Easy handling of tectonic data: the programs TectonicVB for Mac and TectonicsFP for Windows™ ☆

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Abstract

TectonicVB for Macintosh and TectonicsFP for Windows TM operating systems are two menu–driven computer programs which allow the shared use of data on these environments. The programs can produce stereographic plots of orientation data (great circles, poles, lineations). Frequently used statistical procedures like calculation of eigenvalues and eigenvectors, calculation of mean vector with concentration parameters and confidence cone can be easily performed. Fault data can be plotted in stereographic projection (Angelier and Hoeppener plots). Sorting of datasets into homogeneous subsets and rotation of tectonic data can be performed in interactive two-diagram windows. The paleostress tensor can be calculated from fault data sets using graphical (calculation of kinematic axes and right dihedra method) or mathematical methods (direct inversion or numerical dynamical analysis). The calculations can be checked in dimensionless Mohr diagrams and fluctuation histograms.
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1. Introduction

The breakthrough of operating systems supporting graphical user interfaces (GUI) on personal computers in the first half of the 1990s has opened this medium for a broad range of users. TektonikQB (the precursor of the present program TectonicVB, Apple Macintosh platform) and TectonicsFP (Microsoft™ Windows® environment) were among the first programs porting and expanding known code for computing structural geological data to GUIs in order to utilise their graphical abilities (both in display and storing/manipulating graphics) and user-friendly environment. The demand for easy-to-use, stable software existed not only for a workgroup on structural geology at the Institute for Geology and Paleontology of the University of Innsbruck, but also for a wide range of structural geologists worldwide. TektonikQB and TectonicsFP were initially designed for use in brittle tectonics but have been extended subsequently to meet a broad range of tasks in structural geology. Both are easy-to-use programs that allow standard lower hemisphere plots and rose diagrams for tectonic data (planes, lineations, faults) to created. Beside the graphical representation, focus was laid on routines to manipulate fault data and compute paleostress using several methods. The programs have substantially benefitted from suggestions and error reports from collegues, and from several brittle tectonic studies of the workgroup where large amounts of data had to be processed. As the programs also turned out to be useful tools for teaching, special emphasis was given to provide a stable operation, even with non-realistic and wrong input parameters and an extensive help system for beginners.

2. Basic program design

Both programs consist of a main window with a mac/Windows-familar menu bar where all actions can be started by selecting the desired routine. For advanced users most actions can be carried out by keyboard shortcuts, too.

Usually processing structural data takes three steps:

1. Entering data and storing them in datafiles. Planes, lineations and faults have to be treated separately.
2. Manipulating data, proceeding calculations, visualising data.
3. Printing or exporting results (text or graphics) to a word processing-, spreadsheet-, database-, graphics-, GIS or CAD application via clipboard or on-file.

Most of the routines produce a graphic output on the screen. The appearance of lines and plot symbols can be defined by the user.

TectonicVB works with a single plot window. Multiple plots can be combined easily by a command, which holds existing graphics in memory and adds-on additional data. Graphics are automatically copied to clipboard and can directly be pasted into another application that is active in the multifinder. Optionally, the graphics can be saved on-file in PICT-format.

TectonicsFP is designed in MDI program architecture (multiple document interface): each graphics plot is in its own window, and the number of simultaneously open windows inside the main window is not restricted by the application. Graphics can be combined by copy/paste commands or just by drag-and-drop and can be exported to other applications in vector-format via clipboard or alternatively saved to disk in Windows Metafile format.

3. System requirements and installation

TectonicVB runs on any Macintosh computer with colour screen. For operating systems older than MacOS 8.0 the appearance library has to be installed in the system folder. The complete package including the documentation needs approximately 1 MB of hard disk space. The program consists of a single executable file and can be run from any directory. TectonicsFP also consists of a single executable file, runs in any 32-bit Windows environment (Windows95, 98, ME, NT 2000 or XP) and needs to be installed by a setup program. Application and online help require approximately 2 MB of hard disk space.

Both programs are designed to fit into 800 × 600 pixel screen size, in order to support portable computer use for field purposes.

