Geological Survey of Canada
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ABSTRACT

MAGRAV2 is an interactive program for modelling magnetic and gravity data that runs on IBM personal computers (IBM-PC), or compatibles. The program allows forward and inverse 2½-dimensional modelling of gravity and magnetic anomalies from up to 15 bodies. Bodies are defined by their vertical cross-section and their strike extent.

The program is written for a microcomputer equipped with a high-resolution colour monitor in addition to a standard text monitor. The high-resolution colour monitor is used to display measured and calculated anomalies as well as the colour-coded body cross-sections while the text monitor displays only text information. Program control from either a graphics tablet or the keyboard is possible.

The software is written in Microsoft FORTRAN 77 with one 8088/8086 assembler subroutine for sound generation. Colour graphics are handled by the Halo graphics subroutine library. Halo is device-intelligent, allowing this software to be adapted to numerous different graphics peripherals. This user's guide corresponds to version 1.5 of the program. Other software for this workstation configuration allowing display and enhancement of geophysical imagery is also available (GSC Open File 1581).

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APPENDICES :

1.0) INTRODUCTION

Magnetic and gravity data are often interpreted in a two stage process. The first stage involves qualitative analysis of the data displayed in map form, such as colour intensity maps, shaded-relief images or contour maps. Anomaly trends are correlated to known geology and areas of interest are isolated. The second stage involves quantitative analysis such as forward and inverse modelling of data extracted from areas of interest. Forward magnetic modelling involves defining bodies with specified magnetic properties and calculating the theoretical anomaly that would be produced by the body. This calculated anomaly is compared to the measured anomaly and adjustments are made to the body shapes and magnetic parameters until a reasonable match is obtained between the measured and calculated anomalies.

Modelling can be performed in 2, 2½ or 3 dimensions. Two-dimensional modelling involves defining bodies in cross-section and assumes that the bodies have infinite strike extent. In 2½-dimensional modelling, bodies are defined in crosssection but strike extent is variable. Anomalies from both 2 and 2½-dimensional modelling are displayed in profile form. In three-dimensional modelling, where the geometry of the bodies is variable in three dimensions, the measured and calculated anomalies are displayed in map form. Early computer modelling efforts involved calculation of two-dimensional model anomalies by batch job submission to mainframe computers, analysis of the results, and resubmission of the job with modified model parameters. This process was repeated until a satisfactory match was obtained between the measured and calculated anomalies. This batch-type modelling gradually evolved to 2½ and 3 dimensions.

The next major improvement was the development of interactive two-dimensional modelling programs for mainframe computers that utilized monochromatic graphics displays. One example of this type of program is MAGRAV (Haworth et al., 1980; Wells, 1979) which was written in FORTRAN 4 for CYBER mainframe computers and Tektronix storage-tube terminals at the Atlantic Geoscience Centre. The original MAGRAV used the two-dimensional modelling algorithms published by Talwani and Heirtzler (1964). This program was subsequently improved at the Geological Survey of Canada (GSC) by P. McGrath (McGrath et al., 1983), who added inverse modelling capability and F. Lindia who added the end corrections to the two-dimensional magnetic modelling algorithms (Shuey et al., 1973) to make them 2½-dimensional.

This program, MAGRAV2, is a new version of MAGRAV rewritten in Microsoft FORTRAN 77 to run on IBM personal computers or compatibles. MAGRAV2 incorporates the improvements made to the original MAGRAV by McGrath and Lindia as well as numerous improvements added by the author.

To fully utilize MAGRAV2 additional hardware must be added to the basic microcomputer to improve its graphics and computational performance, as well as it's storage capacity. MAGRAV2 uses a high-resolution colour monitor to generate detailed colour graphics and an optional graphics tablet for cursor positioning and program control.

This open file includes a 360 kbyte IBM-format floppy disc containing source code, a test model, and batch files to simplify compilation and linking of the program. After a discussion of the hardware required to use the program, the procedure to create an executable file and usage of the program will be described.

Additional information on the GSC microcomputer workstation can be found in Broome, 1988 and Broome and Turner, 1989. The text for Broome and Turner, 1989 can be found in ASCII format in file "update" on the diskette. Additional update information on MAGRAV2 can be found in file "read.me".

2.0) HARDWARE REQUIREMENTS

The hardware configuration described here was carefully selected to create a functional inexpensive geophysical workstation. Other software is available which requires this equipment configuration (Broome, 1987); therefore, this configuration is recommended to ensure that your workstation will be compatible with this software. MAGRAV2 was written to operate most effectively on the complete system; however, provisions have been made for users who do not have all the equipment recommended for a complete workstation.

MAGRAV2 has three modes of operation to suit different hardware configurations :

Mode 1) Text display only
Mode 2) Colour graphics display with keyboard control
Mode 3) Colour graphics display with graphics tablet control.

Table 1 summarizes the hardware requirements to run MAGRAV2 in the different modes. Essential components for each mode are identified with an "E", recommended components with an "R" and optional components with an "O". Recommended components are those that are not essential for the particular MAGRAV2 mode but are essential for other software releases designed for the workstation (Broome, 1987, 1988).

Component	Mode: 1	2	3
IBM-PC or compatible -IBM-PC/XT or AT -Running MS-DOS or PC-DOS	E	E	E
256 kbyte memory (640 kbyte recommended)	E	E	E
2 - 360 kbyte floppy discs -only 1 floppy disc is required if a hard disc or 1.2 Mbyte diskette is available	E	E	E
Serial port (for digitizer tablet)	R	R	E
Parallel port (for printer)	O	O	O
8087, 80287 or 80387 numeric processor -Strongly recommended for 8088 computers -recommended for 80286 or 80386 computers	R	R	R
Text monitor and display board - Note: the Number Nine board is not compatible with IBM's EGA or VGA graphics adapters. Use a MGA or Hercules board.	E	E	E
High resolution colour graphics board -Supplied software is designed for: the Number Nine Computer Corp., "Revolution" board, 512 x 512 x 8 bit	-	E	E
High resolution RGB Colour monitor -multi-frequency monitors such as the "NEC Multi-sync" or "Electrohome ECM 1311" are a good choice	-	E	E
Graphics tablet -The software is setup for a Summagraphics Bit-Pad-One or compatible, I use a "Kurta IS/One" in Bit-Pad-One emulation mode.	-	-	E
Printer	O	O	O
Hard disc	O	O	O

Table 1 : Hardware required for different modes of operation. "E" indicates essential, "R" indicates recommended as this device is essential for other workstation software, and "O" indicates optional.

2.1) MODE 1 REQUIREMENTS

MAGRAV2 operating in mode 1 will operate on any IBM-PC, IBM-PC/AT or compatible with 256 kbytes of memory and 2 floppy disc drives. The addition of an 8087, 80287, or 80387 numeric coprocessor chip is strongly recommended because it accelerates anomaly computation by a factor of from 2 to 10. With an 8088-based computer, a typical anomaly calculation for one body requires approximately 20 seconds for a 50 point profile; much too long for an interactive environment. With the coprocessor the delay for anomaly calculation is less than 2 seconds. With 80286 and 80386 based microcomputers the speed is doubled by adding the coprocessor.

A hard disc is strongly recommended to simplify program compilation and linking and to simplify program operation. In Mode 1, all information, including observed and calculated anomaly profiles, are typed out on the text monitor in numerical form rather than being presented graphically as in modes 2 and 3. Program operation is controlled by 39 command options which are explained by an on-line help function. Although most program functions are available in mode 1, the absence of graphic display of anomaly profiles and body cross-sections makes the modelling process slower and more difficult.

2.2) MODE 2 REQUIREMENTS

Mode 2 operation requires the addition of a high-resolution colour monitor and graphics adapter to display anomaly profiles and body cross-sections. The program is controlled by the keyboard using the 39 different command options used in mode 1. Body cross-sections and anomaly profiles are drawn colour-coded on the colour monitor. The graphic display resolution of the standard IBM colour graphics adapter (CGA) is inadequate for this application. Therefore, a high resolution graphics adapter was added. The graphics adapter used is the Number Nine Computer Corp.'s "Revolution" board. This board produces an interlaced 512 by 512 pixel display with 256 simultaneously displayable colours out of a palette of over 16 million colours. MAGRAV2 does not require 256 colours but other software designed for this workstation (Broome, 1987, 1988; Broome and Turner, 1989) requires this capability. Other colour graphics boards could be used because all graphic output is generated by the device-intelligent Halo graphics library. Considerations for adapting the program for different hardware such as the EGA graphics adapter are outlined in Appendix D.

