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PDEPTH -

Calculation of depth to magnetic basement from profile data

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PDEPTH - Calculation of depth to magnetic basement from profile data

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Sammendrag:

PDEPTH is a program for automatic calculation of depth to magnetic basement based on a total magnetic field or anomaly profile, and PDEPTH forms an integrated part of the IMP system developed by T:H. Torsvik. PDEPTH utilizes Phillips' method (1975, 1978, 1979) for calculating magnetic basement depths and it is adapted from an original mainframe Fortran program written by Phillips (ADEPTH). Conversely, PDEPTH is written for IBM compatible computers. A program named IMPDEPTH is also available; this program however handles grid-data for automatic scanning and calculation of magnetic basement depths. This report describes how to use PDEPTH and outlines the basic software theory.

Emneord: Geofysikk	Tolkning	Magnetometri
Matematisk analyse		
		Brukerdokumentasjon

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1. INTRODUCTION

PDEPTH is a program for automatic calculation of depth to magnetic basement based on a total magnetic field or anomaly profile, and PDEPTH forms an integrated part of the IMP system developed by T.H. Torsvik. PDEPTH utilizes Phillips' method (1975, 1978, 1979) for calculating magnetic basement depths and it is adapted from an original Fortran program written by Phillips (ADEPTH). The original ADEPTH program and later adoptions such as MAPRAN3 (Thorning 1982) were written for mainframe computers. Conversely, PDEPTH is written for IBM compatible computers (see system specifications in section 6). A program named IMPDEPTH is also available (Torsvik 1992); this program however handles grid-data for automatic scanning and calculation of magnetic basement depths.

2. SOFTWARE THEORY

The magnetic basement is defined as a two-dimensional surface (Fig. 1) constructed from a large number of very thin vertical 'dykes'. The method assumes that every one of these 'dykes' extends to infinity in directions perpendicular to the profile, as well as vertically downwards. The upper termination of the 'dykes' is the basement surface. This depth can vary from 'dyke' to 'dyke'. The 'dykes' placed next to one another give the topography of the magnetic

basement. It is further assumed that each 'dyke' has a magnetization which may differ from that of the adjoining 'dyke'. The depth is estimated by passing a short window along the magnetic profile, estimating a depth for each position of the window. The width of the window varies depending on the wavelength of the anomalies. It has to be assumed that the anomaly within such a given window originates entirely from sources at a certain depth.

The depth expressions are:

$$(1) \quad Z = \frac{n\Delta x}{2}\sqrt{\frac{1}{1/\Phi_n - 1}}$$

$$(2) \quad Z = \frac{\Delta x}{2}\sqrt{\frac{2n+1}{\Phi_n/\Phi_{n+1} - 1} - n^2}$$

where $\triangle x$ is the sampling interval, Φ is the autocorrelation function and n is the number of intervals in the autocorrelation lag. The depth can be estimated from a value of the single autocorrelation at a single lag (1). In practice the first lag (n = 1) is used to estimate depth, while higher lags (n = 2,3,4) are used to check the validity of the estimate. A second solution (2) can be expressed in

terms of the autocorrelation at two successive lags. Sources at different depths can be separated using this formula, i.e. anomalies caused by deep and shallow bodies in the same profile. Fig. 2 illustrates the principles of the interpretation method. A shallow magnetic 'dyke' causes a narrow anomaly. The correlation of the waveform with itself is consequently small. A deep-seated 'dyke' causes a long-wavelength anomaly which will have a higher degree of autocorrelation.

FIGURE 1
The geometry for a thin sheet source and its magnetic anomaly g(x) (after Phillips 1975). The source is of infinite extent in the ±y and +z directions. It terminates at a depth z_1 below the observation plane.

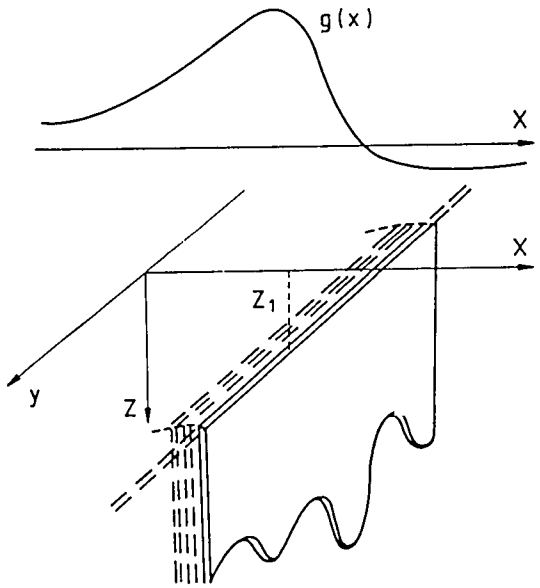
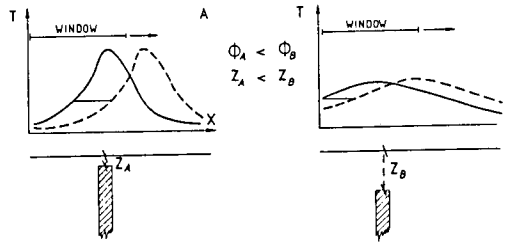


FIGURE 2
Interpretation principle of the autocorrelation method. (A) A shallow magnetic dyke causes a narrow anomaly. The correlation of the waveform with itself is consequently small. (B) A deep-seated dyke causes a long-wavelength anomaly with a higher degree of autocorrelation. The depth is estimated by passing a short window along the magnetic profile and estimating a depth for each position of the window.



