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U.S. Geological Survey Potential-Field geophysical software Version 2.0

by

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Open File Report 92-18

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U.S. GEOLOGICAL SURVEY POTENTIAL-FIELD GEOPHYSICAL SOFTWARE VERSION 2.0

Lindrith Cordell, Jeffrey D. Phillips and Richard H. Godson

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BACKGROUND

The U.S. Geological Survey (USGS) began developing software for reduction and interpretation of potential-field geophysical data shortly after we pioneered the airborne magnetometer in the late 1940's. Originally, each scientist wrote his or her own software, following his or her own unique format. In 1971 we established a standardized binary format for grid, line and point data, thereafter allowing programs developed by many scientists to be shared. The result was a pool of constantly evolving software representing, over time, a combined effort which could not be duplicated without substantial cost in research, development, and mistakes.

Recognizing this software system to be a potentially valuable resource, we provide the system for implementation on microcomputers. Microcomputers are widely available worldwide, and provide a good medium for training and technology transfer, even if the software will eventually be installed on a larger computer, or modified. Although most of these programs have been in use for some time on other types of computers, some are new, and few of the programs have been much exercised and tested on a PC. Some of the programs have been released in earlier Open-File reports (Godson and Mall, 1989, for example) but this version (2.0) of the system represents a major consolidation and upgrade. Some program bugs have been repaired, but others no doubt remain, and new programs are continually being developed. We plan to release upgrades 2.1, 2.2... in due course. Version 2.n will comprise version 2.0 plus upgrade 2.n. In this spirit we ask that users please advise the authors of errors and malfunctions.

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We expect to release many changes and updates of these programs through USGS Open-File Services in the near future. USGS Open-File Services does not maintain records of specific sales, but we will send notice of the updates if purchasers of this version will send to us their date of purchase and an address. We hope all will do this, inasmuch as version 2.0 is rough and we do anticipate fairly extensive updates and additions of new or improved programs.

The programs are not copyrighted and can be freely copied, distributed and modified, although the official version can only be obtained through USGS Open File Services. Authorship of the larger programs is indicated in the help files and source code. However, in many cases the code has been subsequently modified by others. Names of authors of well-known algorithms are mentioned here for identification of the algorithm; full citation will be found in the help (.hlp) files.

DATA FORMAT CONVENTIONS:

Three data types are recognized: grid, line, and point. Normally data are kept in binary format. Programs are included to translate from binary to ascii and vice-versa.

GRID DATA: (Referred to as "standard file" in some of the programs). Gridded input and output to all the programs are in standardized binary grid format, often with file-name suffix ".grd". This format originally accommodated generalized, non-gridded data, and complex numbers, as well. Vestiges of this structure remain in some of the older programs, but it has not generally been maintained. Currently, the standard grid applies only to real-valued scalar data in rectangular cells. The grid file consists of a header record followed by one record for each row of data. Row 1 is the first row stored. Origin is in the lower left (southwest) corner, starting at row 1, column 1. Row numbers increase upward (northward); column numbers increase to the right (eastward).

Header record (23 4-byte words):

id: 56 ascii characters of identification
(character*56).

pgm: 8 ascii characters identifying creating
program (sometimes); character*8.

ncol: number of columns (integer).

nrow: number of rows (integer).

nz: number of words per data element.
Normally nz = 1. (integer).

x0: position of first column of data, in km
or degrees of longitude, e.g. (real*4).

dx: delta x, spacing interval of columns,
normally in the same units as x0 (real*4).

y0: position of first row of data (real*4).

dy: delta y, spacing interval of rows,
normally in the same units as y0 (real*4).