4. Data input and storage

Field data need to be recorded such as dip direction/dip angle for planes and trend/plunge for lineations. Valid dip directions/trends are 0–359° counted clockwise from north, the dip angle/plunge must be between 0° and 89°, measured in downplunge direction. For faults, dip direction/dip of the fault plane and trend/plunge of the fault lineation have to be recorded and optionally the relative sense of slip (normal/reverse/dextral/sinistral). In addition, TectonicsFP uses a quality parameter for the sense of slip after Sperner et al. (1993), which is modified from Hardcastle (1989): 'excellent', 'good', 'poor' or 'not recorded'. In TectonicsFP, the possibility exists to add information about the location, lithology, tectonic unit and remarks to datafiles (Fig. 1).

All tectonic data are stored in text-based files. Both programs use basically the same file format, data are interplatform exchangeable. The user need not have to edit text files directly in an editor but accesses data in an interactive input mask (TectonicVB, Fig. 1 left) or a spreadsheet (TectonicsFP, Fig. 1 right), from where data are automatically stored in the correct format. The input mask/spreadsheet is suited to the type of data being processed, data are checked for validity on input.

Files belonging to older programs for structural geology can be imported. TectonicsFP reads files created by DOS-programs written by B. Sperner (Sperner et al., 1993) and by H. Peresson (Peresson, 1992). TectonicVB imports files created by STEREOPLOT written by N. Mancktelow and files created by FAULTKIN and STEREONET by R. Allmendinger.

5. Visualisation of tectonic data

In order to enable contouring of data, all lower-hemisphere plots are in equal-area (Lambert-) projection.

Planes can be drawn as great circles or poles (Table 1A and B). For lineations the intersection in the lower hemisphere is shown. If numbering is switched on, consecutive numbers are shown beside each record (Table 1B).

Faults can be shown in an Angelier diagram (faults and striae) or Hoeppener diagram (tangent lineations). In the faults and striae-plot the fault plane is shown as a great circle and the lineation as a pole. The tangent lineations-plot displays poles to fault planes in the lower hemisphere projection after Hoeppener (1955). Corresponding lineations are drawn in the pole points as tangents to the common great circle of the fault plane pole and the lineation. In both situations an arrow corresponds to the slip direction and indicates the sense of movement of the hangingwall block. In TectonicsFP, faults with quality values are displayed by different
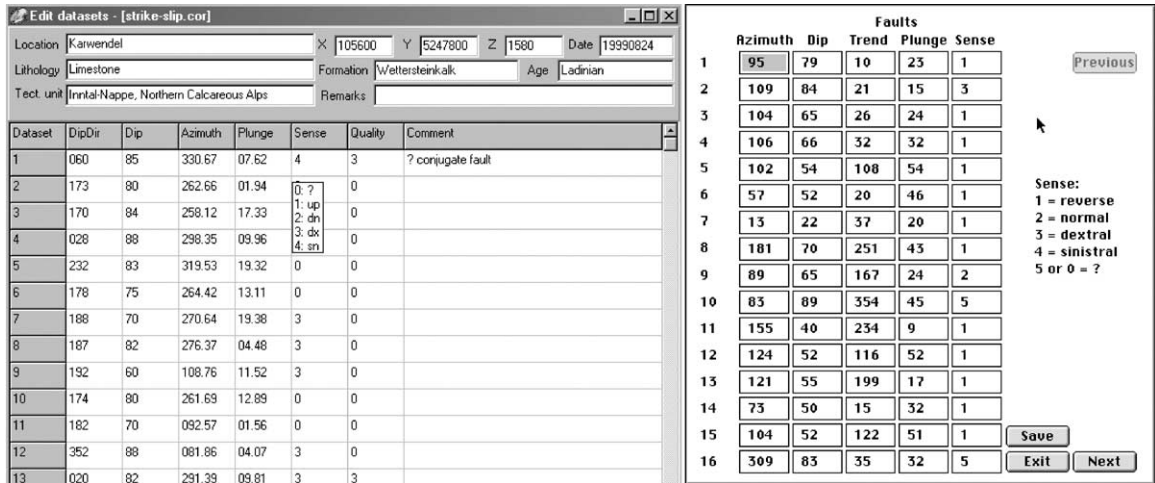
Fig. 1. Window to view and enter fault data in Windows (left) and Mac (right). Small help window gives hints what to enter. Data can be handled similar to spreadsheet programs.