2.3) MODE 3 REQUIREMENTS

Mode 3 operation requires the addition of a digitizing tablet. The program is configured to use the Halo Summagraphics "Bit-Pad-One" locator driver. I use a Kurta digitizer (model: IS/One) running in Bit-Pad-One emulation mode but any compatible tablet could be used. In mode 3, program option selection and body point movement are controlled from the graphics tablet using the graphics tablet cursor. Program control from the graphics tablet is achieved by placing a template over the graphics tablet that identifies areas on the graphics tablet which correspond to different program options. As in modes 1 and 2, the text monitor is used to display prompts, informative listings and error messages. Mode 3 operation is the most interactive modelling environment and the recommended mode of operation.

3.0) COMPILING AND LINKING MAGRAV2

3.1) SOFTWARE REQUIREMENTS FOR COMPILING AND LINKING

Before MAGRAV2 can be used , an executable file must be generated by compiling the FORTRAN source code files and linking them with the FORTRAN, Halo, and MAGRAV2 libraries. To produce an executable MAGRAV2 file, two commercial software products are required :

1) The Microsoft FORTRAN 77 compiler is required. The current version was compiled using version 4.1. (Version 3.31 may work but versions 4.0 and 4.01 cause problems)
2) The Halo graphics subroutine library with Microsoft FORTRAN 77 support for graphics in modes 2 and 3. (Version 2.26 or higher; Halo '88 is essentially the same product)

The Microsoft FORTRAN 77 compiler is required for all modes of operation to compile the five FORTRAN source code files. The source code is broken into five files because there is too much code to be compiled as one module by the compiler. The batch file "compmf.bat" can be used to compile the five files as outlined in Appendix C. The five source code files are; "magrav2.for", "ms1.for", "ms2.for", "ms3.for", and "ms4.for". All of the subroutines are required for mode 3 of operation; however, operation in modes 1 and 2 does not require all the subroutines. A brief description of the purpose of each subroutine, which modes of operation require it, and the source code file in which it is found are included in Appendix B.

To generate an executable file for a system with no digitizing tablet, files not required for modes 1 and 2 can be edited out of the source files. Calls to the deleted subroutines must also be deleted from the main program and other subroutines, or error messages will occur during linking.

Subroutine SOUND is an assembler routine, found in "magrav2.lib" which is used to generate sound to accompany program prompts and error messages. It is not essential to program operation and can be left out if all calls are edited out of the FORTRAN source code.

3.2) THE HALO GRAPHICS LIBRARY

The Halo graphics subroutine library is used to produce graphic output in modes 2 and 3 of operation. Halo is a device-intelligent system for handling graphics on microcomputers produced by Media Cybernetics Inc (see Appendix F). Device driver files are provided for many common microcomputer graphics adapters, printers and positioning devices such as digitizers and mice. These drivers are installed at run time to allow software to be used in different hardware environments. Modifications that may be required for different graphics adapters and digitizing tablets are discussed in Appendix D. Mode 1 operation does not use any Halo subroutines, so an executable MAGRAV2 file can be generated for mode 1 operation without the Halo graphics library, by commenting out any Halo subroutine calls in the FORTRAN source code files before compiling and linking.

The object files produced during compilation and assembly must be linked to each other and to the FORTRAN and Halo libraries to produce the executable MAGRAV2 file. The batch file "mlink.bat" can be used to link the files as described in Appendix C.

4.0) SETTING UP TO RUN THE PROGRAM

4.1) FILES USED BY MAGRAV2

Once a "magrav2.exe" file has been produced you are ready to model. A number of files are required by MAGRAV2 and the program generates others. A list of these files and their purpose follows:

1) Magrav2.exe :
MAGRAV2 executable file you generate by compiling and linking the FORTRAN source code files provided.

2) Halo.dev :
Device driver file used by the Halo graphics. For the 512x484x8 number nine graphics board, this file is Halo file "halonine.dev" renamed "halo.dev. This file and others are provided with the Halo graphics package. "Halo.dev" must be located on the default drive.

3) Logo.pic :
This file is optional . It is a Halo format image file produced by the Halo "gwrite" command. If the file is found on the default drive, the stored image will be displayed on the colour monitor when MAGRAV2 is executed. You can generate your own "logo.pic" file if you have the 'Dr. Halo III' image editing program.

4) Models file :
The models file is generated by the MAGRAV2 and contains models stored by using the "write" option in MAGRAV2. You may name this file whatever you wish. This file allows the user to save models and read them back later for further modelling or inspection. Sample model file "test15.mod" is provided.

5) Recovery file :
This is a scratch file generated on the default drive by MAGRAV2 containing information used by the "RECOver" option to allow modelling steps to be undone. This file is named "magrav.rec".

6) Init.bat :
This file is used to install the Halo locator driver for the Summagraphics Bit-Pad-One digitizing tablet which initializes the serial port. "Init" must be run before MAGRAV2 (Modes 2 and 3).

7) Halobpoi.com :
This file is the Halo locator driver for the Bit-Pad-One digitizing tablet. It is provided with the Halo graphics package and used by "init.bat".

8) Ansi.sys :
"Ansi.sys" is an MS-DOS device driver which must be installed to allow MS-Dos to recognize the ANSI escape sequences used for cursor and screen control on the text monitor. Install "ansi.sys" by inserting "device = ansi.sys" in your "config.sys" file.

4.2) SETTING UP WITH A 1.2 MBYTE FLOPPY OR HARD DISC

If a hard disc or a 1.2 Mbyte floppy disc is included in the system, then files "magrav2.exe", "init.bat", "halobpoi.com", "halo.dev" and the models file can all be placed on one drive. With a hard disc a directory should be set up for MAGRAV2 files.

4.3) SETTING UP WITH TWO 360 KBYTE FLOPPY DISCS

If only two 360 kbyte floppy discs are available all the files used by MAGRAV2 will not fit on one drive. In this case, files "halo.dev", and the models file should be placed on the default drive and a disc containing "magrav2.exe", "init.bat", and "halobpoi.com" should be placed in the other disc drive.

4.4) OPTIONAL USE OF A RAM DISC TO IMPROVE PERFORMANCE

After each significant model change, MAGRAV2 writes a block of data to file "magrav.rec" for use by option **reco** for undoing changes. If "magrav.rec" is locared on a diskette, program operation is slowed considerably. The delay is reduced considerably if a hard disc is used. If 640 kbytes or more memory is available, program execution can be speeded up by 'installing' a RAM disc in memory and making it the default drive. Files "halo.dev" and the models file should be placed on the default drive. "Magrav.rec" will now be created on the RAM disc and updates of "magrav.rec" after model changes will be performed much more quickly. A commercial software package such as "Superdrive" by AST research or the MS-DOS configuration option "vdisc.sys" can be used to create the RAM disc.

4.5) INITIALIZING THE DIGITIZER

If MAGRAV2 is to operate with digitizer tablet control (mode 3), the system must first be initialized for the appropriate digitizer by running batch file "init.bat". This sets up the serial communications port on the computer for the particular locator device used. "Init.bat" executes Halo file "halobpoi.com" to initialize Halo and serial port for the Bit-Pad-One digitizing tablet. The digitizer should be set for 9600 baud, 7 data bits, 1 stop bit, and connected to serial port 1 (com1).

5.0) USING MAGRAV2

MAGRAV2 is loaded and executed by entering the command "magrav2". The program first ask for the name of the models file.

The name of an existing file or the name of a new file you wish to created can be used. A test models file, "test15.mod", provided on the open file disc, should be on the default drive. The program will then ask if graphics are to be enabled. To use the program in mode 1 enter "n" and for modes 2 and 3 enter "y". The program will then display the prompt "Enter option:".

5.1) PROGRAM OPTIONS AND HELP

MAGRAV2 is controlled from the keyboard with 39 four character program command options. Any of the options can be called at any time; however, a logical sequence must be called. Obviously, the option which moves a body cannot be used if no bodies have been defined. If an attempt is made to select an option that cannot be used, a message will be generated to identify the error. The correct starting order of option calls is given by option **help** together with a menu of the possibilities. Option **menu** produces a listing of the 39 possible commands. Within **help**, information describing each of the text options can be obtained. Within help the text monitor is in reverse "black on white" mode. Pressing the <enter> key, returns you to the main program. Two sequences of option calls can be used to get started, depending on whether the model is being generated for the first time or an existing model is to be read in from the models file. To exit the program respond **end** to the enter option prompt.