Data record. Each data record contains one row of scalar, real-valued data. The first word should contain the row coordinate, but in some programs this is not adhered to. Subsequent words contain data: f(1,j), f(2,j)...f(ncol,j), for the j-th row of data. As an example of Fortran grid io:

```
   read or write (..) id,pgm,ncol,nrow,nz,x0,dx,y0,dy
   do 10 j=1,nrow
10 read or write (..) y,(f(i,j),i=1,ncol)
```

All grids are rectangular. Areas within the grid containing no data are flagged by dummy values (DVALS). Most of the programs check these flags for no-data areas and these areas are masked in contouring and other graphics programs. Dvals are identified by a very large number; in many programs by 1.0e+38, normally contained in a data or parameter statement.

LINE AND POINT DATA: In some programs (WERNER, PROFGRD, e.g.) equi-spaced profile data are treated as a one-row grid. In general, however, both line (e.g. flight-line) and scattered-point data (e.g. gravity stations) are handled by the same binary file, referred to in the programs as a post file, often with file-name suffix ".pos" or ".pst". Some inconsistency exists internally among individual programs regarding record-item nomenclature. Here, and as described in the help files, consider the post file to be a binary file containing, for each data point, an identification, the x and y coordinates, and 6 independent variables, sometimes referred to as channels. Programs listed under the MAD (stands for "manipulating aeromagnetic data") group perform utility operations with post files. Post files have no header. The fields of each record are:

id: Identification of the data point, such as line number for profile or flight-line data, or station number for gravity data. Any 8 ascii characters (character *8). In the case of flight-line data, the cardinal and intermediate flight directions can be indicated by two-letter code after the line number, e.g."L100NW ". See help file for MAD programs.

x: the x coordinate, normally decimal degrees of longitude or projected easting in km. (real*4).

y: the y coordinate, normally decimal degrees of latitude or projected northing in km (real*4).

f1,f2,...f6: Six dependant variables, each real*4. Some can be dummies. With gravity data, the sequence convention is: free-air anomaly; Bouguer anomaly including sum of inner and outer zone terrain corrections, if listed in fields 4 and 5, below; elevation in feet or meters; inner zone terrain correction; outer zone terrain correction; and observed gravity in mGals minus 980000.0. With magnetic data the fields occurring after the 8-character id, x and y location values are: total field residual (geomagnetic reference field removed); total field; height above terrain (meters) barometric altitude (meters); fiducial number; and year and Julian day in format XX.XXX.

As an example, input and output of post files can be stated in Fortran as:

```
character*8 id
real *4 x,y,f(6)
read or write (..) id,x,y,f
```

POINT DATA: Referred to in the programs as "xyz" data, which may be either ascii or binary, z being the independent variable in terms of 2-D (normally map) coordinates x and y.

GEOGRAPHIC CONVENTIONS: Longitudes are negative if west of Greenwich and latitudes are negative if south of the equator. Projections are referred to by number according to the following:

1: American polyconic
2: ellipsoidal transverse Mercator (sometimes refered to as UTM)
3: Mercator
4: Lambert. Lower and upper parallels can be specified or default to 33 and 45 degrees.
5: Albers equal area for conterminous U.S. Standard parallels are 29.5 and 45.5 degrees.
6: Albers equal area for Alaska. Standard parallels are 55 and 65 degrees.
7: Albers equal area for Hawaii. Standard parallels are 8 and 18 degrees.
8: reserved
9: spherical transverse Mercator (special for Geological Society of America's "Decade of North American Geology" map series).

PROGRAM EXECUTION: These programs are interactive, but not menu driven. A program is started by typing its name. Parameters and data are communicated to the program either by typing responses to prompts or by means of a namelist-based command file, normally having file-name suffix ".cmd". Command files begin with &parms and end with &. See examples and program help (.hlp) files.

ONLINE HELP: A help file is provided for each program. On-line help is available in the form of a page-wise typing of a particular program's help file. To obtain help, type "pfhelp program", e.g.:

PFHELP FFTFIL

Several .hlp files contain lists of programs and functions. PROGS$.HLP is an alphabetical list of all programs; LIST$.HLP is organized by function. Individual function groups can also be listed with help files: GRIDS$.HLP, POINTS$.HLP, INTERP$.HLP, DISPLAY$.HLP, PROJ$.HLP (geographic projections), FFT$.HLP, and MISC$.HLP.

