A Computer Program Package for Analysis and Presentation of Paleomagnetic Data

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Introduction

The package described in these pages consists of a number of programs for working with paleomagnetic data. They are the fruit of seven years' development with laboratories in Paris, Edinburgh and here, and have benefitted from numerous suggestions from workers in other labs. I am willing and interested in adding new features to the programs, and actively invite your suggestions. In particular, I would like these programs to harmonize well with other packages, so please show me your data formats. Send me specifications and examples of the format used in your laboratory with an explanation of all possible variations. Also include a diagram illustrating the orientation parameters.

The programs are supplied free of charge and no permission is required to copy and distribute them (along with this documentation), but any use of them should be given credit in publication. Likewise, I would like to give credit to the programmers who have directly or indirectly influenced me: Jean Besse, Hironobu Hyodo, Joe Kirschvink, Phil McFadden, Mark Smethurst and Trond Torsvik. I would like to thank all the users who have offered helpful suggestions. I will continue to support these programs for the foreseeable future. All reported errors will be corrected and all suggestions will be considered.

The programs have been written in a compiled BASIC for PC computer. I use an old version of Microsoft Quick BASIC (version 2) because it is produces significantly faster programs than the more recent versions. While I have not tested the programs on all possible machines, they seem to be fully functional on all PC compatible computers running at least MS DOS version 2. Some programs fail with 256 kbyte of active memory, but all run on 512 kbyte. Most graphic screens are supported: CGA, Hercules, EGA and VGA (running as EGA). Plotting programs produce Hewlett Packard Graphics Language (HPGL) files which can be sent to a pen plotter, or more conveniently to any standard printer with an emulator like Print-A-Plot by Insight Corporation. The programs work well in the Microsoft Windows environment, and the HPGL figures can be easily annotated and doctored with graphics packages like Corel Draw. If you succeed in crashing a program, don't be alarmed by the diagnostic messages in French - just hit any key and it will return control to you. (<Ctrl>+<Pause> is a stronger way of interrupting the programs than <Ctrl>+C.)

The directory containing these programs should be named in the PATH command so that they can be easily accessed from the directory containing the data. Note that a run-time library used by all the programs called BRUN20.EXE must be on the path. If you use a Hercules graphics card, then the files SIMCGA.COM, SETCGA.COM and SETMONO.COM must also be on the path.

Data Formats

While several data formats are supported, there is a default

data-file structure which is most easily shared between the programs. These files are readable (and understandable) even without the programs from the package, which means they can be manipulated by other programs such as text editors. Directions are always treated and stored in both geographic (in situ) and stratigraphic (bedding corrected) coordinates. The redundancy of information promotes better analysis habits at the expense of a little memory.

Demagnetization data are stored in files with file-name suffix .PMD (PaleoMagnetic Data). These files start with a line of commentary which should identify the study and the researcher (see table 1 for and example). Then comes a line of orientation data (see figure 1 for the definitions used). The Cartesian coordinates of each measurement are given in core coordinates, and then the same data are given in polar form for geographic and stratigraphic coordinates. Next is recorded a measure of the precision of each measurement, labelled 95 but not a rigorously defined confidence limit. This number is not used by the programs, but should be considered when faced with a questionable demagnetization step. Finally a short commentary can be written for each step to flag interesting or questionable measurements.

Each file contains the data from a single specimen with the same name so that DOS file management utilities can be exploited. This method means that each study will produce many files which you should then organize intelligently into the disk's directory structure. Note that the root directory of any disk is limited by DOS to 112 files, but subdirectories are only limited by the memory capacity of the disk. DOS also requires that file names be no longer than eight characters long.

Directions and poles can be stored in the default format (with file-name suffix .DIR, see table 2 for an example), or in any of a number of more free formats. The programs limit the number of data that can be treated at a time to 200 points. Data is always manipulated in geographic and stratigraphic coordinates in parallel.

Summary of Programs

I have worked on data acquisition and control programs for several magnetometers (CTF, 2G, Molspin, Geofysica) which I am willing to share, but it seems that there are too many lab-specific requirements to make general distribution possible. Data files can also be entered on the keyboard with the program PMENTRY, which will be described in this documentation.

Plots of specimen level data can be created with PMPLOT. Publication quality Zijderveld, stereographic and intensity plots can all be drawn, or it can produce a page showing six different representations of the data as a work copy (for example, figure 2). Program FOURPLOT draws Zijderveld, stereographic and intensity plots for four different samples per page.

Specimen level data is treated with the program KIRSCH (named for Joe Kirschvink who first applied principal component analysis (PCA) to paleomagnetism studies [Kirschvink, 1980]). Data can be displayed in orthogonal (Zijderveld) or stereographic projections. It is easy to jump between projections and coordinate systems, and to tailor the diagram to the particular data set. The data can be edited to fix errors in the files. The main method to find directions is PCA, to determine linear segments anchored to the origin or not, to determine great circles with the data weighted either equally or proportional to their intensities, or to fit small circles (intensities normalized). A Fisher average of the direction

of a single step may also be chosen. The results of any choice are immediately plotted on the same diagram. Having defined a circular path, it is possible to choose sector constraints for McFadden's method [McFadden and McElhinny, 1988] of determining the intersection of great circles. Input is from .PMD files (or other supported formats) and output is in .DIR file formats. Each direction written to the file can be given a commentary.