5.2) TESTING THE PROGRAM

The models file is used to store model information so the user does not have to enter the observed and body data each time he wants to work on the model. To test the program, read in the model from models file "test15.mod". To read in a model one must first determine the names of models stored in the models file. Option **name** will list the models in the current models file and prompt the user to select one. Enter a name (note: model names are case dependent) and then use option **read** to read the model into the program. To calculate the anomaly due to the bodies call text option **anom** or **draw**. The program will type "Calculating anomaly for body n". The calculated anomaly can then be typed on the text monitor out with option **tano**. The body point coordinates and magnetic parameters can be printed out with option **tbod**. If graphics are enabled (modes 2 or 3) the observed and calculated data can be plotted on the graphics monitor along with the cross-sections of the bodies using option **draw**.

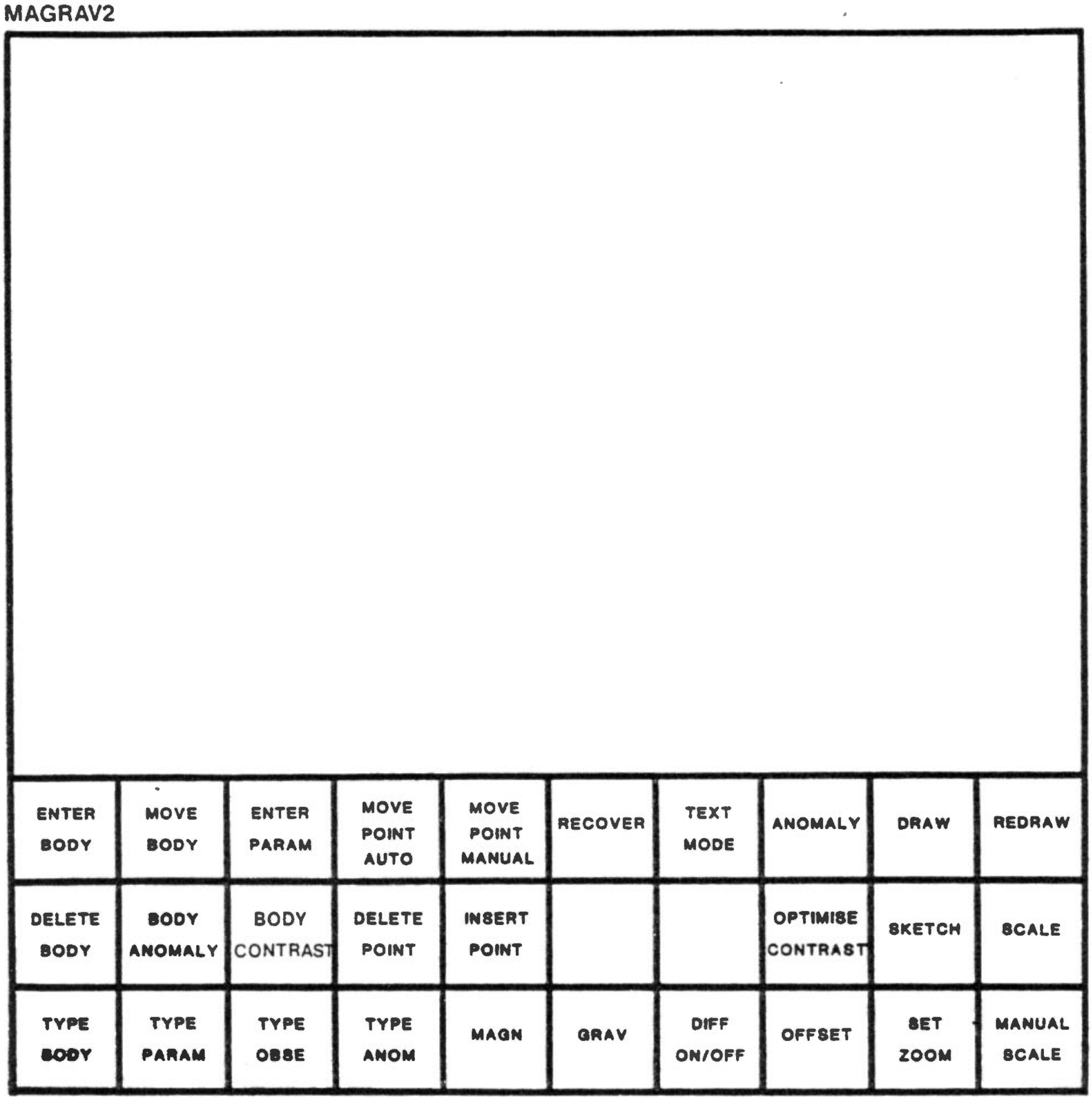

Figure 1 : Program control from the digitizing tablet (mode 3) is obtained by placing the digitizer cursor over the template square representing the desired option and pressing the cursor button. The template is shown at a reduced scale. The black border on the template should be 25.4 cm. The digitizing tablet provides a much easier and faster method for changing body points than using the keyboard.

5.3) USING THE DIGITIZER

If a digitizer tablet is included in the system, mode 3 of operation can be used. Mode 3 of operation allows most program options to be selected from the digitizing tablet. The template, shown in Figure 1, which is placed over the working surface of the digitizer, identifies areas which correspond to different program options. To enter mode 3 of operation, graphics must be enabled and option **tabl** called. Program options can now be selected by placing the digitizer cursor over the appropriate command square on the digitizer and pressing the cursor button. Additional instruction are then printed on the text monitor.

6.0) MODELLING YOUR OWN DATA

To model your own data, execute MAGRAV2 and then select the name of the models file you wish to use. If the program does not find the file you have selected it will ask you if you wish to create a new models file with that name. If you respond "n" the program will again prompt you for the models file name. After the models file is selected and the graphics mode is set, two paths are possible.

If a new model is to be created, the first option selected should be **grav** or **magn** to select the data type. If magnetics mode is selected, the program will ask for the orientation of the profile data, the declination and dip of the geomagnetic field in the profile area, and whether a depth offset is desired for body points. Approximate field declination and dip can be calculated using program DECINC (see Section 11.3). The depth offset is useful for aeromagnetic data modelling since it can be set equal to the survey flight elevation (km) to allow body point depths to indicate the depth below the Earth's surface. If gravity mode is selected, the program will ask for the depth offset only. The next step is to enter the observed data values.

If an existing model is to be retrieved for changes, the model name must first be specified using option **name**. **Name** will list the names of models stored in the current models file and prompt the user to select one of the models. After selecting the model, the model data must be read using option **read**. Once the model is read it may be changed or displayed using other MAGRAV2 options.

6.1) ENTERING OBSERVED DATA

The observed data is entered using option **eobs**. The program will first ask whether data is to be read from a file or entered manually from the keyboard. Data entry from a file is provided as a link between the modelling program and digital sources of profile data such as field magnetometers with internal storage or airborne profile data. Program DISPLAY (Broome, 1987) can be used to extract profile data from gridded potential field data files and store the profile data in MAGRAV2 compatible files. The format for profile files is described in Appendix E.

If manual entry is selected, the program will ask for the "x" profile offset. The "x" profile offset is a constant added to observed data positions which is useful when profiles longer than the current maximum of 100 points are to be modeled. The long profile can be modelled in two or more sections with the "x" offset set so that the "x" coordinate of the last point of the first section equals that of the first point of the next section. The program next asks for the observed data sampling interval and the number of profile readings to be entered. The current maximum profile length of 100 points could be increased by simply re-dimensioning the appropriate arrays in the program. The appropriate number of profile point numbers and data values are now entered. If graphics are enabled, the observed data will be automatically scaled and plotted in green on the colour monitor.

6.2) ENTERING BODIES

Once the observed data has been entered, the next step is to define the body cross-sections by entering body points. At this stage, an understanding of potential field interpretation and the geology of the area becomes important. Potential field interpretation is complicated because of an ambiguity problem which results in an infinite number of combinations of body geometries and magnetic properties that can produce an given anomaly. Geological constraints such as measured magnetic susceptibilities on the profile and knowledge of the structure and contact locations between zones with contrasting susceptibility are important to ensure a realistic model is produced. Body points can be entered from the keyboard using option **ebod** (modes 1,2,3) or more easily from the digitizer tablet (mode 3). When the digitizer cursor is used to locate points, the current cursor coordinates are printed in the top right corner of the text monitor. Up to 25 points can be entered per body and points must be entered in clockwise order or anomalies will not be calculated correctly. Bodies are plotted, in colour, on the graphics monitor if graphics are enabled. Figure

2 shows how bodies are defined within the program. Up to 15 bodies can be created. Each body has a unique number and colour. The body colour is identified in the print-out produced by option **tbod**.