Table 1
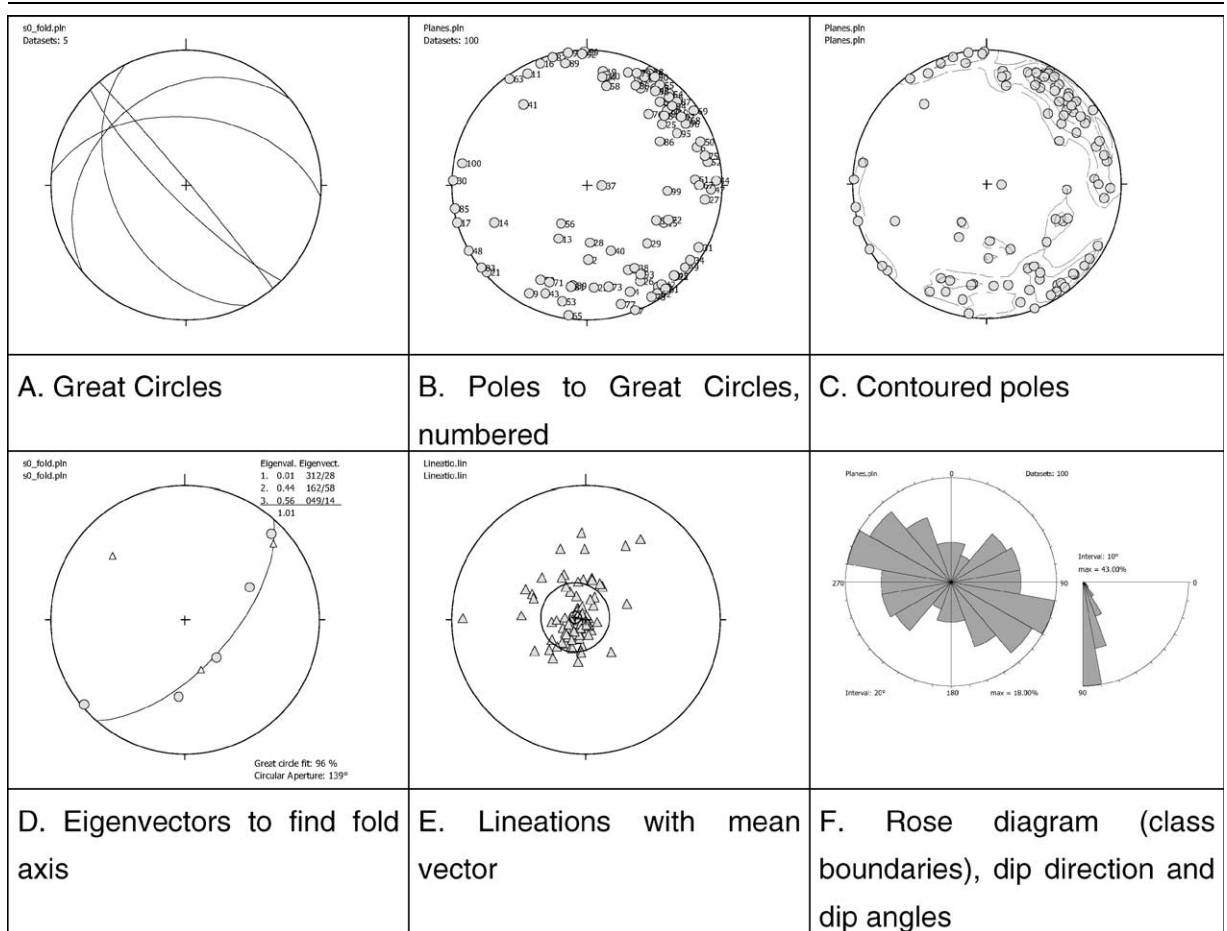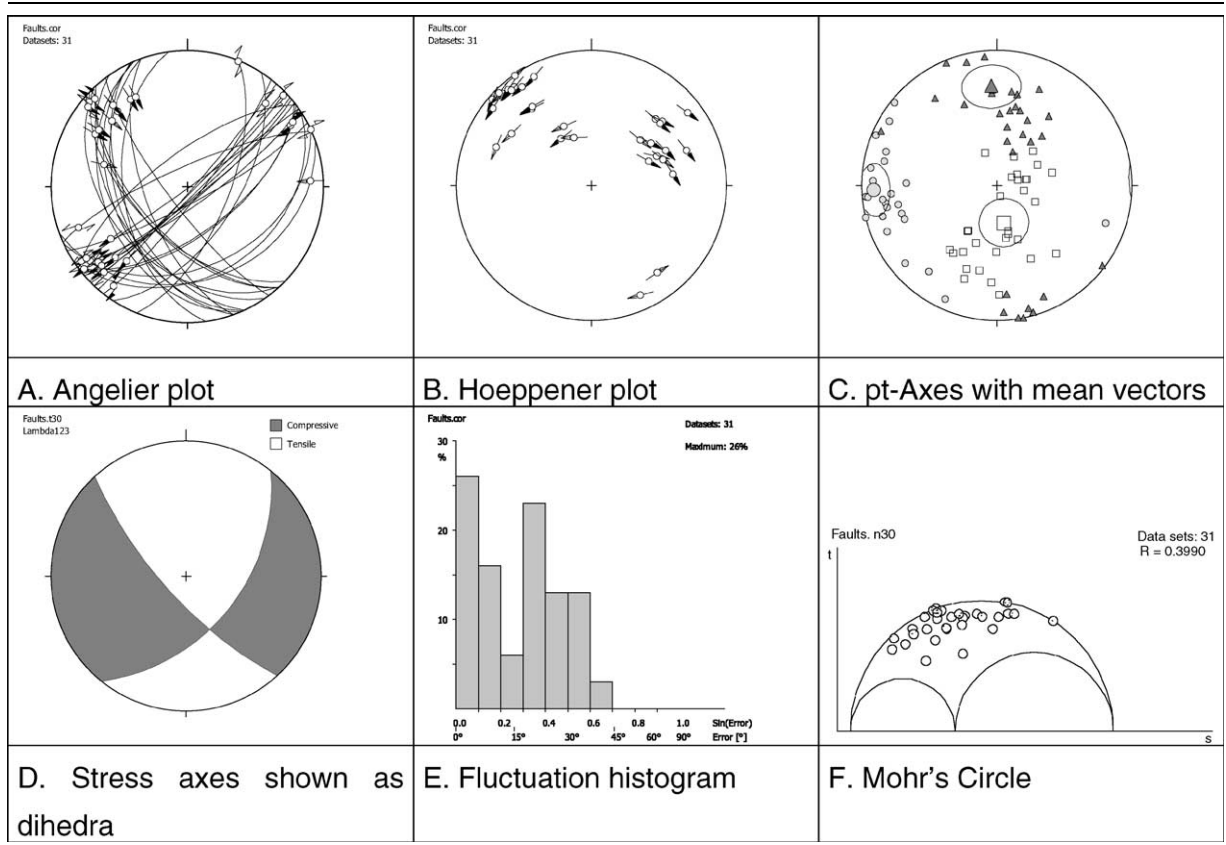Examples for visualisation and computations with planes and lineations