3. OPERATION OF PDEPTH - MAIN MENU

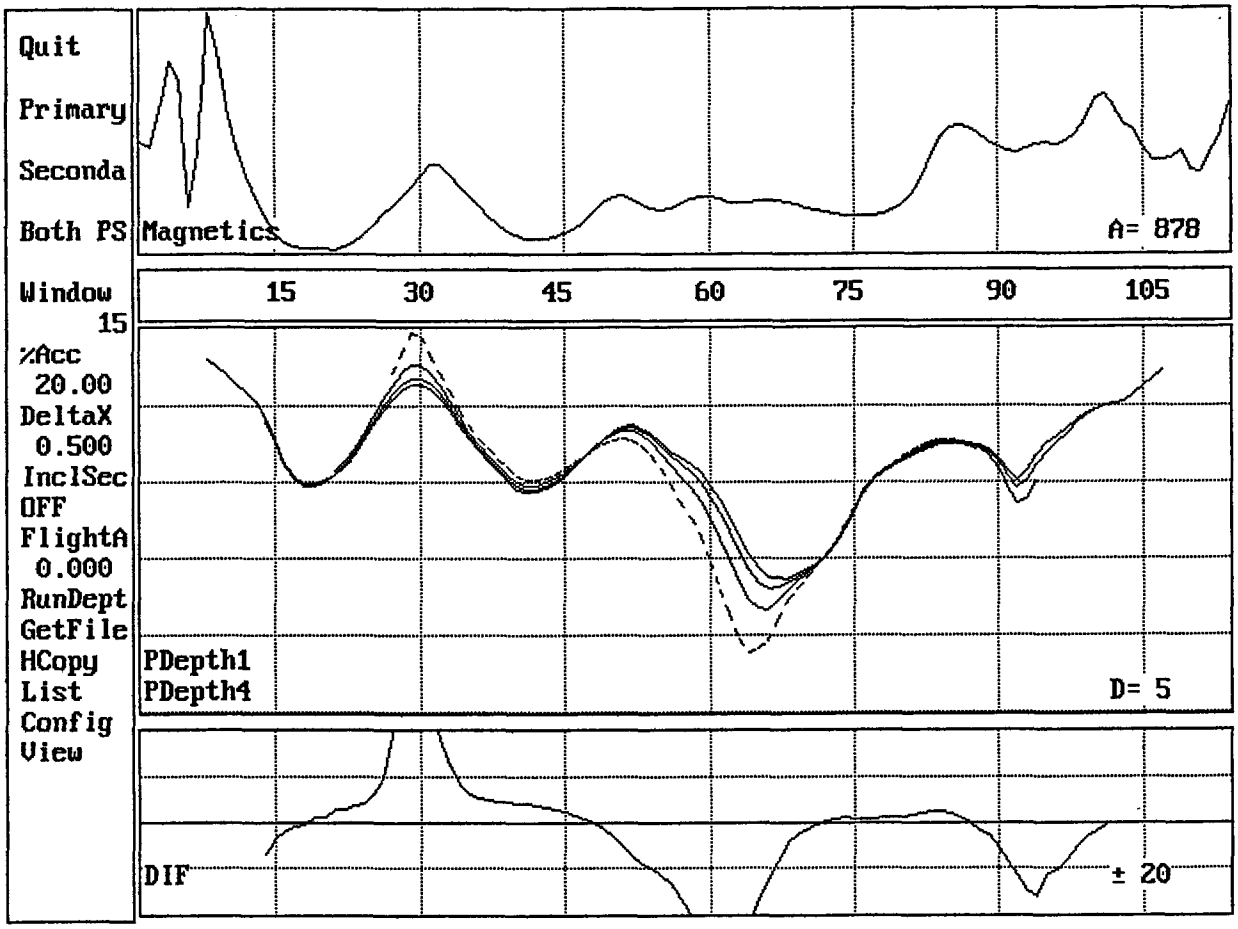
During start-up the program loads a file named DEPTH.OUT which is the last depth-calculation file created by the operator. If this file is not found the program loads a file named DEMO.OUT.

Note If an error is encountered during reading of the DEPTH.OUT file then quit the program and delete DEPTH.OUT by typing DEL DEPTH.OUT under MS-DOS.

The program also loads a system configuration-file named DEPTH.SYS. This file holds information concerning hardcopy facilities, format of input files, monitor type etc.

During start-up a graphical presentation of the last depth estimate is displayed (Fig. 3) together with the main menu options. These options are selected by using the Up/Down cursor arrows. Select option followed by <ENTER> or input from keyboard the first character for the wanted option. In addition the keys PG UP/PG DN control maximum depth (see below), whereas F1 initiates a screen dump to HP LASERJET II/IIIP or HP DESKJET compatible printers.

