g(X_n,Y_m) = \left[\pi^2 \left[\left(\frac{Y_m}{\Delta Y}\right)^2 - \left(\frac{X_n}{K\Delta X}\right)^2 \right] \right]^{-1} ,$$

where X and Y are grid intervals and K is an integer computed internally. This grid operator is symmetrical in four quadrants. Anomaly-trend filtering is achieved by convolving g(X,Y) with the potential field. For a detailed description of the method the reader is referred to Fail and Grau (1963) and Embree and others (1963).

The program will separate anomalies striking SW to NW and W to N or anomalies striking NW to NE and N to E, depending on the option provided in the parameter card. The user supplies the number of rows and columns of the filter, which is computed in the program. As with all convolution processes data is lost on the edges of the grid, so the smallest possible filter should be used. The size would depend on the wavelength of the data. See Robinson (1967) for a practical application of this method.

Input

The one parameter card has the following format:

Columns	Format	Name	Description
1-4	A4	ID	Data set identification.
9-10	I2	KE	The number of rows of the filter. It must be an odd integer.
14-15	I2	LE	The number of columns of the filter. It must be an even integer.

Columns	Format	Name	Description
20	I1	IOP	If left blank anomalies trending SW to NW and anomalies trending W to N will be displayed. If a '1' is punched in this column anomalies trending NW to NE and anomalies trending N to E will be displayed.
25	I1	IPRT	Punch a '1' in this column to print values; otherwise leave blank.
75-80	A6	SNAME	The characters FANF3D must be punched in these columns.

Output

Two printer contour maps are always provided. If IOP = 0, the first map is for anomalies trending SW to NW and the second map for anomalies trending W to N. If IOP = 1 the first map is for anomalies trending NW to NE and the second for anomalies trending N to E.

The data values for two trends are also written out on temporary disk in the same order as the printer contour maps. The data set identification of the second grid is the last three characters of the ID of the first grid followed by a blank.

The following equations may be used to determine the size of the output grids:

Anomalies trending SW to NW (IOP = 0)
beginning row number = (KE + 1)/2
ending row number = NROWS - (KE - 1)/2
beginning column number = LE/2
ending column number = NCOLS - LE/2

Anomalies trending NW to NE (IOP = 1)
beginning row number = LE/2
ending row number = NROWS - LE/2
beginning column number = (KE + 1)/2
ending column number = NCOLS - (KE - 1)/2

Anomalies trending W to N (IOP = 0) or N to E (IOP = 1)
beginning row number = (KE - 1 + LE)/2
ending row number = NROWS - (KE - 1 + LE)/2
beginning column number = LE/2
ending column number = NCOLS - LE/2

The values of the filter used and the convolved data values can be printed if IPRT = 1 on the parameter card.

CONT3D

by

Wayne Buehrer and Paul Zabel

Description

This subroutine computes upward continuation, downward continuation, first derivative, and second derivative according to the method of Henderson (1960).

The calculation is carried out in two steps. The process first goes over the "gridded" anomaly getting the average values on the ten circles about each grid point. Next, the center point value and its associated ring-average values are each in turn multiplied by the appropriate coefficients and the products are summed.

First Step: Eleven radii have been empirically chosen as being sufficient. They are 0, 1, $\sqrt{2}$, $\sqrt{5}$, $\sqrt{8}$, $\sqrt{13}$, $\sqrt{25}$, $\sqrt{50}$, $\sqrt{136}$, $\sqrt{274}$, and $\sqrt{625}$. Each radius has the following number of points on its circumference respectively: 1, 4, 4, 8, 4, 8, 12, 12, 8, 8, 20. For each ring, the anomaly values at each of the grid points that fall on the ring are summed and divided by the number of such points on that ring. This produces eleven values (ring averages) for each point on the grid. These ring averages are stored on a temporary work area on disk until all desired options on the grid have been exercised.

Second Step: Tables of coefficients for each option, upward continuation (UC), downward continuation (DC), first derivative (FD), second derivative (SD), have been stored in the program. Each table, in general, supplies coefficients for up to five grid intervals above or below the data plane (FD and SD only apply for intervals on or below the anomaly plane). For a given point each of the eleven ring averages is multiplied by the corresponding coefficient for that option and interval and these values are summed. This is done for every point in the anomaly plane and for each option selected.

Input

Two parameter cards are needed:

Card 1

Columns	Format	Name	Description
1-4	A4	ID1	Data set identification.
5-7	I3	MNR	The first row on which calculations will begin.
8-10	I3	MXR	The last row on which calculations will be done.
11-13	I3	MNC	The first column on which calculations will begin.
14-16	I3	MXC	The last column on which calculations will be done. The previous four parameters are used in the event a subset of the main grid is desired. If they are left blank the entire matrix is used.
17-18	I2	NN	The number of options that are to follow; it must not exceed 18.

Columns	Format	Name	Description
			OPT(1) is either UC, DC, FD, or SD.
			IK(1) is the grid interval above
19-20	A2	OPT(1)	or below the anomaly plane for which
21	I1	IK(1)	OPT(1) is requested. The following
22-23	A2	OPT(2)	restrictions apply:
24	I1	IK(2)	if, OPT(I) = UC, $1 \le IK(I) \le 5$
"	"	"	OPT(I) = DC, $1 \le IK(I) \le 5$
"	"	"	OPT(I) = FD, $0 \le IK(I) \le 4$
"	"	"	OPT(I) = SD, $0 \le IK(I) \le 3$
70-71	A2	OPT(18)	Only NN consecutive options are read;
72	I1	IK(18)	the remainder may be blank. A blank
			option within these NN options
			causes an error condition.
73	I1	IPRT	Punch a '1' in this column to print
			results; otherwise leave blank.
75-80	A6	SNAME	The characters CONT3D must be punched
			in these columns.

Card 2

Columns	Format	Name	Description
1-72	18A4	IDO	This is an eighteen element array
			which contains the identification
			names that are assigned in sequence
			to each option performed on this
			data set. The number of names punched
			should correspond to the value of
			NN on card 1.

Columns	Format	Name	Description
73-80	F8.0	CONS	A value which is multiplied times the calculated results. If left blank it is set to 1.0.

Output

The first line of output consists of the ID assigned to the data set, the option used in the calculations and the size of the grid. The grid itself is then printed if desired. A printer contour is automatically supplied and the computed matrices are always placed on temporary disk. The four character identifications on temporary disk correspond to the names punched in the variable IDO on parameter card 2.

GRAD3D

by

Richard H. Godson

Description

The gradient values at each grid point or at each grid point on a specified subset of the grid are computed by this subroutine.

Grid dimensions can be determined from the variables I1, I2, M, J1, J2, N and IJ such that

$$1 \leq I1 < I2 \leq M$$

$$L \leq J1 < J2 \leq N$$

where I1 is the beginning row number, I2 is the ending row number, M is the number of rows, J1 is the beginning column number, J2 is the ending column number, N is the number of columns and IJ is the row and column increment. The number of selected rows, NIS and selected columns, NJS is determined by

$$NIS = \frac{I2 - I1}{IJ} + 1 \quad \text{and}$$

$$NJS = \frac{J2 - J1}{IJ} + 1$$

where NIS and NJS are integers greater than 2.

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The slopes in two orthogonal directions at each selected grid point Z(I,J) are determined by the following formulas:

$$SX(I,J) = \frac{1}{2*IJ*H} [Z(I,J+IJ) - Z(I,J-IJ)] \quad \text{and}$$

$$SY(I,J) = \frac{1}{2*IJ*H} [Z(I+IJ,J) - Z(I-IJ,J)]$$

where H is the distance between grid points. At the edges of the grid the above formulas are modified and the slopes determined from values that fall within the grid.

The gradient at each point is then found by simply averaging the two orthogonal slopes:

$$G(I,J) = \frac{SX(I,J) + SY(I,J)}{2}$$

Input

Each data set requires one parameter card and as many additional cards as requested gradients.

Card 1

Columns	Format	Name	Description
1-4	A4	IDT	Data set identification.
11-20	F10.0	H	The grid spacing of the input grid. If left blank it is set to 1.
24-25	I2	NO	The number of gradients to be computed. If left blank, it is set to 1. The number of cards that follow must be equal to NO.
30	I1	IPRT	Punch a '1' in this column to print gradient values; otherwise leave blank.
75-80	A6	SNAME	The characters GRAD3D must be punched.

Card 2

Columns	Format	Name	Description
1-4	A4	IDO	The identification associated with the gradient grid computed from the parameters on this card.
6-10	I5	I1	The first row selected for the subset; it will be set to 1 if left blank.
11-15	I5	I2	The last row selected for the subset; it will be set to the last row of the input matrix if left blank.
16-20	I5	IJ	The multiple of H (grid spacing) to be used over the subset; it will be set to 1 if left blank.
21-25	I5	J1	The first column selected for the subset; it will be set to 1 if left blank.
26-30	I5	J2	The last column selected for the subset; it will be set to the last column of the input matrix if left blank.

Output

If IPRT equals 1 on the input parameter card, the input data grid and the gradient grids are listed. A printer contour map of the gradient grids is always made and the grids are also written on temporary disk with an identification = IDO on card 2.

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by

Robert Terrazas

Description

This subroutine fits, in the least square sense, a surface to a set of data by means of orthogonal polynomials. For a detailed description of the method the user is referred to Caldwell (1961), Forsythe (1957) and Oldham and Southerland (1955).

Definitions and Notations

Notation

x, y	Independent variables.
$\Psi_\ell(y)$	Orthogonal polynomial of degree ℓ in the variable y.
$\Phi_k(x)$	" " " " k " " " x.
z_{ji}	Value corresponding to the grid point (y_j, x_i).
m	The number of points in the x direction (columns).
n	" " " " " " y " (rows).
d	The upper bound for ℓ and k

We define the degree of the surface as the largest of the $(\ell+k)$, where ℓ and k are the respective exponents of y and x which appear as a term of the polynomial whose coefficient is non-zero.

Define the surface:

$$(1) \quad f(x,y) = \sum_{\ell=0}^{d} \sum_{K=0}^{d'} a_{\ell k} \Psi_\ell(y) \Phi_k(x)$$

where $d' = \begin{cases} d & \text{OPTION}(5)=1 \\ d-\ell & \text{OPTION}(5)=0, \end{cases}$

and d is the degree of the surface desired.

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Minimizing:

$$\text{(2)} \quad \frac{\partial \left[\sum_{j=1}^{n} \sum_{i=1}^{m} \left(z_{ij} - \sum_{\ell=0}^{d} \sum_{k=0}^{d'} a_{\ell k} \Psi_{\ell}(y_j) \Phi_k(x_i) \right)^2 \right]}{\partial a_{\ell k}} = 0,$$

we obtain

$$\text{(3)} \quad a_{\ell k} = \frac{\sum_{j=1}^{n} \sum_{i=1}^{m} z_{ji} \Psi_{\ell}(y_j) \Phi_k(x_i)}{\sum_{j=1}^{n} \sum_{i=1}^{m} \Psi_{\ell}^2(y_j) \Phi_k^2(x_i)}, \quad \text{and}$$

$$\text{(4)} \quad \hat{z}_{\ell k}^2 = (\hat{a}_{\ell k})^2 \cdot \sum_{j=1}^{n} \sum_{i=1}^{m} \Psi_{\ell}^2(y_j) \Phi_k^2(x_i), \quad \text{where}$$

$\ell = 0, 1, 2, \ldots, d$

$k = 0, 1, 2, \ldots, d'$

from which the final form of the surface follows.

$$\text{(5)} \quad f(x,y) = \sum_{\ell=0}^{d} \sum_{k=0}^{d'} b_{\ell k} y^{\ell} x^{k}, \quad \text{where } E(b_{\ell k}) = a_{\ell k}$$

Example: $d=2$

OPTION (5) = 1

$$f(x,y) = b_{00} + b_{01}x + b_{02}x^2$$
$$+ b_{10}y + b_{11}xy + b_{12}x^2y$$
$$+ b_{20}y^2 + b_{21}xy^2 + b_{22}x^2y^2$$

OPTION (5) = 0

$$f(x,y) = b_{00} + b_{01}x + b_{02}x^2$$

$$+ b_{10}y + b_{11}xy$$

$$+ b_{20}y^2$$

The orthogonal polynomials used above are defined as follows (x only)

$$\Phi_0(x) = 1$$

$$\Phi_1(x) = -\mu+x$$

$$\cdot$$

$$\cdot$$

$$\cdot$$

$$\Phi_{k+1}(x) = x\Phi_k(x) - \alpha_k\Phi_k(x) - \beta_k\Phi_{k-1}(x), \quad \text{where}$$

$$\alpha_k = \frac{\sum\limits_{i=1}^{m} x_i\Phi_k^2(x_i)}{\sum\limits_{i=1}^{m} \Phi_k^2(x_i)}, \qquad \beta_k = \frac{\sum\limits_{i=1}^{m} \Phi_k^2(x_i)}{\sum\limits_{i=1}^{m} \Phi_{k-1}^2(x_i)}, \qquad \mu = \frac{1}{m}\sum\limits_{i=1}^{m} x_i$$

Input

One parameter card is necessary to execute this subroutine.

Columns	Format	Name	Description
1-30	7A4,A2	TITLE	Any alphanumeric information.
31-34	A4	KD	Data set identification.
37	I1	OPTION(1)	If blank use entire matrix; if 1, select proper subset of matrix.

Columns	Format	Name	Description
38	I1	OPTION(2)	If blank use all elements of least square matrix in computing polynomial. If '1', use selected elements of least square matrix in computing polynomial.
39	I1	OPTION(3)	If blank, continue. If '1', select single degree fit (see columns 47-58 below).
40	I1	OPTION(4)	If blank, continue. If '1', select maximum degree, minimum degree and increment (see columns 47-58 below).
41	I1	OPTION(5)	If blank, d' = d - ℓ. If '1', d' = d (see description).
42	I1	OPTION(6)	If blank don't write residuals on temporary disk. If '1', write residuals on temporary disk.
43	I1	OPTION(7)	Punch a '1' to print values; otherwise leave blank.
47-50	I4	IL ⎫	If OPTION(3) is selected, the desired degree is punched in IL and IM. If OPTION(4) is selected, the lowest degree is punched in IL. The highest degree is punched in IM and the increment in IS. If neither OPTION(3) nor OPTION(4) is selected the program computes all degrees to where the sum of the squares of the residuals is less than 7 orders of magnitude of the sums of the squares of the elements in the matrix.
51-54	I4	IS ⎬	
55-58	I4	IM ⎭	

Columns	Format	Name	Description
59-61	I3	ML	The beginning column number of a subset of the matrix.
62-64	I3	MH	The ending column number of a subset of the matrix.
65-67	I3	NL	The beginning row number of a subset of the matrix.
68-70	I3	NH	The ending row number of a subset of the matrix. The above four parameters are used only if OPTION(1) is set to '1'.
75-80	A6	SNAME	The characters POLY3D must be punched.

Cards with the following format must be supplied if OPTION(2) is '1':

Columns	Format	Name	Description
1-3	I3	IRO	Row subscript.
4-6	I3	IRT	Column subscript. Only one pair of coefficients per card. As many cards as selected elements of the least square matrix desired must be supplied.

After the last subscript card a card with 999 in columns 1-3 must be supplied.

Output

Output to this subroutine consists of the following:

1. Header card parameter and TITLE.

2. Z-square matrix.

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3. Least square matrix.

4. Estimated sums of squares of residuals for selected fits.

5. Computed polynomial.

6. Computed surface.

7. Residuals.

8. Maximum and minimum values and associated statistics.

9. Printer contours of computed and residual values.

10. The computed values are written out on temporary disk

    and if OPTION(6) is set to '1', the residuals are

    also written out. The residual ID is the last three

    characters of the data set identification followed by

    a blank. Although all degrees of fit are written out

    on disk only the first computed and first residual

    are available for later processing.

GRAV3D

by

Lindrith Cordell

Description

This subroutine is designed to calculate a three-dimensional structural model directly from gravity anomaly data by means of the iterative method of Cordell and Henderson (1968). The source of the gravity anomaly is represented as a bundle of vertical prism elements - each prism element having a cross-sectional area equal to one grid square, uniform density, and a vertical position fixed with respect to a specified reference surface. The physical system is illustrated in figure 6, where the reference surface is a horizontal plane delimiting the base of the model.

Two extensions of the procedure described in the paper cited above, have been incorporated into the subroutine. Now the exact formula, modified from Nagy (1966 and 1967), may be used to obtain the gravity effect of the prism elements comprising the model. Also, the reference surface may be an irregular surface defined by means of a data array, as well as a horizontal plane.

Removal of gravity trends and background is crucial. It is generally advisable to extend the data grid well beyond the area of interest, and to use a coarse grid while experimenting with density contrast and the reference surface in order to reduce computation time. Execution time is proportional to the square of the number of field points and on an IBM 360/65 computer is about

$3N(I*J)^2*(10^{-6})$ minutes, where I and J are the numbers of data rows and columns, and N is the number of iterations. This estimate is based on the approximate prism formulae (Cordell and Henderson, 1968, p. 597). Execution time is about ten times greater when the exact prism formula is used. Normally five iterations are about right for preliminary tests. The optimum number of iterations for subsequent runs is best determined from the behavior of the largest error and the root mean square error.

Input

Two parameter cards are necessary to use this subroutine. Optionally, reference surface and model thickness cards can be included.

Card 1

Columns	Format	Name	Description
1-72	18A4	ID	Any alphanumeric information. If gravity data is to be read in from disk (IOPT(3) = 0 or 1), the first four characters must be equal to the input ID on disk.
73	I1	IPRT	Punch a '1' to print computed values; otherwise leave blank.
75-80	A6	SNAME	The characters GRAV3D must be punched.

Card 2

Columns	Format	Name	Description
11-17	F7.0	ZSI	Depth to horizontal reference plane in units of length; see fig. 6 and options 1 and 5.