A. Great Circles

B. Poles to Great Circles, numbered

C. Contoured poles

D. Eigenvectors to find fold axis

E. Lineations with mean vector

F. Rose diagram (class boundaries), dip direction and dip angles

Table 2
Examples for visualisation and computations with faults

A. Angelier plot	B. Hoeppener plot	C. pt-Axes with mean vectors
D. Stress axes shown as dihedra	E. Fluctuation histogram	F. Mohr's Circle

arrows in Angelier and Hoeppener plots (Table 2A and B).

Generally, when data are displayed the user can switch between compatible plots without re-opening them (e.g. between pt-Axes, Angelier- and Hoeppener plots for faults).

6. Data manipulation

6.1. Sorting

For data separation, an interactive sorting routine is provided. Data are displayed in a window with two diagrams (Fig. 2) and can be selected by mouse click or in the list below the graphs and moved to the other side. Check boxes in the Mac version and the "Plot type" option in the "Settings" menu of the Windows version allow the user to switch between great circles and poles for planar data and the faults and striae plot (Angelier diagram), tangent lineation plot (Hoeppener diagram) and P–T–B-axes plot for fault data during the sorting

process. Data which have been moved to the diagram on the right side can be saved to disk (Write to file button).

6.2. Rotation

Rotation of planes, lineations or faults is performed in an interactive rotation window (Fig. 3; select "Rotation" in the "Calculate" menu). On the left side the original data are plotted, on the right-side the rotation axis, and upon selection of the "Apply" button, the rotated data are displayed. Rotation axis and rotation angle have to be typed into the respective text boxes. Positive rotation angles are clockwise looking down-plunge along the rotation axis.

6.3. Combining data sets (TectonicVB)

Datasets can be combined and saved using the "Op.Mode: Open" (operation mode) command in the File menu of TectonicVB. After plotting a dataset, another dataset may be appended and saved in the "Save data" dialog.
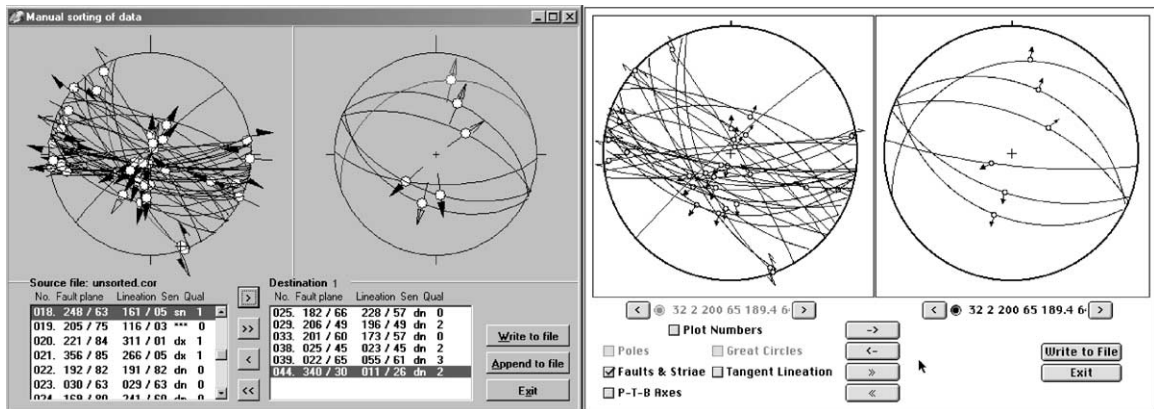
Fig. 2. Graphical sorting routine in Windows (left) and Mac (right) to separate a heterogeneous fault dataset. Faults can be selected either with mouse pointer in diagram or in list below each plot and moved by arrow buttons from left to right or vice-versa.
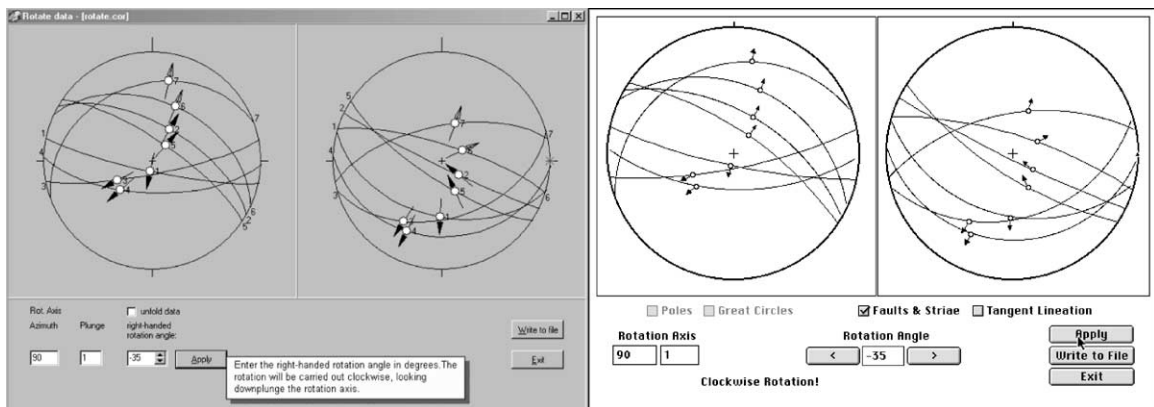

Fig. 3. Rotation windows for TectonicsFP (left) and TectonicsVB (right).