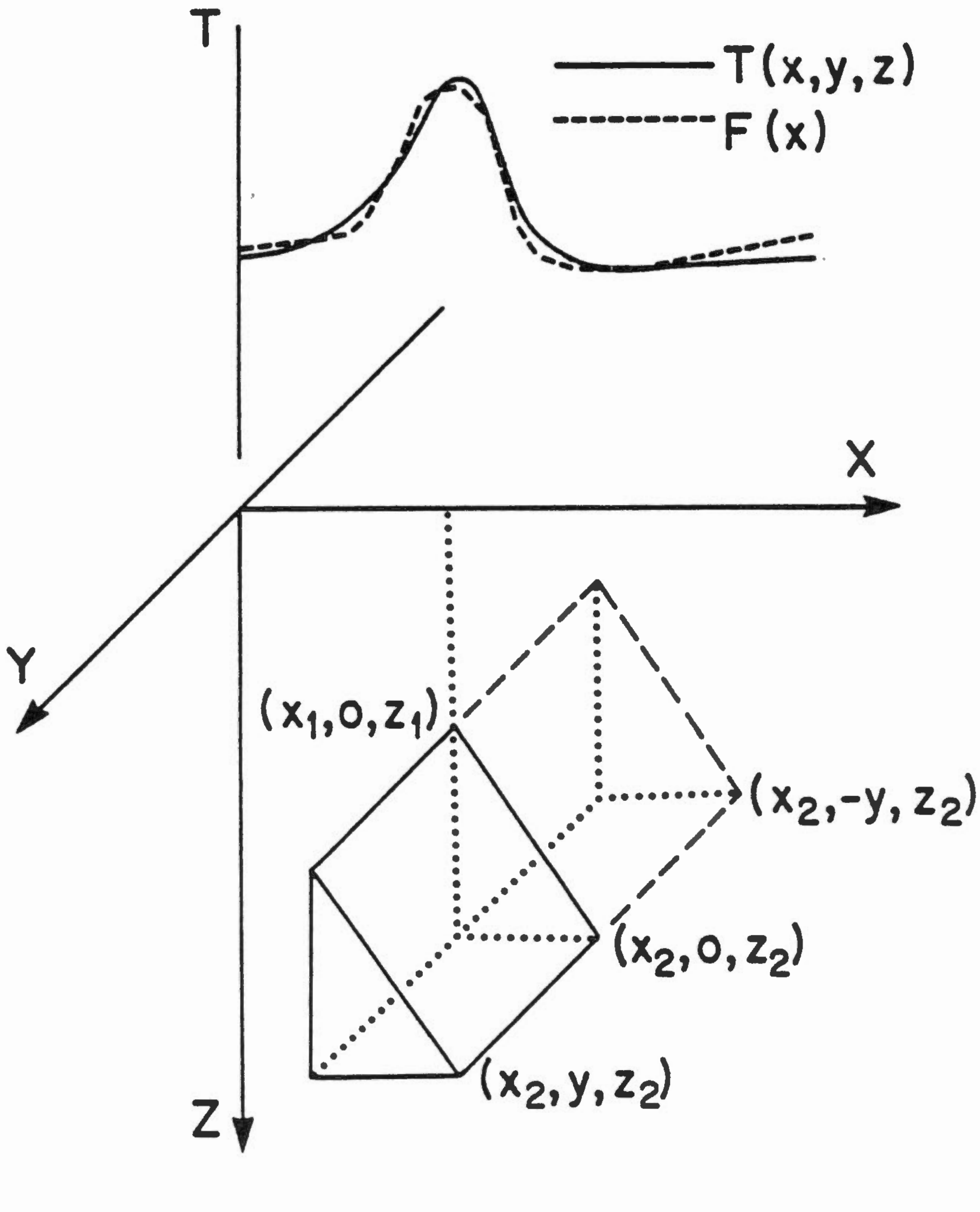

Figure 2 : This diagram shows the geometry used by MAGRAV2 to define bodies. The screen display shows only the x-z plane through points (x1,0,z1) and (x2,0,z2). The half-strike length distance, or strike extent, used by the 2½-dimensional modelling algorithm is equal to y.

Body number	**body colour**
1	red
2	yellow
3	turquoise
4	purple
5	orange
6	blue
7	pink
8	light blue
10	brown
11	dark green
12	navy blue
13	white
14	moss green
15	grey

As body points are entered they are compared to existing body points. If the position of the new point is very close to an existing point, the new point position is set equal to the old. The separation between points must be greater than the size of the small box in the lower left corner of the screen for the new point position to be retained. The next step in defining your model is to enter the body parameters.

6.3) ENTERING BODY PARAMETERS

Body parameters are entered using option **epar** or by selecting "enter parameter" on the digitizer tablet (mode 3). The first parameter the program will ask for is the body strike extent. The strike extent entered is the distance from the central cross-section of the body to each end of the body. The length of the body is therefore, twice the strike extent with the anomaly calculated over the centre cross-section. Next, the program will ask for the minimum, actual and maximum magnetization or density contrast depending on whether you are in gravity or magnetics mode. The minimum and maximum values set the range within which automatic contrast setting options, such as **cont**, can vary the density or magnetization. This range would be set from measurements of density or susceptibility of rock samples along the profile or by looking up representative ranges for rock types identified along the profile.

The magnetic susceptibility of a rock is a measurement of the degree to which the rock can be magnetized. Since rock magnetic susceptibility is the usual rock property measured in the field, the relationship between magnetic susceptibility and magnetization is important for use of the program. The magnetization is the magnetic moment per unit volume and is related to magnetic susceptibility as follows :

$$k = M / H$$ where in cgs units;

k = Magnetic susceptibility (dimensionless)
M = intensity of induced magnetization (emu/cc)
H = intensity of the geomagnetic field (oersted)
(1 oersted = 100000 gamma)

Magnetization is expressed in cgs units of 10^{-5} emu/cc in the program. Conversion of susceptibility from cgs to SI units is achieved by dividing by 12.57.

If you are in magnetics mode the program will also ask for the declination and dip of the body magnetization. For most magnetic modelling, magnetization is induced by the geomagnetic field and is therefore in the same direction as the geomagnetic field. If remanent magnetization is present, the direction entered should be the direction of the vector sum of the remanent and induced magnetization vectors. The magnetization value entered in the program should be the amplitude of this vector sum.

6.4) CALCULATING AND DISPLAYING THE ANOMALY

Once body points,body parameters, and observed data have been entered, the model anomaly may be calculated using option **anom**. In mode 1, the program will ask you to enter the body number for which the anomaly is to be plotted. Entering a specific body number will result in the anomaly from that body being plotted colour-coded to the body cross-section plot. Entering "0" will result in the composite anomaly from all defined bodies being plotted in white. In modes 2 and 3 the program will calculate the combined anomaly from all the bodies defined. The anomaly can also be typed on the text monitor using option **tano**, or if graphics are enabled, drawn on the colour monitor using option **draw** or from the tablet using options "draw", "sketch", or "redraw". If changes to body points or parameters are made, anomalies are automatically recalculated and the composite anomaly plotted in white whenever the colour display is drawn.

The observed and calculated anomalies are automatically scaled to fill the plot window on the graphics screen the first time it is drawn. If the observed data contains a constant background it can be removed for plotting purposes by calling text option **offs**. Calling "offset" from the tablet gives the user the option of automatic offset calculation based on the entire profile or manual offset definition. If manual offset definition is selected, a vertical line appears in the profile window. The user must then select the point on the profile where the observed and calculated data should have the same level, thus defining the offset. Offset and model changes may require re-scaling of the anomaly plot window. This re-scaling can be done automatically with text option **asca** and tablet option "scale; or manually with text option **msca** and tablet option "manual scale". The zero level in the anomaly window is indicated by a grey line. When the screen display is redrawn, the anomaly window limits are printed on the text screen.

7.0) OPTIMIZING THE MODEL

Once the body and anomaly data have been entered into the program, other options may be called to modify model parameters. The model can be changed either manually or automatically. When optimizing the model, care must be taken to ensure that the model remains relevant to the known geological constraints. Manual optimization of the model is recommended in the early stages of developing the model since the interpreter can ensure the model fits within the geological constraints. Automatic methods are useful when the model is thought to be close to being correct, to make final adjustments.

7.1) MANUAL OPTIMIZATION

After the initial model has been created, adjustments to model parameters are usually required to improve the match between the observed data and calculated anomaly. Manual changes to body cross-sections can be made using text options: **mpoi** (move point), **dpoi** (delete point), and **ipoi** (insert point) or using the corresponding digitizer options. If a body point is found in more than one body you will be asked to select in which body the point should be moved.