Columns	Format	Name	Description
18-24	F7.0	RHO	Density contrast in units of grams/cm^3.
25-31	F7.0	W	Grid interval in units of length.
32-34	I3	NMAX	Iterations desired. If blank, less than or equal to zero, or greater than 50, it is set to 5.
35-37	I3	NSTAR	Exact prism formula option. NSTAR is the first iteration for which the exact formula is used, i.e. the approximate prism formulae will be used for iterations 1, 2, ..., NSTAR-1; and the exact formula will be used for iterations NSTAR, NSTAR+1, NSTAR+2, ..., NMAX. If blank or NSTAR is greater than NMAX, the exact formula is not used. If option 3 = 2, NSTAR = NMAX = 1. Normally, NSTAR is blank for preliminary runs, NSTAR = NMAX - 2 for the final run.
38-44	F7.0	EPS	Error toleration option. If EPS is specified, computation will stop when the largest gravity error is numerically less than EPS or after the NMAX iteration, whichever comes first. If not desired, leave blank. If the exact formula is to be used for the last several iterations, this field should be left blank.

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Columns	Format	Name	Description
45-46	I2	IOPT1	If the reference surface delimits the top of the model, set to '1'. If the reference surface delimits the base of the model, set this option = 2. If the reference surface delimits the bisection, i.e., a surface halfway between the top and base of each prism element comprising the model, set to '3'.
47-48	I2	IOPT2	If units of length for parameters ZSI and W are given in kilometers, punch a '1'. If units are miles, punch a '2' and if they are kilofeet, punch a '3'.
49-50	I2	IOPT3	If a model thickness array t(i,j) is not included with input, this variable is left blank. In this case gravity data values will be read in from disk.

If both thickness and gravity data values are input, this option is equal to 1. In this case the program will modify results from a previous run, without the need of repeating the calculation. For each iteration

Columns	Format	Name	Description
			the model thickness at a given grid point is obtained as a factor of its original value. By indicating t = 0 over an appropriate subset of the input model thickness array, this mode can be used to restrict the model beneath a certain part of the data grid, as might be indicated from outcrop or drill information.
			If a model thickness array is input, but a gravity data array is not, this option = 2. In this mode the program is used as an anomaly stimulator. The gravity field of the given model is calculated once by means of the exact formula. If this option = 2, columns 32-44 may be left blank.
51-52	I2	IOPT4	If punched card output is not wanted, leave blank. If set to 1, the calculated gravity field of the model, thickness of the model, and depth to the top of the model (base, if IOPT1 = 1) are punched on cards in the formats indicated in columns 53-68.

Columns	Format	Name	Description
53-60	2A4	FMTG	If IOPT4 is blank, skip this field.
			If IOPT4 = 1, indicate format for the calculated gravity set. i.e., (10F7.3).
61-68	2A4	FMTS	If IOPT4 is blank, skip this field.
			If IOPT4 = 1, indicate the format for the thickness and depth data sets.
69-70	I2	IOPT5	If the reference surface is a horizontal plane at depth = ZSI, leave blank. Normally this is the case. If the reference surface is not a plane, IOPT5 = 1. In this case the surface ZS(i,j) is defined by card input, as described below.

Reference surface d(i,j) cards

If IOPT5 is blank, skip this data set. One parameter card followed by the array cards are necessary for this data set. The parameter card has an A4,2I3 format for an identification and the number of rows and columns, respectively, of the data set. Punch the array in 10F7.0 format. They are read in by rows, i.e. ZS(1,1), ZS(1,2), etc., row 1, column 1 being at the upper left corner of the grid. Note that this data must be consistent with the conditions of IOPT1 and IOPT2. Each row starts on a new card.

Model thickness t(i,j) cards

If IOPT3 is blank, skip this data set. One parameter card followed by the array cards are necessary for this data set. The parameter card has an A4,2I3 format for an identification and the number of rows and columns, respectively, of the data set. Punch the array in 10F7.0 format as described above. Note that these data must be consistent with the conditions of IOPT1 and IOPT2. Each row starts on a new card.
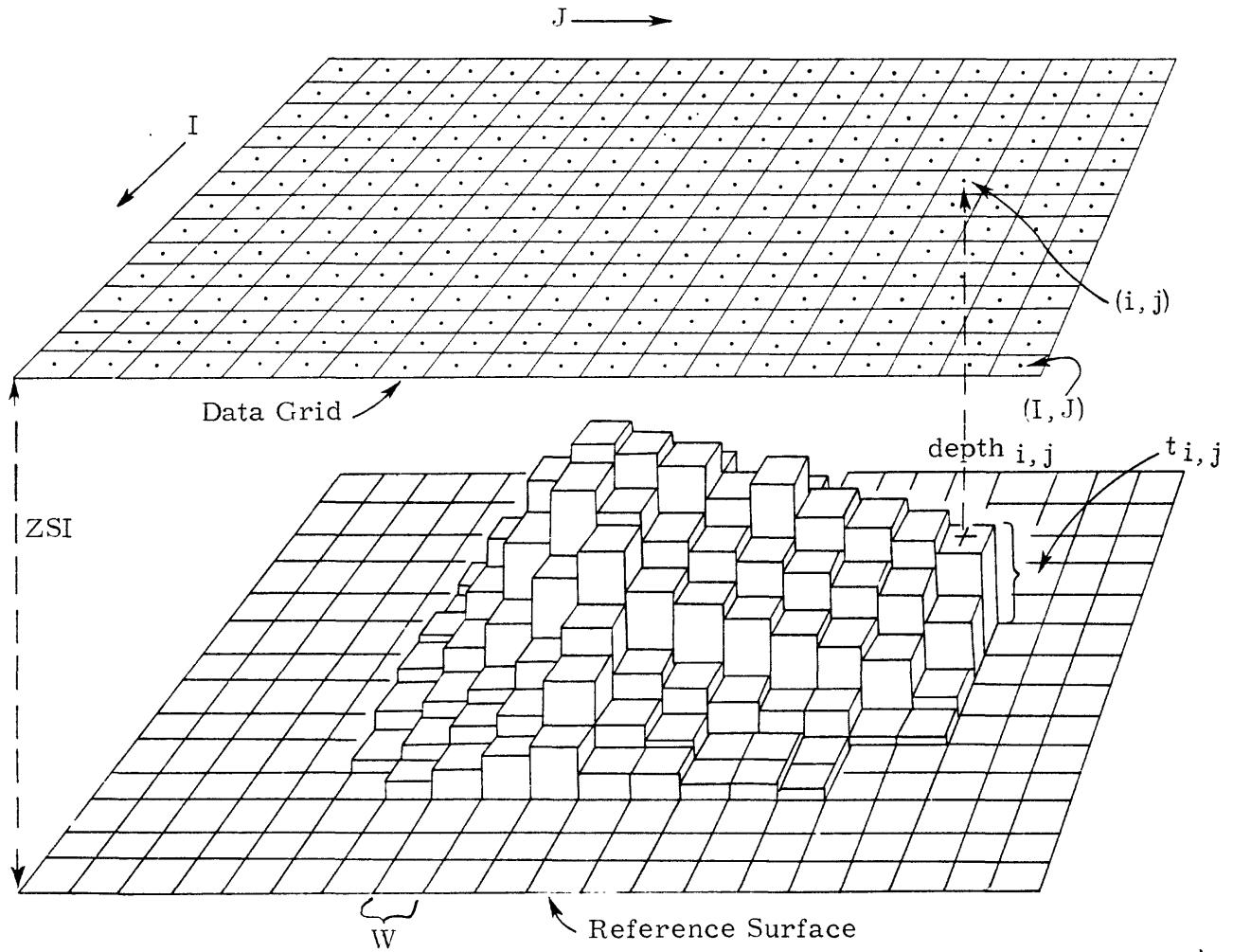
Figure 6. - Illustration of a data grid and a prismatic model with the base as a reference surface.

Note that IOPT1, IOPT3, IOPT5, parameter ZSI t(i,j), if used, should be checked to ascertain that the model does not extend above the surface of the observation. Should this occur the error message: "Reference plane ZSI or surface ZS(i,j) is not properly defined" is printed and the subroutine is aborted.

Output

The input parameters are printed along with an explanation of the options taken and the type of gravity calculation that will be performed. A table is printed that includes the row and column index, and the following six values: reference surface, model thickness, depth, gravity data, calculated gravity, and gravity error, if IPRT on input card 1 is equal to 1.

Printer contour maps are provided for all the appropriate values mentioned above and also, the same data sets are written out on temporary disk. The data set identification, for the six sets mentioned above are, in order: RSUR, THCK, STRC, INPG, CALG and RESG. These data set identifications are used if additional processing is desired.

MAGM3D

by

Dave Handwerker, Paul Zabel and Gordon Andreasen

Description

This subroutine computes magnetic values on a grid over a magnetic body when the model is described as shown under Input and proper values of the declination of polarization, the inclination of polarization, and the inclination of the earth's field are properly selected (Andreasen and Zietz, 1969). A complete description of the mathematical technique can be found in Zietz and Andreasen (1967).

Input

Each data set must contain a parameter card and one or more angle cards.

Parameter card

Columns	Format	Name	Description
1-4	I4	IREF	The reference number for the data set. All cards in a data set must have the same reference number.

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Columns	Format	Name	Description
5	I1	ID	A '1' in this column identifies the card as a parameter card.
6-10	F5.2	AL(1)	The minimum X value of the magnetic body in the direction of magnetic north.
11-15	F5.2	AL(2)	The maximum X value of the magnetic body in the direction of magnetic north.
16-20	F5.2	BE(1)	The minimum Y value of the magnetic body at a right angle to magnetic north and in the X-Y plane.
21-25	F5.2	BE(2)	The maximum Y value of the magnetic body at a right angle to magnetic north and in the X-Y plane.
26-30	F5.2	GA(1)	The minimum Z value of the magnetic body. It must be greater than 0.
31-40	E10.2	GA(2)	The maximum Z value of the magnetic body. It must not exceed 10^{17}. (10^{16} should be used to simulate ∞). GA(2) - GA(1) is the thickness of the body.
41-45	F5.2	X1	The minimum value in the X direction for determining the length of the X-axis.

Columns	Format	Name	Description
46-50	F5.2	X2	The maximum value in the X direction for determining the length of the X-axis. X2 - X1 is the length of the X-axis.
51-55	F5.2	DXY	The increment, ΔX, taken along the X-axis = ΔY, the increment taken along the Y-axis.
56-60	F5.2	Y1	The minimum value in the Y direction for determining the length of the Y-axis.
61-65	F5.2	Y2	The maximum value in the Y direction for determining the length of the Y-axis. Y2 - Y1 is the length of the Y-axis. See fig. 7 and Output for clarification of the above parameters.
75-80	A6	SNAME	The characters MAGM3D must be punched in these columns.

Angle card

Columns	Format	Name	Description
1-4	I4	IREF	The reference number which must be the same as the number on the preceding parameter card.
5	I1	ID	A '2' in this column identifies the card as an angle card.

Columns	Format	Name	Description
6-10	I5	MP	An integer ID which may be used to identify a specific angle card.
11-15	F5.2	RH	Tne declination of polarization measured parallel to the X-Y plane, increasing from the positive X to positive Y. The declination of the polarization is 0° on the X-axis.
16-20	F5.2	RV	The inclination of polarization measured as the vertical angle below the X-Y plane.
21-25	F5.2	RI	The inclination of the earth's field measured in the X-Z plane, increasing downward from 0° on the positive X-axis.
66-69	A4	MAPID	A four character alphanumeric ID used to identify the output grid on disk.
70	I1	IPR	Punch a '1' to print values; otherwise leave blank.
75-80	A6	SNAME	The characters MAGM3D must be punched in these columns.

Output

A listing of the input parameters, TRG factors, the map ID, the number of rows and columns, the maximum and minimum values and a printer contour map are always provided. Optionally, a table of the gridded magnetic anomaly values are also printed.
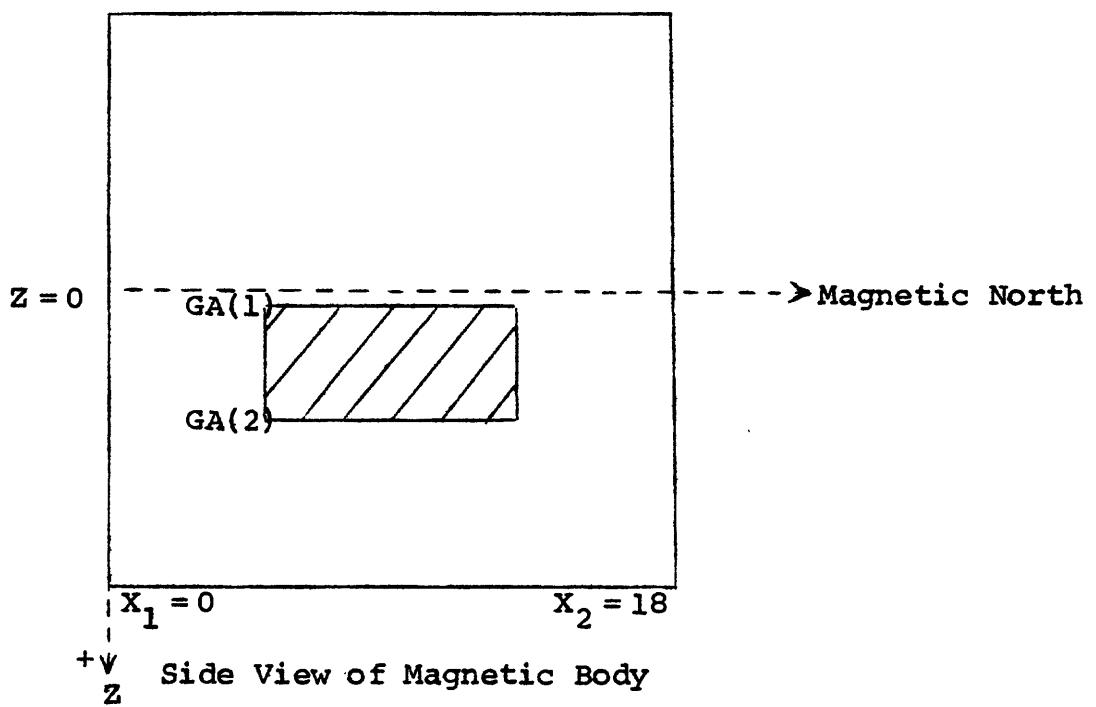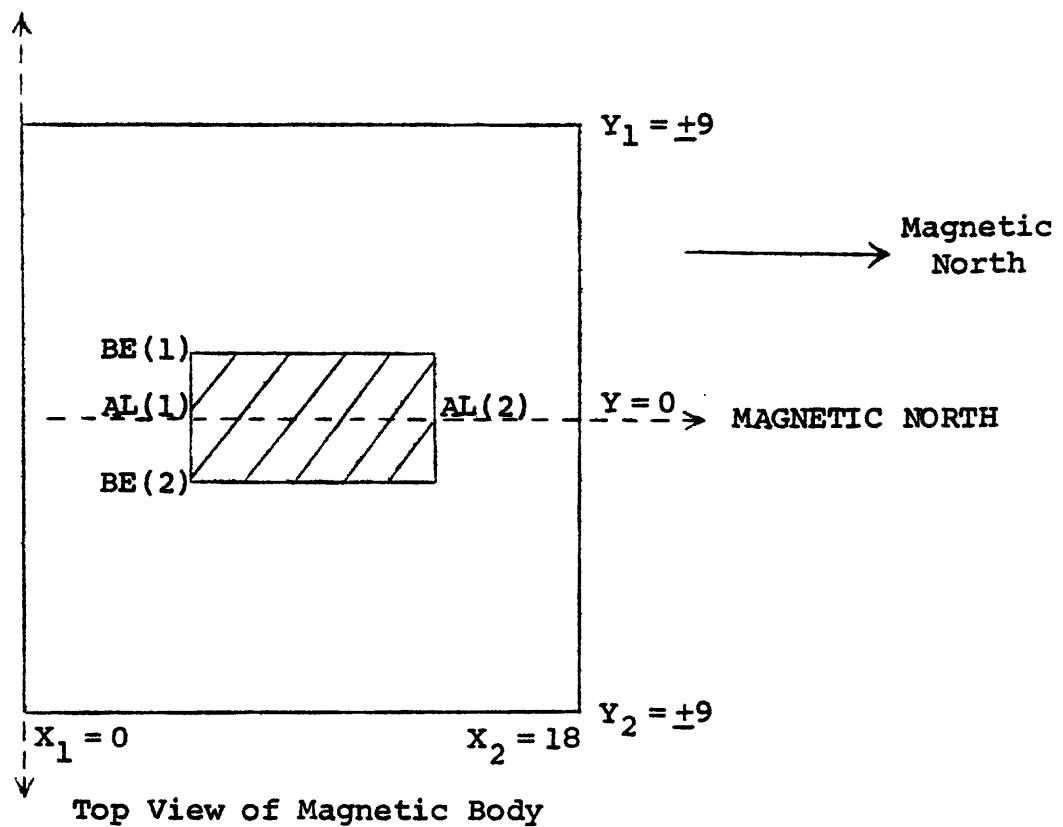
Figure 7. Top and side views of a magnetic body within the limits of a data grid.

The gridded anomaly values are always placed on temporary disk. The size of the output grid is determined by the following equations:

$$\text{Number of rows} = (X2 - X1) / \Delta X + 1$$

$$\text{Number of columns} = (Y2 - Y1) / \Delta Y + 1$$

The number of rows or columns must not exceed 64.