7. Data processing

7.1. Planes and lineations

7.1.1. Rose-diagram

Both dip direction/trend and dip angle/plunge can be counted and displayed in circular histograms (Table 1F). Two styles of rose diagrams are supported: class center or class boundaries. The histograms can be colour-filled.

7.1.2. Contouring

The contouring routines are based on a counting routine published by van Everdingen et al. (1992). Data are counted and contoured either by a 1%-counting circle (Circle counting method) or by a Gaussian distribution ($k = 100$, Gauss counting method) after Robin and Jowett (1986).

7.1.3. Mean vector

The mean vector of lineations or poles to planes can either be calculated after Fisher (1953)—''Fisher statistics'' or Wallbrecher (1986)—$R\%$ and center. If selected by the user a small circle is displayed around the mean vector to display the cone of confidence for a user-defined prediction probability in the graphical output window (Table 1E). The computer programs calculate the mean vector and the aperture of the confidence cone as numerical results. For Fisher statistics a concentration parameter (precession, closeness; Fisher, 1953) is calculated which ranges between 2 (uniform distribution) and infinity (parallel fabrics). If $R\%$ and Center method is selected the programs calculate a concentration parameter R (''Prozentueller Regelungsgrad'') and the spherical aperture after Wallbrecher (1986). R ranges between 0% (uniform distribution) and 100% (parallel fabrics). The spherical aperture equals the radius of the

small circle of a spherical normal distribution with equal *R*%-value as the given data.

7.1.4. Eigenvectors

The three orthogonal eigenvectors of the "orientation tensor" for the orthorhombic Bingham distribution (Bingham, 1964) are determined. Each datum is regarded as a point of unit mass on a sphere. The axes of minimum and maximum moment of inertia of the distribution and their corresponding eigenvalues (normalised) are calculated (Woodcock, 1977). The eigenvectors are plotted in a lower hemisphere diagram together with the common great circle of the two eigenvectors with the larger eigenvalues.

Numerical output comprises the great circle fit which describes how the data are arranged along a great circle (Wallbrecher, 1986). Cluster distributions yield values near 0%, great circle distributions near 100%. If the great circle fit is larger than 50%, the circular aperture is printed. It describes the size of the section of the great circle with unimodal circularly distributed data (von-Mises distribution, Wallbrecher, 1986). If the great circle fit is smaller than 50%, the small circle fit is printed. It describes how close data resemble a radial-symmetrical distribution and becomes 100%, if the data form clusters or small circles and 0% if the data are distributed along great circles.

7.2. Faults

7.2.1. Correction

Most field measurements of fault data with the Clar compass are not exact, the lineation not exactly lying on the fault plane. To avoid calculation errors, the lineations are brought onto the fault plane (Command "Correct Data" in the "File" menu). The lineation and the pole to the fault plane define an auxiliary plane that intersects with the fault plane. The intersection of this auxiliary plane and the fault plane is taken as the corrected lineation. The file name extension ".cor" is added to the file name during the operation.

7.2.2. Paleostress calculation

During the last twenty years a number of methods for calculating the paleostress tensor have been presented: e.g. direct inversion (Angelier, 1979), numerical dynamical analysis (Spang, 1972), analysis of pressure and tension axes (Turner, 1953; Marrett and Allmendinger, 1990) and the right dihedra method (Angelier and Mechler, 1977). Most of these algorithms are only applicable to datasets with certain geometries or a large amount of data (e.g. Sperner et al., 1993). Therefore, depending on the geometry of the dataset, one individual method may be more suitable for calculating the paleostress tensor over others. All methods mentioned previously are available in both programs (Table 3).