Manual changes to magnetization or density contrasts can be made with text option **epar**. Information on the other options that can be used for changing the model can be obtained using the text option **help**.

7.2) AUTOMATIC OPTIMIZATION

The program also allows the user to automatically move body points using text option **maut** and to optimize body density or magnetization using option **cont**. Both text-mode automatic optimization methods generate a best least-squares fit between the entire calculated and observed profiles.

A wider range of automatic optimization is available from the tablet. To optimize body contrast the user may select "optimise contrast" to optimize the density or magnetization of all bodies for a best least-squares fit between the entire observed and calculated profiles. Alternately option "body contrast" allows optimization of the density or magnetization of a single body to fit a specific segment of the observed profile.

The automatic optimization routines work properly only if the model produces a calculated anomaly reasonably close to the observed data. If the body point or body contrast is poorly constrained, the automatic point movement may produce unreasonable results due to the mathematical accuracy limitations of the program.

Automatic contrast optimization varies the density or magnetization contrasts of the body within the minimum and maximum limits entered in text option **epar** or tablet option "enter parameters". This allows realistic limits to be placed on body parameters which conform to the known geology. If automatic optimization is used for magnetic models where the body magnetization direction has been set different from the field direction to account for remanent magnetization, the model will be optimized by changing the magnitude of the resultant magnetization vector. As explained previously, the resultant is the vector sum of an induced component determined by the susceptibility of the body and a fixed remanent component. Since the remanent component is fixed, the induced component should be optimized to fit the model rather than the resultant which indicates the total magnetization. For this reason, automatic contrast optimization is not recommended where a remanent magnetization component is included in the model.

8.0) OTHER PROGRAM FUNCTIONS

8.1) RECOVERY

During the optimization process, changes are often made which are undesirable. Option **reco** allows the user to undo the most recent changes of the program. The number of program steps saved defaults to 10 but may be changed using option **conf**. After each significant change to the model, it is saved in file "magrav.rec". Each call to option **reco** undoes one change.

8.2) ZOOM

The screen resolution can be a limitation to the modelling process for complex or very detailed models. For this reason a zoom function has been implemented which allows a portion of the screen display to be blown up to fill the screen. The area to be zoomed can be defined using text option **zoom** or using the "set zoom" command on the digitizer tablet. Once the zoom area has been defined, the user can generate the full profile display by calling text or tablet options **draw** or generate a zoomed display by calling text option **sket** or tablet option "sketch". All program command options work in both the "sketch" and "draw" display modes. There is a minimum size ro the area that can be "zoomed" because redrawing extremely small areas is very slow and may cause failure of the Halo zoom function.

Zooming out to increase the display beyond the ends of the profile can be accomplished using text option **msca** or tablet option "manual scale". This is a useful feature which allows bodies to be extended beyond the profile ends to eliminate edge effects.

8.3) SAVING THE MODEL

If model changes are made, the revised model must be written to the models file, before exiting from the program, using option **writ**; otherwise, changes will be lost. The model name can be left unchanged, in which case the previous model can be overwritten, or the model name can be changed to create a new model in the models file. A maximum of 20 models can be stored in a models file.

8.4) SIMULTANEOUS GRAVITY AND MAGNETIC MODELLING

MAGRAV2 allows simultaneous modelling of both gravity and magnetics for a given model. To use this feature enter either a gravity or magnetic model as described and then call text or tablet options **grav** or **magn** to change modelling mode. After the modelling mode is set, enter observed data and body parameters for that mode. Once both gravity and magnetic observed data and body parameters have been entered, the current modelling mode can be switched back and forth by calling text or tablet options **magn** and **grav**. The current program mode is indicated by a "G" or an "M" in the upper left corner of the colour display. Modelling of both gravity and magnetic data allows the model to be constrained more completely than using one mode alone however in practice magnetization and density boundaries seldom coincide, complicating the modelling process.

8.5) OPENING NEW MODELS FILES : OPTION "OPEN"

A new option **open** has been added. This option allows other models files to used or created without leaving the program. Models can be transferred from one file to another by reading a model from one file and then closing the file, opening a new models file and writing the model to the new models file.

8.6) SAVING SCREEN DISPLAYS : OPTION "SAVE"

Option **save** allows the model display to be saved as a Halo-format ("*.pic") image file together with a matching Halo-format ("*.pal") palette file. Halo-format files can be read by program DISPLAY (Broome, 1987) to produce colour hard copy on a Tektronix 4696 colour ink-jet plotter. Halo compatible image manipulation software such as "Dr. Halo" and "Image-Pro", available from Media Cybernetics, can also be used to annotate or edit the saved image file before printing. File "magrav2.pal" is a Halo-format palette file which contains the colours used by MAGRAV2.

8.7) OPTION : "CONF"

Option **conf** allows the number of program steps saved in the recovery file to be changed and the graphics tablet response time to be modified. The size of the recovery file is controlled by the number of saved program steps. Users without hard disks may choose to set the number of recovery steps to zero to avoid delays after each model modification caused by the slow response of floppy disks.

The wide execution speed range of IBM-compatible microcomputers caused problems with graphics tablet response time. The original program was designed with delays appropriate for a workstation using a slow 8088 microprocessor. On faster microcomputers using Intel 80286 and 80386 microprocessors, delays are reduced resulting in duplicate point entry from the graphics tablet. In the new version of MAGRAV2, the user can set the graphics tablet response, using option **conf**, to suit his hardware and personal preference.

9.0) CONVERTING MAGRAV2 FOR VERTICAL GRADIENT MODELLING

MAGRAV2 can be easily modified for vertical gradient modelling by making some changes to subroutine MAG. The modifications use the depth offset to calculate the magnetic anomaly at two different heights one meter apart. The difference between these anomalies is an approximation to the vertical gradient of the field. The observed vertical gradient data should be entered in units of gammas/metre to match the calculated anomaly. Appendix F contains a modified version of subroutine MAG called MAGVG. This method of calculating the vertical gradient doubles the amount of computation required therefore anomaly calculation takes twice as long.

10.0) MODIFICATIONS AND DISTRIBUTION

Many individuals have expressed interest in MAGRAV2 and other programs used by this microcomputer based workstation. By releasing this program into the public domain, is hoped that the program will receive widespread use. This use will probably lead to modifications, improvements and corrections to errors that may exist in the program. The author would appreciate if a description of any significant modifications or corrections to the program could be sent to me so that they can be incorporated in later versions of the program. Please distribute only unmodified versions of the program.

11.0) UTILITY PROGRAMS

11.1) MODELS FILE CONVERSION : MODCVT

Version 1.5 of MAGRAV2 allows 15 bodies with up to 25 points to be defined. This changes results in models files created by previous version of the program being incompatible with the new version. Program MODCVT converts format models files to the new models file format. Without this utility old models would have to be manually entered into the new version. The source code for MODCVT is found in file "modcvt.for". MODCVT contains no Halo subroutine calls.

11.2) PROFILE PLOTTING : PROPLT

PROPLT allows models files, created manually or written by program DISPLAY (Broome, 1987) to be plotted on Epson FX-Series dot-matrix printers. Horizontal and vertical scale are user-selected allowing profile plots to be generated at a scale matching existing geological maps. The position of each profile point is marked on the baseline and a line grid is overlain on the profile to facilitate anomaly measurement. The source code for PROPLT is found in file "proplt.for". PROPLT contains no Halo subroutine calls.

11.3) I.G.R.F. CALCULATION : DECINC

A new program, called DECINC, is included with the MAGRAV2 Open File. DECINC calculates the magnetic field declination and inclination values required for magnetic modelling at the profile location. DECINC prompts the user for geographic coordinates, altitude above sea level, and time then calculates International Geomagnetic Reference Field (IGRF) declination and inclination values (Cain et al.,1967; Peddie et al., 1982). IGRF values are calculated by a subroutine written by G. Haines of the GSC. The IGRF is a quantitative description of the earth's main magnetic field defined by a series of solid internal spherical harmonics up to and including the 8th degree and order. Source code for the program is provided, as well as coefficients files for IGRF 1970 ("igrf70.dat") and IGRF 1985 ("igrf85.dat"). Coefficients files for the Definitive Geomagnetic Reference Field (DGRF) for 1970 ("dgrf70.dat"), 1975 ("dgrf75.dat") and 1980 ("dgrf80.dat") are also included. Source code for program DECINC is found in file "decinc.for". DECINC contains no Halo subroutine calls.