MAGA3D

by

B. F. McMahon, R. E. McIntire and Richard H. Godson

Description

This subroutine computes the anomalies caused by magnetic distributions of arbitrary shape in a three-dimensional modeling procedure (McMahon, 1966). Given the magnitude and direction of the polarization, the total magnetic intensity at grid points in a North-South vertical coordinate frame is calculated for the following type bodies:

  a.   A North-South oriented rectangular plate. These will be referred to as 'Plate, N-S'.

  b.   A rectangular plate oriented arbitrarily, having at least one of the dimensions not parallel to some coordinate axis. These will be referred to as 'Plate, arbitrary'.

  c.   A rectangular parallelepiped bounded by North-South, East-West and horizontal planes. These will be referred to as ' Parallelepipeds, N-S'.

  d.   A rectangular parallelepiped oriented arbitrarily. These will be referred to as 'Parallelepipeds, arbitrary'.

The program allows for the computation of the magnetic intensity of up to 1000 plates and/or parallelepipeds. The plates or parallelepipeds may be grouped into as many as fifty groups with separate answers given for each group.

Input

Several control cards are necessary to run this subroutine.

Card 1

Columns	Format	Name	Description
1	I1	KODE	A '1' must be punched in this column.

Columns	Format	Name	Description
3-74	18A4	TITLE	Any alphanumeric information.
75-80	A6	SNAME	The characters MAGA3D must be punched in these columns.

Card 2

Columns	Format	Name	Description
1	I1	KODE	A '2' must be punched in this column.
4-7	A4	ID1	The ID of the data set which will be written out on disk.
8-11	A4	ID2	The ID of the field data which will be read in from disk (not used if IFIELD is blank).
16-20	I5	IFIELD	Leave blank if data set is not to be read in from disk; otherwise any non-zero integer.
21-25	I5	IGROUP	The number of magnetic groups (maximum = 50).
26-35	F10.2	CONST	A constant value added to total intensity to get sum.
36-45	F10.0	THETA	The magnetic inclination.
50	I1	IPR	Leave blank if intensity values are to be printed; otherwise any number.
55	I1	IZZ	If only Z values on a grid are to be read, place a '1' in this column; otherwise leave blank. See card 5 for a further explanation of this variable.

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Card 3   (Three cards are required even if 2nd and 3rd are blank)

Columns	Format	Name	Description
1	I1	KODE	A '3' must be punched in this column.
4-75	18I4	IELEM	The number of elements for each group. Four position field for each group (maximum total of 1000 elements). Not necessary when Z values on a grid are read in.

Card 4

This card describes the dimensions of the grid on which total magnetic intensity is computed at regularly spaced points (fig. 8). For a given grid, fixed in the X-Y plane, values at several Z levels can be calculated by supplying ZMIN, ZMAX, and Z. If only one level is required, then ZMIN = ZMAX = the level and $\Delta Z = 0$.

If the values on the grid are to be compared with field data read in from disk, then:

XMAX = number of rows, XMIN = 1.0 and DELX = 1.0,

YMAX = number of columns, YMIN = 1.0 and DELY = 1.0,

ZMAX = ZMIN = level of field observations and DELZ = 0.

Columns	Format	Name	Description
1	I1	KODE	A '4' must be punched in this column.
4-11	F8.0	XMIN	The minimum value in the X direction for determining the grid.
12-19	F8.0	YMIN	The minimum value in the Y direction for determining the grid.
20-27	F8.0	ZMIN	The minimum level at which the magnetic values are to be computed.
28-35	F8.0	DELX	The increment in the X direction for determining the grid.

x-y Plane

Z min

Z max

X

(XMAX, YMIN)   (XMAX, YMAX)

ZMIN   Y

Z

ZMAX   (XMIN, YMIN)   (XMIN, YMAX)
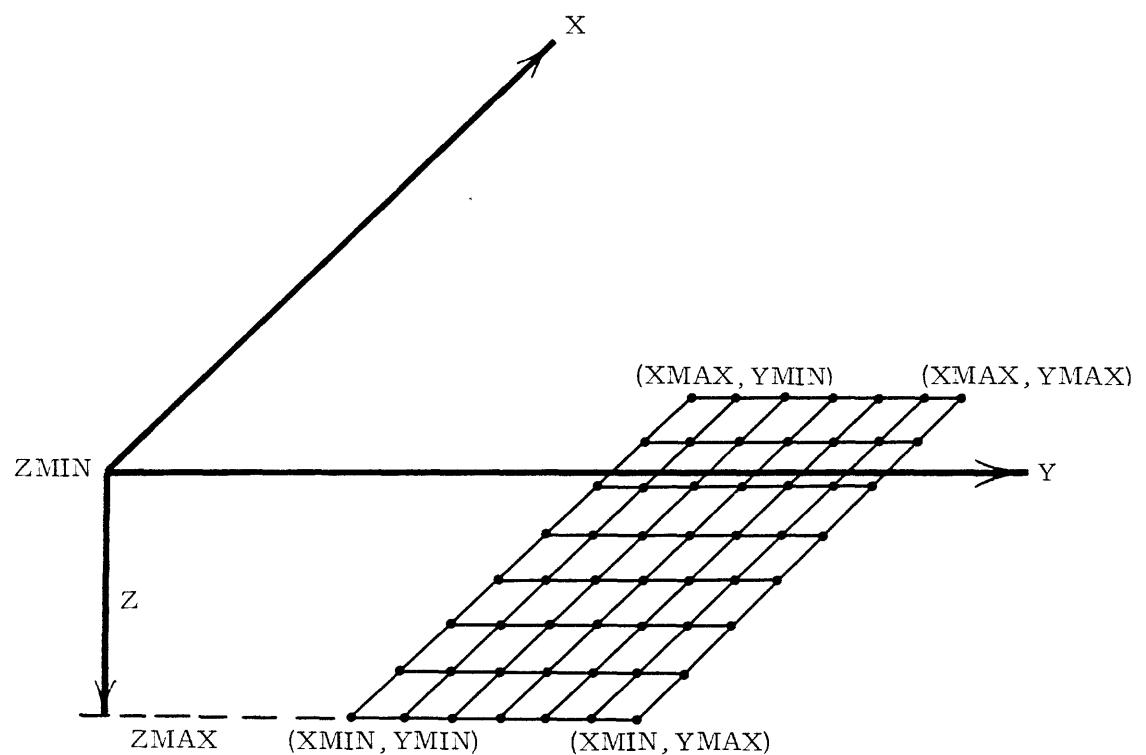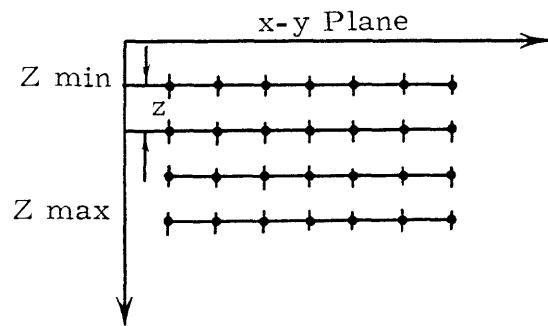
Figure 8. - A cross sectional and a plane diagram of a North-South
vertical coordinate grid frame.

Columns	Format	Name	Description
36-43	F8.0	DELY	The increment in the Y direction for determining the grid.
44-51	F8.0	DELZ	The increment in the Z direction for determining the number of levels at which the magnetic values are computed.
52-59	F8.0	XMAX	The maximum value in the X direction for determining the grid.
60-67	F8.0	YMAX	The maximum value in the Y direction for determining the grid.
68-75	F8.0	ZMAX	The maximum level in the Z direction at which the magnetic values are computed.

The number of rows and columns are computed by the following equations and they must not be greater than 64:

$$\text{Number of rows} = (XMAX - XMIN) / DELX + 1.0$$

$$\text{Number of columns} = (YMAX - YMIN) / DELY + 1.0$$

Card 5

The type of card or cards that follow will depend on how the values for the dimensions of the plate or parallelepiped magnetic bodies that comprise the model are read in.

1. One method is to digitize a map, e.g. a topographic map, thereby obtaining Z (height) values at each point on a N-S grid. The four values that surround a grid cell are averaged to obtain a mean value for the cell. The grid is then considered to be a series of N-S parallelepipeds with the thickness being the distance between grids. The program computes the X and Y values for each of the elements. The number of elements is (NR-1) * (NC-1) (maximum = 1000). The following parameter card is required in this case.

Columns	Format	Name	Description
1-5	I5	NR	The number of rows in the grid.
6-10	I5	NC	The number of columns in the grid.
11-20	F10.0	ZPLANE	An elevation which is above the highest grid value. It is a depth reference plane from which all grid values are subtracted.
21-30	F10.0	ZDEPTH	The depth below the reference plane, which will be the bottom depth of the model.
31-40	F10.0	XDIST	The distance between the grid points (thickness of the parallelepipeds).
41-50	F10.0	POLARZ	Polarization (susceptibility * earth's field in gammas).

The grid point values are read from cards by columns (north-south direction) starting from the lower left corner of the grid in a 10F7.0 format. Each column must start on a new card.

2. The second method of constructing a model is to describe the various elements individually (fig. 10-13). It is sometimes convenient to designate various elements as members of some group. Figure 9 below illustrates how groups might be selected when various elements are used in combination to approximate a magnetic source with irregular bounds.

The input format requires that the data cards describing the elements be assigned to some numbered group and that the numbered groups of cards follow each other in order.

There is, however, no special ordering of the data cards for elements within a group. Aside from their "Natural" grouping in the examples above, all the elements shown could be considered as members of the same group for the purposes of the program. In practice, though, this tends to be confusing and troublesome when changes are made for successive models.

Also, a group may contain only one element, and this can be useful in the case of a single parallelepiped which adequately approximates some isolated region of the model.

Figure 9. - Arrangement of elements into groups.
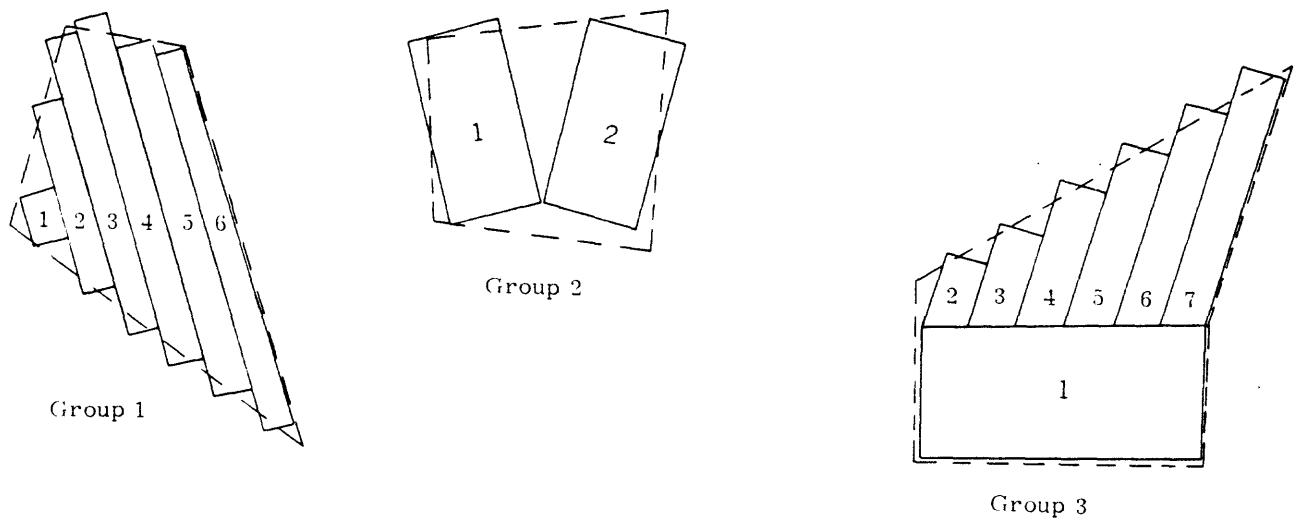
— — — — Indicates bounds of regular region

Group 1) Elements 1-6, Arbitrary Plates

Group 2) Elements 1-2, Parallelepipeds, Arbitrary

Group 3) Element 1, N-S Parallelepiped, Elements 2-7, Arbitrary Plates

The following formats are used with this method:

Plate, N-S (fig. 10)

Columns	Format	Name	Description
1	I1	KODE	A '5' must be punched in this column.
2-7	F6.0	XI1	X_1 coordinate.
8-13	F6.0	XI2	X_2 coordinate.
26-31	F6.0	ETA1	Y_1 coordinate.
50-54	F5.0	ZETA1	Z_1 coordinate.
55-59	F5.0	ZETA2	Z_2 coordinate.
70-74	F5.0	THICK	Thickness of the plate.
75-79	F5.0	POLARZ	Polarization (susceptibility * earth's field in gammas).
80	I1	METHOD	A '1' must be punched in this column.

Plate, Arbitrary (fig. 11)

Columns	Format	Name	Description
1	I1	KODE	A '5' must be punched in this column.
2-7	F6.0	XI1	X_1 coordinate.
8-13	F6.0	XI2	X_2 coordinate.
14-19	F6.0	XI3	X_3 coordinate.
26-31	F6.0	ETA1	Y_1 coordinate.
32-37	F6.0	ETA2	Y_2 coordinate.
38-43	F6.0	ETA3	Y_3 coordinate.
50-54	F5.0	ZETA1	Z_1 coordinate.
55-59	F5.0	ZETA2	Z_2 coordinate.
60-64	F5.0	ZETA3	Z_3 coordinate.
70-74	F5.0	THICK	Thickness of the plate.
75-79	F5.0	POLARZ	Polarization (susceptibility * earth's field in gammas).
80	I1	METHOD	A '2' must be punched in this column.

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Parallelepiped, N-S (fig. 12)

Columns	Format	Name	Description
1	I1	KODE	A '5' must be punched in this column.
2-7	F6.0	XI1	X_1 coordinate.
8-13	F6.0	XI2	X_2 coordinate.
14-19	F6.0	XI3	X_3 coordinate.
26-31	F6.0	ETA1	Y_1 coordinate.
32-37	F6.0	ETA2	Y_2 coordinate.
38-43	F6.0	ETA3	Y_3 coordinate.
50-54	F5.0	ZETA1	Z_1 coordinate.
55-59	F5.0	ZETA2	Z_2 coordinate.
60-64	F5.0	ZETA3	Z_3 coordinate.
75-79	F5.0	POLARZ	Polarization (susceptibility * earth's field in gammas).
80	I1	METHOD	A '3' must be punched in this column.

Parallelepiped, Arbitrary (fig. 13)

Columns	Format	Name	Description
1	I1	KODE	A '5' must be punched in this column.
2-7	F6.0	XI1	X_1 coordinate.
8-13	F6.0	XI2	X_2 coordinate.
14-19	F6.0	XI3	X_3 coordinate.
20-25	F6.0	XI4	X_4 coordinate.
26-31	F6.0	ETA1	Y_1 coordinate.
32-37	F6.0	ETA2	Y_2 coordinate.
38-43	F6.0	ETA3	Y_3 coordinate.
44-49	F6.0	ETA4	Y_4 coordinate.

Columns	Format	Name	Description
50-54	F5.0	ZETA1	z_1 coordinate.
55-59	F5.0	ZETA2	z_2 coordinate.
60-64	F5.0	ZETA3	z_3 coordinate.
65-69	F5.0	ZETA4	z_4 coordinate.
75-79	F5.0	POLARZ	Polarization (susceptibility * earth's field in gammas).
80	I1	METHOD	A '4' must be punched in this column.

Output

The title, the data set identifications and a printer contour of the magnetic intensity on the grid are always provided. If IPR on parameter Card 2 is blank, the magnetic intensity values for each grid point for each group plus the total of all groups is printed in tabular form.

If field values are read in from disk for comparison with the model a printer contour of these values is also provided and if the number of rows and columns of the field values and model values are equal, the residual is computed and a printer contour provided.

The total magnetic intensity values generated by the model are always written out on temporary disk with an identification = ID1, which is specified on parameter card 2. If models are generated at several Z heights, only the last one is placed on temporary disk.

When a residual is computed, it is placed on temporary disk with an identification equal to the last three characters of ID1 followed by a blank.

PLATE, N-S

METHOD, M=1

TABULATE: $X_1, X_2, Y_1, Z_1, Z_2, \Delta$ THICKNESS
X_1 IS THE SOUTHMOST OF X_1 AND X_2

NOTE   In all cases, the origin of the
coordinate system is to be chosen
such that all X, Y, and Z values
will be positive.
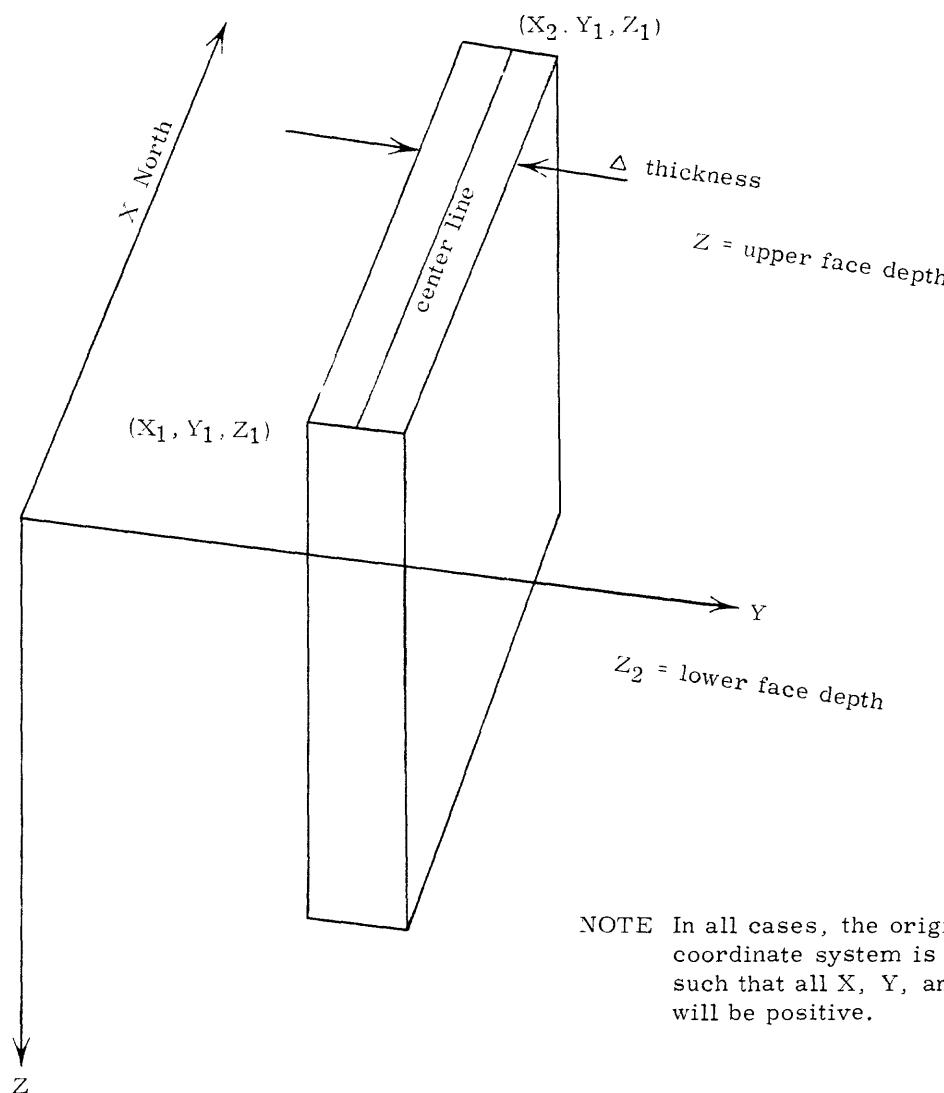
Figure 10. - Plate, N-S, in a three-dimensional coordinate system.