Table 3

Numerical results of direct inversion as displayed in TectonicsFP

```
Filename: E:\normal.cor
Plot name: normal.cor
Plot type: Direct Inversion – Sigma123 shown as stress
axes
Sigma1: 138 / 84
Sigma2: 296 / 06
Sigma3: 026 / 02
Stress ratio: 0.1425
Datasets total: 23
Sense substituted: 1
Negative sense expected for 1 datasets
No. fault lin. se er delta
001 192/82 191/82 dn 04 78
002 030/63 029/63 dn 05 20
003 169/80 241/60 dn 03 72
004 182/66 228/57 dn 14 42
005 190/73 215/71 dn 01 55
006 186/82 242/76 dn 04 78
007 209/50 213/50 dn 10 10
008 206/49 195/49 dn 01 01
009 042/78 002/74 dn 03 57
010 038/85 037/85 dn 03 74
011 318/85 015/81 dn 05 53
012 201/60 173/57 dn 10 25
013 204/66 203/66 dn 03 36
014 188/82 218/81 dn 05 78
015 192/50 191/50 dn 01 03
016 034/75 041/75 dn 00 48
017 025/45 023/45 dn 08 19
018 022/65 055/61 dn 08 24
019 195/66 180/65  05 38, * nev
020 200/65 189/65 dn 01 34
021 230/63 185/54 dn 11 24
022 220/70 231/70 dn 11 43
023 340/30 011/26 dn 11 54
```

Listed are stress axes (Sigma1–3) and ratio and total number of data. For datasets with unknown sense of shear, reverse movement is assumed for calculation. Those data are marked by asterisk. Opposite sense of movement in respect to calculated stress tensor is expected for data labelled with "nev" (negative expected value). "er" (error) denotes dihedral angle between measured lineation and direction of calculated maximum shear stress. "delta" is dihedral angle between measured lineation and stress vector (cf. Sperner et al., 1993).

For determination of the paleostress tensor, the most important step is the splitting of inhomogenous data sets from an outcrop into homogenous subsets (Sorting step, Section 6.1, Fig. 2). From the cogenetic subsets, the best fit theta angle (angle of internal friction) can be calculated by iteration (option "P–T-axes" in the "Calculate" menu), under the assumption that a single friction angle is valid for all data. The best fit theta angle is needed as an input parameter for the calculation of kinematic axes and for paleostress calculation with the NDA method (see later). The mean vectors of the P-,
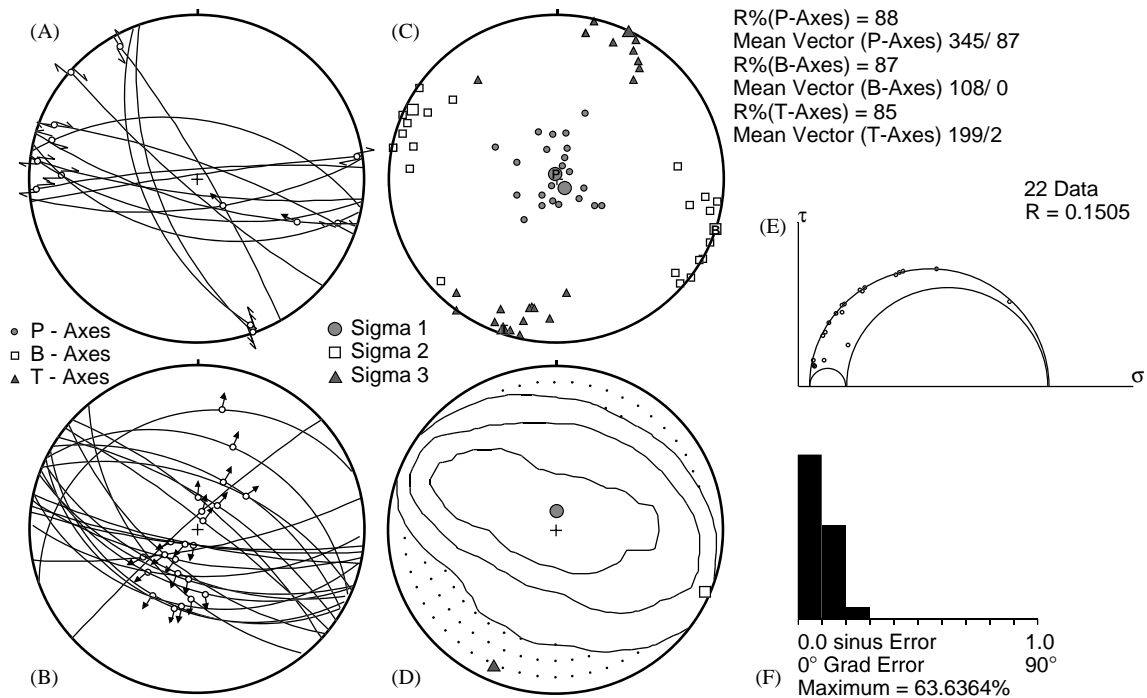
Fig. 4. Example of paleostress analysis (graphical output of TectonicVB): (A) & (B) Homogeneous data subsets after sorting of inhomogeneous data set. (C) kinematic axes of dataset B with mean vectors (large circle, square and triangle marked with P, B and T, respectively). For comparison, main axes of paleostress ellipsoid resulting from direct inversion are plotted into diagram. (D) contoured dihedra and stress axes as obtained by right dihedra method for dataset B. (E) dimensionless Mohr circle for dataset B. (F) fluctuation histogram for dataset B.

