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MICROCOMPUTER TECHNIQUES AND APPLICATIONS

Microcomputer software for structural geologists

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Abstract—Many microcomputer programs allow efficient storage, manipulation and analysis of structural data These programs can facilitate traditional analyses by accelerating time consuming graphical and numerical methods as well as allowing new quantitative analytical procedures that would be either impossible or impractical without an easily accessible computer Excellent programs exist that store and manage structural data, display and analyse orientations, analyse strain in brittle and ductile rocks, and model folded and faulted strata The essential characteristics of the best of these programs are reviewed and guidelines for software selection suggested

INTRODUCTION

THE increased accessibility of cheap and powerful microcomputers and geologically relevant programs has provided new tools with which to analyse complex and multivariate deformation processes in three-dimensional space and time In surveying software to assist with these tasks we have concentrated on the two main hardware architectures for personal computers, IBM PCs (and compatibles) and Apple Macintoshes There are hundreds of different models of computers from dozens of manufacturers claiming compatibility with the IBM PC standard. The property they have in common is that they run the MS DOS or PC-DOS operating systems In contrast, Macintoshes are made only by Apple and have their own operating system.

The highly competitive PC compatible market led to machines of this type being cheaper than Macintoshes. The graphical user interface of the latter, however, quickly enabled first time users to become proficient in using the computer During 1990, however, the MS Windows 3 graphical user-interface became available for PC compatible computers, and Macintoshes now compare in price with many PC compatibles. Which computer to buy is now likely to depend on which can run your favorite software

Software of interest to geologists can be divided into two categories: general purpose and geology specific. General purpose software has greatly increased efficiency in the earth sciences where its advent has coincided with a transition from descriptive to quantitative methology. Many geoscientists now rely on spreadsheet and database programs to organize and manipulate their data. Graphing modules in many integrated packages allow hypotheses to be visualized and tested efficiently. Computer aided drafting (CAD) programs ease the preparation and modification of diagrams and accelerate the construction of balanced cross sections.

Geology specific software, which automates traditional procedures and applies new, numerically intensive methods, has become increasingly powerful and accessible. Of particular interest to field and structural geologists are programs to (1) store and manage structural data; (2) display and analyse orientations; (3) analyse strain in brittle and ductile rocks, and (4) model folded and faulted strata. For the field geologist, these programs allow timely data analysis which can test hypotheses and delineate critical areas for future study.

This note is the outcome of a workshop "Microcomputers in the Field" organized by the Commission on Tectonics, a branch of the International Union of Geological Sciences. About 40 programs were examined before, during and after the workshop. In this note, we point out what features are available and important in programs of interest to field oriented structural geologists. We shall first outline features of general applicability and then look at each of the above four categories, identifying specific requirements and suggesting guidelines for software selection. Individual programs are not discussed, mainly because the programs examined at the workshop, almost all of which have since been modified by their authors, represent only part of the software in existence. A list of the programs examined is, however, given in the Appendix.

GENERAL FEATURES

Non-commercial software can be considered as either shareware or public domain. Shareware and public domain products can be copied (beware of viruses!), but users of the former are asked to send a small fee to the author. Software acquired by this method can be outstanding but may be idiosyncratic if it grew out of the author's own requirements, also, an author is under no obligation to provide the support and maintenance expected of commercial products. Most commercial software is well worth the investment, although users should obtain either a demonstration version, a money back guarantee, or high recommendations from a colleague before making a purchase.

A good program should have some of the following attributes.

(a) *Correct output:* the most insidious aspect of computer-aided analysis is the possibility of program errors. To check output from a program, it should be compared with results from manual techniques and other programs. The algorithms used by the program should be available as source code or reference citations. Major errors in commercial or shareware programs are rare.

(b) *Friendly user interface:* a 'friendly' interface allows users easy communication and rapid familiarization with a program. Interfaces may be either conversational (also known as sequential) or menu driven, of which the latter are generally easier to master. Interfaces are friendlier if prompts have modifiable default values, so that first time users can immediately produce output by pressing the ⟨Enter⟩ key, and an undo facility that returns users to the previous menu or prompt. On line help screens are useful for guiding users through program options. A friendly interface is case insensitive and recovers from erroneous replies without crashing. Macintosh programs are more standardized than DOS programs, so many Macintosh users require their programs to respect fully the standard Macintosh interface.

(c) *Comprehensive instructions:* most programs come with manuals or printable text files; on line help usually cannot provide all the information necessary to install and execute a program and interpret its results. Tutorials and sample data files are useful.

(d) *Device compatibility:* users need to evaluate their computers for input and output device compatibility with programs. While Macintosh devices are fairly standardized, the large range of devices available to IBM PC compatible computers puts the responsibility for checking hardware compatibility on users. Some programs will require specialist input devices such as digitizers, be sure that you know the exact requirements before buying.