PLATE, ARBITRARY

METHOD, M=2

TABULATE: $X_1, X_2, X_3, Y_1, Y_2, Y_3, Z_1, Z_2, Z_3$,   THICKNESS
X_1 IS THE SOUTHMOST OF X_1 AND X_2
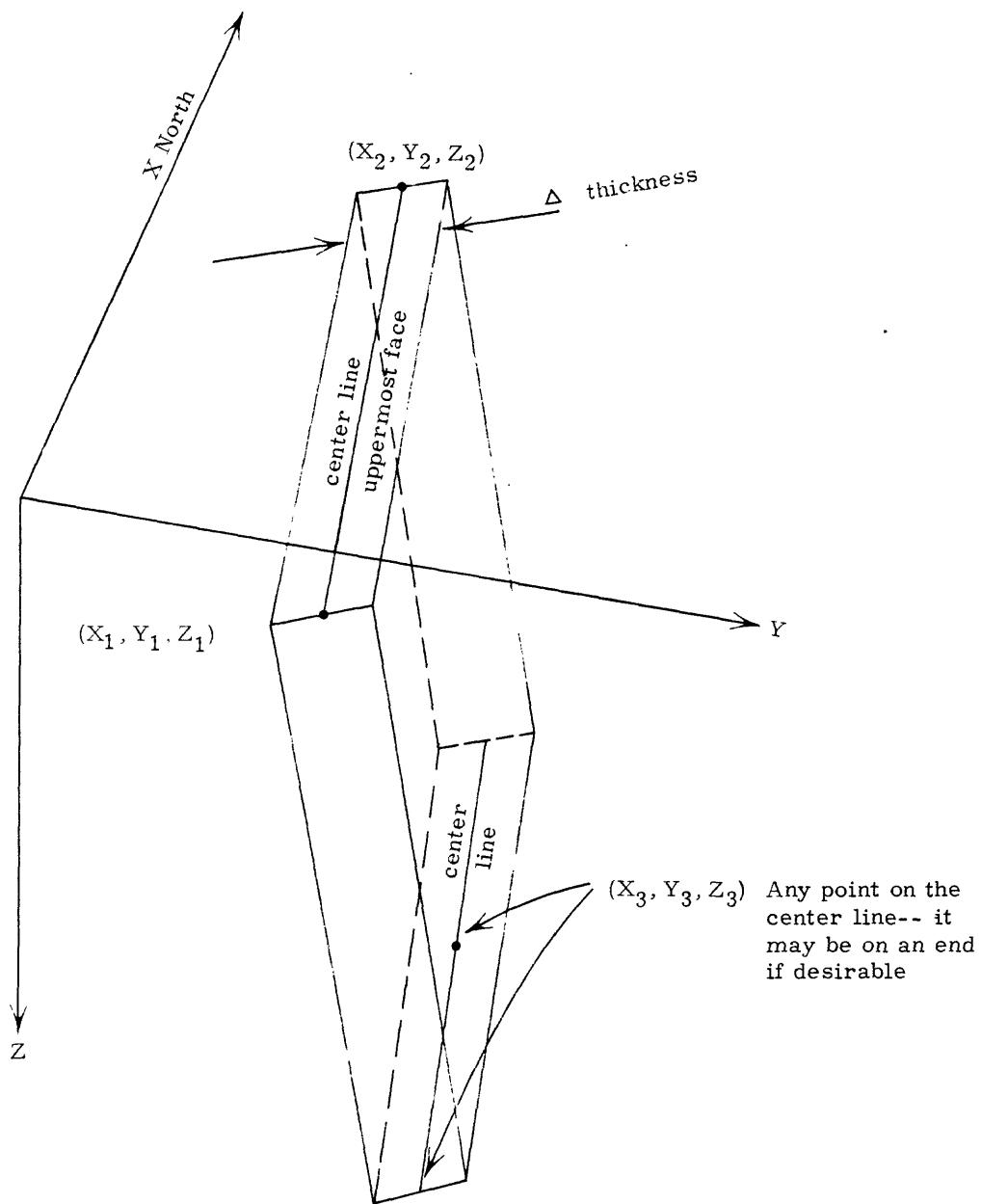
Figure 11.- Plate, arbitrary, in a three-dimensional coordinate system.

PARALLELEPIPED, N-S

METHOD, M=3

TABULATE: $X_1, X_2, X_3, Y_1, Y_2, Y_3, Z_1, Z_2, Z_3$

X_1 IS THE SOUTHMOST OF X_1 AND X_2
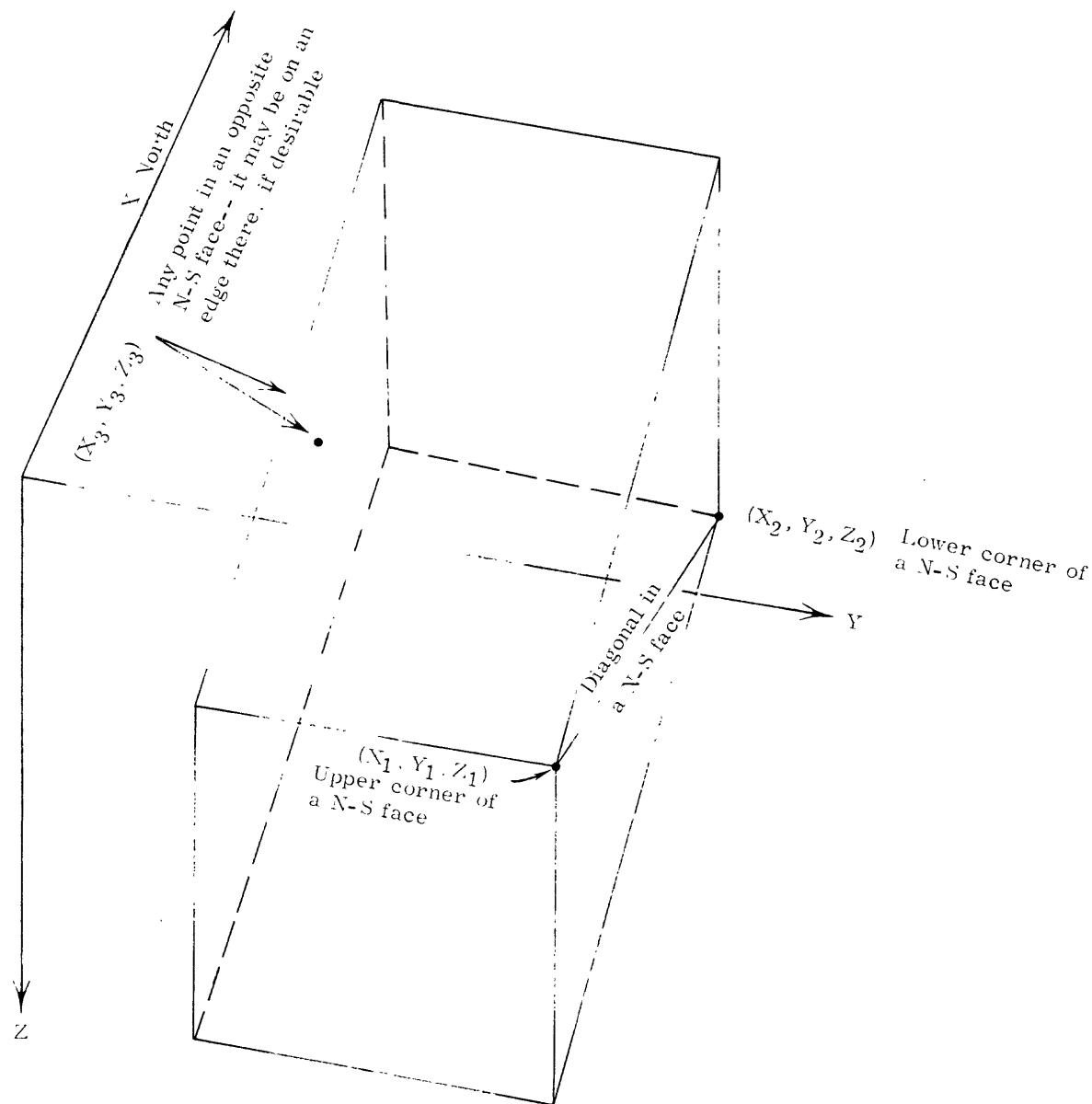
Figure 12.- Parallelepiped, N-S, in a three-dimensional coordinate system.

PARALLELEPIPED, ARBITRARY

METHOD, M=4

TABULATE: $X_1, X_2, X_3, X_4, Y_1, Y_2, Y_3, Y_4, Z_1, Z_2, Z_3, Z_4$
X_1 IS THE SOUTHMOST OF X_1 AND X_2
AND Y_2 MUST BE TO THE LEFT OF Y_1
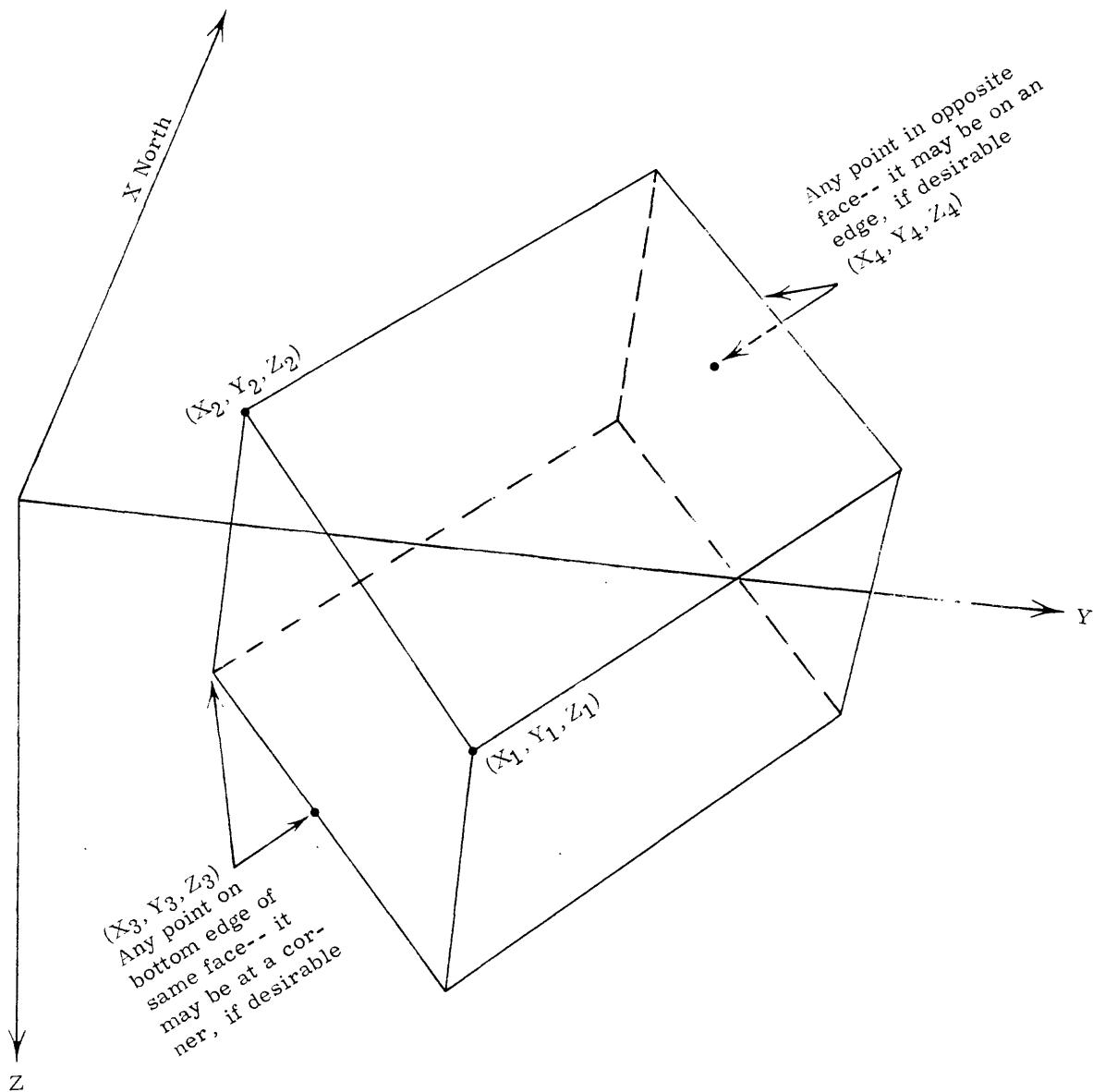
Figure 13. - Parallelepiped, arbitrary, in a three-dimensional coordinate system.

MAGR3D

by

Lindrith Cordell

Description

Total magnetic intensity fields, as measured in airborne geophysical surveys, can be converted analytically into a gravi-tational equivalent. The process, called the "pseudogravity" transformation by Baranov (1957) is carried out in terms of hypo-thetical physical properties. These are not, of necessity, authentic. However, where the density and magnetization of the source of the anomaly can be estimated and can reasonably be inferred as uniform, then the pseudogravity and the actual gravity fields should be similar, and can be compared.

In this subroutine the pseudogravity transformation is carried out by convolution in the frequency domain. The notation and derivations are given in Cordell and Taylor (1971); only the use and the general design of the computer program itself are discussed here.

Total magnetic intensity anomaly data (ΔT) which are obtained from a square grid and should tend to a constant value (normally zero) around the borders of the data grid are read in from disk. Output comprises the discrete Fourier transforms of the ΔT and the pseudogravity fields, and the calculated pseudogravity field itself. If digitized actual gravity anomaly data are available, an option provides for also calculating the Fourier transform of the actual gravity fields, and the difference between the pseudo- and actual gravity fields.

From the digitized total magnetic intensity data array ΔT we obtain the discrete Fourier transform $A^T_{k_1k_2}$ by means of the Fast Fourier Transform subroutine DHARM, described in IBM publication H20-0205-3: System/360 Scientific Subroutine Package. Following the notation of equation 20 and related discussion in Cordell and Taylor (1971), we obtain the pseudo gravity anomaly g' by the inverse transform

$$g'_{j_1j_2} = \sum_{k_1=0}^{N_1-1} \sum_{k_2=0}^{N_2-1} A^{g'}_{k_1k_2} e^{2\pi i \left(\frac{k_1j_1}{N_1} + \frac{k_2j_2}{N_2} \right)} \; ; \; \text{for} \; \begin{matrix} j_1 \\ j_2 \end{matrix} = 0,1,\ldots, \begin{matrix} N_1-1 \\ N_2-1 \end{matrix} \; ,$$

where the discrete pseudogravity Fourier transform $A^{g'}$ is derived

from the magnetic transform A^T according to

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$$A_{k_1 k_2}^{g'} = A_{k_1 k_2}^{T} \Big/ \sqrt{\frac{2\pi}{\gamma}\frac{J}{\rho}}\, e^{2\pi\omega\frac{z}{s}} \left\{ \left[-\frac{(k_1/N_1)^2}{\omega}\tau_{01} - \frac{(k_1/N_1)(k_2/N_2)}{\omega}\tau_{02} \cdots \right. \right.$$

$$\left. + i(k_1/N_1)\tau_{03}\right]t_{01} + \left[-\frac{(k_1/N_1)(k_2/N_2)}{\omega}\tau_{01} - \frac{(k_2/N_2)^2}{\omega}\tau_{02} \cdots \right.$$

$$\left. \left. + i(k_2/N_2)\tau_{03}\right]t_{02} + \left[\omega\tau_{03} + i(k_1/N_1)\tau_{01} + i(k_2/N_2)\tau_{02}\right]t_{03}\right\} ,$$

for integers $k_1 \epsilon [0,1...\frac{N_1}{2}]$, $k_2 \epsilon [0,1...\frac{N_2}{2}]$ except $k_1 = k_2 = 0$,

where

$$\omega = \sqrt{(k_1/N_1) + (k_2/N_2)}$$

z = level of magnetic data relative to gravity data

s = grid interval

$\vec{\tau}_0$ = unit vector in direction of earth's inducing field

$\vec{t}_0$ = total magnetization unit vector

J = magnetization (contrast)

ρ = density (contrast)

In view of the spectral symmetry of real-valued functions, the pseudogravity transform array can be completed for wave numbers $k_i > \frac{N_i}{2}$ by substituting $-k_i$ for $(N_i - k_i)$ in the expression above.