FIGURE 3
Main menu options in PDEPTH and the three graphic windows displaying original magnetic data (Window 1), depth estimates (Window 2) and depth errors (Window 3). Data stations (points) are indicated below Window 1.



The main menu has the following options:

OPTION	EFFECT
QUIT	END PROGRAM (EXIT TO DOS)
PRIMARY	DISPLAY PRIMARY DEPTH ESTIMATES
SECONDARY	DISPLAY SECONDARY DEPTH ESTIMATES
BOTH PS	DISPLAY PRIMARY AND SECONDARY DEPTHS
WINDOW	SET WINDOW LENGTH
%ACC	SET SELECTED ACCURACY OF DEPTH ESTIMATE
DELTAX	SET DATA SPACING IN KILOMETRES
INCLSEC	INCLUDE SECONDARY DEPTH SOLUTION
FLIGTHA	SET FLIGHT ALTITUDE
RUNDEPTH	RUN DEPTH ESTIMATE
GETFILE	SELECT INPUT-FILE FOR DEPTH ESTIMATE
HCOPY	GRAPHICAL HARDCOPY
LIST	WRITE DEPTH ESTIMATES TO PRINTER
CONFIG	CONFIGURE SYSTEM
VIEW	READ DEPTHS IN WINDOW 2
PG UP/ PG DN	INCREASE/DECREASE DEPTH IN WINDOW 2
F1	COPY GRAPHIC IMAGE TO LASERJET/DESKJET

3.1 PRIMARY

The primary data solution is automatically displayed after calculating depth to magnetic basement (option RUNDEPTH). The graphic display is organized in three windows - Window 1 (top window) shows the original magnetic anomaly, Window 2 (intermediate window) displays primary, secondary or alternatively combined depth-solutions (see below), whilst Window 3 (bottom) displays depth errors.

In the primary option four depths are shown, i.e. depths 1 to 4. Depth 1 is always the most reliable (drawn in yellow colour) and the difference between depth 1 and 4 is indicated in the lower window. Depth errors are most commonly reported

in meters/kilometres (e.g. ADEPTH & MAPRAN3). We have, however, converted true depth errors to an percentage error of depth1 since depth-errors inevitable increases with increasing dephts.

3.2 SECONDARY

The graphic display in the secondary option is similar to the primary option, but Window 2 now shows the secondary data solution given by 3 depth estimates. Window 3 shows the percentage error associated with depth1. Note that in the secondary option that depth1 or depth2 can represent the best depth-estimate. In option BOTH PS (see below) the secondary solution is 'flagged' on the best depth estimate.

3.3 BOTH PS

This option displays the Depth1 estimate in the primary solution together with best secondary depth estimate. In the primary solution the first depth is always the best estimate, but in the secondary solution depths 1 or 2 are 'flagged' for the best depth estimate. Hence, the secondary depth-curve is constructed by a combination of depth 1 or 2. The used depth solution can be seen from the LIST option (see later).

3.4 WINDOW

This option sets the number of data-points used in the autocorrelation window (Phillips 1975). 15 is a good starting value for a profile with 100 points or more, and increasing values will smooth the depth results. During input of window length we have indicated an upper window-length which is dependent on the maximum depth of interest (5 kilometres default) and the sampling interval. This maximum window-length of interest is calculated from:

```
WindowLength = (2*MaxDepthOfInterest) / (SamplingInterval)
```

The maximum depth of interest are changed by pressing the <PG UP> or <PG DN> keys which will affect the depths indicated in Window 2.

3.5 %ACC

This option allows the user to change the display in the lower error window (Window 3). Depth errors are shown in percentage and the diagram shows the zero base line together with ±%ACC selected by the operator.

3.6 DELTAX

This option is used to set the sampling interval along the profile. Set sampling interval in kilometres (e.g. 0.5 represents a sampling interval of 500 meters). If X and Y UTM co-ordinates are stored in the input file it is possible to calculate an average sampling interval (see option GETFILE).

3.7 INCLSEC

With this option you select to include (ON) or ignore (OFF) secondary data solutions when using option RUNDEPTH.

3.8 RUNDEPTH

After having (1) loaded a file (option GETFILE), (2) set the window-length (option WINDOW) and (3) defined the sampling interval (option DELTAX), depths to magnetic basement are automatically calculated using this option. In this option three sub-programs are used dependent on the number of data-points (DEP300.EXE, DEP700.EXE and DEP1024.EXE). Maximum number of data-points are 1024.