The program PMSTAT is used to study data at the site level or higher (e.g., locality, region, craton). There is an editor which can prepare the data for analysis. Among the editor's functions, all directions with a given commentary can be eliminated with a single command, so that, for instance, low temperature components can be treated separately from high temperature components even though they are stored together in the same file. Calculations, such as partial untilting or calculation of poles from directions, can be done on the data set, and the results can be written to a .DIR file. Directions are plotted on a stereograph, which can be manipulated interactively to show the data in the best way. Averages are found using McFadden's method (which is identical to a Fisher average if there are only directions and no great circles in the sample) and are plotted on the same diagram. The data can be rotated such that the average is set to the pole, and analysis of the distribution can be carried out (co-inclination and declination plots of Fisher, Lewis and Embleton [1987]). Syntilting diagrams are easily made, and the optimum degree of untilting can be determined by parametric simulation - constituting the fold test of Watson and Enkin [1993].

Stereographs of data (for example, figure 3) can be produced with the program STERPLOT, which can produce publication quality work. Several sets of data can be superimposed on one another.

A variety of small calculations can be performed with PMCALC: pole calculated from a direction, direction from a pole, site determined from a direction and a pole, the angle between two directions, the normal to two directions, bedding corrections, determining the bedding correction from directions in geographic and stratigraphic coordinates, and determine the number of samples from and 95.

PMENTRY

PMENTRY produces files in the .PMD format, entered from the keyboard using either Cartesian or polar coordinates. The program starts by reading the directory to find all .PMD files present. Then the program asks for the units of data entry. Whatever the choice, the .PMD file will convert the data to Am2 for moments and A/m for magnetizations.

Then the main menu is presented:

Option [Cartesian Data Entry, Polar Data Entry, Edit, Directory, ?help, Quit]?

Commands are entered by typing the highlighted letter of the desired option. Each option will now be described.

Cartesian Data Entry: The program asks for the sample name (which is the same as the file-name holding the data). A simple carriage return (CR) enters the previously used sample. Enter M to go back to the main menu, D to have a list of the .PMD files in the directory, or N to get the next file on the list. The number of a file followed by a period can be entered instead of the file name. If the filename does not correspond to a pre-existing file, then either the name has been mistyped or the sample is being entered for the first time. If the latter case is true,

then enter Y (for "yes") to open a new file. The program asks for the file header line (e.g., study, year, researcher), the orientation parameters, , , s and d, and the sample volume. The parameter is the azimuth of the orientation line marked down the core and is 90ø less the plunge of that line. If you measure your samples with respect to a line marked down-dip on the top of the core, then is the azimuth of that line, but is the negative of the dip. s is bedding strike (using the right hand rule, i.e., strike = bedding down dip azimuth - 90ø) and d is the bedding dip.

Then the demagnetization step is requested. Up to four characters can be used, and it is recommended that one use a letter and up to 3 digits (e.g., T580 or 580C for thermal demagnetization at 580øC). Typing CR alone repeats the previous step.

Each component is requested in turn. The program assumes you are entering data in the core's coordinate system (X along an arrow marked on the top of a specimen, Z down core and Y by the right hand rule). If your data is in geographic coordinates, make sure that and are set to 0. At any time you may enter 999, which brings you back to the main menu. The 95 may be left as 0, since this value is never used in the programs, but it can be a useful indication of the quality of individual steps. Finally, you may enter a commentary for the step. If the magnetization increases by more than 10% or decreases to less than 50% then a default commentary marking this is suggested. You can override the defaults with a commentary of your own.

After the last step is entered, type in 999 for the next step to return to the menu.

Polar Data Entry: This command works exactly as the Cartesian data entry described above, except that Declination, Inclination and Magnetization/Moment are requested instead of X, Y, and Z.

Edit: The same edit routine is included in PMENTRY and KIRSCH. The most recently used file is read into memory. (If you want a new file, enter it in one of the data entry routines and then type 999 to exit to the main menu.) Then the header line and the orientation data are displayed.

The program asks "Modify these parameters?" to which the user may respond Y (for "yes"). If the parameters are correct, a CR takes the default response of N (for "no"). If a modification is requested, then the following menu is offered:

Mod SampleName,ID,Alpha,Beta,Strike,Dip,Volume, Finish?

Sample Name: If a new sample name is given, a new file will be opened, an the old file will stay, unmodified.

ID: Change the header line with the suggested format: Study, Year, Researcher. Then, if the file is examined by anybody at any time, they should, in principle, be able to identify the sample.

Alpha, Beta, Strike, Dip: Change the orientation parameters. All the directions are then recalculated according to the new parameters.

Volume: Change the sample volume (cm3). The Cartesian coordinates of the moments in core coordinates are assumed to be correct and thus the magnetizations are changed.

Finish: Do not change any other parameters and continue to the next step.