Input

Three parameter cards are necessary to run this subroutine.

Card 1

Columns	Format	Name	Description
1-4	A4	ID(1)	Data set identification of the magnetic data which is on disk.

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Columns	Format	Name	Description
5-8	A4	ID(2)	Data set identification of the gravity data which may be on disk (not used if IOPT1 is not 1).
9-72	16A4	ID(3-18)	Any alphanumeric information to be used for a title.
75-80	A6	SNAME	The characters MAGR3D must be punched in these columns.

<div align="center">Card 2</div>

Columns	Format	Name	Description
1-3	I3	N1	The number of columns in the input data set.
4-6	I3	M(1)	An integer such that $N1 = 2^{M(1)}$.
7-9	I3	N2	The number of rows in the input data set.
10-12	I3	M(2)	An integer such that $N2 = 2^{M(2)}$.

Note: The data grid is indexed from point (0,0) in the upper left-hand corner to point (N1-1,N2-1) in the lower right-hand corner. N1 and N2 must be some power of 2, e.g., 8, 16, 32, 64,... etc. For example, if N1 = N2 = 32, then M(1) = M(2) = 5. Normally N1 = N2.

Columns	Format	Name	Description
13-15	I3	IOPT1	A '1' in column 15 will read in from disk an actual gravity anomaly data for comparison with the calculated pseudogravity spectrum and pseudogravity field. If not desired, leave blank.

Columns	Format	Name	Description
16-18	I3	IOPT2	A '1' in column 18 will punch the pseudogravity, Fourier series coefficients and the pseudogravity anomaly values on cards in a 6D13.6 format. If not desired, leave blank.
19-25	F7.0	AO	Inasmuch as the 0,0 wave number term is undefined, the pseudogravity anomaly entails an arbitrary constant. In cases where gravity data are available, this datum can be specified here, for purposes of comparison. The A_{00} term is also related to the Gauss mass M, in that $M \geq A_{00}$ $(N1N2s^2/2\pi\gamma)$. If not desired, leave blank.

Card 3

Columns	Format	Name	Description
1-7	F7.0	RHO	Density (contrast) in gm/cm^3.
8-14	F7.0	SUSP	Magnetic susceptibility in emu.
15-21	F7.0	TO	Intensity of the earth's inducing field, in gammas, in the direction of the unit vector.
22-28	F7.0	D'	Declination in degrees, see fig. 14. Computation is done in terms of the azimuth angle D. It is convenient to orient the data grid so that +x is

Columns	Format	Name	Description
			east and +y is south. Then D' represents conventional magnetic declination, and D = D' - 90°.
29-35	F7.0	RI	The inclination in degrees, see fig. 14.
36-42	F7.0	RJR	Intensity of natural remanent magnetization, in gauss, in direction of the input vector.
43-49	F7.0	SIGMA	Remanent magnetization declination in degrees, see fig. 14 and definition of D' above.
50-56	F7.0	THETA	Remanent magnetization inclination in degrees, see fig. 14.
57-63	F7.0	Z	Level of magnetic data relative to gravity and pseudogravity data, in kilometers. Note that the Z direction is positive downward so that if pseudogravity were to be calculated at ground level from magnetic data measured in the air then Z would be negative.
64-70	F7.0	DX	Grid interval in kilometers.

Output

Printed output consists of a listing of the input parameters and the complex discrete Fourier series coefficients of the total magnetic intensity field and of the pseudogravity array. A printer contour map is provided for the pseudogravity values.
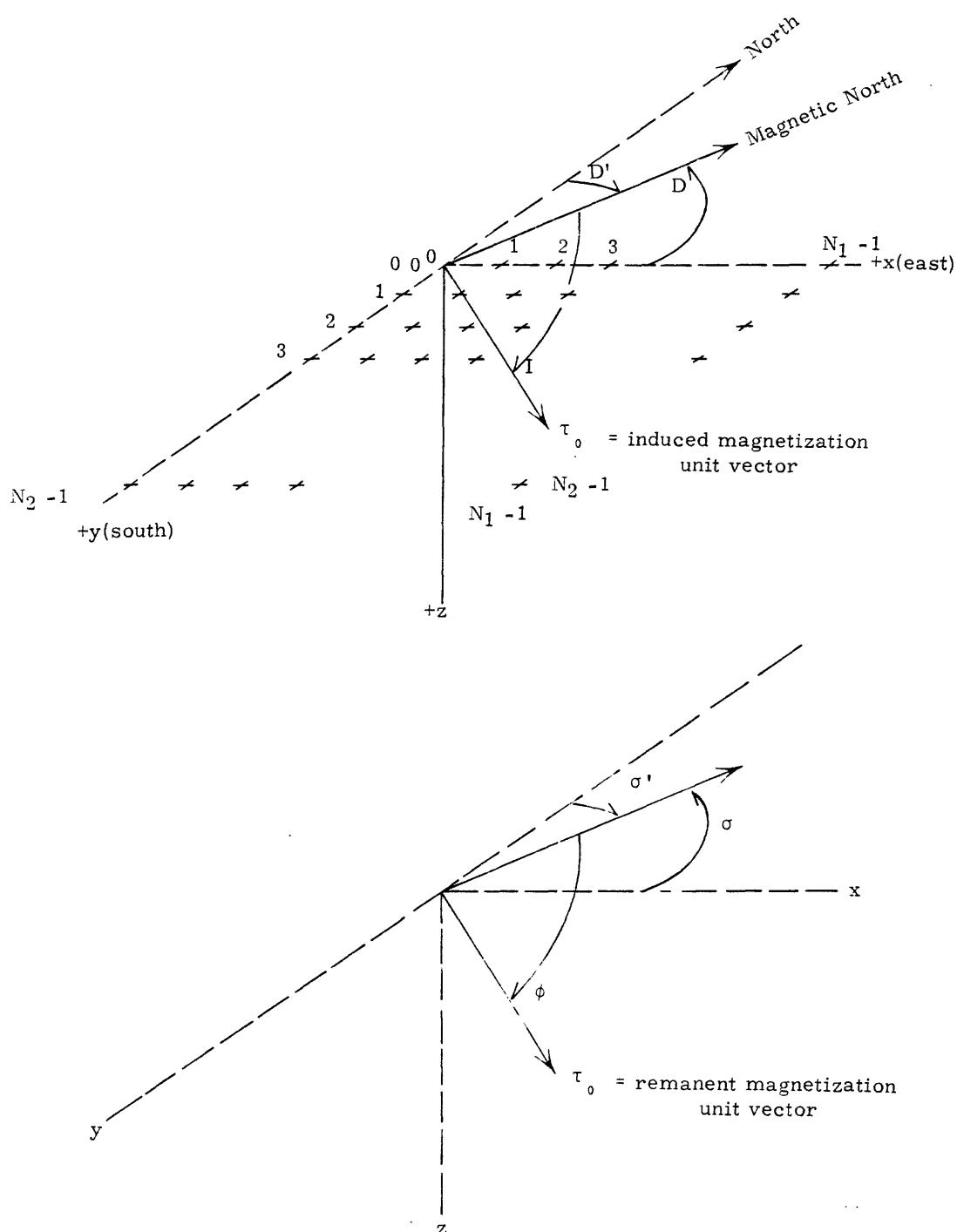
Figure 14.- Orientation diagram

Note that computation is based on angles D and σ', measured conventionally from the +x axis. In order to conform to standard geographic orientation, however, the computer program uses D' (input) and σ' (optional output), measured from true north, positive if east, negative if west. Note that D'=D+90° and σ'=σ+90°. If +x is east and +y is south, as shown, then D' is numerically equal to magnetic declination. In the figure, D' is about +20° (D is about -70°).

If IOPT1 is equal to 1, the complex discrete Fourier coefficients of the actual gravity array are printed along with a printer contour map of the actual gravity values. The difference between the pseudo-gravity and actual gravity values is computed and an average error and an RMS error are also calculated.

The pseudogravity data values are written on temporary disk with an identification = ID(1) on parameter card 1.

PHYP3D

by

Lindrith Cordell and Patrick T. Taylor

Description

In geophysical studies, information about bulk magnetization and density of inaccessible material can be obtained indirectly by analysis of observed geomagnetic and gravity fields. Knowledge of the shape of the source is not required. However, magnetization and density must be assumed to be invariant within the same closed volume. The subroutine implements the analysis of Cordell and Taylor (1971), who discuss the notation, derivations, and limitations of the method. The use and general design of the computer program itself is considered here.

Total magnetic intensity anomaly data ΔT and gravity anomaly data Δg obtained on a square grid are read in from disk. Each field must tend to a constant value (normally zero) around the borders of the data grid. Gravity and magnetic data may be measured on different levels as in the case of airborne magnetic survey data used in combination with gravity data measured on the ground. Output comprises the total magnetization vector divided by the density, and the minimum possible value of the Koenigsburger ratio Q. These quantities are uniquely determined. Other results can be obtained in terms of assigned or limiting values of other physical properties, as described in the cited paper.

From the digitized ΔT and Δg anomaly data we obtain the discrete Fourier transforms $A^T_{k_1 k_2}$ and $A^g_{k_1 k_2}$ by means of the Fast Fourier Transform subroutine DHARM, described in IBM publication H20-0205-3: System/360 Scientific Subroutine Package. From Equation (9) of the original paper, we have, in terms of the three components of the unknown vector $\frac{\vec{J}_0}{\rho}$, the linear system of equations

$$A^g_{k_1 k_2} \, (C_{k_1 k_2} \cdot \frac{J}{\rho} t_0) = A^T_{k_1 k_2} \, ,$$

for integers $k_1 \epsilon [K_{1_{min}}, K_{1_{max}}]$, $k_2 \epsilon [K_{2_{min}}, K_{2_{max}}]$, except $k_1 = k_2 = 0$;

where

$$\vec{C}_{k_1 k_2} = \frac{2\pi}{\gamma} e^{2\pi\omega\frac{z}{s}} \{ [- \frac{(k_1/N_1)^2}{\omega} \tau_{01} - \frac{(k_1/N_1)(k_2/N_2)}{\omega} \tau_{02} \cdots$$

$$+ i(k_1/N_1)\tau_{03}]\vec{i}_0 + [- \frac{(k_1/N_1)(k_2/N_2)}{\omega} \tau_{01} - \frac{(k_2/N_2)^2}{\omega} \tau_{02} \cdots$$

$$+ i(k_2/N_2)\tau_{03}]\vec{j}_0 + [\omega\tau_{03} + i(k_1/N_1)\tau_{01} + i(k_2/N_2)\tau_{02}]\vec{k}_0 \} \ ; \ \text{and}$$

$$\omega = \sqrt{(k_1/N_1)^2 + (k_2/N_2)^2}$$

z = level of magnetic data, relative to gravity data.

s = grid interval

$\vec{\tau}_0$ = unit vector in direction of earth's inducing field

$\vec{t}_0$ = total magnetization unit vector

J = magnetization (contrast)

ρ = density (contrast)

Collecting together the real and imaginary parts of the complex terms A^g, A^T, and C yields two equations for each wave number, i.e.

$$(ReA^gReC_1 - ImA^gImC_1) \frac{J}{\rho} t_{01} + (ReA^gReC_2 - ImA^gImC_2) \frac{J}{\rho} t_{02} \cdots$$

$$+ (ReA^gReC_3 - ImA^gImC_3) \frac{J}{\rho} t_{03} = ReA^T; \quad \text{and}$$

$$(ReA^g ImC_1 + ImA^g ReC_1) \frac{J}{\rho} t_{01} + (ReA^g ImC_2 + ImA^g ReC_2) \frac{J}{\rho} t_{02} \quad \cdots$$

$$+ (ReA^g ImC_3 + ImA^g ReC_3) \frac{J}{\rho} t_{03} = ImA^T.$$

Inasmuch as the 0,0th term is excluded and each wave number yields two equations, we have a total of $2[(K_{1_{max}} - K_{1_{min}} + 1)$ $(K_{2_{max}} - K_{2_{min}} + 1) - 1]$ equations involving linear combinations of the three components of the vector $\frac{J}{\rho}\vec{t}_0$, for which we obtain a solution in the least-squares sense by means of subroutine DLLSQ (IBM publication cited above).

As output, the program lists $\frac{J}{\rho}$; t_{01}, t_{02}, t_{03}; $(\vec{\tau}_0 \cdot \vec{t}_0)$; arccos $(\vec{\tau}_0 \cdot \vec{t}_0)$; and Q_{min}, as discussed in the original paper. As an option, the program also lists paleo-magnetic pole positions for a sequence of values of Q between Q_{min} and infinity.

Because both ΔT and Δg are real-valued functions, their discrete Fourier transforms can be obtained simultaneously, thereby saving computer time and core requirements. We define on the points $j_1 = 0,1,\ldots N_1-1$; $j_2 = 0,1,\ldots N_2-1$, the discrete complex function

$$F_{j_1 j_2} = \Delta T_{j_1 j_2} + i\Delta g_{j_1 j_2} \quad,$$

from which we obtain the discrete complex Fourier transform

$$A_{k_1 k_2} = \frac{1}{N_1 N_2} \sum_{j_1=0}^{N_1-1} \sum_{j_2=0}^{N_2-1} F_{j_1 j_2} e^{-2\pi i (\frac{k_1 j_1}{N_1} + \frac{k_2 j_2}{N_2})} \quad.$$

Making use of the spectral symmetry of the complex Fourier series, we unscramble the $A_{k_1 k_2}$ coefficients, yielding

$$\text{ReA}^T_{k_1 k_2} = \frac{1}{2} (\text{ReA}_{k_1 k_2} + \text{ReA}_{N_1 - k_1, N_2 - k_2})$$

$$\text{ImA}^T_{k_1 k_2} = \frac{1}{2} (\text{ImA}_{k_1 k_2} - \text{ImA}_{N_1 - k_1, N_2 - k_2})$$

$$\text{ReA}^g_{k_1 k_2} = \frac{1}{2} (\text{ImA}_{k_1 k_2} + \text{ImA}_{N_1 - k_1, N_2 - k_2})$$

$$\text{ImA}^g_{k_1 k_2} = \frac{1}{2} (-\text{ReA}_{k_1 k_2} + \text{ReA}_{N_1 - k_1, N_2 - k_2}) ,$$

$$\text{for } k_1 = 0, 1 \ldots N_1/2; \quad k_2 = 0, 1 \ldots N_2/2$$

Input

Two parameter cards are necessary for execution of this subroutine.

Card 1

Columns	Format	Name	Description
1-4	A4	ID(1)	The data set identification of the magnetic data on disk.
5-8	A4	ID(2)	The data set identification of the gravity data on disk.
9-72	16A4	ID(3-18)	Any alphanumeric information to be used for a title.
75-80	A6	SNAME	The characters PHYP3D must be punched in these columns.

Card 2

Columns	Format	Name	Description
1-3	I3	N1	The number of columns in the input data set. It must not be greater than 32.

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Columns	Format	Name	Description
4-6	I3	M(1)	An integer such that N1 = $2^{M(1)}$.
7-9	I3	N2	The number of rows in the input data sets. It must not be greater than 32.
10-12	I3	M(2)	An integer such that N2 = $2^{M(2)}$.

Note: The data grid is indexed from point (0,0) in the upper left-hand corner to the point (N1-1,N2-1) in the lower right-hand corner. N1 and N2 must be some power of 2, e.g., 8, 16, 32, 64, ... etc. For example if N1 = N2 = 32, then M(1) = M(2) = 5. Normally, N1 = N2.

Columns	Format	Name	Description
13-15	I3	K1MIN	Upper and lower bounds of wave numbers used in least-squares solution; see note below.
16-18	I3	K1MAX	
19-21	I3	K2MIN	
22-24	I3	K2MAX	

Note: Simultaneous equation system uses discrete Fourier series coefficients:

$A_{k_1 k_2}$ for K_I = KIMIN, KIMIN+1, ... KIMAX

where I = 1,2; and $0 \leq$ KIMIN < KIMAX $\leq$ N1/2.

Normally, KIMIN = 0 and KIMAX is either 2 or 3. Normally, data fields 13-15 and 19-21 are left blank. The 0,0th term is skipped automatically.

Columns	Format	Name	Description
25-31	F7.0	D'	Declination in degrees, see fig. 14. Computation is done in terms of the azimuth angle D. It is convenient to orient the data grid so that +x is east, +y is south. Then D' represents conventional magnetic declination and D = D' - 90°.
32-38	F7.0	RI	Inclination in degrees, see fig. 14.

Columns	Format	Name	Description
39-45	F7.0	Z	Level of magnetic data relative to gravity data, in kilometers. Note that the Z direction is positive downward, so that if gravity is measured on the ground and the magnetic field is measured in the air, then Z is negative. Normally $Z \leq 0$.
46-52	F7.0	DX	Grid interval in kilometers.
53-54	I2	IOPT1	Paleo-geomagnetic pole computation. If not desired, leave columns 53-80 blank. If desired, punch a '1' in column 54 and latitude in the following two data fields. Paleo-pole positions are calculated for values of Q between Q_{min} and infinity.
55-61	F7.0	RLAT	Mean latitude of field surveys in degrees. Note that $-90° \leq RLAT \leq 90°$, positive if north, negative if south. If IOPT1 is $\neq$ 1, leave blank.
62-68	F7.0	RLONG	Mean longitude of field surveys in degrees. Note that $-180° \leq RLONG \leq 180°$, positive if east, negative if west. If IOPT1 is $\neq$ 1, leave blank.

Comment

The accuracy and possibly even the physical meaning of the results here depend strongly on the fidelity of the supposedly homogeneous model. This cannot be stipulated. However, it is plausible to compare the pseudogravity anomaly based on the derived magnetization vector, with the observed gravity anomaly. We recommend very strongly that this be done.