(e) *Compatible and flexible input–output formats:* in addition to hardware considerations, users should ensure that programs support the input and output formats of their choice. It should be possible to input data to a program by identifying a data file, whilst some programs allow you to input data directly from the keyboard or digitizer. Many programs detect and recover from bad input data. Users should be sure that a program supports the output options appropriate to their needs, for example, high resolution laser printing for publication-ready diagrams.

(f) *Efficient, rapid analysis:* users should check that their hardware will run programs at acceptable speeds. In general, most programs do not require a math coprocessor and execute reasonably quickly, others only provide acceptable analysis speed with the math chip. For instance, one strain analysis we performed took over 2 h on a microcomputer without a math chip and 30 s on a compatible computer with a math chip.

STORAGE AND MANAGEMENT OF STRUCTURAL DATA

While data have to be carefully organized to allow hypotheses to be tested, individual programs require data to be presented in specific and differing formats. Users faced with these demands can benefit from using software specifically designed to store and manage data.

Data of interest to structural geologists are mainly (1) from maps and cross-sections where the physical dimensions of rock units and their bounding contacts are of greatest interest, and (2) descriptions of orientation or shape. Software for (1) comes under the general heading of "Geographical Information Systems" (GIS), that for (2) falls in the realm of more traditional databases and/or spreadsheets (DB/SS). A GIS is defined as a computer based system to capture, store, edit, manipulate and display geographically referenced data. Ideally, software to manage both types of data should be integrated such that one could, for example, identify part of an on screen map with a pointing device and go straight to a summary of the orientation or strain data from that area. However, the combination of GIS and DB/SS in one program, flexible enough to meet the needs of most users, remains a goal for structural applications.

Some 'hypermedia' programs such as HYPERCARD for Macintosh computers provide a short term bridge between GIS and DB/SS software. Such programs use a 'stack of cards' concept where a single file can have cards with maps and cards with orientation or other locality data. Different stacks can easily be linked with one another, and orientation data from the cards placed in text files as input to other programs. The programs are remarkably easy and flexible to use due to their modularity and the English like syntax of the programming language. Despite limitations in graphical resolution, hypermedia programs represent a good way of organizing data in graphical form where the map is mostly a pictorial guide to the location of data.

At a less sophisticated level, map data can be efficiently compiled and edited using general purpose CAD packages. CAD is also invaluable for drawing cross sections: the basic outcrop and drillhole data can be put on one layer and left untouched while multiple, easily modifiable interpretive overlays can be generated to create an optimum interpretation.

Most database packages, are commercial products not designed with the geologist in mind, but can be used to select and sort orientation data into subsets for analysis. The same can be said of spreadsheet programs that have a substantial number of database functions. However, the more powerful and flexible such a general purpose package, the more difficult it is to learn and use effectively.

The general purpose database and spreadsheet programs all provide a shell from which a dedicated structural data manager can be built. Implementation of such managers can be approached in two ways.

Firstly, most packages provide a menu driven front end allowing (1) creation of database/spreadsheet files, (2) entry of data into the defined data structures, and (3) extraction and formatting of data subsets. Although this requires little user training, the design of data structures and search queries is left entirely to the user who may initially be quite unfamiliar with such concepts. A long term problem is that applications developed in this way are likely to require such design decisions to be made afresh each time the package is used. This can lead to the very lack of standardization which use of a data management package should avoid. Such applications also require considerably more 'keying' to perform a particular task than might otherwise be necessary.

Secondly, programs using the high level language incorporated in most data management packages can be written. In this way, systems closely tailored to the needs of structural geologists can be devised. All design decisions can be programmed into the system to ensure standardization and full data validation and security can be established. Tailored systems are used by some geological surveys.

DISPLAY AND ANALYSIS OF ORIENTATIONS

Analysis of orientations, a central part of most structural projects, has traditionally involved the manual construction of stereoplots. Computer analysis has many advantages, and high quality stereoplotting programs, producing both graphical output and analytical measures of orientation clustering, are numerous. Most programs have additional features such as (1) the use of data type, geographical location and stratigraphic horizon to select subsets for plotting, (2) sophisticated statistical analyses, and (3) automated map based domain analysis. In general, the more a program does, the greater the effort involved in learning how to run it and enter data. Users should be careful not to acquire a program so complex that it never gets used.

A basic program for displaying and analysing orientations should have the following features.

(a) *Flexible data input formats*: many programs accept planar data as dip direction and dip, right-handed strike and dip, or strike, dip and quadrant, and linear data as trend and plunge, or pitch on a reference plane. In addition, many programs allow the rotation of orientations before processing. The ability to select and combine subsets allows greater analytical flexibility.