Although IGRF declination and inclination values may not exactly match measured values they are sufficiently accurate for most modelling applications. The five magnetic field models produce slightly different declination and inclination values but the differences are generally not significant for modelling.

12.0) DISCLAIMER

This program is provided on an "as is" basis. Every attempt has been made to ensure this program is as free from errors as possible however, neither The Geological Survey of Canada nor any of its staff members are liable for any errors in the program or any problems associated with use of the program.

13.0 REFERENCES

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APPENDIX A

Files supplied on the Open File 1334, Version 1.5, disc :

Microsoft FORTRAN source files:

1	magrav2.for
2	ms1.for
3	ms2.for
4	ms3.for
5	ms4.for
6	magrav.cmn
7	decinc.for
8	proplt.for
9	modcvt.for

Microsoft Assembler files

10	sound.asm

Libraries

11	magrav2.lib

Batch files

12	compmf.bat
13	mlink.bat
14	cmf33.bat
15	mlink33.bat
16	init.bat

Models file

17	test15.mod

Miscellaneous files

18	update
19	magrav2.pal
20	read.me
21	igrf75.dat
22	igrf85.dat
23	dgrf75.dat
24	dgrf80.dat
25	dgrf70.dat

APPENDIX B

Subroutine description :

1) Name..modes requiring it.... location of the source code
2) What it does.
3) Other routine calls
(Argument descriptions are given in the source code)

NOTE: Subroutine calls not found in this list are calls to the "Halo" graphics subroutine library.

In alphabetical order :

AMOVE M: 1,2,3 MS3.FOR

Routine to set up variables and arrays for subroutine "DFS001" for use during automatic point position optimization.

AMPBOD M: 2,3 MS3.FOR

Routine to automatically adjust the density or magnetization contrast of individual bodies to achieve a best least-squares fit of user-specified part of the observed and calculated profiles.

AMPL M: 1,2,3 MS3.FOR

Routine to automatically adjust the density or magnetization contrast of all bodies to achieve a best least-squares fit of the observed and calculated profiles.

ASCALE M: 2,3 MS2.FOR

This subroutine automatically scales the anomaly plots to fit the screen window.

CALCAN M: 1,2,3 MS3.FOR

This subroutine calls the appropriate gravity or magnetic anomaly calculation subroutine to calculate the anomalies from any bodies with new or changed parameters or point positions.

CALFUN M: 1,2,3 MS3.FOR

Routine called by "DFS001" to calculate anomaly values during automatic point location optimization.

CHECK M: 3 MS3.FOR

This subroutine compares body point positions to existing body points. If the new point position is within the distance specified in variables "xdis" and "zdis" from an existing point a flag is set. This check removes the need for absolutely accurate cursor positioning.

CHKERR M: 1,2,3 MS4.FOR

Print Halo error messages on the text monitor.

CONFIG M: 1,2,3 MS3.FOR

Routine to prompt the user for a digitizer delay factor and the number of program steps to be saved for option **reco**.

CURPOS M: 3 MS4.FOR

Draw cursor crosshair on the screen, calculate the cursor world coordinates, and display them on the text monitor.

DEGCOS M: 1,2,3 MS1.FOR

This function calculates the cosine of an angle input in degrees.

DEGSIN M: 1,2,3 MS1.FOR

This function calculates the sine of an angle input in "degree".

DELAY M: 3 MS4.FOR

Generate a delay when using the digitizing tablet.

DELBOD M: 1,2,3 MS2.FOR

Allows entire bodies to be deleted.

DELE M: 1,2,3 MS2.FOR

This subroutine prompts the user, in text mode, for body numbers and point numbers for point deletion.

DELETE M: 1,2,3 MS3.FOR

This subroutine deletes points in bodies.

DELTAG M: 1,2,3 MS1.FOR

This function is used by subroutine "GRAVC" when calculating gravity anomalies.

DFS001 M: 1,2,3 MS1.FOR

This subroutine is used to optimize point positions and gravity or magnetic contrast values. A more detailed description of the program and parameters is given in the source listing.

DFS002 M: 1,2,3 MS1.FOR

This subroutine is used by DFS001 to find the best fit of the calculated gravity or magnetic anomaly for a particular degree of freedom. A more detailed description of the subroutine and parameters is given in the source listing.

DIGIT M: 3 MS4.FOR

Read the cursor location from digitizer output and scale it.

EOBSE M: 1,2,3 MS2.FOR

This subroutine prompts the user to enter observed data offset, sample spacing, number of readings in the profile, and observed data values from the keyboard

GRAP M: 3 MS4.FOR

Interpret command options from the digitizing tablet.

GRAVC M: 1,2,3 MS3.FOR

This subroutine calculates the gravity anomaly for one body.

GRINIT M: 2,3 MS2.FOR

This subroutine initializes the Halo graphics, loads the graphics device driver, and sets the colours for the screen display.

HELP M: 1,2,3 MS2.FOR

This subroutine prints out informative text messages describing the different command options.

IDBODY M: 3 MS4.FOR

Determine if a point identified by the digitizer cursor is within any of the defined bodies.

INIDIS M: 2,3 MS4.FOR

Routine to set the Halo viewport and world coordinates.

INSE M: 1,2,3 MS2.FOR

This subroutine prompts the user (in text mode) for the body number, point number, and point coordinates for a point to be inserted an existing body.

INSERT M: 1,2,3 MS3.FOR

This subroutine inserts new body points

LCVAR M: 1,2,3 MS3.FOR

Calculates the position of the first blank character in character strings.

MAG M: 1,2,3 MS3.FOR

This subroutine calculates the magnetic anomaly for one specified body.

MENU M: 1,2,3 MS2.FOR

Prints a list of the available text options on the text monitor.

MSCALE M: 2,3 MS4.FOR

Routine to allow manual scaling of the models display.

OPEN M: 1,2,3 MS2.FOR

Allows models files to be closed and opened within the program.

PARAM M: 1,2,3 MS3.FOR

This subroutine prompts the user to enter body gravity/magnetic parameters from the keyboard.

PLANOM M: 2,3 MS4.FOR

Routine to plot the calculated anomaly on the colour monitor.

PLBOD M: 2,3 MS4.FOR

Routine to plot body outlines on the colour monitor.

PLOBS M: 2,3 MS4.FOR

Routine to plot the observed anomaly on the colour monitor.

POIN M: 1,2,3 MS2.FOR

This subroutine prompts the user (in text mode) for body numbers, point numbers and new point coordinates for point movement.

POLYIN M: 3 MS4.FOR

Routine to determine if a point is inside a polygon.

READF M: 1,2,3 MS2.FOR

This subroutine is used to read a model from the models file with the current name.

REAN M: 1,2,3 MS3.FOR

This subroutine clears arrays "calc" and "ianom" to zero for initialization purposes.

RECO M: 1,2,3 MS2.FOR

This subroutine is used to read the most recent record from the recovery file into the common block. This allows the user to go back to previous steps by "undoing" changes.

REMDUP M: 1,2,3 MS2.FOR

Routine that searches for and removes duplicate points from bodies.

ROBSE M: 1,2,3 MS2.FOR

This subroutine allows the user to read observed profile data from an ASCII file.

SAV M: 1,2,3 MS2.FOR

This subroutine is used to write the common block to the recovery file after every significant change so that previous steps can be recovered with option "RECO".

SAVEH M: 2,3 MS2.FOR

Routine to save the colour display as a Halo-format image file together with a palette file.

SOUND M: 1,2,3 (not essential) SOUND.ASM

This 8086/8088 assembler subroutine makes sounds of different frequency and duration to accompany error messages and prompts. This subroutine can be removed without affecting the utility of the program.

TSCA M: 1,2,3 MS3.FOR

This subroutine types plot scaling parameters, and other informative information about the current program status.

TYPANO M: 1,2,3 MS3.FOR

This subroutine types the composite or individual calculated anomalies on the text monitor.

TYPAR M: 1,2,3 MS3.FOR

This subroutine types the gravity or magnetic contrast parameters for all bodies on the text monitor.

TYPBOD M: 1,2,3 MS3.FOR

This subroutine types body points and parameters for selected bodies or all bodies.

TYPOBS M: 1,2,3 MS2.FOR

This subroutine is used to print out the observed data on the text monitor in text mode.

WHAT M: 1,2,3 MS2.FOR

This subroutine is used to interpret text mode commands. A character string read in from the keyboard is compared to a set of commands and an value used in computed "go to" statements is returned.

WRITEF M: 1,2,3 MS2.FOR

This subroutine is used to write a model with the current name to the models file.

APPENDIX C

Compiling and linking procedure.