Program input allows for specified high and low wave number bounds. In probably all practical applications only the first few wave number terms are pertinent, and K1MIN = K2MIN = 0. A retrospective estimate of optimum wave number cut-off can be made by comparing the gravity and pseudogravity amplitude spectra.

In the published example, Cordell and Taylor (1971), the authors exphasized the application of this analysis to the determination of the paleomagnetic pole position. It may be also useful as an ancillary step in structural modeling of geophysical data and in evaluating the importance of remanent magnetization.

Output

Printed output consists of a listing of the input parameters and the computed physical property terms: total magnetization unit vector, vector inner product, beta and minimum Q. Optionally, if virtual paleo-magnetic pole positions are computed, a table of Q's, sigmas, thetas, latitudes, and longitudes is listed.

This is the only subroutine in the system that does not have data in gridded form as output. Therefore, no printer contour map is made nor are gridded data values written on temporary disk.

PLOT3D

by

David L. Nelson and Paul Zabel

Description

This subroutine will plot a perspective drawing of gridded data on the EAI 430 plotter using the method of Nelson (1966). The array of data can be viewed from any angle and an option is provided to delete points not visible from the viewing angle. The points on the plot can be connected by straight lines or a histogram of the figure can be drawn.

Several plots can be made with one call to this subroutine; the number depends on the size of the plot and the maximum size of the paper in the X direction, which is 36 inches, as the plots are drawn next to each other in the X direction with a one inch interval between them.

Input

One parameter card is required for each plot.

Columns	Format	Name	Description
1-4	A4	ID	Data set identification. This variable serves two purposes; one, it is used to identify the data set read in from disk and secondly, it may be used to indicate that the last data array is to be replotted using new parameters. The second option is specified by placing the word 'SAME' in these columns. As many 'SAME' cards as desired may be used.
5	I1	MODE	This parameter specifies the type of plot. The following options are possible: 1- all points plotted with straight line connections. 2- all points plotted and connected as a histogram. 3- invisible points deleted, straight line connections. 4- invisible points deleted, connected as a histogram.
6-10	F5.0	THETA	The angle of the observer's line of sight, measured in degrees from the Z axis. See fig. 15.

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| Columns	Format	Name	Description
11-15	F5.0	PHI	The angle of the observer's line of sight, measured in degrees from the X axis. See fig. 15.
16-20	I5	ISTART	These six parameters are used to define a subset of the data array. When they are left blank the whole array is plotted. See fig. 15.
21-25	I5	IDELTA	
26-30	I5	ISTOP	
31-35	I5	JSTART	
36-40	I5	JDELTA	
41-45	I5	JSTOP	
46-55	F10.0	AMAX	The maximum value of the array to be used in the plot.
56-65	F10.0	AMIN	The minimum value of the array to be used in the plot. The vertical scale is normalized to AMAX and AMIN, and values outside of this range are deleted. If left blank the maximum and the minimum values of the data array are used.
66-70	F5.0	SIZE	The size in inches of the plot in its maximum X or Y dimension. If left blank it is set to 8.
71-74	F4.0	ZSIZE	The size in inches in the vertical dimension. If left blank it is set to 8.
75-80	A6	SNAME	The characters PLOT3D must be punched.
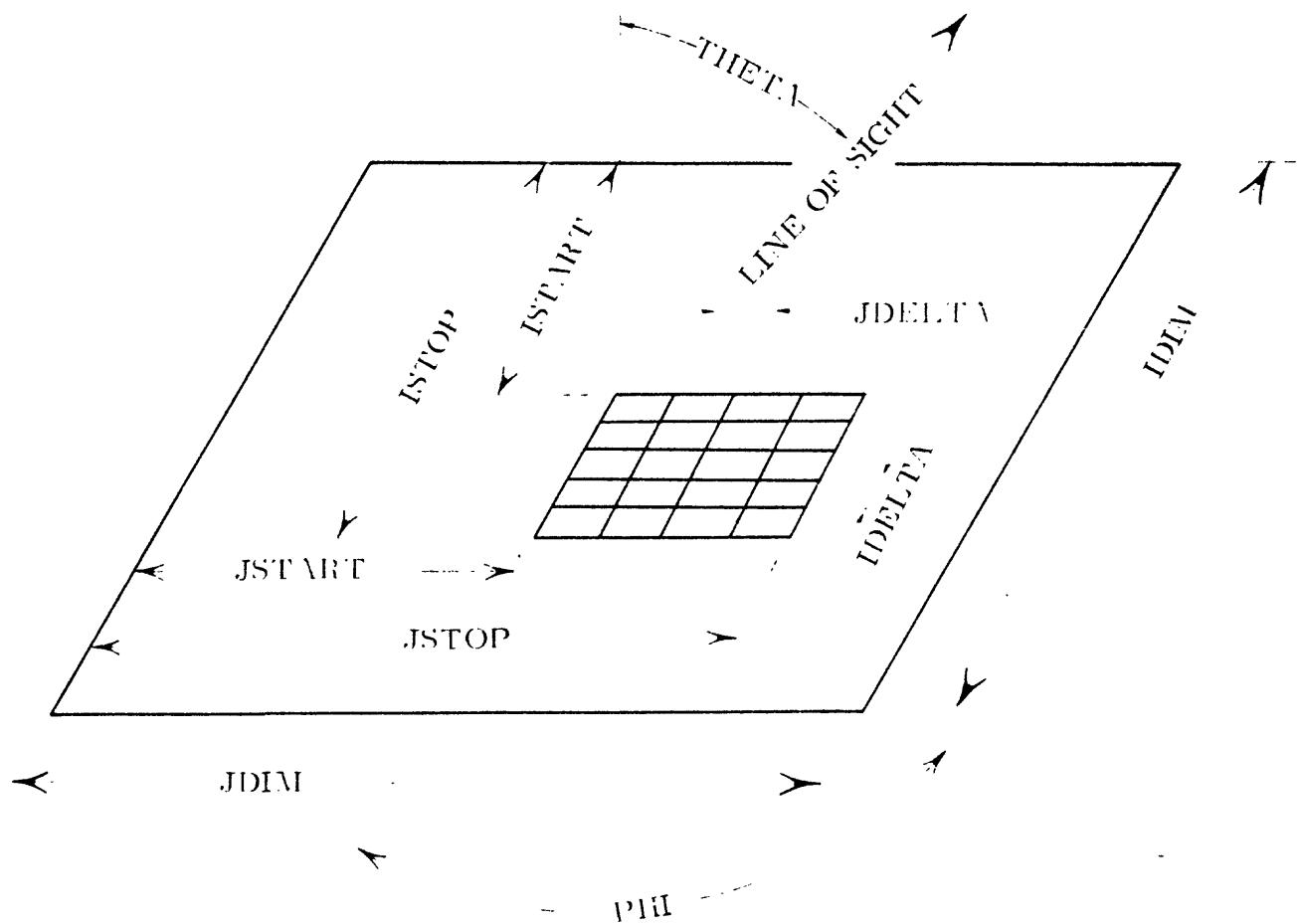
Figure 15.- View of entire array showing the region to be plotted and the observer's line of sight.

Output

The generated plots are written on an unlabeled 9-tracked magnetic tape. Printer output consists of the parameters used in generating a plot and a message saying "End of Plot n" after each plot, where n equals the number of the plot.

PRPL3D

by

Richard H. Godson

Description

Gridded data may be contoured on a line printer by this subroutine which is a modification of the printer contour routine used in most of the other 3D subroutines in GEOPAC. Several parameters can be supplied in order to satisfy the plot requirements of different projects.

The most useful aspect of this subroutine is the ability to plot the data at any scale, e.g. 1/100,000, the only restriction being that the width of any plot can not be greater than 13 inches, the approximate width of standard printer paper. The following formula computes the width of the plot in inches:

WIDTH = [(JMAX-JMIN)*(GDIST * FACTOR)]/SCALE - .1, where

JMAX = Ending column to be plotted,

JMIN = Starting column to be plotted,

GDIST = Ground distance between grids in any of five units; inches, feet, miles, meters or kilometers.

FACTOR= Factor to convert ground distance to inches.

For GDIST in inches, FACTOR = 1

" " " feet, " = 12

" " " miles, " = 63360

" " " meters, " = 39.37

" " " kilometers, " = 39370,

SCALE = The denominator of the scale of the plot, e.g. 100,000, 250,000, 500,000, etc.

It is usually necessary to plot most areas in two sections at scales of 1/100,000 or less. As an example, with one kilometer grid spacing at a scale of 1/100,000, the maximum number of columns that can be plotted on one plot is 32. There is no restriction on the number of rows as they are plotted down the length of the printer.

In addition to the scale and number of rows and columns to be plotted, the minimum and maximum values to be contoured, the contour interval or the number of contours to be drawn can be specified. The program will compute the minimum and maximum values if they are not specified. When no contour interval or number of contours is given, twenty contour levels will be printed. If both the interval and number of contours are specified, the number takes precedence. In no case may more than 35 contour levels be printed per plot. The levels are distinguished by the numerals one through nine and the letters A through Z, in that order.

If erroneous input parameters are punched that would produce plots greater than 13 inches wide or with more than 35 contour levels, the subroutine will print appropriate messages and recompute the values so that a plot will be printed, even though it may not be exactly what is wanted.

Plotting procedure

The plotting process consists of linear interpolation in two directions within grid points. One row at a time is scanned for all possible contour levels and the symbols corresponding to particular contour levels are printed at the nearest print chain position corresponding to the horizontal position determined from the interpolation process. Similarly, linear interpolation between rows is performed when the number of vertical print positions exceeds the number of rows.

When the scale is such that the number of print positions in the horizontal or vertical direction is less than the number of columns or rows, respectively, of the input data, the matrix is interpolated and reduced so that the number of data values will correspond to the number of print positions.

Input

Two parameter cards are necessary to use this subroutine.

Card 1

Columns	Format	Name	Description
1-4	A4	ID	Data set identification.
6-10	I5	IMIN	Minimum row number to be contoured.
11-15	I5	IMAX	Maximum row number to be contoured.

Columns	Format	Name	Description
16-20	I5	JMIN	Minimum column number to be contoured.
21-25	I5	JMAX	Maximum column number to be contoured.
			If the above four variables are left
			blank, the entire matrix is contoured.
26-35	F10.0	XMIN	Minimum data value to be used in
			the plot.
36-45	F10.0	XMAX	Maximum data value to be used in
			the plot.
			If the above two variables are left
			blank, the program will compute
			the minimum and maximum data values.
46-55	F10.0	CINTV	The contour interval.
56-65	I10	NUMC	The number of contour levels to be
			printed.
			If the above two variables are left
			blank, twenty contour levels are
			printed.
75-80	A6	SNAME	The characters PRPL3D must be punched.

Card 2

Columns	Format	Name	Description
1-10	F10.0	GDIST	The ground distance between grid
			points. If left blank it is set to 1.
17-20	A4	UNITS	The units of ground distance, which
			must be one of the following: INCH,
			FEET, MILE, METR or KILO. If left
			blank it is set to KILO.

Columns	Format	Name	Description
21-30	F10.0	SCALE	The denominator of the scale requested, e.g., 50000, 100000, etc. If left blank it is set to 100000.

Output

The input parameters are printed above the printer contour map. Beneath the map are printed the alphanumeric symbols used in the plot and their corresponding values.

CTUR3D

by

Wolf Research Corporation, Richard H. Godson and Margaret Roberts

Description

This subroutine will contour a data set on an EAI 430 data-plotter using the Wolf Research contouring program (1969) and a modification of an executive program developed by Margaret Roberts (1971) of the U. S. Geological Survey in Denver, Colorado.

The entire input data set (maximum 64 rows and 64 columns) or a subset of the matrix, greater than or equal to a 4x4 size, may be plotted. In order to specify a desired subset, it is neces-sary to understand how the input array $Z(I,J)$ is orientated. The origin $Z(1,1)$ is the lower left corner of the plot and increasing I corresponds to an increase in the X direction (columns) while increasing J corresponds to an increase in the Y direction (rows). This concept is reversed from the standard GEOPAC notation where the I subscript refers to the row number and the J subscript refers to the column number.

The horizontal and vertical sizes in centimeters are specified by the user. The maximum in either direction is 71.12 cm. The plot is centered on the plotter bed and optionally registration marks are drawn in the corners and at the midpoint of each side of the plot.

A three-line legend may be printed at the lower left corner of the plot. The user supplies 144 characters of alphanumeric infor-mation which are printed 72 characters per line. The third line gives the maximum value of the input data and the contour interval if it is a constant. The third line may be omitted by setting SWITCH (24) = .TRUE. or the entire legend may be omitted if SWITCH (6) = .TRUE..

Before plotting, the data values may be smoothed by using a specified constant and averaging a value with the average of the four neighboring points. The amount of the smoothing is specified by variable C on the plot parameter card.

Segmented plots

The data set may be broken into segments and multiple plots prepared. This is useful when the desired plot is larger than the plotter bed size or when fine detail is required. The following diagram of array Z shows how the variables NX and NY on the header card are used in breaking the array into segments.
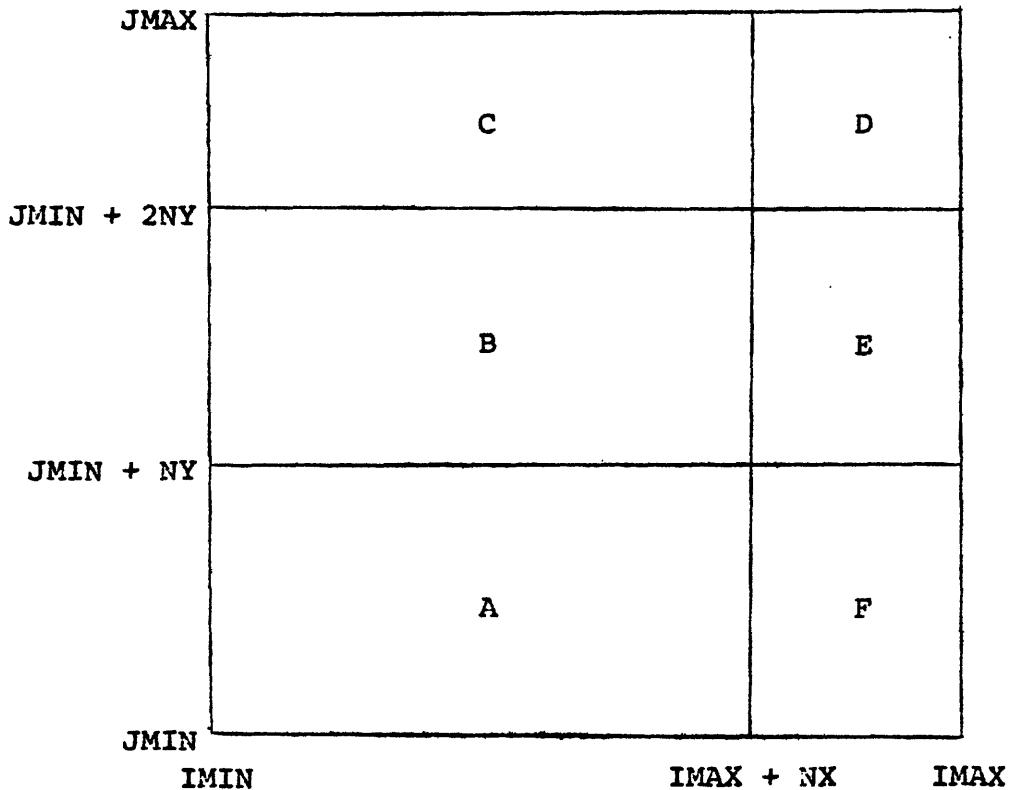

Figure 16. Array Z broken into segments

Parts A and B are NX by NY in size, while parts C, D, E and F are smaller but they will be plotted to correct scale if their dimensions are greater than or equal to three.

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Polar plots

In this type of presentation the diameter of the plot is specified by the variable SCALE and the number of degrees in the plot by the variable ARC. ARC is the number of degrees in a counterclockwise direction from a vertical line extending upward, away from the center of the plot. IMAX is at 0° and IMIN is at ARC degrees. If ARC < 0°, all references to counterclockwise and ARC should be replaced by clockwise and absolute value of ARC, respectively.

On this plot there is an undefined inner circle of radius, INRADS, where points on the circumference are equal to JMIN. Those points whose row numbers are less than JMIN will fall within this circle. Points on the circumference of the plot are equal to JMAX.

The plot may be rotated PHI degrees but the skew angle THETA is not used.

Grid overlays

Lines corresponding to the grid lines may be optionally drawn on top of the plot or only tick marks at the bottom and left edges of the plot may be drawn. If the plot is polar, it is sometimes difficult to correlate input locations with the locations on the plot. Any number of equally spaced concentric arcs (circles for 360° polar plots) around the center and any number of lines radiating from the center can be drawn.

In addition to the grid lines, either a character specified by the user or the input data values can be plotted at the grid locations. These can be plotted at any multiple of the grid interval so that the plot will not become too crowded with printing.

Maximum and minimum

If desired, the program will find all high and low centers by fitting a Lagrangian polynomial to each interior grid intersection. The program uses the point $Z(I,J)$ and eight adjacent intersections to fit a second order polynomial. A + symbol is printed at the location of the center and the character H or L above to indicate a high or low center. If the number of digits of precision (NUMPLC) is specified as not zero, then the value of the center is also printed, either in integer, exponential or floating point format.

Contour levels

There are four ways to specify the manner in which contour labelling will be done.

1. A given constant interval (FINTER) will be used by the program to increment contour values from the minimum to maximum values as follows:

$$Z_{MIN} \le n \cdot FINTER \le Z_{MAX}$$

where n = $\pm$0, $\pm$1, $\pm$2, ...

2. A first contour value (CON1ST) may be stated, in which case:

$$Z_{MIN} \le CON1ST + n \cdot FINTER \le Z_{MAX}$$

where n = 0, 1, 2, ...

3. Up to 99 specific contour values, which may need not be evenly spaced, may be supplied by the user. This is useful where the data varies several orders of magnitude, making a constant interval impractical.