Then the demagnetization data is displayed, 10 lines at a time. If there are no lines to modify, just enter a CR in

response to the question: "Modify which line?". Otherwise enter the number of the incorrect line, to bring up the menu:
Mod Step,X,Y,Z,Alpha95,Commentary,Erase, Finish?
Step: Change the demagnetization step name.
X, Y, Z: Change the values of one of the components in units of moment (Am2). The power of 10 is entered following an "E". The direction are recalculated if a component is changed.
Alpha95: Change the uncertainty level.
Commentary: Change the commentary of the demagnetization step.
Erase: Delete the line from the file. The program asks for confirmation before the action is performed.
Finish: Do not change any other values in the line and rewrite the 10 lines to the screen.
If any value was modified, the program asks if you want to save the file (in .PMD format). If you answer "Y" then confirmation is requested because the pre-existing file will be irrecoverably overwritten. Note that even if you do not save the modified file, the data in the program keeps its modified form.
Directory: To change the disk and sub-directory where the data are stored. (I prefer to exit the program, change directory, and then start the program anew.)
?Help: Writes a list of the main menu commands.
Quit: Exits the program. The program asks "Quit the program? (Y/N)" to confirm the request.

PMPLOT

This program creates HPGL plot files of demagnetization data at the sample level. Call the program from the directory where the demagnetization data reside.

First the program asks for the Data. Protocol. For example, to use the standard .PMD file format, just enter 1, or even a CR by itself since that format is the default. The number of protocols supported will increase as users send me their laboratory's format. Then the suffix for the data files is requested and the program reads the directory and tells you how many files are present. The program asks:
Path for plot files [.HPG] ('.' for local directory) (default: C:\PLOT\):
It is highly recommended that you create a directory C:\PLOT\ to which the plot files will be written. A simple CR uses the default directory, or a different directory can be given. The present directory can be entered as a dot (".").

Then you are asked:
What do you want to plot:
All :(0) Zijderveld Core, Geo, Strati; Stereograph Geo, Strati; Intensity
Zijderveld : (1) Core; (2) Geographic; (3) Stratigraphic coordinates
Stereograph: (4) Core; (5) Geographic; (6) Stratigraphic coordinates
Intensity vs Step (7) option (default = 0) : ?
If you enter 0 then a page with six plots (see figure 2) will be produced for each specimen. Otherwise a single large plot will be made for each.

Finally you are asked if you want to do all the files in the directory. If you answer Y, then a HPGL file will be written for each data file (with the same filename but with the suffix .HPG). Answering N (or just a CR) means that you will be prompted for each file in turn. You are also prompted for the .HPG file name. Enter M to return to the main menu or to quit.

The version of HPGL used is quite primitive (HP7470 version) so the drawings can be sent to most pen-plotters. Since I have designed these programs for use with a laser printer, there has been little effort spent trying to keep pen motion down to a minimum.

The HPGL import to Corel Draw is problematic. My version 2.01 of Corel Draw reads the files just fine, but there are problems with subsequent versions which they are finding difficult to fix.

FOURPLOT

Often it is not advantageous to show the data in various coordinate systems (e.g., when there are no bedding corrections) but it is useful to show several samples on a page. FOURPLOT prepares HPGL files of Zijderveld, stereographic and intensity plots of four samples on a page.

The program starts off very similar to PMPLOT. It asks for the coordinate system (core, geographic, or stratigraphic) for all the plots, and then asks if it should do all the files in the directory. If you answer Y then it will produce files PAGE1.HPG, PAGE2.HPG, ..., until they are all done. If you do not request all the files be done then the program will prompt you for the name of a .HPG file and then the names of the four files to fill the page. Entering M will leave a blank row. Before asking you for the next page, it will first request if you want to quit the program. You can keep looping through four files at a time until you are finished.

KIRSCH

KIRSCH is used to analyze individual specimens. Since one typically is interested with the characteristic behaviour of a whole site, it is highly recommended that you have print-outs of the PMD data files and the graphs from PMPLOT or FOURPLOT before starting any serious analysis of specimen demagnetizations.

The analysis is done interactively, showing you the results graphically on the screen. The first thing the program must know is the screen type. Answer "E" for EGA or VGA screens. If the screen type is Hercules (option "H") make sure the 3 files SIMCGA.COM, SETCGA.COM and SETMONO.COM are available on the PATH. Then the program asks you for the data protocol. At present there are four options:1:Enkin(*.PMD):STEP Xc(Am2) Yc(Am2) Zc(Am2) MAG(A/m) Dg Ig Ds Is a95 comment
2:Santa Cruz (*.SRT): Sample, Step, Dc, Ic, Dg, Ig, Ds, Is, J(emu/cc), Q
3:HEADER (a, b, s, d, v) / STEP Xc Yc Zc comment
4:HEADER (a, b, s, d, v) / STEP Dc Ic M comment
Again, I am willing and interested to include other data protocols. Next, you are asked for the data file-name suffix (i.e., the three characters after the dot).

The program reads the directory and asks to what file (.DIR) you wish to write directions (the output file can be changed with command "O" in the main menu). The main menu follows:
[Output File (.DIR), Read file, *Zijderveld, *Stereograph,
Edit, Directory & Data Format, Look at .DIR file, ?help, Quit]?
The starred commands are used for selecting directions.
Output File: Select a new .DIR file for output. Note that you do not enter the suffix.
Read file: The program responds
Sample Name(*.PMD),or number with '.'[M: menu, D: directory, N: next file]?

