S-CUBED

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INTERACTIVE GRAPHICS PACKAGE FOR THE MEGATEK 7250 TERMINAL OF THE SEISMIC ANALYSIS STATION AT THE CENTRE FOR SEISMIC STUDIES

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FINAL REPORT

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~~We have developed~~ This document describes five software modules, developed for the "maps" color graphics terminal (MEGATEK 7250) of the Seismic Analysis Station (SAS) of the Centre for Seismic Studies (CSS). These modules permit interactive graphic analysis of:

(1) Signal and noise windows selected from a seismogram for purposes of optimal interactive signal-to-noise filtering of raw data;

(2) Earthquake fault plane solutions; → over

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(3) Three-dimensional representations of geographic, tectonic and geophysical information on the surface of the globe.

(4) Two-dimensional maps in any of eleven different projections.

(5) Seismic rays and associated parameters such as travel-times in a spherically symmetric earth model.

Examples of screen displays are provided in this report together with a description of the capabilities offered by each module.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

I. INTRODUCTION

This is the final report for contract number MDA903-81-C-0521 covering the period 7 August 1981 through 6 August 1982. The principal objective of S-CUBED (S^3) under this contract was to develop an interactive graphics software package for the "maps" terminal of the Seismic Analysis Station of the Centre for Seismic Studies opened by DARPA in Rosslyn, Virginia.

This package was to be developed on a MEGATEK WHIZZARD 7250 intelligent color graphics terminal. The object of the software was to provide seismic analysts with (a) interactive access to computer-based geographical data, (b) graphic representation of seismic source characteristics and (c) graphic representation of seismic wave paths.

The software was developed at the S-CUBED plant in La Jolla, California, using a 9600 baud direct communication line to the computing facility at the Lawrence Berkeley Laboratory, Department of Computer Science and Mathematics.

The software was demonstrated at the Rosslyn Center for Seismic Studies on May 29, 1982. This report includes a brief description of the capabilities afforded by the five modules for which development was initiated under this contract.

In addition, the software development team shared its experience with other developers of the Centre for Seismic Studies at a DARPA workshop in Asilomar, California, June 6 through 10, 1982. Summaries of contributions to this workshop are included in a separate report: DARPA-GSD-82-04.

The Seismic Analysis Station (SAS) of the Centre for Seismic Studies (CSS) has been organized around two main components:

1. A MEGATEK 7000 monochrome terminal, used for the interactive display and manipulation of seismic waveforms.

2. A MEGATEK 7250 color terminal (the "map" terminal) dedicated to the display of geophysical information other than seismic waveforms -- maps, tectonic information fault plane solutions, wave paths — and to the specialized processing of individual seismic traces.

The effort accounted for in this report was for the development of software appropriate for use on the MEGATEK 7250 terminal, used in serial mode over a remote communication link.

The hardware was delivered at S-CUBED on February 1, 1982, and was transfered to CSS on April 23, 1982. Demonstration of the software at the CSS computing facility was prepared between May 1, 1982 and May 28, 1982 and conducted on May 29, 1982.

The development of this package was seriously impaired by a major hardware failure on March 25, 1982. Nevertheless, the basic functionality of the package could be restored in time for the May 29, 1982 demonstration.

The results of this development effort consisted of five major modules which are described in the following pages.

1. A module for interactive, signal-to-noise optimal filtering of seismic traces.

2. A module for interactive determination of earthquake fault-plane solutions.

3. A module for interactive display of tectonic, seismological, and geographical information in three dimensions.

4. A module for interactive construction of two-dimensional maps in eleven different projection systems.

5. A module for two-dimensional calculations and display of body-wave ray paths in a spherically symmetric earth model.

II. INTERACTIVE SIGNAL-TO-NOISE FILTERING OF SEISMIC TRACES

This module uses an estimate of the signal-to-noise spectral ratio in a seismic trace to help the user design a filter interactively. The filtered trace possesses enhanced S/N ratio and permits easier identification and picking of phases. Briefly, the procedure runs as follows. The user keys-in the name of an event and of a station and channel through which the event was observed and recorded. The selected seismogram is displayed at the top of the screen. The user then selects a signal window and a noise window. The frequency spectra calculated from the two windows are displayed in a log-log plot in the lower left of the screen.