TEST DATA: Command files for some of the major programs, and test data sets, are provided in the \pf\test directory. To see a list of programs having test materials, type:

PFHELP TESTDATA

ORGANIZATION: The install file and certain other files are contained in the root directory of the INSTALL disk. The recommended organization is a main directory PF with subdirectories BIN SOURCE HELP PLOT CONTOUR and TEST. Executable routines should be in the BIN directory and this added to one's path statement in the AUTOEXEC.BAT file. If the programs will not be modified, recompiled, or further tested, only the HELP and BIN directories need remain online.

PROGRAM COMPILATION: The programs were compiled under the Microsoft MS-DOS operating system using Microsoft Fortran versions 5.0 and 5.1 and were linked with the large Fortran memory module containing in-line, floating-point instructions (LLIBFOR7.LIB). A few programs requiring several linked modules are listed below. Executable code will run only on computers having a math coprocessor (8087, 80287, or 80387). Executable files are provided on the disks. The following sequence suggests how the programs could be recompiled, if required, under DOS 5.0 with MS-Fortran 5.0 or 5.1.

I. Create main directory PF and sub-directories: PLOT SOURCE BIN TEST CONTOUR and HELP, and copy the programs into their appropriate directories (or use the INSTALL routine on disk 1).

II. Make the plot library and compile all programs that use graphics. This can be done in one step by means of the MS Fortran "nmake" command, using the file MAKEPLOT.50 (for MS Fortran 5.0), or MAKEPLOT.51 (for MS Fortran version 5.1) provided in the \pf\source directory. For example:

1. cd \pf\source
2. nmake makeplot.50
3. run the test program EXAMPLE

Programs using graphics which can be compiled, along with the plot library, by the nmake procedure are:

EXAMPLE
CONTOUR
GRAFEDIT
GRAVPOLY
MAGPOLY
SAKI

WERNER
PROFGRD
PROFSPEC

The graphics-based programs can also be compiled individually, if required. The following is the specific compilation sequence for the plot library, :

1. cd \pf\plot
2. copy *.obm *.obj
3. fl/c *.for
4. fl/c /Gt28000 tline.for
5. lib @plot50.res (or lib @plot51.res for MS Fortran 5.1) The .res files contain responses for the MS Fortran library command.
6. copy plot.lib \pf\bin\plot.lib
7. del *.obj

The plot library is a USGS-developed plotting system. Graphics programs must be liked to this library as well as to the MS Fortran graphics library. As an example:

1. cd \pf\source
2. fl EXAMPLE.FOR /link \pf\bin\plot.lib+graphics.lib /e
3. copy EXAMPLE.EXE \pf\bin
4. del *.obj
5. del *.exe

To compile the contour program separately go to the pf\contour directory and run the COMPILE.BAT program:

1. cd \pf\contour
2. compile

III. Compile the rest of the programs. The simplest way is to copy all the source code into the \pf\bin directory, then compile and delete *.for and *.obj files.

1. cd \pf\bin
2. copy \pf\source*.for
3. There are four compiling situations: simple programs, compound programs, large-array programs, and (as described above) programs with graphics.

Simple programs (most of them) can be compiled with the command "fl PROGRAM.FOR". We used the following to take advantage of the /e /f and /packc options to make more compact and efficient(?) executables. (The /packc option may not be compatible with assembly-language programs and therefore should not be used with programs involving graphics.):

fl PROGRAM.FOR /link /e /f /packc

Compound programs require several segments, the first defining the name of the .EXE file. These were compiled using the command "fl PROGRAM.FOR PROG2.FOR PROG3.FOR.../link etc". These programs are:

BOUNDARY BOUND1 BOUND2 FOURT
CHESS SFFTMG SFOURT CFFTFIL
FFTFIL SFFTMG SFOURT SFFTFIL
GRAFEDIT GRAF2
GRDREM DATE DISKIO EXIT PACK REMLOG TIME
SAKI SAKI2
TAYLOR SFFTMG SFOURT
VARMAG VARMAG2
MAD Programs belonging to the MAD set of programs (stands for "manipulating aeromagnetic data") must be linked with MADSUBS.LIB, compiled as a library of object files. The MADSUBS.LIB library and all MAD programs can be compiled with the commands:

1. cd \pf\source
2. nmake makemad

Large-array programs require the /Gt option (it's case sensitive) of the fl command. These programs are:

WERNER /Gt1200
GI3 /Gt1800
TLINE /Gt28000 (in the plot system)

HARDWARE: The programs are only practical on at least a 286 and preferable a 386 or higher microcomputer with a math coprocessor. Graphics have been tested on several CGA, EGA and VGA graphics boards. The only hard-copy device supported is a Hewlett_Packard or compatible plotter using the Hewlett-Packard Graphics Language (HP-GL).

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REFERENCE: Godson, R.N, and Mall, M. R., 1989, Potential-field geophysical programs for IBM compatible microcomputers, version 1.0: U.S. Geological Survey Open-File Report 89-197, 23 p.

PROGRAMS LISTED BY CATEGORY

UTILITY PROGRAMS FOR POST, FLIGHT-LINE, AND XYZ POINT DATA FILES

A2POS	converts ascii files in post format to binary post files. See POS2A and POS2AGRF (part of the MAD suite of programs).
A2XYZ	converts free-format ascii xyz files to binary. See XYZ2A.
CKVALUE	checks a post file for values within a given range (part of the MAD suite of programs).
ES	Three-dimensional gridding of point data at arbitrary elevations, by Cordell method.
EXTRACT	rectangular subset from data in xyz or post format.
FLDEL	deletes a flight line from a MAD post file (part of the MAD suite of programs).
FLDIST	calculates distance on ground between data points, given a MAD post file (part of the MAD suite of programs).
FLGET	extracts a flight line from a MAD post file (part of the MAD suite of programs).

FLSPECS	prints minimum, maximum and other specifications of the flight lines in a MAD post file (part of the MAD suite of programs).
FLTOPO	calculates topography elevations from height above terrain in a MAD post file (part of the MAD suite of programs).
G2XYZ	converts grid points to an xyz file (part of the MAD suite of programs).
GRAFEDIT	interactive graphic editing of xyz and post data sets by inspection of provisional grid.
G_SCREEN	average close-together gravity stations. A suite of programs to Manipulate Aeromagnetic (flight-line) Data in post format. The programs in the MAD suite are A2POS, POS2A, PHIST, CKVALUE, CKGRAD, PSORT PWINNOW, PSCREEN, FLSPECS, FLDEL, FLGET, TIEDEL, FLDIST, FLTOPO, and G2XYZ.
MINC	creates 2D grid from randomly spaced data using minimum curvature.
PHIST	prints a histogram of values in a post file (part of the MAD suite of programs).
POS2A	converts a post file to ascii format. See A2POS (part of the MAD suite of programs).
POS2AGRF	same as POS2A but adds a marginal graph (part of the MAD suite of programs).
PROFGRD	extract an arbitrary profile from a grid.
PROF2SAK	converts one-row grid (profile) obtained from PROFGRD to ascii xyz file modified for input to SAKI.
PSCREEN	extracts one post file record per grid cell (part of the MAD suite of programs).
PSORT	sorts a post file on user-given channels (part of the MAD suite of programs).
PWINNOW	winnows by keeping only every nth record in a post file (part of the MAD suite of programs).
TIEDEL	deletes all tie (cross) lines in an array of post files (part of the MAD suite of programs).

XYZMAX	gives maximum and minimum of xyz and post files.
XYZ2A	converts an xyz file from binary to ascii. See A2XYZ.