If you enter "M", the program returns to the main menu. Enter

"D" to see a list of all files. Each file in the list is given a number which can be entered (followed by a ".") instead of the filename. Type "N" to read the next file following the one in memory at the present.

*Zijderveld: The Zijderveld diagram (orthogonal component plot) is drawn and at the bottom is written the sample name, the coordinate system ("geographic" or "stratigraphic"), and the maximum intensity of remanence. Following that is a list of the steps and the corresponding numbers which identify each point on the diagram. Horizontal projections are marked with solid squares (green on colour screens) and the vertical projections are marked with open (blue) squares. The (N,N), (E,Up) projection is useful for north-south declination components because it does not distort the inclination. East-west declination components are better visualized with the (N,Up), (E,E) projection.

Many options are available. Type "?" to write a list to the screen as follows:

```
Z I J D E R V E L D   w i t h   K I R S C H V I N K
ARROWS: translate plot              PAGE UP/DOWN: enlarge:reduce
N: Number mode (toggle)             L: Line mode (toggle)
X: Coords (Geo/Strati toggle)       Y: Projection (NN-EUp / NUp-EE
toggle)
Z: Representation (Zijderveld / Stereograph toggle)
HOME: original state
E: Erase a step (on the screen only, not in the file)
R: Reread the file (to bring back erased steps)
                                                  code in the output
D: Kirschvink Direction                                Dir Kir
O: Kirschvink Direction through the Origin             DirOKir
F: Fisher mean                                         DirFish
P: Direction of a Point                                Point
G: Kirschvink Great Circle (weighted by intensity)      GC Kir
I: Kirschvink Great Circle (intensities normalized)     GCnKir
S: Kirschvink Small Circle                              SC Kir
C: Sector Constraints for Great Circle              GC con1, GC con2
W: Write the determined direction to the file
T: Calculation of distance between data points and Kirschvink line
Q or END: EXIT ZIJDERVELD DIAGRAM
```

The commands should be self-explanatory. Beware when eliminating several steps, because the numbers for the steps are recalculated each time. Thus it is a good idea to eliminate from the later steps to the earlier steps. When you ask to determine a direction, the program asks you from what step to what step. The fit is immediately drawn over the data and the direction with its uncertainty are given in the top left corner (the maximum angular deviation, Kirschvink 1980, is given as the uncertainty for PCA fits, and 95 for Fisher averages). Circles cannot be represented on a Zijderveld diagram, so you must toggle to the Stereograph representation (command "Z") to see the fit.

When you are pleased with a chosen direction, type "W" to write it the output file. It is highly encouraged to give a commentary to every direction written. I have a system of criteria for the quality of a fit, and label each direction with a letter from "A" (good) to "E" (awful). "P" indicates a low temperature component (LTC) in the present field direction and "S" marks an LTC in a strange direction. "I" marks an intermediate temperature component. Then in PMSTAT, it is a

simple matter to eliminate, say, all "E" quality directions or to keep only "P" directions. There is no substitute, however, for taking good notes while analyzing data. Without a record of what steps were eliminated and what subjective observations you make, it is difficult to reproduce your work.

The "T" command prints out the perpendicular distances from the data points to the line in 3-dimensional space which best fits those points. (It is the sum of squares of those distances which is minimized when principal component analysis is used to fit a line to data.) The perpendicular distance from the origin to the line is also calculated. If the deviation from the origin is similar or smaller than the mean deviations of the data around the line, then you are encouraged to force the line through the origin.

*Stereograph: The stereograph and intensity plot are drawn to the screen and can be manipulated in the same way as the Zijderveld diagram.

Here is the procedure for fitting a great circle with sector constraints to the data. First, you must decide how to weight the data. One is usually trying to isolate the high temperature component which is hidden in the low intensity final steps of demagnetization. As McFadden and McElhinny (1988) point out, if the data are weighted according to the intensity of remanence at each step (command "G"), a pretty great circle will be fit to the first few points with high intensity and the result will be biased towards the low temperature component. On the other hand, if the last steps are just too noisy, giving equal weight to each point (command "I") can give a garbage fit.

There is hardly a case envisionable where it is not to your advantage to define sector constraints to a circle you fit. The hidden component must be further along the circle than the last points measured. If the great circle you fit is truly the result of two components with overlapping demagnetization spectra, the path cannot subtend more than 180ø. After entering command "C", the program asks for the first constraint. Pick a declination and inclination around the last reliable demagnetization step, and maybe a bit back if the data is noisy. The program then finds the closest point on the circle. For the second constraint, it is preferable to give the antipode of the low temperature component rather than the antipode of the first demagnetization step (as suggested by McFadden and McElhinny, 1988). (I was tempted to make this selection automatic, but then decided that people might abuse this option and stop critically analyzing their data.) To this end, you should fit the first few points (command "D") before you fit the circle and record this direction on a piece of paper. The constraints are then drawn on the great circle. You can modify the constraints by an additional call of command "C". The last constraints are remembered and you can give new values based on the old. Pay careful attention that the two constraints are less than 180ø apart. If not, the intersection algorithm in PMSTAT will fail.