The power ratio of signal-to-noise is plotted on the same frequency scale as the spectra in the lower right. The user may then select a frequency band in which signal/noise ratio is high. The frequency limits selected by the user are then taken to be the corner frequencies of a three-pole bandpass Butterworth filter. The entire time series is then filtered (forwards and backwards) and the result displayed immediately below the original trace. In the current implementation, the user can then pick phases interactively using either the original or the filtered seismogram.

The code is simultaneously command-driven (for the solution of traces to be analyzed) and menu-driven (for the manipulation of the display, and selection of frequency and time windows). In tests executed to date, it has proved to yield a superior selection of the filter parameters required to isolate a seismic signal from a noisy seismogram.

Figures 1 and 2 illustrate the main capabilities of this code as well as the screen display made available to the user upon execution.

SEISMIC ANALYSIS STATION

SPECIALIZED PROCESSING OF SEISMIC TRACES

- Signal-to-Noise Interactive Filtering.
- Menu-Driven, Joystick Controlled.
- Color Coded Display.
  - Interactive Scaling and Scrolling of Seismic Trace.
  - Selection of Noise and Signal Windows.
  - Display of Amplitude Spectra and Dimensionless Signal-to-Noise Spectral Ratio.
  - Selection of Pass-Band.
  - Phaseless Filtering of Trace and Display of Filtered Time Series.
  - Interactive Timing of Either Filtered or Original Trace.

Figure 1.