(b) *Multiple types of graphical output*: stereographic and equal-area projections, both lower and upper hemisphere, form the most important kind of output. Rose diagrams displaying two dimensional data can also be useful. The size of these diagrams should be specifiable. Planes can usually be displayed either as points, representing normals, or as great circles. Scatter plots, showing individual orientations as point markers keyed to a data subset, and contoured density diagrams are available in nearly all programs. Density, with user specified intervals, is indicated by area patterns or contour lines. Several methods of estimating density are available, although users should realize that the more complex the algorithm, the fewer the people able to interpret the diagram correctly.

(c) *Statistical analysis:* since orientations are entered as numbers, statistical analysis is easily accomplished

Moment of inertia analysis, in which the eigenvalues and eigenvectors of the orientation matrix are calculated, can provide a quantitative measure of orientation distribution and should always be available. Several programs provide advanced statistical analysis, sometimes using algorithms developed for paleomagnetic research. These are more appropriate to complex, multi cluster data sets than are moment of inertia techniques.

ANALYSIS OF STRAIN IN BRITTLE AND DUCTILE ROCKS

Although their numerical and graphical demands have hindered the application of strain analysis techniques, their use is being greatly accelerated by the increased availability of microcomputers and appropriate software.

In brittle analysis, faults of known orientations and senses of movement can be analysed to find: (1) the orientations of the smallest (P) and largest (T) infinitesimal strain axes for a fault; (2) the infinitesimal strain and rotation of a region due to a population of faults with known weighting using moment tensor summation, or (3) a regional average stress tensor. For the latter, computer based techniques assume that (a) stress in an area was relatively homogeneous and unmodified by faults, and (b) fault striae correspond to the direction of initial slip and maximum resolved shear traction on the fault plane.

Brittle deformation programs typically require the input of the orientation of several fault planes, their striae and senses of slip. The programs display these orientations and the strain (stress) axes on projections. Most programs devoted to inverting fault slip data for stress analysis find the orientations of the principal stress axes and a parameter giving the relative magnitude of the intermediate stress with respect to the other two. The moment tensor summation provides additional and complementary information, assuming that the geologist enters weighting information such as displacement, gouge thickness, or trace length. The last decade has seen a proliferation of different methods, so many programs provide access to multiple techniques. Some programs attempt to characterize the average internal friction of the region.

To analyse deformation in ductile rocks, several finite strain techniques need to be available because of the strengths and weaknesses of the various methods. Many programs implement a wide range of analyses, using R_f/ϕ and related methods to estimate object strain and center to center methods to estimate matrix strain.

Traditional graphical methods like the Fry and R_f/ϕ techniques can be implemented in generic spreadsheets and relatively simple plotting programs. Newer methods, such as the enhanced normalized Fry method, require manipulation of the data by a fast microcomputer with a math coprocessor. Before purchasing a strain analysis program, users should ensure that it can analyse enough objects for a statistically significant result.

Most ductile strain analysis programs require the user to acquire a text file of object locations and/or dimensions independent of the strain analysis program. Elliptical object shapes are best defined using least squares estimation of their centres and major and minor axes. Two dimensional object locations and dimensions can be determined using direct screen digitizing or a digitizing tablet. Screen digitizing can be accomplished by attaching a transparency of the sample to a computer screen with a 1:1 aspect ratio. However, errors due to perspective point distortion on curved screens and the limited resolution of computer screens make these techniques suitable for classroom rather than research use. Digitizing tablets have the advantage of higher accuracy, commonly to 0.1 mm. Most digitizing programs can write text files specifying the positions of points which can then be used as input to a strain analysis program. However, the tablets have a confusing variety of data collection and transmission modes, and so many digitizing programs are very hardware specific. Potential users should contact authors of digitizing programs for advice. These are sometimes included with strain analysis programs, and it would be worthwhile checking out details before buying a tablet. Advances in high resolution scanning and image analysis should improve the automation of data acquisition in the near future.

MODELLING OF FAULTED AND FOLDED STRATA

Modelling programs, which vary greatly in friendliness, sophistication and price, can test the feasibility of structural hypotheses. Most forward modelling programs for thrusts begin with undeformed strata and use the geometry of fault bend folds to generate a deformed cross sectional model with many episodes of deformation, each specifiable in terms of fault geometry and displacement. Backward modelling programs do the opposite. Some programs model fault propagation folds and listric normal faults. Some allow the user to specify that fault bend and fault propagation folds be associated with layer parallel slip, whereas others assume vertical simple shear. Many programs allow out of sequence faults and back thrusts. Most programs assume no movement of material oblique to the plane of section, which is thus assumed to be parallel to the direction of tectonic transport. In some programs, the original thickness of each stratigraphic unit is constant, in others it may be varied. Output can be either line drawings, showing the traces of stratigraphic contacts and faults, or text files where traces have to be drawn by hand using boundaries between different patterns. Some programs can model maps and block diagrams.