In order to generate executable files from the source code provided, you need the following software products:

1) A Microsoft FORTRAN 77 Compiler (Version 4.1)
   (version 4.0 and 4.01 of the compiler have some problems, if you have these versions try to update to version 4.1)

3) The Halo Graphics subroutine library with Microsoft FORTRAN support (Version 2.26 or higher)
   (Halo '88 is essentially the same)

4) MS-DOS (PC-DOS) operating system.(Version 2.00 or higher)

Compiling and linking MAGRAV2

The following steps will produce an executable MAGRAV2. The batch files provided are set up for a hard disc where all files are in the same directory.

1) Compile the 5 FORTRAN source files :

a) magrav2.for
b) ms1.for
c) ms2.for
d) ms3.for
e) ms4.for
f) magrav.cmn

The FORTRAN source code for magrav2 is divided into 6 files because the Microsoft compiler is unable to compile all the code in one run. The batch file "compmf.bat" can be used to compile and link source code files. Terminate the batch file after compilation is complete using "<ctrl><break>. File "magrav.cmn" must also be on the default drive or in the include path definition used by Microsoft. To compile "magrav2.for", enter : 'compmf magrav2 <enter>' When you have run "compmf.bat" on all of the source code files you will have 5 object files :

a) magrav2.obj
b) ms1.obj
c) ms2.obj
d) ms3.obj
e) ms4.obj

2) Link the object files and libraries to produce "magrav2.exe"

The batch file "mlink.bat" provided to link all the files and libraries together is written for a hard disc drive where all the files are stored on the same drive. If you do not have a hard disc, the libraries can be stored on different discs which are inserted in the drive when requested by the linker program. An alternative is to edit "mlink.bat" to indicate the correct locations of the files.

The following files are used during linking and should all be in the same directory.

a) magrav2.obj
b) ms1.obj
c) ms2.obj
d) ms3.obj
e) ms4.obj
f) magrav2.lib
g) the FORTRAN library
h) halodvxx.obj (Halo file)
i) halof.lib (Halo file)
j) link.exe

To run the magrav2 linker simply type : 'mlink <enter>'

3) Note for users of Microsoft FORTRAN ver. 3.31 :

The source code supplied may compile and link using older versions of the compiler. Files "cmf33.bat" and "lmf33.bat" are batch files which were used for compiling and linking with version 3.31. File "mlink33.bat" is a version 3.31 MAGRAV2 linker batch file. I no longer use the old version so the files may require some modification for compilation and linking with the old compiler. Good luck.

Compiling and linking DECINC, MODCVT, and PROPLT

PROPLT, MODCVT, and DECINC use no Halo subroutines and can be compiled and linked using batch file "compmf.bat". Instead of interrupting the batch process after compilation as with MAGRAV2, hit the <enter> key to initiate linking and production of an executable file.

APPENDIX D

Program modification notes :

Changing the program for use with different hardware should be relatively easy. Most changes will be necessary because different graphics boards and digitizers are being used. Halo supplies device drivers for most popular graphics boards and digitizers which minimizes the modifications; however, some changes may be necessary due to the different capabilities of the equipment. Some of the possible trouble areas are outlined here but others probably exist that have not been considered.

1) Within subroutine GRINIT, the different colours are initialized using Halo subroutine "setcpa". The subroutine parameters are; colour index, red intensity, green intensity, and blue intensity. "Setcpa" is a board specific Halo function that is not used for boards with less than 256 simultaneously displayable colours. A different colour setting subroutine call may be required here.

The rubberband lines and boxes used for point movement and setting the zoom area depend upon "XOR"ing the lines and boxes onto the screen so that they can be non-destructively removed (See explanation in the Halo manual). The background colour for the body window is set to colour number 127 so that when rubberband lines are drawn in colour 128 the binary XOR of 127 and 128 results in 255 which is defined as white in GRINIT. This causes the rubberband lines and boxes to appear in white on the screen. If a board with different colour setting routines and palette size is used, the correct colour number relationship must be maintained to ensure that the rubberband function will work correctly.

2) The software supplied is set up for use with a Bit-Pad-One compatible digitizing tablet. Use of a different digitizer may require redesign of the digitizer control template. Subroutines DIGIT, CURPOS,and GRAP may require modification to maintain correct cursor position and program control as well. Program option control is achieved in subroutine GRAP by calculating variables "izcom" and "ixcom" which are used in computed "go to" statements to branch to different program options. Different digitizers may require different scaling factors for calculating "izcom" and "ixcom" form digitizer coordinates "jx" and "jz". Note the "-i8" term in file "init.bat" this indicates interrupt 8 is used for the digitizer. If you have another device using interrupt 8 you may have to change this. If you change the interrupt specified in file "init.bat" be sure to also change the interrupt number in Halo call "call setloc" in subroutine grap.

3) If a mouse is to be used for positioning in mode 3 of operation,

subroutine GRAP will need extensive modification to allow program control. Since mice are not absolute positioning devices program control must be obtained through the use of pop up menus.

4) The program is currently set up for a two monitor system. If you try to use it on a single monitor system, the text intended to be written on the text monitor will scroll the graphic display off the screen. The program could be crudely modified for a single monitor system by making it redraw the graphic display after every text message.

5) **Modification for EGA and VGA graphics adapters:**

MAGRAV2 has been modified at Queen's University by undergraduate student Troy Wilson to operate using a ATI EGA Wondercard instead of the Number Nine Graphics Adapter. The system still uses two monitors but the ATI EGA Wondercard is much less expensive than the Number Nine Graphics Adapter. I have not tested the revised software but I am assured it works well. Changes to the software include:

1) Use of the Halo driver for the ATI card instead of the Number Nine driver. (renamed to "halo.dev")

2) Modifications to accommodate the reduced palette of 16 out of 64 colours on the ATI card compared to the 256 out of 16 million+ of the Number Nine card.

A number of changes to subroutine GRINIT in file "ms2.for" were required. The changes were made to a version 1.4 copy of MAGRAV2 but could easily be transferred to version 1.5. A listing of the modified GRINIT follows with the changes in **bold** text.

```
c ************************************************************
      SUBROUTINE GRINIT
c
c purpose : To initialize the "Halo" graphics functions
c           of the program; read and display a "Halo"
c           format image file on the screen and initialize
c           the drawing colours
c
c parameters : iscope - set = 1, for graphics initialized
c                       set = 2, for  graphics not initialized
c
      character*20 fil,ans
      integer*2 itcol,ibcol,itsize,ibsize
      logical*2 fex
$include:'magrav.cmn'
c
      colour(1) = '       red'
      colour(2) = '    yellow'
c Colour changed from turquoise to pale green to adapted for c
Queen's University Geological Sciences system.
```

```
      colour(3) = 'pale green'
      colour(4) = '    purple'
      colour(5) = '    orange'
      colour(6) = '      blue'
      colour(7) = '      pink'
      colour(8) = 'light blue'
      colour(9) = '     green'
      colour(10)= '      gray'
c
c
c "halo.dev" is a device driver file provided by halo for
c   your specific graphics board.
c
      if(iscope.eq.1) then
        write(*,*)'Graphics already initialized'
        return
      endif
      write(*,'(/a\)')' Do you want graphics enabled (y/n) : '
      call sound(20,200)
      read(*,'(a)') ans
      if (ans.eq.'n'.or.ans.eq.'N') then
        iscope = 2
        return
      endif
      fil = 'halo.dev'
      inquire(file=fil,exist=fex)
      if(fex.eqv..false.) then
        write(*,*)'ERROR,Graphics device driver file "halo.dev"'
        write(*,*)' must be present on the default drive!'
        write(*,*)' Graphics initialization aborted.'
        call sound (15,6000)
        iscope = 2
        return
      endif
      fil = '"halo.dev"'
      call setdev(fil)
      call inqerr(ifun,ierr)
      if(ierr.ne.0) then
        write(*,*)'ERROR reading "halo.dev" file'
        write(*,*)' Graphics not initialized!'
        iscope = 2
        return
      endif
c Initgraphics mode set to '4' for ATI EGA to adapted for Queen's
c University Geological Science's system.
      call initgr (4)
c Call 'MONO', a HALO Graphics subroutine added to allow for a two
c moniter system.(Jan. 88).
      call inqerr(ifun,ierr)
      call mono(4)
      if(ierr.ne.0) then
        write(*,*)'ERROR initializing graphics,'
```

```
          iscope = 2
          call sound(15,6000)
          return
        endif
c
c "setcpa" sets the colours used for bodies etc.
c
c Colours are indexed for ATI EGA to adapted for Queen's
c University Geological Science's system (Jan. 88).
        call setxpa(0,0)
        call setxpa(1,36)
        call setxpa(2,62)
        call setxpa(3,23)
        call setxpa(4,40)
        call setxpa(5,46)
        call setxpa(6,1)
        call setxpa(7,37)
        call setxpa(8,27)
        call setxpa(9,18)
        call setxpa(10,7)
        call setxpa(11,24)
        call setxpa(12,16)
        call setxpa(13,32)
        call setxpa(14,56)
        call setxpa(15,63)
        call setcol (0)
        call clr
c
c "logo.pic" is a "Halo" image file displayed at the start
c  of the session.
c
        fil = '"logo.pic"'
        call gread (fil)
        call setiee (1)
        write(*,'(/a)')' Graphics  system  initialized  for'
        write(*,'(a/)')' Graphics Card matching chosen HALO.DEV file'
        iscope = 1
c
c Set up Fast Text
c
c colour indices adapted for Queen's University Geological Sciences
        itcol = 15
        ibcol = 14
        call ftcolo (itcol,ibcol)
        call chkerr
        itsize = 1
        ibsize = 8
        call ftsize(itsize,ibsize)
        call chkerr
        call ftinit
        call chkerr
        return
```