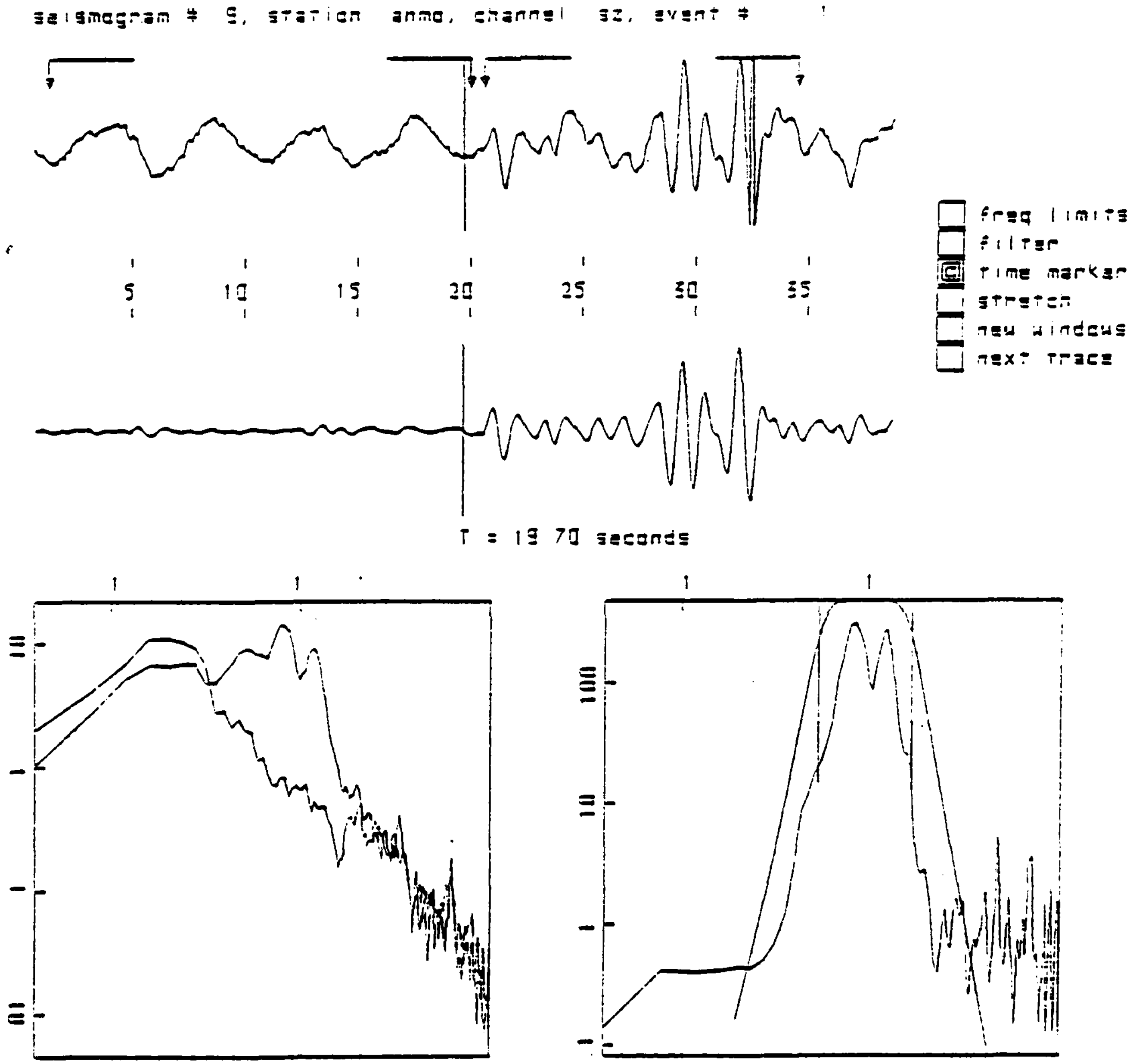

Figure 2. Screen display and management for the signal-to-noise filtering module for specialized processing of seismic traces.

III. INTERACTIVE DETERMINATION OF EARTHQUAKE FAULT PLANE SOLUTION

The determination of fault plane solutions based on the polarity of P-wave first motions is a well known procedure. It is also notoriously difficult to implement in the form of an automatic algorithm because it does not lend itself to treatment by classical inversion techniques. In particular, many subtle features in the data often require input which reflects more the analyst's judgment than quantifiable properties of the observations. For example, whenever two observations are in conflict, a fact which can only be determined when the entire data set has been assembled and a solution has been attempted, this conflict can usually be resolved only as a result of a choice made by the analyst as to which datum takes precedence over the other one. This choice in turn depends on information known to the seismologist, but which is often nonquantitative, and difficult to track. For example, ancillary information, such as "This station is usually a high quality, reliable station", can be included in a knowledge base pertinent to this particular problem, but can be used only by a program endowed with "expert system" characteristics.

We have developed a program which circumvents these difficulties by relying on an effective analyst-machine interaction. This is a menu-driven interactive program designed to position the nodal planes relative to first motion data plotted on the focal sphere by manipulating a three-dimensional image of the focal sphere. It is implemented on a VAX 11-780 computer under the UNIX operating system, but is written in standard FORTRAN 77, so as to be as transportable as possible. The interactive device is a MEGATEK 7250 intelligent color graphics terminal, equipped with joystick, key pad, and keyboard accessories. The basic graphics software package called by this module is the WAND* package. Current implementation is for terminals equipped with an RS-232 serial interface, but this has negligible impact from a user's point of view since speed of execution is not a limiting factor.

Our experience with this program shows that a new user with no prior training in the determination of focal solutions can learn how to use it in less than one hour. A trained analyst can determine a solution (or a composite solution) in at most a few minutes for any given event. The program also generates standard graphical (equal area) representations of the solution as well as a complete description of the nodal planes and slip vectors (strike, dip, rate and plunge). Figure 3 summarizes the capabilities of the code, and Figures 4 through 7 depict various views of the focal sphere accessible to the analyst via menu selections.

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*WAND is a copyrighted software package from the MEGATEK Corporation.

SEISMIC ANALYSIS STATION
EARTHQUAKE FAULT PLANE SOLUTIONS

- Interactive Focal Solutions from P-Wave First Motions.
  - Menu-Driven, Joystick and Keypad Control.
  - Color Coded Symbols.
- Interactive Displays (Orthographic Projection).
  - Positioning of Nodal Planes Relative to Data on Focal Sphere.
  - Positioning of Data Relative to Fixed Nodal Planes.
  - Output of Current Solution (Strike, Dip, Rake, Plunge).
  - Convenient Composite Focal Solutions.
- Noninteractive Displays.
  - Equal Area (Lambert-Schmidt) Representation of Current Solution.
  - Equal Angles (Wulff) Representation of Current Solution.