Remember that although the same data are presented with stereographs and Zijderveld diagrams, the eye sees very different features with these two methods. It is highly encouraged to jump back and forth between these two representations with the command "Z".

Edit: Same as in program PMENTRY (above).

Directory & Data Format: To change the disk and sub-directory from

where the data are read. Note that the output is always into the directory from which the program was called. If you want to stay in the same directory, enter ".". The data protocol and data file-name suffix can also be changed here.

Look at .DIR file: Prints the contents of the output file to the screen.

?Help: Writes to the screen a list of the main menu commands.

Quit: To exit the program. The program asks "Are you sure (Y/N)" to confirm the request.

PMSTAT

This powerful program is used for most analysis of paleomagnetic directions and poles. It reads in data in many different formats, displays the directions on a stereograph and performs a number of analytical functions on the data, immediately showing the results graphically.

The program starts off asking for the screen type, as at the beginning of KIRSCH. Then the data protocol is requested. Data can be read into the program in any of a number of formats. All (except for type 0, my .DIR format) can accept data with any number of decimal places, placed anywhere on the line. The only important aspect of any given format is that the data be placed in the correct order, each entry separated by at least one space. At the end of each line, you may include a comment, such as the site number. Note that comments should be at most 17 characters long to be displayed prettily in the edit routine. The formats supported at this time are shown on the following screen:

```
Data Protocol
notes: 'g' for in situ (geographic), 's' for corrected
(stratigraphic)
       'S' for Site, 'P' for Pole
If protocol includes Kappa and N after other data, select negative of
option
 0: Enkin (*.DIR) format (ID Code Dg Ig Ds Is a95)
 1: Dec Inc      or  Long Lat          2: Inc Dec      or  Lat Long
 3: Dec Inc a95  or  Long Lat A95      4: Inc Dec a95  or  Lat Long
A95
 5: Strike Dip (D=Strike-90, I=90-Dip) 6: DipDir Dip
(D=DipDir-180,I=90-Dip)
 7: Dg    Ig   Ds    Is   or           8: Ig   Dg    Is   Ds    or
    LongS LatS LongP LatP                 LatS LongS LatP LongP
 9: Dg    Ig   Ds    Is   a95  or     10: Ig   Dg    Is   Ds    a95
or
    LongS LatS LongP LatP A95             LatS LongS LatP LongP A95
11  LongS LatS LongP LatP dp dm       12: LatS LongS LatP LongP dp dm
13: Dg Ig Strike Dip                  14: Ig Dg Strike Dip
15: Dg Ig DipDir Dip                  16: Ig Dg DipDir Dip
17: Dg Ig Ds Is LatS LongS            18: Dg Ig Ds Is LatS LongS a95
19: BEGIN / Dg Ig DipDir Dip (McFadden Format)
```

Most of these formats should be self-explanatory. For instance, for format 12, each line of the file must contain six numbers: the site latitude and longitude, the pole latitude and longitude, and then the uncertainty ellipse axes dp and dm, followed by the optional comment/identifier. If you will be using parametric simulations of site data, for example to perform Watson and Enkin's (1993) fold test, each site must have its kappa and N. Include these numbers using the negative of the corresponding format. For example, format

-9 requires 7 numbers in each line: the mean declination and inclination in geographic coordinates, the declination and inclination in stratigraphic coordinates, alpha 95, kappa, then N, followed by the optional comment/identifier.

Format 19 is the same as is used in Phil McFadden's programs: any number of lines of comments can be placed at the top of the file, terminated by a line with the word BEGIN (upper or lower case). Each following line includes the declination and inclination in geographic coordinates and the dip direction (i.e., the bedding down dip azimuth) and the dip angle. In formats which include bedding orientations, the direction in stratigraphic coordinates is calculated, so calculations are always done in geographic and stratigraphic coordinates in parallel. Formats 5 and 6 are useful for finding mean bedding corrections. The orientations are converted to normals to the bedding planes.

It is easy to program other formats into this routine and suggestions are welcome.

After accepting the data protocol, the program asks for the file name suffix for the data files. The protocol and the suffix can be changed at any time during the session using command "D" in the principal menu. Then the output file name (with automatic suffix .DIR) is requested. This output file can be changed at any time with the command "O" in the principal menu.

The principal menu is:

[Output File, ReadIn File, Stereo (Analysis), Edit, Calculations,
Write .DIR file, Directory & Protocol, ? Help, Quit]

Output File: Average directions can be written into a .DIR file, the name of which is specified with this command.

Read In File: You may enter the name of the data file or the number corresponding to its position on the directory list (displayed by entering "D" here) followed by a dot ("."). Entering "N" chooses the next file following the one presently in memory. If you choose not to enter data now, type "M". If there is already data in memory, you are asked:

Empty out data presently in memory? (Y/N, default = N) :

to which you should respond "Y" if you want to start from scratch, or "N" if you want to add the new file to the data already entered.

Then the first 20 lines of data are listed and the program directly goes to the edit routine described below.