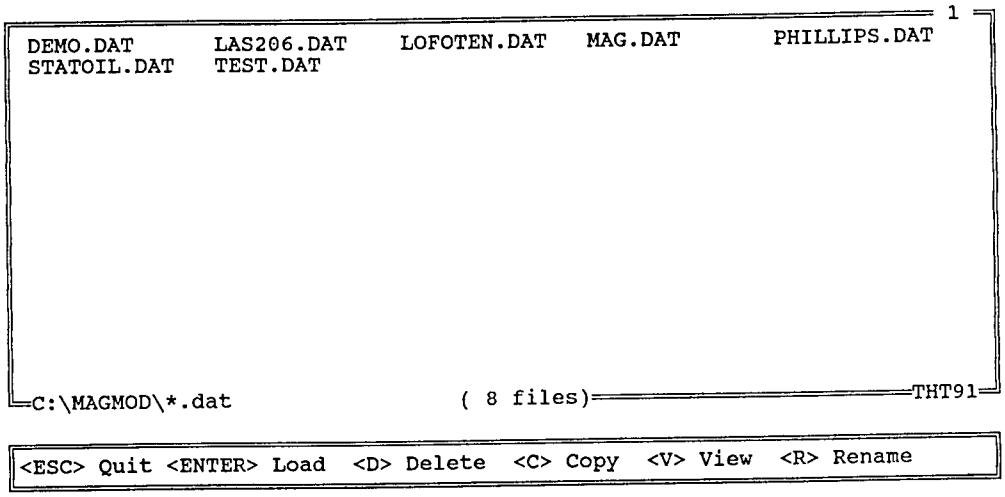
3.9 FLIGTHA

Use this option to set a flight or measuring altitude. This value (in kilometre, e.g. 0.5 for an altitude of 500 meters) is subtracted from all depth estimates.

3.10 GETFILE

This option allows the operator to load a new file for later calculation of magnetic basement depths. Any file extension is allowed and the operator is prompted for a file mask (e.g. *.DAT). If the operates wish to change the current directory use the cursor up arrow to edit the directory. The current directory is scanned and a sorted list of files is displayed (Fig. 4). A file is then loaded using cursor arrows followed by <ENTER>. Use keys PG UP or PG DN if there are several pages of data-files. This option also allows the operator to DELETE, COPY, VIEW or RENAME files (Fig. 4).

FIGURE 4
GETFILE option. Files are sorted and displayed. Select file using cursor arrows followed by <ENTER>.



After selecting a file, a standard file-format is indicated (format of the last loaded file which is saved on the DEPTH.SYS file) on the screen. Change format if neccessery, i.e. number of lines of header, total number of columns, location of anomaly column and data-spacing in kilometre (Fig. 5). For calculation of data-spacing type c in data-spacing field followed by X UTM column and Y UTM column. This must only be done for linear profiles which has nearly the same data-spacing. An average spacing is calculated, but also minimum and maximum spacing values are displayed.

FIGURE 5
Definition of file format after selecting a file in option GETFILE. Three top lines of file are displayed. Adjust file format to fit the selected file.

```
LINE1          :48675.0
LINE2          :48650.0
LINE3          :48787.0
-------------------------------------------------------------------------
Spline Fitting            (y/n):n
Lines of Header                 :0
Total number of colums          :1
Anomaly Colum                   :1
Data spacing (km, c=calculate) :.5
```

3.11 HCOPY

This option starts hardcopying of plots to a HP-GL compatible pen plotter or a HP LASER printer (e.g. LASERJET IIIP) which accepts HP-GL codes. The communication-port is selected under PLOTTER PORT (see option in CONFIG below), or alternatively the operator may plot the data to a file (see Plot to file in option CONFIG).

3.12 LIST

This option provides a listing to printer of primary and secondary depth estimates. An example of listing of primary solution is shown in Fig. 6.

FIGURE 6
Example of listing of data to printer. Listing contains information such as data spacing, number of data-points, window-length and flight altitude followed by location, magnetic data, errors (Dif-Ac) and depths 1 to 4.

Data spacing: 0.5000 Number: 114 Window: 15 F. Altitude 0.000

Primary Data:

No.	Location	Magnetic	Anomaly	Hilbert	Dif-Ac	Depth1	Depth2	Depth3	Depth4
1	0.00	48675.0	227.44	-4.64	0.00	0.00	0.00	0.00	0.00
2	0.50	48650.0	201.04	-114.95	0.00	0.00	0.00	0.00	0.00
3	1.00	48787.0	336.64	-147.35	0.00	0.00	0.00	0.00	0.00
4	1.50	48960.0	508.25	-30.05	0.00	0.00	0.00	0.00	0.00
5	2.00	48900.0	446.85	321.64	0.00	0.00	0.00	0.00	0.00
6	2.50	48435.0	-19.55	245.27	0.00	0.00	0.00	0.00	0.00
7	3.00	48630.0	174.05	263.66	0.00	0.00	0.00	0.00	0.00
8	3.50	49135.0	677.66	-2.58	0.00	0.39	0.00	0.00	0.00
9	4.00	49000.0	541.26	408.42	0.00	0.49	0.00	0.00	0.00
10	4.50	48800.0	339.86	488.20	0.00	0.60	0.00	0.00	0.00
11	5.00	48650.0	188.46	511.24	0.00	0.72	0.00	0.00	0.00
12	5.50	48550.0	87.07	481.26	0.00	0.83	0.00	0.00	0.00
13	6.00	48465.0	0.67	463.63	0.00	0.96	0.00	0.00	0.00
14	6.50	48395.0	-70.73	417.97	-0.16	1.15	1.20	0.00	0.00
15	7.00	48337.0	-130.13	373.58	-0.10	1.44	1.47	0.00	0.00
16	7.50	48300.0	-168.52	308.28	-0.07	1.77	1.79	0.00	0.00
17	8.00	48286.0	-183.92	255.40	-0.05	1.93	1.95	0.00	0.00
18	8.50	48284.0	-187.32	208.31	-0.03	2.03	2.04	0.00	0.00
19	9.00	48282.0	-190.72	176.99	0.04	2.05	2.03	0.00	0.00
20	9.50	48278.0	-196.11	140.55	0.05	2.00	1.98	0.00	0.00
21	10.00	48277.0	-198.51	104.62	0.10	1.91	1.89	1.85	0.00
22	10.50	48285.0	-191.91	61.24	0.10	1.79	1.77	1.73	0.00
23	11.00	48305.0	-173.31	24.70	0.11	1.66	1.63	1.58	0.00
24	11.50	48333.0	-146.70	-7.41	0.12	1.46	1.43	1.38	0.00
25	12.00	48368.0	-113.10	-27.93	0.15	1.26	1.22	1.16	0.00
26	12.50	48404.0	-78.50	-37.37	0.20	1.07	1.02	0.94	0.00
27	13.00	48435.0	-48.90	-40.16	0.35	0.92	0.85	0.74	0.57
28	13.50	48470.0	-15.29	-40.45	0.49	0.80	0.72	0.57	0.32
29	14.00	48505.0	18.31	-32.11	0.69	0.74	0.65	0.48	0.04
30	14.50	48550.0	61.91	-14.12	0.62	0.73	0.64	0.47	0.11
31	15.00	48587.0	97.51	37.95	0.44	0.79	0.71	0.57	0.35
32	15.50	48589.0	98.12	103.55	0.33	0.90	0.83	0.72	0.57
33	16.00	48556.0	63.72	157.27	0.26	1.06	1.01	0.92	0.80
34	16.50	48513.0	19.32	179.73	0.21	1.25	1.21	1.14	1.04
35	17.00	48478.0	-17.08	190.86	0.18	1.43	1.40	1.34	1.25
36	17.50	48440.0	-56.47	196.54	0.16	1.59	1.56	1.50	1.42
37	18.00	48400.0	-97.87	188.14	0.16	1.72	1.70	1.64	1.56
38	18.50	48370.0	-129.27	168.97	0.17	1.86	1.83	1.78	1.70
39	19.00	48344.0	-156.67	146.77	0.18	1.99	1.96	1.90	1.81
40	19.50	48327.0	-175.06	116.49	0.17	2.09	2.06	2.00	1.91
41	20.00	48318.0	-185.46	88.52	0.17	2.13	2.10	2.05	1.97
42	20.50	48314.0	-190.86	58.76	0.16	2.12	2.09	2.04	1.97
43	21.00	48316.0	-190.26	30.44	0.14	2.08	2.06	2.01	1.94
44	21.50	48324.0	-183.65	2.92	0.12	2.02	2.00	1.96	1.91
45	22.00	48335.0	-174.05	-21.40	0.08	1.92	1.90	1.88	1.84
46	22.50	48353.0	-157.45	-47.97	0.05	1.80	1.79	1.77	1.76
47	23.00	48382.0	-129.85	-66.95	0.02	1.68	1.68	1.67	1.67
48	23.50	48417.0	-96.24	-73.74	-0.01	1.56	1.56	1.55	1.57
49	24.00	48450.0	-64.64	-62.83	-0.05	1.45	1.45	1.45	1.50
50	24.50	48470.0	-46.04	-40.51	-0.09	1.35	1.35	1.37	1.44
51	25.00	48475.0	-42.44	-15.20	-0.14	1.28	1.29	1.32	1.42
52	25.50	48465.0	-53.83	5.66	-0.19	1.26	1.27	1.32	1.45
53	26.00	48445.0	-75.23	11.59	-0.23	1.30	1.32	1.37	1.53
54	26.50	48430.0	-91.63	2.75	-0.28	1.38	1.41	1.48	1.66

3.13 CONFIG

This option sets communication ports, configuration of plots and graphic monitor types (EGA or VGA). A complete list of sub-options is shown below. Use up/down cursor arrows to edit the various options.

OPTION	ALTERNATIVES
Plotter Port	lpt1: lpt2: com1: com2:
Baudrate	300 600 1200 2400 4800 9600
Parity	n (none) e (even) o (odd)
Databits	7 or 8
Stopbits	2 or 1
X-length in cm.	10 to 40 cm (horizontal axis)
Y-length in cm.	2 to 25 cm (vertical axis)
Plot anomaly	y or n (include/exclude)
Plot Primary Depths	y or n
Plot Primary Errors	y or n
Plot Secondary Depths	y or n
Plot Secondary Errors	y or n
Plot Both Pri-Secondary	y or n
Plotter Type	PEN or LASER
Plotter Format	3 or 4 (A3/A4)
Plotter Pen	1 to 8
Plotter Speed	0 to 20
Monitor	EGA or VGA
Plot to File	n (no) or file-name
Printer Port	as plotter port (se above)
Plot Size LASER DUMP	1(small),2,3,4(full size)

Notes:

(1) Options such as baudrate, parity, databits and stopbits are only required to be set for serial communication (com1: or com2:)

(2) A4 paper (max X length is 19 cm) is inserted in the plotter in a vertical position.

(3) The options shown above are stored in a file named DEPTH.SYS.