Figure 3.

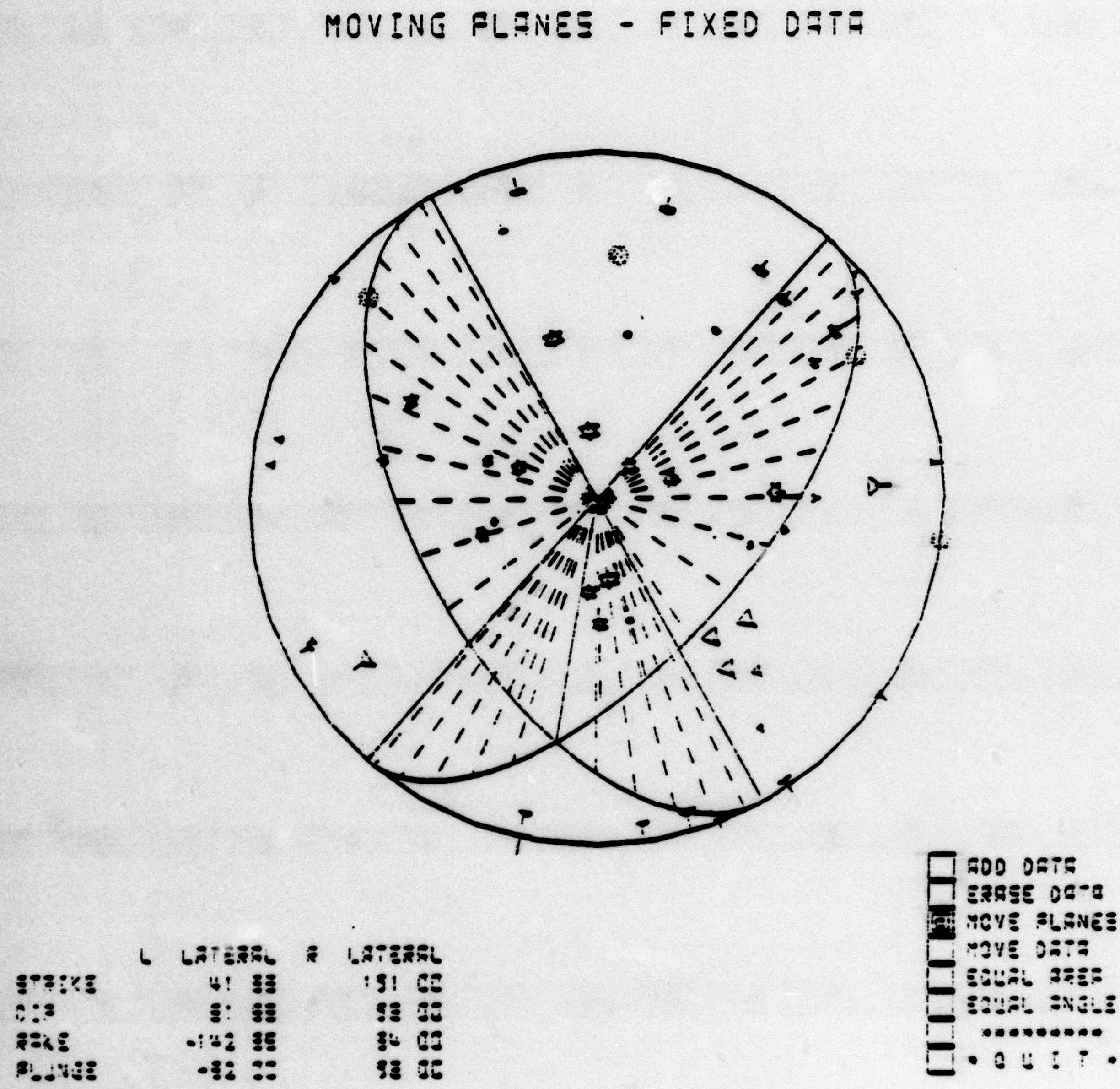

Figure 4. Screen display for orthographic projection of the focal sphere and nodal planes for interactive determination of focal solutions.