4. The program will determine a reasonable contour interval based on the user's data.

Contour labelling

Contours can be labelled in either fixed, floating or exponential mode. The number of digits in the mantissa of the label (NUMPLA) is specified and optionally n leading digits or n trailing digits may be suppressed. Open contours are labelled on both ends at the borders of the plot and closed contours are labelled at the lowest point on the contour. Instead of labelling every contour line, every nth contour can be labelled. Suppression of all contour labelling or suppression of labelling of open contours on specified sides of the plot are options.

Contour drawing

Contour lines may be dashed by setting appropriate values for IDASH on the plot card or certain contour levels may be enhanced (darkened) by repeatedly drawing over the same contour. By using a combination of line dashing and full line drawing with or without enhancement, readability is improved with some data. This technique is accomplished using the variable ISOLID on the plot card, which specifies at which contour line interval a solid line will be drawn while the other lines are dashed.

Contour suppression

An option is provided to suppress drawing contour lines when they are so close together that they cannot be distinguished from each other and leave a large blacked area. The user may state that if more than a certain number (2.0 < POLES < 99.0) of contour lines pass through a grid box, the grid box will be considered a pole and no contour lines are plotted in that grid box. If POLES=0.0, there is no line suppression. Care must be taken in specifying pole suppression; sometimes large portions of a plot may be deleted and small fluctuations in the data lost.

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Another type of contour suppression is automatically invoked but can be overridden by setting SWITCH (8) = .TRUE.. This feature checks the size of the minor axis of a closed contour and if a high/low center label will not fit within the contour, it is deleted with no warning. This can be dangerous with some types of data and to preserve this type of suppression but have a more flexible control over the size of closed contours to eliminate, the variable ISUPP is used. If a closed contour consists of less than ISUPP number of points, the contour is not drawn. The number of points per size of closed contour cannot be predetermined precisely as it is a function of grid size and interpolations per grid square (NUMBR). A trial and error method for each type of plot will be necessary but a good starting value might be ISUPP = 50. This feature has proved to be very useful with airborne radiation data where the plot contains many small irregular closures that obscure the general picture. If SWITCH (8) = .TRUE. and ISUPP = 0, then contour suppression is bypassed.

Input

Several parameter cards are necessary for this subroutine:

1. Header card

2. Plot card

3. Marker card (included only if IPTION(5) = 1 on the header card)

4. Contour card

5. Contour levels card (included only if NUMV $\neq$ 0 on the contour card)

6. Switches card (included only if ICHNG = 1 on the plot card)

7. Polar plot card (included only if SWITCH(17) = .TRUE.)

8. Legend cards

Header card

Columns	Format	Name	Description
1-30	7A4,A2	TITLE	Title for printed output.
31-34	A4	CID	Data set identification.
39-43	I5	CN	The number of input data rows.
44-46	I3	CM	The number of input data columns.

Columns	Format	Name	Description
47	I1	IPTION(1)	A '5' must be punched in this column.
48	I1	IPTION(2)	Leave blank.
49	I1	IPTION(3)	Blank = input matrix printed; 1 = input matrix not printed.
50	I1	IPTION(4)	Blank = input data not smoothed; 1 = input matrix smoothed, see C on plot card.
51	I1	IPTION(5)	Blank = no input points plotted; 1 = input array or a subset is plotted on the contour map. See instructions for marker card.
52	I1	IPTION(6)	Blank = no grid overlay for cartesian plot; 1 = tick marks at left and bottom of plot; 2 = full grid overlay. For polar grid overlay see SWITCH (20)
53	I1	IPTION(7)	Blank = start a new plot; 1 = continue on current plot.
54	I1	IPTION(8)	Blank = the data set will form one plot; 1 = the data set will be segmented into multiple plots, each composed of a subset of Z which is NX by NY.
61-65	I5	NX	The number of columns plus one (intervals) of a subset of the input matrix to be plotted as one contour map when IPTION(8) = 1. $NX \geq 3$.

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Columns	Format	Name	Description
66-70	I5	NY	The number of rows plus one (intervals) of a subset of the input matrix to be plotted as one contour map when IPTION(8) = 1. NY ≥ 3.
75-80	A6	SNAME	The characters CTUR3D must be punched in these columns.

Plot card

Columns	Format	Name	Description
1-6	F6.3	SCALE	The size in centimeters of the plot in the horizontal or X direction. 1.0 ≤ SCALE ≤ 71.12. If the plot is polar SCALE is the diameter of the plot.
7-9	I3	IMIN	Minimum column subscript to be contoured.
10-12	I3	IMAX	Maximum column subscript to be contoured.
13-15	I3	JMIN	Minimum row subscript to be contoured.
16-18	I3	JMAX	Maximum row subscript to be contoured.
19-28	G10.0	SCALEY	The size in centimeters of the plot in the vertical or Y direction. 1.0 ≤ SCALEY ≤ 71.12.
29	I1	NUMPLC	The number of places in the mantissa of a center label. 0 ≤ NUMPLC ≤ 8.
30	I1	NUMPLA	The number of places in the mantissa of a contour label. 0 ≤ NUMPLA ≤ 8.

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Columns	Format	Name	Description
31	I1	NUMSUP	The number of leading digits to be suppressed in a contour label. $0 \le$ NUMSUP ≤ 8.
32	I1	NOSUPA	The number of trailing digits to be suppressed in a contour label. $0 \le$ NOSUPA ≤ 8.
33-34	I2	ISOLID	The interval at which a solid contour line might be wanted if dashed contour lines are drawn (see IDASH(2) below).
44-46	F3.0	POLES	Minimum number of contours passing through any side of the grid box which would indicate a pole. $2.0 \le$ POLES ≤ 99.0.
47-49	I3	IDASH(1)	For solid line drawing leave IDASH(2) blank. IDASH(2) $\ne 0$ gives dashed lines. A line is IDASH(1) units followed by a blank space of IDASH(2) units, followed by a line of IDASH(3) units, followed by a blank space of IDASH(4) units, etc. One unit is 0.05 inches.
50-52	I3	IDASH(2)	
53-55	I3	IDASH(3)	
56-58	I3	IDASH(4)	
59-63	F5.2	THETA	Plot skewed by THETA degrees in a clockwise direction from the Y axis. $-180.0 <$ THETA < 180.0

Columns	Format	Name	Description
64-68	F5.2	PHI	Plot rotated PHI degrees counter-clockwise relative to center of plot. $-180.0 < $ PHI $ < 180.0$.
69	I1	ICHNG	Blank = default value for switches; 1 = values for switches specified by user, in which case a switches card must be completed.
71-74	I4	ISUPP	The number of points in a closed contour less than which no contours will be drawn.
75-76	I2	ILABEL	Leave blank to label every contour; otherwise label every ILABELth contour.
77-80	F4.3	C	Smoothing factor which is used only if IPTION(4) = 1. $0 \le C \le 1$. If C = 1 no smoothing is done. Z(I,J) will be smoothed to C*Z(I,J)+(1-C)* (average of 4 neighboring points).

Marker card

This card is included only if IPTION(5) = 1 on the header card. The marker card contains information for printing characters or values at grid intersections on the map.

Columns	Format	Name	Description
1-10	G10.0	JOB	1 = print CHAR at each grid inter-section. 2 = print CHAR at each grid intersection except where data

Columns	Format	Name	Description
			not defined. 3, 4, 5 or 6 = print the data value at each grid intersection except where the data is not defined. If JOB = 3 or 4 the sign of the data value will not be printed. If JOB = 4 or 6, the right margin will be adjusted so that the printing will not go off the plot.
15	A1	CHAR	The character to be printed if JOB = 1 or 2.
21-30	G10.0	IDELTA	Grid increment in the I direction.
31-40	G10.0	JDELTA	Grid increment in the J direction.
41-50	G10.0	NUMRPL	The number of digits to be printed if JOB = 3, 4, 5 or 6. $0 \le$ NUMRPL ≤ 8.
51-60	G10.0	NUMSPR	The number of leading digits to be suppressed if JOB = 3, 4, 5 or 6. $0 \le$ NUMSPR ≤ 8.
61	L1	FORM	F = Data values are to be in exponential form if JOB = 3, 4, 5 or 6. T = Data values are to be in integer form if JOB = 3, 4, 5 or 6.

The entire input array Z will be plotted over the contour map if IDELTA = 1 and JDELTA = 1. A subset may be plotted by setting IDELTA and JDELTA $\neq$ 1 (e.g., if IDELTA = 2, JDELTA = 2, then points Z(IMIN,JMIN), Z(IMIN+2,JMIN+2), etc. will be plotted).

Contour card

Columns	Format	Name	Description
1-10	G10.0	FINTER	Contour interval.
11-20	G10.0	NUMV	Number of contour levels. 0 < NUMV $\leq$ 99. If FINTER is to be used, set NUMV = 0. If FINTER = 0 and NUMV = 0, program selects the contour levels based on the data. If FINTER = 0 and NUMV $\neq$ 0, then specific contour levels are set.
21-30	G10.0	CON1ST	The value of the first contour level if SWITCH(16) = .TRUE. and NUMV = 0.
31-40	G10.0	INDEXC	The interval at which a heavier contour line (determined by REPEAT) will be drawn with no poles suppression.
41-50	G10.0	REPEAT	The number of times the contour lines will be repeatedly drawn in order to create heavier lines. Leave blank if heavier lines not desired. This is an integer variable.
51-60	G10.0	HIGHT	The height of a character in centimeters. If blank it is set to .60.
61-70	G10.0	WDTH	The width of the character in centimeters. If blank it is set to .54.

Columns	Format	Name	Description
71-80	G10.0	NUMBR	The number of interpolations per grid square if SWITCH(28) = .TRUE.. If used, 5 $\leq$ NUMBR $\leq$ 9. In certain cases a small number will cause looping and repetition of contours. In this case it is necessary to increase the value of NUMBR.

Contour levels card

This card is used if NUMV $\neq$ 0 on the contour card. The card is formatted 8G10.0. The desired contour levels are completed 8 per card until NUMV levels are punched. The levels must be listed in ascending order.

Switches card

This card is completed if ICHNG = 1 on the header card. All switches must be defined, even those having the same value as the default values.

Columns	Format	Name	Description
1-30	30L1	SWITCH(1-30)	A 30 element array of switches. See after the description of the legend cards the definition of the switches and their default values. Use F for .FALSE. and T for .TRUE. in the appropriate columns.
31-35	I5	IFORMC(1)	Floating point specification for center label if SWITCH(26) = .TRUE.. Format is Fn.k where IFORMC(1) = n
36-40	I5	IFORMC(2)	and IFORMC(2) = k.

Columns	Format	Name	Description
41-45	I5	IFORML(1)	Floating point specification for contour labels if SWITCH(27) = .TRUE.. Format is Fn.k where IFORML(1) = n
46-50	I5	IFORML(2)	and IFORML(2) = k.
51-60	G10.0	BASE	If SWITCH(26) = .TRUE. or SWITCH(27) = .TRUE., the output value in floating point is (value-BASE)*FACTOR. Normally BASE = 0.
61-70	G10.0	FACTOR	See BASE, above. Normally FACTOR = 1.

Polar plot card

This card is necessary only if SWITCH(17) = .TRUE.

Columns	Format	Name	Description
1-10	G10.0	ARC	The number of degrees of the plot measured from north.
11-20	G10.0	INRADS	The radius in centimeters of the undefined circle in the middle of the plot. This is a real variable.
21-30	G10.0	RADII	The number of equally spaced concentric arcs in the grid.
31-40	G10.0	SPOKES	The number of radiating lines in the grid.

RADII and SPOKES are integer variables and need to be completed only if SWITCH(17) = .TRUE. and SWITCH(20) = .TRUE..

Legend cards

Two cards are required even if SWITCH(6) = .TRUE.. Each card contains 72 characters (18A4) which form one line of the legend that appears in the lower left corner of the plot.

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Switches in common area OPTION

Switch	Default Value		Description
1	.FALSE.	.FALSE.	Label high/low centers using exponential format.
		.TRUE.	Label high/low centers using integer format.
2	.FALSE.	.FALSE.	Label contours using exponential format.
		.TRUE.	Label contours using integer format.
3.	.FALSE.	.FALSE.	Label contours.
		.TRUE.	Do not label contours.
4	.FALSE.	.FALSE.	Write a form flash command on the SC4020 plot tape.
		.TRUE.	No operation.
5	.FALSE.	.FALSE.	Draw registration marks.
		.TRUE.	Omit registration marks.
6	.FALSE.	.FALSE.	Write legend.
		.TRUE.	Omit legend.
7	.FALSE.	.FALSE.	Label all contours.
		.TRUE.	Label only zero contours.
8	.FALSE.	.FALSE.	Contour suppression of closed contours by checking the center label size and the ISUPP variable value.
		.TRUE.	Omit contour suppression by checking the center label size.

Switch	Default value		Description
			It will however check the value of the variable ISUPP, which can be set to 0 for no suppression.
9	.FALSE.	.FALSE.	Terminate plot output.
		.TRUE.	Omit final plot output and build up plots.
10	.FALSE.	.FALSE.	Do not initiallize plotter.
		.TRUE.	Initiallize plotter.
11	.FALSE.	.FALSE.	Label open contours on left edge of plot.
		.TRUE.	Suppress labelling of open contours on left edge of plot.
12	.FALSE.	.FALSE.	Label open contours on top edge of plot.
		.TRUE.	Suppress labelling of open contours on top of plot.
13	.FALSE.	.FALSE.	Label open contours on right edge of plot.
		.TRUE.	Suppress labelling of open contours on right of plot.
14	.FALSE.	.FALSE.	Label open contours on the bottom edge of plot.
		.TRUE.	Suppress labelling of open contours on bottom edge of plot.
15	.FALSE.	Not used.	

Switch	Default value	Description	
16	.FALSE.	.FALSE.	CON1ST is not used.
		.TRUE.	CON1ST is used (see contour card).
17	.FALSE.	.FALSE.	Cartesian plot.
		.TRUE.	Polar plot.
18	.FALSE.	.FALSE.	Search for high/low centers and label.
		.TRUE.	Do not search for centers.
19	.TRUE.	.FALSE.	Character printing (do not use for EAI).
		.TRUE.	Character drawing (use for EAI).
20	.FALSE.	.FALSE.	No polar overlay.
		.TRUE.	For polar overlay (use only if SWITCH(17) = .TRUE.)
21	.FALSE.	.FALSE.	For character output.
		.TRUE.	No character output.
22	.FALSE.	.FALSE.	No stops in plotting.
		.TRUE.	Plotter stops after completion of each contour level.
23	.FALSE.	Not used.	
24	.FALSE.	.FALSE.	Third line of legend is output, giving highest contour level and contour interval if it is constant.
		.TRUE.	Third line of the legend omitted.

Switch	Default value		Description
25	.FALSE.	.FALSE.	Normal high/low search.
		.TRUE.	Modified search routine will result in fewer highs and lows.
26	.FALSE.	.FALSE.	Center labels are not floating point.
		.TRUE.	Center labels are floating point (see Switches card).
27	.FALSE.	.FALSE.	Contour labels are not floating point.
		.TRUE.	Contour labels are floating point (see Switches card).
28	.FALSE.	.FALSE.	The number of iterations per grid square is computed by the program. (This will usually be 9.)
		.TRUE.	The number of iterations per grid square is specified by NUMBR on the contour card.
29	.FALSE.	Not used.	
30	.FALSE.	Not used.	

Output

The subroutine prints most of the input parameters plus the switches for common area OPTION. Optionally the input data matrix is printed. The message 'start contours' is printed when the subroutine starts tracing contours through the matrix. At the end of each plot the message 'EAI plot terminated' is printed and at the end of the subroutine the message 'Wolf Research contour program terminated' is printed. The plot tape is a nine-track unlabelled tape.

The input parameters are checked for validity and limits and when an error is detected the values of the four variables IERR0, IERR1, IERR2, and IERR3 are printed and subroutine execution is terminated. The following table shows the values printed for each type of error detected.

	Value	Error	Parameter Requirements
IERR0	1	Bad beginning or end specific contour level.	Contour range must be in range of data values.
IERR1	1	Bad POLES	POLES = 0. or 2. $\leq$ POLES $\leq$ 99.
	2	Bad NUMPLC	0 $\leq$ NUMPLC $\leq$ 8.
	4	Bad IDASH	IDASH(2) = 0 or IDASH(1 to 4) $\leq$ 0.
	8	Bad REPEAT	0 $\leq$ REPEAT $\leq$ 50.
	16	Bad INDEXC	0 $\leq$ INDEXC.
IERR2	1	Bad SCALE or DRIVER	SCALE must be less than 71. for the EAI plotter and > 1.0 and DRIVER must = 5 or 6.
	2	Bad SCALEY	Must be less than 71. for the EAI plotter and > 1.0.
	4	Bad FINTER	Must allow for at least one and less than 200 contour levels.
	8	Bad FINTER and NUMV	Either = 0.
	16	Bad NUMV	NUMV $\leq$ 99.
	32	Bad NUMV	NUMV $\geq$ 0.
	64	Bad PHI	-360 $\leq$ PHI $\leq$ 360.
	128	Bad THETA	-360 $\leq$ THETA $\leq$ 360.
IERR3	1	Bad DRIVER	1 $\leq$ DRIVER $\leq$ 7.
	2	Bad IMIN, IMAX JMIN or JMAX	1 $\leq$ IMIN < IMAX $\leq$ 64. 1 $\leq$ JMIN < JMAX $\leq$ 64.

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APPENDIX

Program execution

Each subroutine is executed by placing a card with the six character subroutine name in columns 1-6 and optionally an input file number in columns 9 and 10 and/or an output file number in columns 14 and 15 in front of the parameter cards for that subroutine. If columns 9 and 10 are left blank, the default number is 11 and similarly the default number for columns 14 and 15 is 15. The output file for those subroutines that write a plotter tape (PLOT2D, PLOT3D and CTUR3D) is 9, but the user does not have to specify it.