UTILITY PROGRAMS FOR GRIDS

ADDGRD	performs point-by-point arithmetic operations (+,-,*,/, mask) between two grids of equal size.
ASCII2SF	converts standard grid from ascii to binary. See SF2ASCII.
COMPGRD	compares edges of two grids for compatibility in merging.
DECIMATE	samples grid at integer intervals.
EMPTY	makes a grid of all dvals, primarily for use with JMRG
ES	Three-dimensional gridding of point data at arbitrary elevations, by Cordell method.
G2XYZ	converts grid points to an xyz file (part of the MAD suite of programs).
GHIST	histogram of a grid.
GMERGE	puts multiple input grids into one output grid with no interpolation. see JIGSAW,TILT,UTILITY.
GRAFEDIT	interactive graphic editing of xyz and post data sets by inspection of provisional grid.
GRDMAX	gives minimum and maximum of grid values.
GRDREM	convert grid to image format, for viewing with program DISPLAY.
GRD_STAT	calculates the mean, sum, RMS difference, and standard deviation of one grid or of the difference between two grids.
ID	prints the header information of a grid file.
INSERT	inserts a subgrid into a master grid.
JIGSAW	trims boundaries of a grid for merging (See MAGMERG, UTILITY).

JMRG merges two grids by spline-weighted interpolation MAGMRG merges two grids by cubic-spline interpolation.

MEGAPLUG extrapolate data over no-data areas in large grids. (plug function in UTILITY is used for small grids).

MINC creates 2D grid from randomly spaced data using minimum curvature.

PROFGRD extract an arbitrary profile from a grid.

PSCREEN extracts one post file record per grid cell (part of the MAD suite of programs).

REGRID interpolate 2D grid at a specified increment using cubic splines or linear interpolation.

SCALE scales one grid to another by least squares.

SF2ASCII converts standard-format grid from binary to ascii.

SHODVALS quickly shows areas of no data on terminal.

SKIM replaces grid values above and(or) below given levels with assigned max, min values.

TILT adds a plane with specified edge gradients to a grid.

TRANSPOS transposes rows and columns of a grid. See also program UTILITY.

TRIMGRD trims no-data (dvals) borders of a grid

UTILITY operations on a grid: extract subgrid, list, rotate, transpose, change header, edit and convert to xyz file.

INTERPRETATION AND ANALYSIS

AVER2D fast low pass filtering of grid data by averaging operator.

BOUNDARY automatically performs horizontal-gradient method of Cordell and Grauch to find physical-property boundaries.

CHESS arbitrary-surface continuation by Cordell-Hildenbrand chessboard method.

CORREL	compares the grid-point values of two grids and outputs a grid of correlation coefficients.
ES	Three-dimensional gridding of point data at arbitrary elevations, by Cordell method.
FFTFIL	3D linear operators (continuation, pseudogravity, etc.) with FFT.
GI3	3D gravity inversion by Cordell-Henderson method.
GRADIENT	performs directional-derivative operations on grid.
GRAVPOLY	3D forward gravity modeling using Talwani method, modified to allow for exact formula and to invert for density.
GRD_STAT	calculates the mean, sum, RMS difference, and standard deviation of one grid or of the difference between two grids.
IGRFGRID	International Geomagnetic Reference Field (IGRF) calculated on either a draped or constant-elevation surface grid.
IGRFPT	components of the geomagnetic reference field at a specified location and date.
MAGPOLY	3D forward magnetic modeling using Talwani method, modified to allow for exact formula and to invert for magnetization.
MEDIFILT	median filter applied to a grid.
MINC	creates 2D grid from randomly spaced data using minimum curvature.
NORMAL	Grids of three unit normal vectors from a grid, used for shaded-relief imaging
PFGRV3D	3D forward gravity calculation of effect of sources having irregular upper and lower surfaces by Parker-Blakely method. See PFMAG3D.
PFMAG3D	3D forward magnetic calculation of sources having irregular surfaces by Parker-Blakely method.
SAKI	semi-automatic 2.5D gravity and magnetic modeling using generalized inversion and graphics.
SURFIT	fit surfaces of up to 19th order to input grid using orthogonal polynomials.
TAYLOR	arbitrary-surface continuation by Cordell-Grauch Taylor's series method.