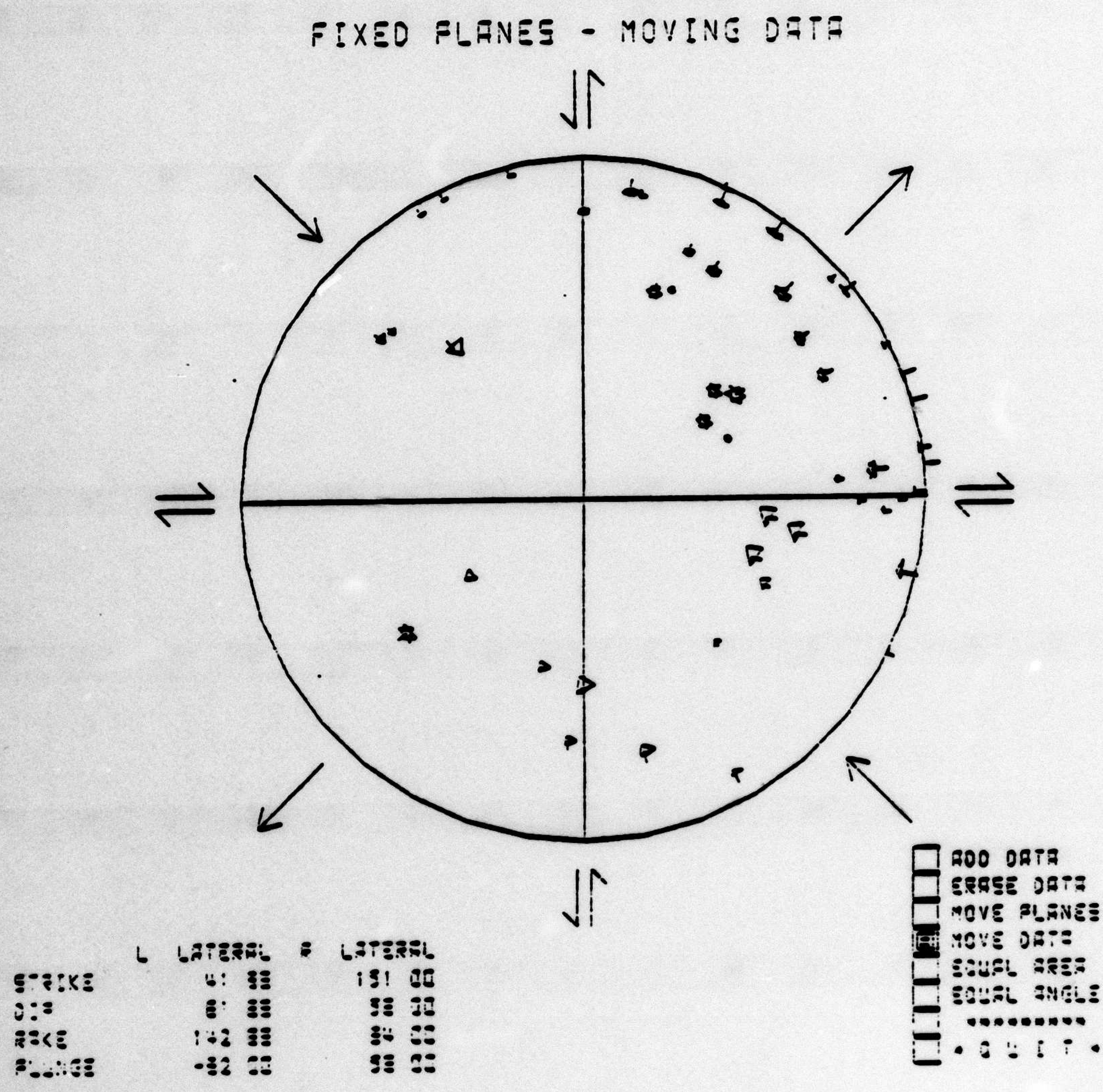

Figure 5. Screen display of quadrantal distribution of earthquake first motions on the focal sphere.