The first parameter card for each data set for each subroutine is distinguished by the subroutine name in columns 75-80.

Example 1.

To read a profile from cards, filter and plot the filtered profile.

Job card.

//EXEC GEOSYS

//GO.SYSIN DD *

PROF2D

12C4   PROF2D

(10F7.0)   12

21.2 18.6 10.5 3.1 5.2 8.6 9.9 11.2 14.0 15.3

16.8 18.0

FILT2D

12C4   30.   FILT2D

PLOT2D   15

12C4 PLOT OF DATA SET 12C4 GAMMAS   KILO   PLOT2D

/*

Example 2.

To place two gridded data sets from cards onto disk, fan-filter both data sets in four azimuths, fit a polynomial to one data set and printer contour the filtered output of the other data set.

Job card

//EXEC GEOSYS

//GO.SYSIN DD *

INPT3D

| LAKA | 50 | 50 | | (7F10.0) | | INPT3D |

5620. 5810. 5920. 6010. 6220. 6340. 6500.

etc. (358 data cards needed for this data set)

| CALD | 40 | 30 | | (5F14.0) | | INPT3D |

5820. 5785. 5700. 5660. 5610.

etc. (240 data cards needed for this data set)

FANF3D

| LAKA | 9 | 8 | | FANF3D |

| LAKA | 9 | 8 | 1 | FANF3D |

POLY3D

| TENTH DEGREE POLYNOMIAL LAKA | 1 | 10 | 10 | POLY3D |

FANF3D

| CALD | 7 | 4 | | FANF3D |

| PRPL3D | 15 | | PRPL3D |

| CALD | 1 | 40 | 1 | 15 | 50 | PRPL3D |

| 2. | KILO | 50000. |

| CALD | 1 | 40 | 16 | 30 | 50 | PRPL3D |

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```
2.              KILO         50000.

FANF3D

CALD    7   4   1                                              FANF3D

PRPL3D  15

CALD    1   40  1   15              50.                        PRPL3D

2.              KILO         50000.

CALD    1   40  16  30              50.                        PRPL3D

2.              KILO         50000

/*
```

    Several things should be noticed from the above example:
1) both data sets are placed on disk with one call to INPT3D,
2) the LAKA data set is fan filtered twice with one call to
FANF3D but the CALD data set is fan filtered twice with two calls
to FANF3D. This is necessary because the output of the fan filter
is going to be printer contoured. 3) the PRPL3D subroutine card
has 15 specified as the input file - the output file from the
FANF3D subroutine. 4) the CALD data set must be contoured in two
parts at a scale of 1/50000.

Overlay structure

The following tree structure shows how the program is structured under an OS overlay. It is somewhat generalized, as only the main module is typed for each branch; all the modules are mentioned in the control statements on the following pages.

```
                              MAIN
                   OVERLAY    ONE
┌──────┬──────┬──────┬──────┬──────┬──────┬──────┬──────┬──────┬──────┬──────┬──────┬──────┬──────┬──────────┬────────┐
│PRPLOT│PRPL3D│POLY3D│PHYP3D│MAGR3D│MAGM3D│MAGA3D│INPT3D│GRID3D│GRAV3D│GRAD3D│FILT3D│FANF3D│CONT3D│ SOFTWARE │PLOTTER │
└──────┴──────┴──────┴──────┴──────┴──────┴──────┘      └──────┴──────┴──────┴──────┴──────┴──────┴──────────┘
                      OVERLAY TWO                                        OVERLAY THREE
        ┌──────┬──────┬──────┬──────┬──────┬──────┐                  ┌──────┬──────┬──────┐
        │TALW2D│PROF2D│MAGM2D│GRET3D│GRED3D│FILT2D│CONT2D            │CTUR3D│PLOT3D│PLOT2D│
        └──────┴──────┴──────┴──────┴──────┴──────┘                  └──────┴──────┴──────┘
                                                              OVERLAY FOUR
                                                        ┌──────┬──────┬──────┐
                                                        │PARTS │ZDUMP │SMOOTH│
                                                        └──────┴──────┴──────┘
                                              OVERLAY FIVE
                                        ┌──────┬──────┐
                                        │TRACER│MARKER│
                                        └──────┴──────┘
                                  OVERLAY SIX
            ┌──────┬──────┬──────┬──────┬──────┬──────┬──────┐
            │STAR  │POINTS│PLRGRD│LEGEND│ERROR │CENTER│AXES  │
            └──────┴──────┴──────┴──────┴──────┴──────┴──────┘
                        OVERLAY SEVEN (REGION)
            ┌──────┬──────┬──────────┐
            │LETTER│CPLOT │ MODULES  │DOUBLE
            │      │      │PRECISION │
            └──────┴──────┴──────────┘
```

Figure 17. Generalized overlay tree structure.

Control Cards

```
//LKED.SYSIN DD *

OVERLAY ONE

INSERT PRPLOT

OVERLAY TWO

INSERT GRED3D,CONST,POLY,TID

OVERLAY TWO

INSERT GRET3D,SECOND,POLY

OVERLAY TWO

INSERT PROF2D,ZMON

OVERLAY TWO

INSERT PRET2D

OVERLAY TWO

INSERT FILT2D,CMPW,FRSP,WTDY

OVERLAY TWO

INSERT CONT2D,DTCMP,COMPK

OVERLAY TWO

INSERT TALW2D

OVERLAY TWO

INSERT MAGM2D

OVERLAY ONE

INSERT START,ORIG,EAIZZZ,LINE,EAIPLT

INSERT STNDBY,STOP,XOUT,PINSRP,SYMBL
```

```
INSERT XTRACT,SCRIBE,NUMBER,ANOTE

INSERT SETLIB,ECOD4,EAICOM

OVERLAY THREE

INSERT PLOT2D

OVERLAY THREE

INSERT PLOT3D,PLT3D,PTT3D,EXTSCH

OVERLAY THREE

INSERT CTUR3D,LABELS,GETBIT,INDEF

INSERT PLOTER,ISHIFT,SHIFT,IOR,OR

INSERT OUROR,AND,IAND,OURAND,POLAR

INSERT OPTION,FLPT,LINES,ERRCOD,PLOTR

INSERT LIMITS,VARIES,WORKER,GUIDES,POLE

INSERT STARTS,BEGIN,INITAL,PRINTS

INSERT SIGNAL,PSTOPS,RESULT,FALLOW

OVERLAY FOUR

INSERT SMOOTH

OVERLAY FOUR

INSERT ZDUMP

OVERLAY FOUR

INSERT PARTS

OVERLAY FIVE

INSERT MARKER

OVERLAY FIVE

INSERT TRACER
```

OVERLAY SIX

INSERT LEGEND,UNPACK

OVERLAY SIX

INSERT CENTER

OVERLAY SIX

INSERT PLRGRD

OVERLAY SIX

INSERT AXES

OVERLAY SIX

INSERT POINTS

OVERLAY SIX

INSERT ERROR

OVERLAY SIX

INSERT STAR,GUIDE,FOLLOW,PIECES,CONLAB

OVERLAY ONE

INSERT GRID3D

OVERLAY ONE

INSERT FILT3D,FILTER

OVERLAY ONE

INSERT FANF3D

OVERLAY ONE

INSERT CONT3D

OVERLAY ONE

INSERT GRAD3D,GRAGD

```
OVERLAY ONE

INSERT POLY3D,BOLAR

OVERLAY ONE

INSERT MAGA3D,MAG1,MAG2,MAG3,MAG4,ROTA,CKTAN

OVERLAY ONE

INSERT GRAV3D,GPLOT

OVERLAY ONE

INSERT MAGR3D,TRANS,DHARM

OVERLAY ONE

INSERT PHYP3D,DHAR,DLLSQ

OVERLAY ONE

INSERT INPT3D,IPLOT

OVERLAY ONE

INSERT PRPL3D,JPLOT

OVERLAY ONE

INSERT MAGM3D

OVERLAY SEVEN(REGION)

INSERT CPLOT

OVERLAY SEVEN

INSERT IHCLATN2,IHCLSCN,IHCLSQRT

INSERT IHCLASCN,IHCLLOG,IHCLTNCT,IHCLEXP

OVERLAY SEVEN

INSERT FLABEL,LETTER
```

Catalogued procedure

```
//GEOSYS PROC TAPE=SCRTCH,DISK=USGS01

//GO EXEC PGM=GEOPAC

//STEPLIB DD DSN=SYS2.GEOPAC,DISP=SHR,VOL=SER=USGS01,UNIT=2314

//GO.FT05F001 DD DDNAME=SYSIN

//GO.FT06F001 DD SYSOUT=A

//GO.FT07F001 DD SYSOUT=B,DCB=BLKSIZE=80

//GO.FT09F001 DD DSN=PLOT,LABEL=(,NL),UNIT=(2400,,DEFER),

//           DISP=(NEW,KEEP),DCB=(BLKSIZE=8000,BUFNO=1),

//           VOL=SER=&TAPE

//GO.FT10F001 DD DSN=PROFILE,VOL=SER=&DISK,UNIT=2314,

//            DCB=(RECFM=VBS,BLKSIZE=500),DISP=(MOD,KEEP)

//GO.FT11F001 DD DSN=SYS1.WORK1,VOL=SER=&DISK,UNIT=2314,

//            DCB=(RECFM=VBS,BLKSIZE=500),DISP=(OLD,KEEP)

//GO.FT12F001 DD DSN=GREV,VOL=SER=&DISK,UNIT=2314,

//            DCB=(RECFM=VBS,BLKSIZE=500),DISP=(MOD,KEEP)

//GO.FT14F001 DD DSN=GRID,VOL=SER=&DISK,UNIT=2314,

//            DCB=(RECFM=VBS,BLKSIZE=500),DISP=(MOD,KEEP)

//GO.FT15F001 DD DSN=SYS1.WORK3,VOL=SER=&DISK,UNIT=2314,

//            DCB=(RECFM=VBS,BLKSIZE=500),DISP=(OLD,KEEP)

//GO.FT16F001 DD DSN=&&CONT3D,UNIT=SYSDA,SPACE=(CYL,(1,1)),

//            DCB=(RECFM=VBS,BLKSIZE=500)
```
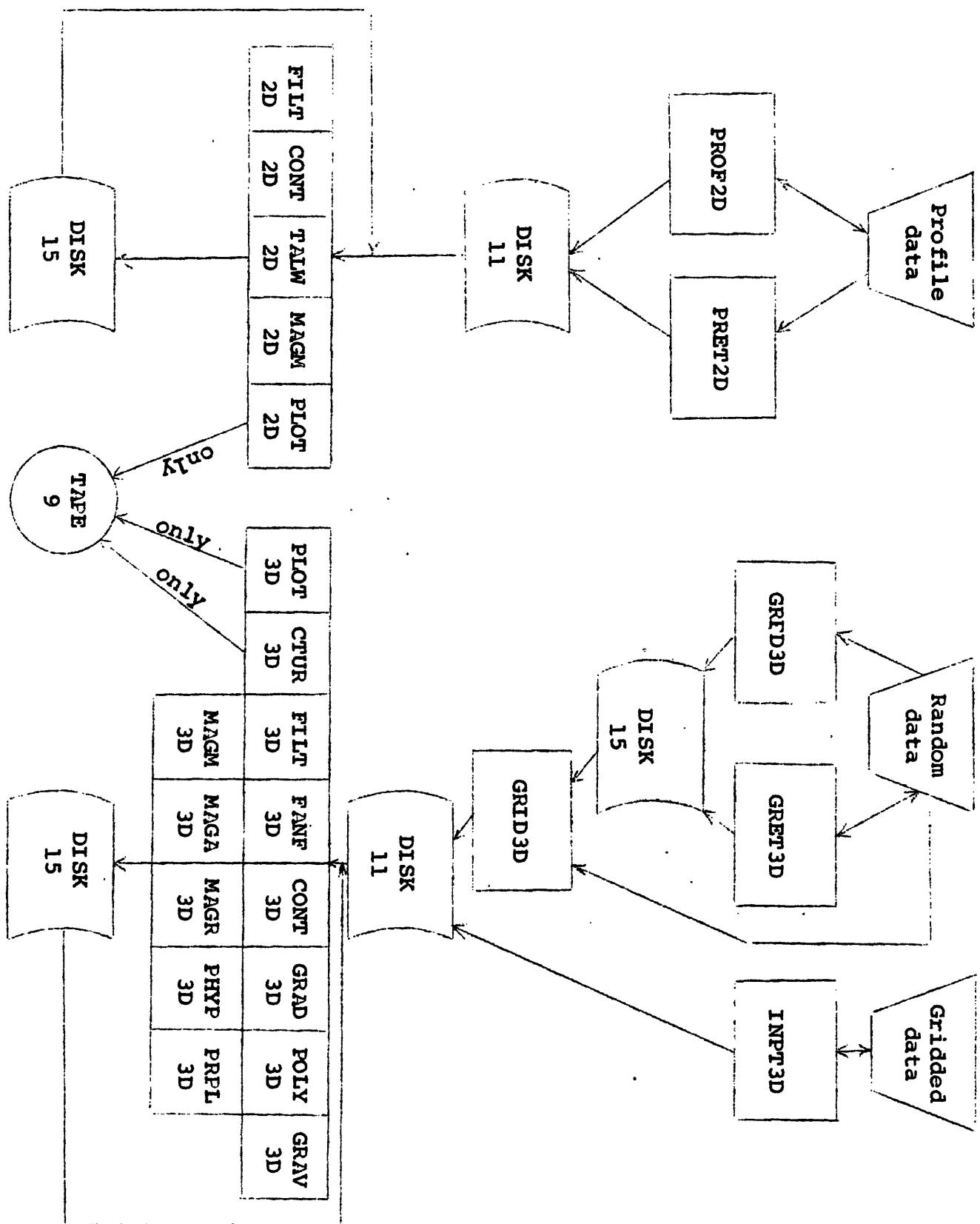
Two-dimensional format

Two records are written in unformatted binary form for each profile.

Record One

Type	Length	Description
Alphanumeric	4 bytes	Data set identification.
Integer	4 bytes	Number of values in the data set.
Integer	4 bytes	A value corresponding to the type of data values, i.e. detrended, filtered, etc. See the individual subroutines for these values.
Real	4 bytes	The distance between data values. If not specified it is set to one.
Real	4 bytes	The maximum data value.
Real	4 bytes	The minimum data value.

Record Two

Type	Length	Description
Real	4 bytes per data value	All the data values.

The following example shows how a profile would be read:

```
READ(IDISK,END=999) ID,N,ITYPE,DELX,YMAX,YMIN

READ(IDISK) (Y(I),I=1,N)
```

Three-dimensional format

The records are written in unformatted binary form. The number of records per data set is equal to the number of rows plus one.

Record One

Type	Length	Description
Alphanumeric	4 bytes	Data set identification.
Integer	4 bytes	Number of rows in the data set.
Integer	4 bytes	Number of columns in the data set.

Remaining Records

Type	Length	Description
Real	4 bytes	Data values of each row.
	per column	

The following example shows how a data set would be read:

```
READ(IDISK,END=999) ID,NROW,NCOL

DO 10 I=1,NROW

READ(IDISK) (Z(I,J),J=1,NCOL)

10 CONTINUE
```

Gravity storage format

The records are written in unformatted binary form. The number of records per data set is equal to the number of stations plus one.

Record One

Type	Length	Description
Alphanumeric	20 bytes	Data set identification.
Integer	4 bytes	Number of stations in the data set.

Remaining Records

Type	Length	Description
Alphanumeric	16 bytes	Station identification.
Integer	4 bytes	Day of the meter reading.
Integer	4 bytes	Month of the meter reading.
Integer	4 bytes	Year of the meter reading.
Integer	4 bytes	Time in hours of the meter reading.
Integer	4 bytes	Times in minutes of the meter reading.
Integer	4 bytes	Degree of station latitude.
Real	4 bytes	Minutes of station latitude.
Integer	4 bytes	Degrees of station longitude.
Real	4 bytes	Minutes of station longitude.
Real	8 bytes	Station elevation.
Alphanumeric	4 bytes	Elevation accuracy code.
Alphanumeric	4 bytes	Meter number.
Real	8 bytes	Gravity of the base station.
Real	4 bytes	Simple Bouguer anomaly computed with a density of 2.67.

Type	Length	Description
Real	8 bytes	Computed gravity value of the station.
Real	4 bytes	Terrain correction.
Real	4 bytes	Complete Bouguer anomaly computed with a density of 2.67.

The following example shows how a data set would be read:

```
READ(IDISK,END=999)   (JD(I),I=1,5),N

DO 10  I=1,N

READ(IDISK)   (IST(J),J=1,4),IDA,IM,IY,IT,ITM,

*LATD,LATM,LONGD,LONGM,ELEV,ELEVA,MN,GBV,SBA,COG,TC,CBA

10   CONTINUE
```

File Definitions

File 5 is the card reader.

File 6 is the printer.

File 7 is the card punch.

File 9 is an unlabeled nine-track tape used as output for the plotter subroutines, PLOT2D, PLOT3D and CTUR3D.

File 10 is a disk or storage file for profile data that is used by subroutines PROF2D and PRET2D.

File 11 is a disk work file used as output by the data preparation subroutines PROF2D, PRET2D, GRID3D, and INPT3D. This file is then used as input to all the data reduction subroutines.

File 12 is a disk or tape storage file for gravity and is used by subroutine GRET3D.

File 14 is a disk or tape storage file for gridded data and is used by subroutine INPT3D.

File 15 is a disk work file used for many purposes. It serves as an output file for subroutines GRED3D and GRET3D, which is then used as input to the gridding subroutine GRID3D. Its main use, however, is as an output/input file for the data reduction subroutines. The input and output files have the same format so processed data sets can be reentered into subroutines.

File 16 is a temporary disk work area used by subroutines CONT3D, MAGM3D and MAGA3D.