end

4) Modifications to Halo calls in files "magrav2.for", "ms2.for" and "ms4.for". Where the colour indices had to be modified:

-All calls to subroutine plbod with colour index 127 should now use colour index 14. (change "call plbod (0,127)" to "call plbod (0,14)")

- Change all ocurrences of "call setcol (255)" to "call setcol (15)".

- Change "call setcol (17)" to "call setcol (12)" in subroutine plobs.

- Change "call setcol (127)" to "call setcol (14)"
  and "call setcol (18)" to "call setvol (13):
  in subroutine planom.

- Change "call inithc (cursz,cursx,255)" to "call inithc (cursz,cursx,15)" and "call setcol(128)" to "call setcol(1)" in subroutine curpos

- Change "call setcol (128)" to "call setcol (1)" in section "set zoom" of subroutine grap.

APPENDIX E

The profile file format :

The profile file is an ASCII file formatted as follows :

Record (1)
- The number of reading on the profile(integer)

Record (2)
- The profile sample spacing in km (real)

Record (3) to (number of readings on the profile + 2)
- observed data values, entered 1 per line (real)

All data are free formatted; therefore, readings entered in integer form will automatically be converted to real.

APPENDIX F

Sources

This section provides addresses for some of manufacturers and distributors of software and hardware mentioned in the publication.

1) The Halo graphics subroutine library,
   Image-Pro image processing package, and
   Dr. Halo image editing software are produced by :

   Media Cybernetics, Inc.,
   8484 Georgia Avenue, Suite 200,
   Silver Spring, Maryland,
   USA, 20910.

   Ph: 301-495-3305

2) The "Revolution" colour graphics board is available from :

   Number Nine Computer Corp.,
   725 Concord Avenue, Cambridge,
   MA 02138, USA.

   Ph: 617-492-0999

3) The Microsoft FORTRAN compiler is produced by :

   Microsoft
   16011 NE 36th Way,
   Box 97017, Redmond, WA
   98073-9717

APPENDIX G

Modifications to subroutine MAG to allow modelling of vertical gradient data.

```
c*****************************************************************
      SUBROUTINE MAG(IBOD)
c
c purpose : To calculate the magnetic anomaly for body "ibod"
c
c  sources bio computer note 66-1-c april 1966
c   program mag written for pdp-11 by d.heffler,agc,bio 19
c   cdc3150 fortran program mag2new,agc,bio,197...
c
c  modified for 2.5 dimensional bodies by Franca Lindia
c  using equations published by Shuey and Pasquale(1973)
c  in the journal "Geophysics".
c
c Modified by John Broome (June,1986) to calculate vertical
c  gradient anomalies (MODIFICATIONS IN CAPITAL LETTERS). The
c  vertical gradient anomaly is given in gammas/metre.

$include:'magrav.cmn'

      complex zi,zi1,zi2,yi,fn1,fn2,fn,yrlc,qpx,qpz,qxsm,qzsm,czero
      complex rsum,x21zi
c
      write(*,*)'Calculating v. gradient an. for body',ibod
      nf = nfield(itype)
      if(rhomag(ibod,2).eq.0.) return
      cdipd = degcos(dip)
      sdipd = degsin(dip)
      sdd =   degcos(xton-dec)
      cdip =  degcos(bdip(ibod))
      sdip =  degsin(bdip(ibod))
      sd =    degcos(xton-bdec(ibod))
      cdy =   degcos(90.-(xton-bdec(ibod)))
      sdt =   degsin(xton-dec)
      cdipsd = cdip*sd
      cdpcdy = cdip*cdy
      rhobod = rhomag(ibod,2) * 2.0
      y = bdy(ibod)
      ysq = y**2
      yd = 1.0/ysq
      yi = cmplx(0.,yd)
      npt = npts(ibod)
      czero = cmplx(0.,0.)

c  check each field point

      NPASS = 0
```

```
      do 3100 k = 1, nf
C
C ADD 1 METRE TO Z CONSTANT FOR SECOND PASS
C
3150     NPASS = NPASS + 1
         IF(NPASS.EQ.2) ZCON(2) = ZCON(2) + 0.001
C
        qxsm = czero
        qzsm = czero
        rsum = czero
        x1 = x(1,ibod) - xpos(k,itype)
        z1 = z(1,ibod) + zcon(2)
        if(z1.le.0.) goto 9999
        r1 = sqrt( x1**2 + z1**2 + ysq )
        zi1 = cmplx(0.,z1)
        do 3000 j = 2, npt
          x2 = x(j,ibod) - xpos(k,itype)
          z2 = z(j,ibod) + zcon(2)
          if(z2.le.0.) goto 9999

c  if 2 points the same check the point after

          if(x1.eq.x2.and.z1.eq.z2) goto 3000
          z21 = z2 - z1
          x21 = x2 - x1
          zi = cmplx(0.,z21)
          x21zi = x21 + zi
          zi2 = cmplx(0.,z2)
          r2 = sqrt( x2**2 + z2**2 + ysq )
          fn1 = x21zi/(x1+zi1) * (1.0 + r1/y)
     +       +  yi* (x1*z21 - z1*x21)
          fn2 = x21zi / (x2+zi2) * (1.0 + r2/y)
     +       +  yi*(x2*z21 - z2*x21)

c top and bottom of log >0. since "zcon" not = 0

          if(fn1.eq.czero) goto 9999
          if(fn2.eq.czero) goto 9999
          fn = fn2/fn1
          yrlc = clog(fn)
          qpx = zi/x21zi * yrlc
          qpz =  -x21/x21zi * yrlc
          qxsm = qxsm + qpx
          qzsm = qzsm + qpz
          rsum = rsum + yrlc
          x1 = x2
          z1 = z2
          zi1 = zi2
          r1 = r2
3000    continue
        qtot = real(qxsm)
        pxtot = aimag(qxsm)
```

```
        pztot = aimag(qzsm)
        rytot = aimag(rsum)
        h =  cdipsd*pxtot + sdip*qtot
        v = cdipsd*qtot - sdip*pztot
        hy = cdpcdy*rytot
        calc(ibod,k) = (v*sdipd + (h*sdd - hy*sdt)*cdipd) * rhobod
C
C IF NPASS = 1, THEN CALCULATE THE ANOMALY 1 M HIGHER
C IF NPASS = 2, THEN CALCULATE THE DIFFERENCE BETWEEN THE
C   TWO VALUES FOR THE VERTICAL GRADIENT VALUE IN
C   GAMMAS/METRE.
C
        IF(NPASS.EQ.1) THEN
          CALTMP = CALC (IBOD,K)
          GO TO 3150
        ELSE
          CALC(IBOD,K) = CALTMP - CALC(IBOD,K)
          ZCON(2) = ZCON(2) - 0.001
          NPASS = 0
       ENDIF
C
3100  continue
      ianom(ibod) = -1
      return

c    error

9999  continue
      write(*, *) 'Body :', ibod, ' Point :', k
      write(*, *) ' Cannot be calculated with present algorithm'
      write(*, *) ' Value out of range '
      write(*, *) ' Anomaly set to zero'
      write(*, *) ' Use "GRAV" or "MAGN" command'
     +           ,' to set a larger Z constant'
      do 10000 k = 1, nf
        calc(ibod,k) = 0.0
10000 continue
      ianom(ibod) = 0
      return
      end
```