(4) On the hardcopy we have only drawn DEPTH1 and DEPTH4. Depth4 is stippled. In the secondary option DEPTH1 and 3 (stippled) are drawn.

(5) Note that a file-name can be defined for plotter port such as a HP-GL file can be printed later by copying the file to a plotter (e.g. COPY filename LPT1:)

(6) All plotter settings (excepth PLOT SIZE LASER-DUMP applies to HP-GL compatible pen plotters or LASERJET's which accepts HP-GL code (select PEN or LASER in option PLOTTER TYPE). LASER-DUMP plots always assumes the PRINTER PORT setting.

FIGURE 7
Example of hardcopy using a HP-GL plotter. (A) The magnetic anomaly, total amplitude is printed. (B) Primary data solution, DEPTH1 and DEPTH4 (stippled). (C) Depth errors indicated as DEPTH1 ± percentage error. Vertical lines represent data-point locations (point 15,30 etc.).

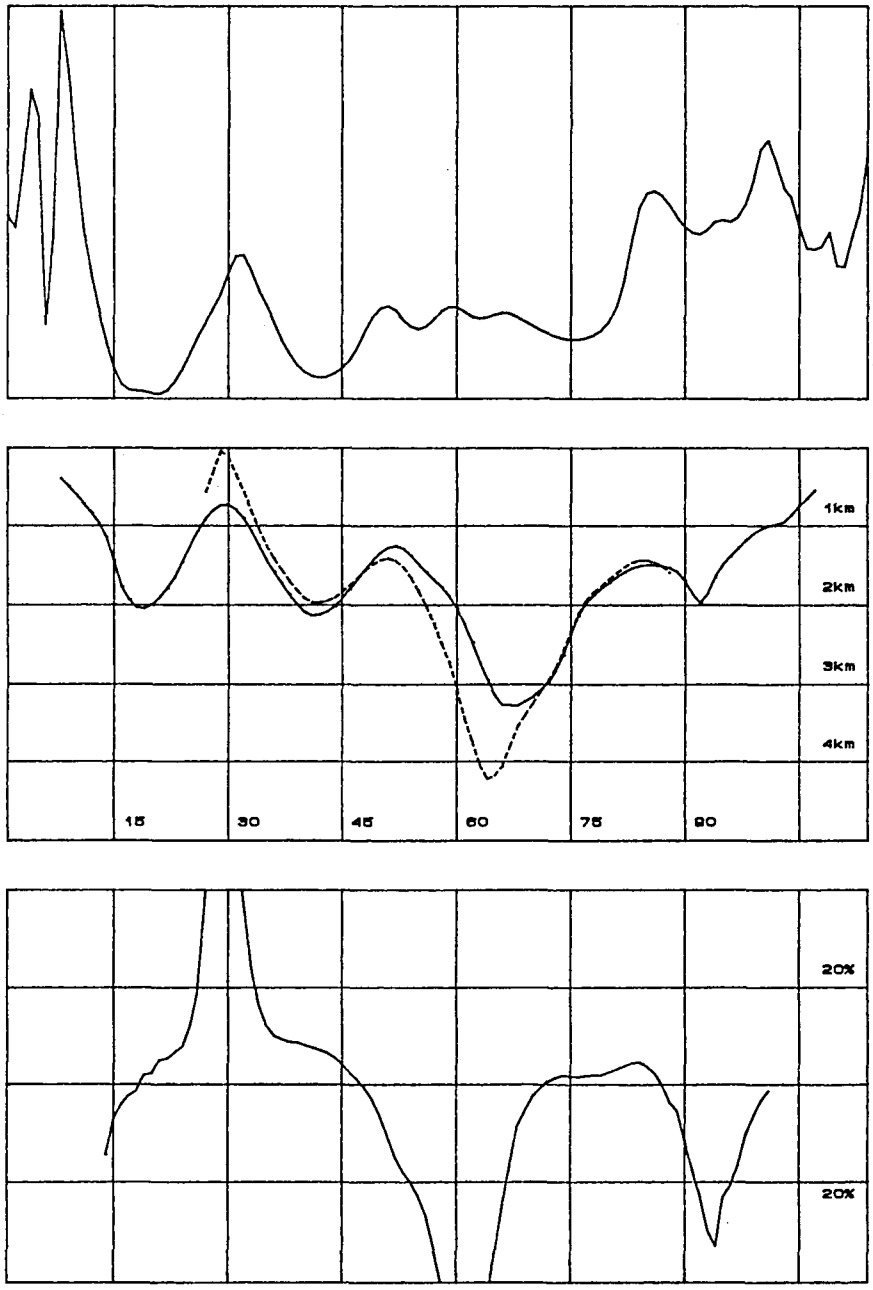
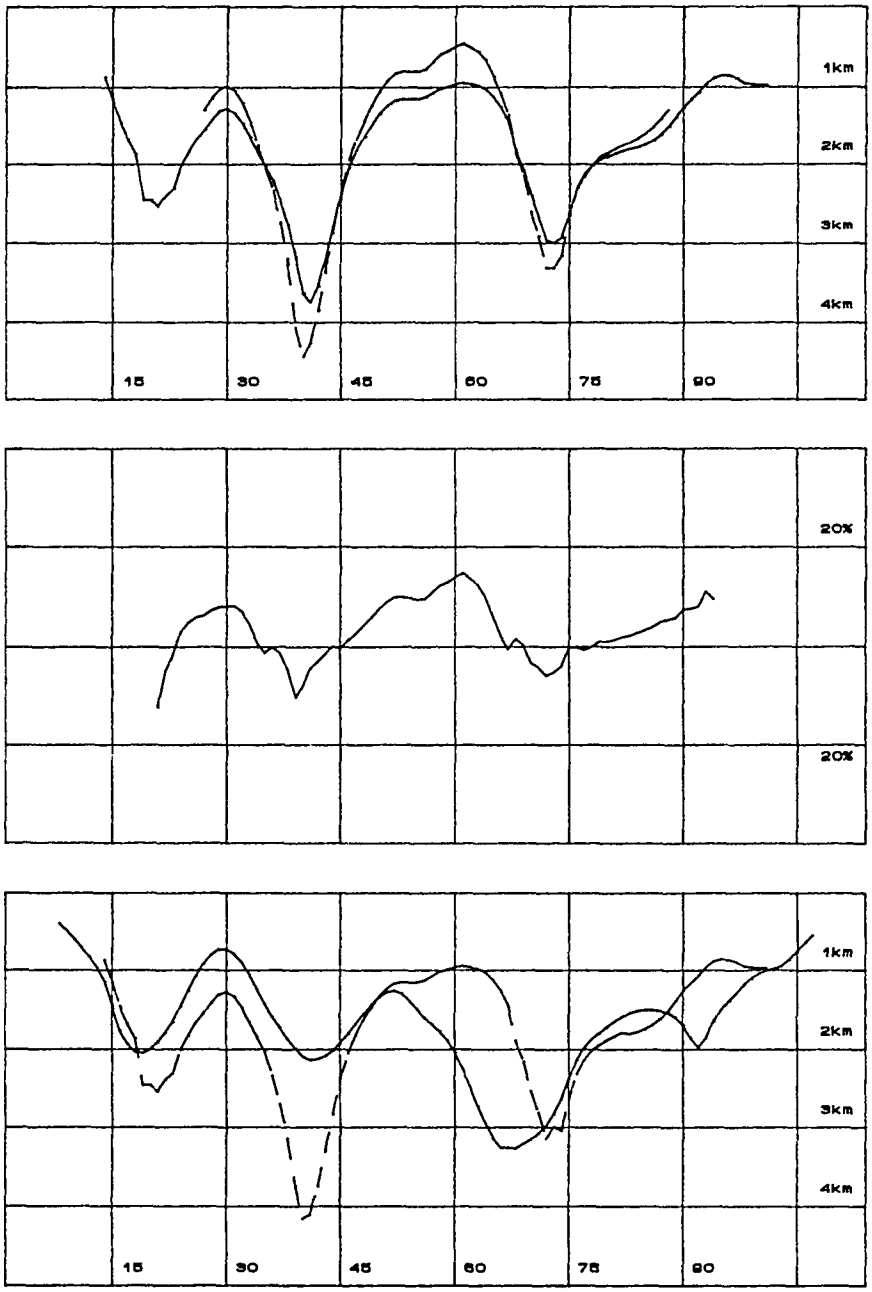