TERRACE batch program to terrace grids by Cordell-McCafferty method, augmented by Phillips.

VARMAG magnetic-terrain correction by Grauch variable- magnetization method.

WERNER automatic depth-to-magnetic-source on profiles, by Werner deconvolution.

FFT-BASED PROGRAMS

BOUNDARY automatically performs horizontal-gradient method of Cordell and Grauch to find physical-property boundaries.

CK_FFT Checks that selected number of rows and columns will not be changed internally by program FFTFIL.

DE_PREP restores operations of PREP following Fourier transform of grid. See PREP.

FFTFIL 3D linear operators (continuation, pseudogravity, etc.) with FFT.

F_ADD arithmetic operations with registered FFT coefficient (.cof) files. See FFTFIL.

F_AMP grid of log of amplitude of FFT spectrum. See FFTFIL.

F_A_AMP grid of log of area-weighted fft spectrum. See FFTFIL

F_AZIM Tapered azimuthal filter in FFT domain. Useful for reduction to magnetic pole at low magnetic latitudes.

F_COF modifiable source code for user-designed FFT filters in frequency domain. See FFTFIL.

F_DECOMP Isostatic compensation for geologic loads by Cordell-Zorin-Keller method.

F_GRAV gravity effect of density model in frequency domain. See TERRACE and FFTFIL.

F_MAG magnetic effect of magnetization model in frequency domain. See TERRACE and FFTFIL.

F_POT gravity-potential effect of density model in frequency domain. See TERRACE and FFTFIL.

F_RTP reduction to pole incorporating azimuthal filter for low magnetic latitudes.

F_SRAS grid of area-weighted radial amplitude spectrum

F_STRIP Low-pass like filter by Cordell stripping filter method. See FFTFIL.

PFGRV3D 3D forward gravity calculation of slabs having irregular surfaces by Parker-Blakely method. See PFMAG3D.

PFMAG3D 3D forward magnetic calculation of sources having irregular surfaces by Parker-Blakely method.

PREP detrend and extrapolate grid prior to FFT by Cordell method, to reduce effect of wrap around. See FFTFIL.

PROFFILT frequency-domain filters on 1d data, similar to FFTFIL. Operates on fft obtained by PROFFT. Self-prompting.

PROFFT 1d fft of profiles (in 1-row grid format). See also PROFFILT and PROFSPEC.

PROFSPEC plots spectrum of FFT coefficients output from PROFFT. See also PROFFT, PROFFILT, (part of PROFPROG suite).

DISPLAY, CONTOUR AND IMAGE PROGRAMS

CONTOUR general purpose contouring and map generation program

DISPLAY image display

EXAMPLE demonstrates compilation and use of the plot system

GRDREM convert grid to image, for viewing with program DISPLAY

NORMAL Grids of three unit normal vectors from a grid, used for shaded-relief imaging

PLOT PLOT.LIB library of USGS plotting system subroutines

PMASK makes a point mask for image files

SHODVALS quickly shows areas of no data on terminal.

FORWARD AND INVERSE GEOGRAPHIC PROJECTION PROGRAMS

GENPROJ Forward and inverse projection of post and xyz files.

PRJGRD geographic projection of data in grid form using cubic splines (Polyconic, UTM, Lambert, Mercator, or Albers projections are available).

PRJPT geographic projection of one input latitude, longitude coordinate at a time.

MISCELLANEOUS

EXAMPLE the source code demonstrates use of the plot system

FORC batch file to compile and link a simple program

HELP1 help file viewer activated by PFHELP

LIST list of program names

MTYPE types ascii files one page at a time

PFHELP types individual help files.

RDEL deletes multiple files

PROGS$ annotated list of programs, listed alphabetically

POINTS$ \
GRIDS$ |
INTERP$ |
FFT$ > annotated lists of programs by category
DISPLAY$ |
PROJ$ |
MISC$ /