Edit: After listing the first 20 lines of data, the following list of commands is offered:

List, Erase a pole, erase a Series, erase according to Commentary,
Antipode, Finish? (default: F) :

List: To display the 20 lines of your choice, answer the question "List starting at which line" unless there are fewer than 20 lines of data, in which case it displays all the lines.

Erase a pole": The program asks "Direction to erase (0 for none)". Enter the line number you want to delete. A <CR> with no number is equivalent to choosing "0" and no action is taken. The lines are renumbered with each deletion, so it is preferable to start from the bottom and work up.

Erase a Series: In order to get rid of a series of lines give the first and last line numbers in response to: "First direction to eliminate (0 for none)", and "Last direction to eliminate (0 for none)".

Erase according to Commentary: You can get rid of all lines which

have commentaries starting with the same characters. For instance, I always enter the comment "P" for low temperature components in the present field direction. The program asks, "Erase directions with commentaries starting with what letters?". If I wish to analyze all the directions which are not present field, I would enter "P", and all those lines would be eliminated from the list.

Antipode: If the data contains both polarities, it is necessary to switch them all over to a single polarity before performing an average. The program asks "Reverse which direction (0 for none)". For great circles, the pole does not change, but the sector constraints are flipped to the other polarity. The word "Antipode" is added to the commentary of the line affected.

Finish: After all editing is finished, the default response "F" takes you out of the editor to the main menu.

Calculations: Within this routine, calculations that you can do on individual data points in the program PMCALC (described below) can be performed on a whole data file. These calculations affect the values in memory but not on the disk. The results can then be written to a new file (in .DIR format) with the "W" command in the main menu.

Partial Untilt: Enter the percent untilting. The results replace the values in stratigraphic coordinates, leaving the values in geographic coordinates unchanged. So, for example, if you perform a 60% untilting, and then produce a "Syntilting" plot the 100% point corresponds to 60% untilting and the 50% point corresponds to 30% untilting.

Directions to Poles: Directions in geographic and stratigraphic coordinates are converted to virtual geomagnetic poles. The 95 column is filled with B95= dp*dm corresponding to the values in stratigraphic coordinates. Some data protocols include the site location. If the sites have not already been entered then the program asks for a common site for all the data. Note that performing a syntilting plot on VGP's will give nonsensical results because the routine assumes rotations about horizontal strikes. There is the option of producing a true VGP syntilting plot when within the Stereograph routine.

Write .DIR file: It is often useful to save data after editing or doing calculations, or to convert from any of the various data formats to the .DIR format. Remember to give these new data files different names from the original.

Stereo (Analysis): Analysis takes place in this routine with the data displayed on a stereograph. The numerous option are displayed to the screen by typing "?".

S T E R E O G R A P H o f D I R E C T I O N S

ARROWS: Move the centre of the diagram
PAGE UP/DOWN: enlarge/reduce the diagram
HOME: put the diagram back to its original state
N: Number mode (toggle) L: Legend mode (toggle)
A: error Angle mode (toggle) P: Pole/Direction mode (toggle)
E: Erase a direction (on the screen only, not the file)
X: Coordinates (Geo / Strati toggle) Y: Projection (Equal Angle/Area toggle)
M: McFadden Mean (equivalent to Fisher Mean if there are no Great Circles)

G: Calculate best fitting Great Circle
W: Write mean direction to the file
F: Fold Test (Direction-Correction formulation)
S: Syntilting diagram, and Fold Test (Parameter Estimation formulation)
I: Inclination Analysis, and Inclination Fold Test (Parameter Estimation)
B: Block Rotation Fisher Analysis for Inclination
Blocks indicated by first letter of comment
R: Rotate the directions such that the average is at the pole
C: Co-Inclination plot to test distribution (after R)
D: Declination plot to test distribution (after R)
Q or END: exit Stereograph routine
?: this message

N: Number toggle; L: Legend toggle

The stereograph is drawn with solid lines and symbols (green for grass, on colour screens) for the lower hemisphere and dashed lines and open symbols (blue for sky) for the upper hemisphere. You can toggle off the numbering of each point with the command "N". Note that circles are identified near their first sector constraints (and they are given no identification if constraints are not given - which should be relatively rare. See documentation of program KIRSCH for a discussion of sector constraints). The list of points at the bottom of the screen can be toggled off with the command "L", which is useful if more than about 20 points are being plotted.

A: error Angle toggle

The 95 circles can be drawn around each point with the command "A". Uncertainty ellipses around poles (dp, dm) are drawn for data entered with applicable formats. Note that the data in geographic coordinates in this case are the site positions, but the ellipses are always drawn around the poles (i.e., the data in stratigraphic coordinates).

P: Pole / direction toggle

When analyzing directions it is customary to have 0ø (North) at the top of the screen and the directions go around clockwise. The command "P" toggles the diagram for analyzing poles: 0ø (Greenwich) at the bottom and the directions going around counterclockwise (i.e., you look down on the North Pole).

E: Erase a direction

A direction can be erased with the command "E". The computer asks "Direction to erase (0 for none)". If you type a simple <CR>, no action is taken. Remember that when a direction is erased, all subsequent directions are renumbered, so it is best to erase from the last towards the first. If a large number of directions are to be eliminated, it is better to go out to the main menu and then use the editor.