Programs for modelling folds are generally forward modellers, which may allow at least two episodes of deformation. The degree to which the user can control fold geometry and kinematics varies considerably.

SUMMARY AND CONCLUSIONS

Although the microcomputer revolution, which is affecting most aspects of the geological sciences, has been brought about mainly by advances in computer engineering and computer science, the efforts of geologists to capitalize on these advances are commendable Most programs of interest to structural and field geologists, whether public domain, shareware or commercial, are the product of a good understanding of the relevant geological principles as well as considerable programming effort on the part of their authors For well established niches of analysis like stereoplotting, geologists are advised to acquire software written by others rather than write their own because the quality of the computer programming has become extremely high. Although users should first try using shareware or public domain programs, they should not shrink from buying commercial software. The time saved and the analytical opportunities realised through the use of good geological software makes most commercial products remarkably good value

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APPENDIX

Below are listed the names of some of the geology specific programs examined during the workshop After each name are its main purpose, architecture (IBM compatible or Macintosh), owner, status (public domain (P), shareware (S), commercial (C) or under development (D)), cost and other comments

CLUSTRAN/DXN-STAT Two programs for statistical treatment of sets of two and three dimensional orientations IBM Good documentation S Gillett, 2395 Wildflower Dr , Carson City, NV 89704, U S A. (C) $500 (academic $100)

EG DBASE Database management of field data IBM C W Thomas, British Geological Survey, West Mains Road, Edinburgh EH9 3LA, U K (D)

FABRIC Display and analysis of orientations IBM J Starkey, Department of Geology, University of Western Ontario, London, Ontario, Canada N6A 5R7 (P) Can $5

FAULT Models thrust systems and fault bend folds with vertical simple shear IBM and Mac Good documentation M S Wilkerson & S I Usdansky, Wilkerson & Associates, 8 Villard Ct , Champaign, IL 61820, U S A (C) $495 (academic $195)

FAULT KINEMATICS Analysis of brittle deformation, finds "P" and "T" axes, carries out Molnar's moment tensor summation, applies P-T dihedra method of Angelier & Mechler Mac Good documentation R W Allmendinger, R A Marrett & T Cladouhos, Department of Geological Sciences, Cornell University, Ithaca, NY 14853 1504, U S A (S) $15 (academic), $100 (commercial)

FLTBND Models thrust systems with fault bend folds IBM B R Klappstein, Department of Geology, University of Alberta, Edmonton, Canada T6G 2E3 (D)

INSTRAIN Analysis of ductile strain, Fry, enhanced normalized Fry and R_f/ϕ methods IBM and Mac Good documentation E Erslev & D. McEachran, RockWare Inc, 4251 Kipling Street (Suite 595), Wheat Ridge, CO 80033, U S A (C) $200

OGS FIELDLOG Storage, processing and display of field data, provides a link between the commercial programs AutoCAD and dBase IBM Good documentation Precambrian Section, Ontario Geological Survey, 77 Granville Street, Toronto, Ontario, Canada M7A 1W4 (C) Can $20

ORIENT Display and analysis of orientations, establishment of cylindrical domains IBM Good documentation F W Vollmer, Department of Geological Sciences, S U N Y , New Paltz, NY 12561, U S A (S) $20

ROCKPIX Display and analysis of orientations, etc IBM Good documentation P Guth, 252 Lower Magothy Beach Road, Severna Park, MD 21146, U S A (S) $7 50

SCHMIDTMAC Display and analysis of orientation data Mac Paper in *Computers and Geosciences* A Pecher, Institut Dolomieu, 15 rue Maurice Gignoux, 38031 Grenoble, France (S) Ff 50

STEREO Display and analysis of orientation data IBM and Mac Good documentation D McEachran, RockWare Inc, as for INSTRAIN (C) $275

STEREONET Display and analysis of orientation data Mac Good documentation R W Allmendinger, as above. (S) $7 50

STRAIN SAMPLER Analysis of ductile strain, Fry and R_f/ϕ Mac D de Paor, Department of Earth & Planetary Sciences, The Johns Hopkins University, Baltimore, MD 21218, U S A (P) $7 50

THRUSTRAMP Models thrust systems with fault bend and fault propagation folds IBM and Mac Good documentation S Usdansky & R H Groshong, Wilkerson & Associates, as for FAULT (C) $495 (academic $195)

TRIPOD Display and analysis of orientations, axial projections, etc IBM Relevant FORTRAN code published, good documentation Gaia Software Inc , #340, 999 8th Street S W , Calgary, Alberta, Canada T2R 1J5 (C) Can $7500 (academic $900, demo $30)