B- and T-axes represent an approximation to the main stress axes (Fig. 4C).

A different approach to calculate the orientation of the stress tensor is the right dihedra method of Angelier and Mechler (1977)—option "Dihedra" in the "Calculate" menu. For a given fault plane, all possible positions of the compression axis on a grid, with the resolved shear stress parallel to the slip direction in accordance with the shear sense form the compressive dihedra. All compressive dihedra of a fault set are superposed and contoured. The exact positions of the axes of the stress ellipsoid are given by the eigenvectors of the superposed compressive dihedra (Fig. 4D).

Additionally, it is possible to calculate the complete paleostress tensor (the orientation and the relative magnitudes of the axes of the stress ellipsoid, expressed by the *R*-value) by direct inversion (Angelier, 1979) or by numerical dynamic analysis (Spang, 1972; options "Direct Inversion" and "NDA" in the "Calculate" menu. The direct inversion method minimizes the angles between the calculated directions of maximum shear stress acting along the fault planes (β) and therefore only works with data sets where the fault planes are distributed homogenously in space. The numerical dynamic analysis calculates the orientations

of the principal axes of the paleostress tensor from the summation of individual tensors for every plane (i.e. the P–T-axes) and then minimizes the angle. The results of the calculations are stored in a table which can be displayed on the screen (option "Show Data" in the "File" menu on Mac; automatically displayed in the results window on Windows).

The orientation of the principal axes of the paleostress tensor are displayed either in a plot with the principal axes of the stress ellipsoid, or in a dihedra ("beachball") plot showing the compressive and distensive dihedra of the stress tensor (options "Sigma 1/2/3" and "Fault Plane Solution" in the "Plot" menu).

The quality of the calculation is checked in the normalised Mohr circle plot for three-dimensional stress (option "Mohr Circle" in the "Plot" menu), where the relative values of shear (τ) and normal stress (σ_n) are shown (Fig. 4E). The shear conditions for each fault plane are calculated after a graphical solution by Wallace (1951).

In the fluctuation histogram (option "Fluct. Histogram" in the "Plot" menu), the angular deviation of the calculated maximum shear stress in the fault plane from the measured striae is plotted in a histogram (frequency [%] on the vertical, and sine of deviation angle on the

horizontal axis, Fig. 4F). The maximum of the deviations in the far left and a steep slope towards the right of the diagram indicates a homogenous dataset, whereas a deviation larger than $20°$ or a second maximum indicates a heterogenous data set.

8. Future plans

It is planned to merge both programs into a common Java project to produce a single interplatform shareware product. A major new feature will be the access of tectonic data directly from databases.

8.1. Availability

TectonicVB is a freeware program and can be downloaded from http://geopal.uibk.ac.at/tvb/front.html.

TectonicsFP offers a freeware version with restricted graphics export which can be downloaded at http://go.to/TectonicsFP

Acknowledgements

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