X: Coordinates toggle; Y: projection toggle

You can toggle the coordinate system (Geographic / Stratigraphic) with command "X". Command "Y" toggles between equal area and equal angle projections.

M: calculate Mean direction

You can find the mean direction of the directions displayed on the screen with the command "M". If the data consists uniquely of directions (or poles), the mean is simply the familiar Fisher mean. If there are great circles, the McFadden and McElhinny (1988) best estimate of the intersection is determined. This is an iterative method which requires an

initial point to start from. If there are directions included in the data set, the initial point is the Fisher average of these directions. If the circles have sector constraints (which should usually be the case) the initial point is the Fisher average of these constraints. If the set consists of circles with no constraints, the program asks for an initial point. You do not have to be accurate, because the iteration is very quick, so just give a point in the expected hemisphere.

G: Great circle

It is also possible to find (command "G") the best great circle which fits the data using Principal Component Analysis (Kirschvink, 1980). The error angle in this case is the "maximum angle of dispersion".

W: Write mean direction to file

Once an average direction has been calculated, it can be written to the file (specified with command "O" from the main menu) with command "W". Before it is written, however, you are asked to enter a commentary: "Commentary? [Q to return without writing]". Enter "Q" <CR> if you decide not to write the direction to the file. It is highly encouraged that you include a brief description for each average, because they all look the same in the file.

R: Rotate to pole; C: Co-inclination plot; D: Declination plot:

Fisher, Lewis and Embleton (1987) suggest a graphic method to test if the distribution of directions is Fisher-distributed. The first step in the analysis is to rotate the data such that the average is at the pole with command "R". I have so far included commands to produce two of the diagrams suggested by Fisher et al.: "C" for the co-inclination plot and "D" for the declination plot. In either case, you are asked for the coordinate system ("Strati [S] or Geo [G]"). Then the data is plotted with the "sample quantile" along the x-axis, and the "experimental quantile" along the y-axis. The graphs are set up such that they should produce straight lines through the origin if the directions are Fisher-distributed. Finally you are prompted for the name of a file to write the data to if you want to produce a hard copy of the graph using any plotting program. The first column is the "sample quantile", the second column is the "experimental quantile", and the third column is the site identifier.

Fold Tests and Inclination-Only Analysis

It is possible to get a qualitative indication of whether or not the fold test is positive for a given data set merely by considering the Fisher precision parameters of the average in geographic and stratigraphic coordinates. One of the important features in these programs is that data is always processed in the two coordinate systems in parallel. Remember, however, that the often used K-ratio fold test formulation (McElhinny, 1964) is statistically invalid (McFadden and Jones, 1981).

S: Syntilting diagram, and parameter estimation fold test:

Watson and Enkin (1993) argue that the fold test should not be performed in terms of a hypothesis test, but rather as a parameter estimation problem. In particular, the concentration of directions, as measured by the Fisher precision parameter, will in general vary as a function of the degree of untilting (around horizontal axes). If the maximum is at 100% then the fold test is positive while if the maximum is at 0% then the fold test is negative. The actual size of the maximum is not

important. Such a diagram is calculated with the command "S" (for syntilting). There are a number of mechanisms which give a maximum which is not at 0% or 100%. The most talked about is the possibility that the remanence was acquired during tectonism. Another mechanism is deformation of the magnetic matrix by the tilting process. The most common, probably, is incomplete separation of components. Since the latter two mechanisms are not restricted to giving a maximum between 0% and 100% folding, I present calculations from -50% to 150%. It is too easy to look at a curve from 0% to 100% which increases or decreases monotonically to the limits and interpret there to be a maximum (minimum) when in fact the data have been contaminated and the maximum is outside the range of the diagram. My opinion is that only if a marked maximum exists between 30% and 70% should one should consider syntilting acquisition as a possibility.

If you have included N and k for each site (data formats 0 or negative) then you can use parametric resampling to determine a confidence interval for the degree of untilting which gives maximal concentration (this is the fold test formulation proposed by Watson and Enkin, 1993). You are asked for the number of simulations and then a measure of the uncertainty of the bedding measurements (as measured by their circular standard deviation). Fisher samples are chosen to simulate each site and the maximum of the k vs degree of untilting curve is determined. The histogram which builds up on the screen shows the positions of these maxima. At any time the calculations may be interrupted by hitting any key. After the total number of simulations is done (or when the simulations are interrupted) the median (50 percentile) and 95% confidence limits (2.5 and 97.5 percentiles) are calculated. If 100% untilting is within the range of maxima but 0% is not, then the fold test is positive. Finally, you are asked if you want a file created with the positions of the maxima so you can make a hard copy of the histogram using a standard scientific graphing program.