FIGURE 8
Example of hardcopy using a HP-GL plotter. (A) Secondary data solution, DEPTH1 and DEPTH3 (stippled). (B) Depth errors. (C) Plot of both primary (DEPTH1) and secondary (DEPTH1 or 2) data solution.



A

B

C

3.14 VIEW

This option allows the operator to read the depths interactively in Window 2. A cross will appear in Window 2 and this cross can be moved around using cursor arrows. X (=distance alonge profile in kilometres) and D (=depth in kilometres) are displayed at the bottum left of the screen. End or Quit procedure by pressing the <CR>/<ENTER> or <ESC> key.

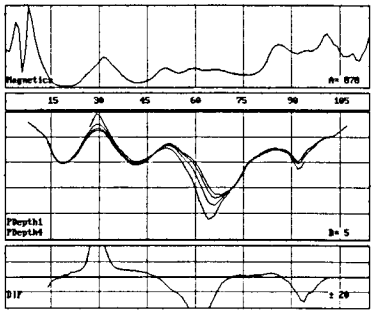
3.15 PG UP / PG DN KEYS

This option increase/decrease the maximum depth in Window 2 in steps of one kilometre.

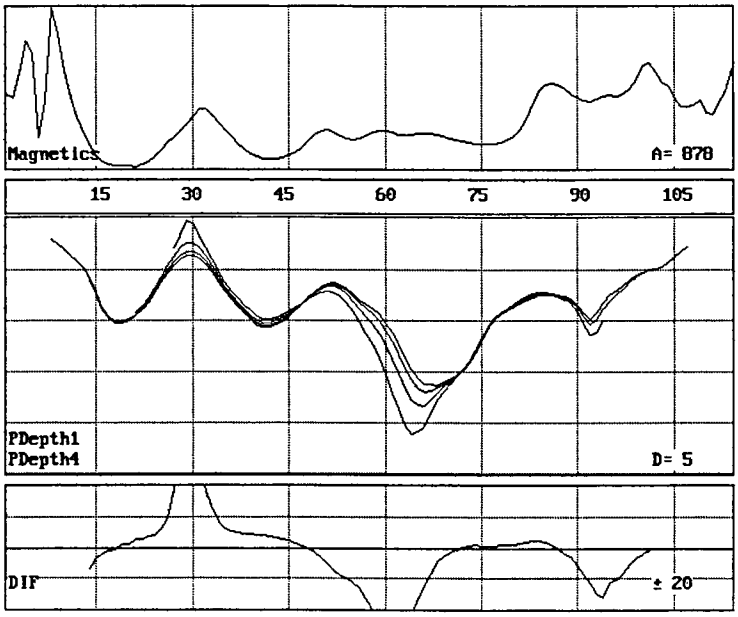
3.16 F1 KEY

F1 function key activates plotting/screen-dump to a HP LASERJET/DESKJET compatible printer (Fig. 9). Four plot-sizes are available, i.e. 1 (X width=4.8cm), 2 (X width=9.7cm), 3 (X-width=14.5cm) and 4 (full size, X width=19.4cm). This option uses the communication port set for PRINTER (see option CONFIG), or a file-name can be defined in option CONFIG. This file can later be plotted under MS-DOS using the command COPY <filename> LPT1:

FIGURE 9
Examples of screen-dump to LASEJET/DESKJET printer in Size 1 (A) and Size 2 (B). Size 4 uses full width of paper.



A



B

4. INTERPRETATION OF DATA

Fig. 7 shows a magnetic profile (A). The profile (B) underneath the magnetic profile shows the primary depth synthesis of that profile. The depths are shown in kilometres below the observation plane. The lowermost curve (C) indicates the reliability of the depth estimates in percentage (DEPTH1±percentage error). The real difference in metres between the first and the fourth lag is provided in the LIST option (Fig. 8). If the difference is within the thresholds given by the two horizontal lines (C), the depth synthesis is accepted (±20% in our example). A positive difference suggests that the sources of the magnetic anomaly are three-dimensional, and therefore the corresponding depths should be rejected. The opposite case, where the difference is negative, is evidence of one-dimensional (very flat) topography of the magnetic basement. Also in this case the model is invalid and the depths should be rejected.

5. TEST OF SOFTWARE

PDEPTH has been numerically tested against the original ADEPTH program (Phillips 1978, 1979) and MAPRAN3. Indeed Figure 7 and the table listing in Fig. 6 uses the test-example listed by Phillips (1978, 1979). The results are identical.

6. SYSTEM REQUIREMENTS

PDEPTH is developed for IBM compatible computers operated under MS-DOS (version 3 or later). The following hardware is required:

- IBM compatible AT (80286, 80386 or 80486)
- Mathematical co-processor (80287,80387 or 80487)
- EGA or VGA graphic monitor
- Minimum 1Mbyte RAM
- Minimum 20MByte Harddisk
- HP-GL compatible pen-plotter/LASERJET IIIP (HCOPY)
- HP Deskjet/Laserjet II/Laserjet IIIP printer (F1)
  (any printer for listing of data in option LIST)

Note

PDEPTH is very memory consuming and the operator may have to adjust the AUTOEXEC.BAT and CONFIG.SYS files in order to free as much memory as possible.

7. PROGRAM MODULES - FILE FORMATS

PDEPTH is supplied on one floppy disk which contains the following programs and files:

PDEPTH.EXE	Main depth program
DEP300.EXE	Help program for depth calculations
DEP700.EXE	Help program for depth calculations
DEP1024.EXE	Help program for depth calculations
DEPTH.SYS	System file (see below)
DEMO.OUT	Demonstration test file

Temporary files created by the system

DEPTH.OUT	Depth file created by DEP300/700/1024 This file contains all depth estimates for use in PDEPTH
TEST.DAT	Data file created by PDEPTH and used as input file in DEP300/700/1024.
PAR.INN	Parameter file created by PDEPTH and used in DEP300/700/1024.

The operator uses the option GETFILE to import profiles into the system. No special data format are required since data-format can be specified during input. The simplest form of file only contains one column with magnetic data-values.

Note

If an error occur during loading of PDEPTH it is likely that an error is present in the file DEPTH.OUT. Delete DEPTH.OUT under MS-DOS (DEL DEPTH.OUT).

8. INSTALLATION

a. Create a sub-directory named MAGMOD on the harddisk
   (MS-DOS command: MD MAGMOD)

b. Copy floppy disk to sub-directory MAGMOD
   (MS-DOS command: COPY *.* C:\MAGMOD

c. Add sub-directory MAGMOD to the path-command in
   the AUTOEXEC.BAT file.

d. Execute PDEPTH
   (MS-DOS command: PDEPTH)

e. Adjust PLOTTER/PRINTER interface and graphic
   monitor type using option HCOPY in the main menu.

9. REFERENCES

Phillips, J.D. 1975: Statistical analysis of magnetic profiles and geomagnetic reversal sequences. Ph.D. thesis. Stanford University, 134 pp.

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Thorning, L. 1982: Processing and interpretation of aeromagnetic data in The Geological Survey of Greenland. Grønlands geol. unders. Report 114, 42 pp.