F: direction-correction Fold test:

The "Direction-Correction" fold test formulation is performed with command "F". (Note: this method has been described in my doctoral thesis (1990), but seems to have been indefinitely stalled in publication - so use at your own risk.) The "DC" graph is plotted, with the C axis (horizontal) being the expected deviations produced by the bedding correction for each site, and the D axis (vertical) being the observed deviations. (To be specific, the C value is the angle between the mean in geographic coordinates and the back-correction of the mean in stratigraphic coordinates), and the D value is the angular separation between the mean (geographic coordinates) and the site direction projected onto the circle connecting the mean and the back correction.) The best fitting line going through the origin (with its associated 95% confidence limits) are also plotted. This graph should be inspected for outliers before interpreting the fold test. For example, a point with the incorrect polarity will invalidate the test, but it should be readily apparent from the graph. If the slope on the DC graph 1, then the directions (in geographic coordinates) and corrections are correlated and the fold test is positive (i.e., remanence is probably prefolding). On the other hand, if the slope is 0, then the directions and corrections are not correlated and fold test is negative (i.e., remanence is probably postfolding). If an

intermediate case exists, or if the data are too few or are too dispersed or the corrections are too small, then the test is indeterminate. The bedding corrections are determined from the directions in geographic and stratigraphic coordinates under the assumption of a horizontal axis of rotation. If the correction is more complicated (e.g., if poles instead of directions are analyzed) the test will only be approximate.

I: Inclination-only analysis:

When declination information is lost (uunknown relative vertical axis rotations), it is still possible to calculate a mean inclination. I have included the method introduced in Enkin and Watson (1994), accessed with command I. For simple cases where the inclination is not too close to vertical and kappa is not too low, the result is similar to McFadden and Reid's (1982) maximum likelihood method (but much simpler!). Otherwise the calculation is trickier and involves some numerical integration - so it takes longer. The other caveat is that the 95% confidence interval is not symmetrical in these cases. If all the sites have the same bedding correction, only the values before and after tectonic correction are calculated. Otherwise a syntilting diagram, similar to that produced by command S, is calculated. If N and kappa are included for each site, then it is possible to do a parametric simulation parameter estimation to find the most likely optimal degree of untilting (Watson and Enkin, 1993) thus making an inclination-only fold test.

B: Block rotation Fisher analysis:

A more robust method of calculating inclination when declination information is lost is Block Rotation Fisher analysis (Enkin and Watson, 1994), accessed by command B. The method assumes that the data come from several rigid blocks. These blocks are denoted by the first character of the comments. So, for example, sites from the first block could be labelled A. Then sites from the second block could be labelled B. The third block could be labelled A again. The mean inclination is essentially the Fisher average of all the sites after the mean declinations of the blocks have been rotated to a common azimuth. As in option I, if there are different beddings, a syntilting diagram is created and a Watson and Enkin (1993) fold test can be performed.

Q: Quit:

The Stereograph mode is terminated by entering either "Q" or <End>.

Directory and Protocol: Like the same command in KIRSCH. The program asks you for the disk and the path name for the directory where the data are to be found. Directions are always written to the directory from which the program was called. Then the program offers you the list of supported data protocols which you select by number, and finally it asks you for the file name suffix. If there is no suffix, enter a <space>.

?Help: types out a brief list of the Main Menu commands

Quit: before exiting, the program asks for confirmation.

STERPLOT

The program STERPLOT produces files with Hewlett Packard Graphic Language (HPGL) commands to create stereographic projections of data in files with any of a number of formats. The commands of the main menu are mostly identical to those of PMSTAT, so only the different

```
commands will be documented:
[OutputFich(.HPG),InputFich(.DIR),InputFich(Nonformat,),Options,
         Plot,Append plot,Edit,Repertoire,?help,Quit]?
Options:  The following screen (translated into English appears):
1: diameter (cm)                        10
2: symbol size (cm)                     .1
3: coordinates (2:geo, 3:strati)        3
4: proj (1:equal angle, 2:equal area)   2
5: minimum latitude (ø)                 0
6: number the points                    Y
7: a95 circles                          Y
8: plot the poles of great circles      N
9: directions (D) or poles (P)          D
10:line between points                  N
11:line for upper hemisphere            3
12:title
Which option to be modified? (0 to exit)
```

Most of the options are self-explanatory. Option 5, "minimum latitude", is useful if you are interested in plotting details which are found close to the pole. When option 6, "number the points", is set to "Y", a small number is plotted up and to the right of each point. Option 7 plots either 95 circles of confidence or (dp, dm) ellipses of 95% confidence for poles, depending on with what format the data was input. With option 9, "direction" mode places 0ø (north) at the top and the declination goes around clockwise, while "pole" mode places 0ø (Greenwich) at the bottom and the longitude goes around counter-clockwise. Lower hemisphere lines are always drawn solid, but upper hemisphere lines can be dashed (3), solid (-1) or not drawn at all (0), or any of the other HPGL line patterns. The default for the title (option 12) is the same as the input file. If you don't want a title, input a space.

Plot: creates a new file (with the name entered with the command "F") with HPGL commands to produce a stereograph. If you enter "P" without giving a new filename, no action is taken. This is to protect you from covering over the preceding diagram by accident.

Append Plot: Use this command to plot data onto an already existing stereograph, that is, append new HPGL commands to the end of the specified file. This is useful if you wish to, say, plot a reference APWP on a diagram with the poles from a given region. The Append command plots the data only - it does not initiate the plot nor draw the stereograph net. So the first data is plotted with command P, but subsequent data sets are plotted with command A.