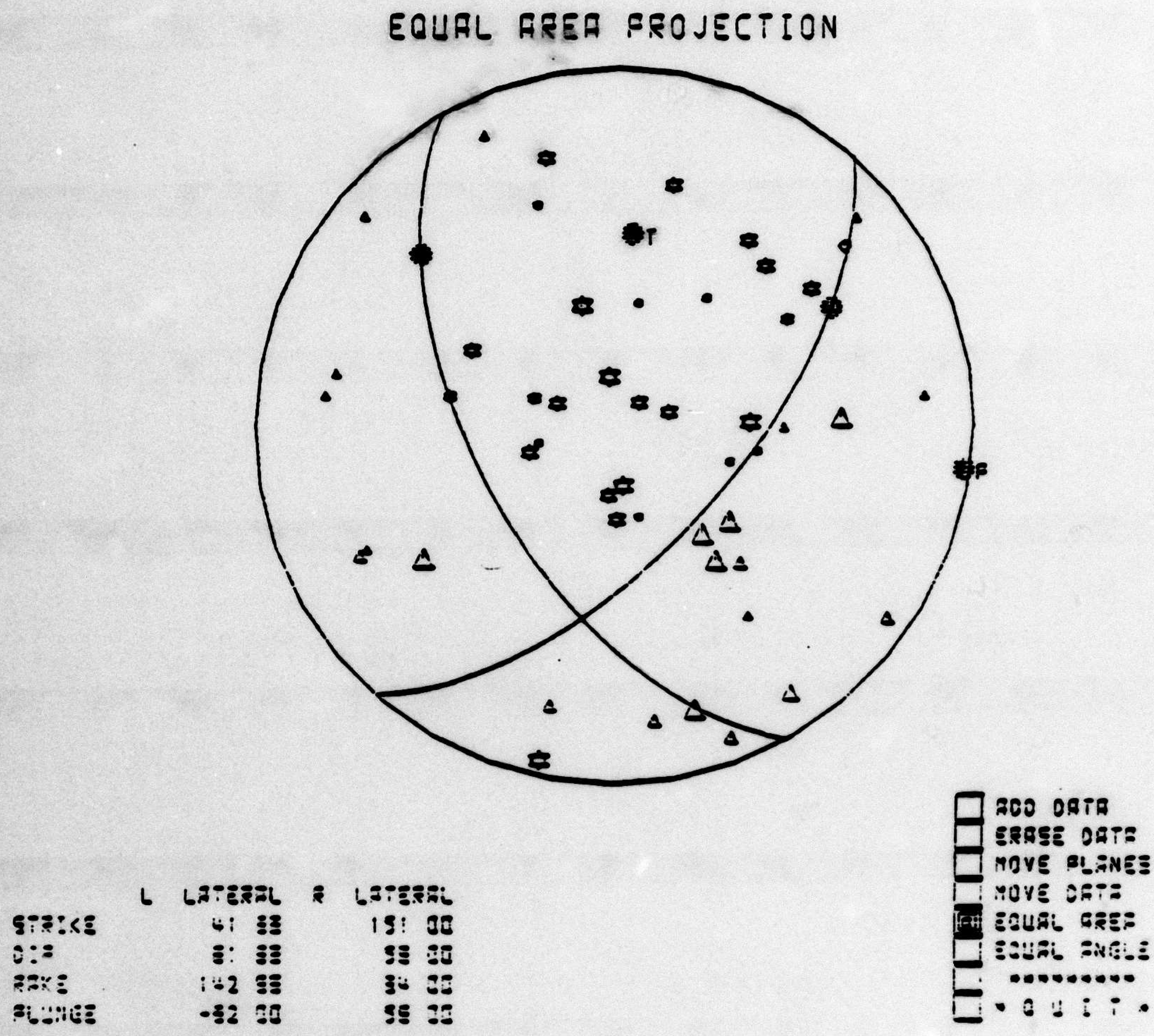

Figure 6. Equal-area (Wulff) projection of the focal sphere.

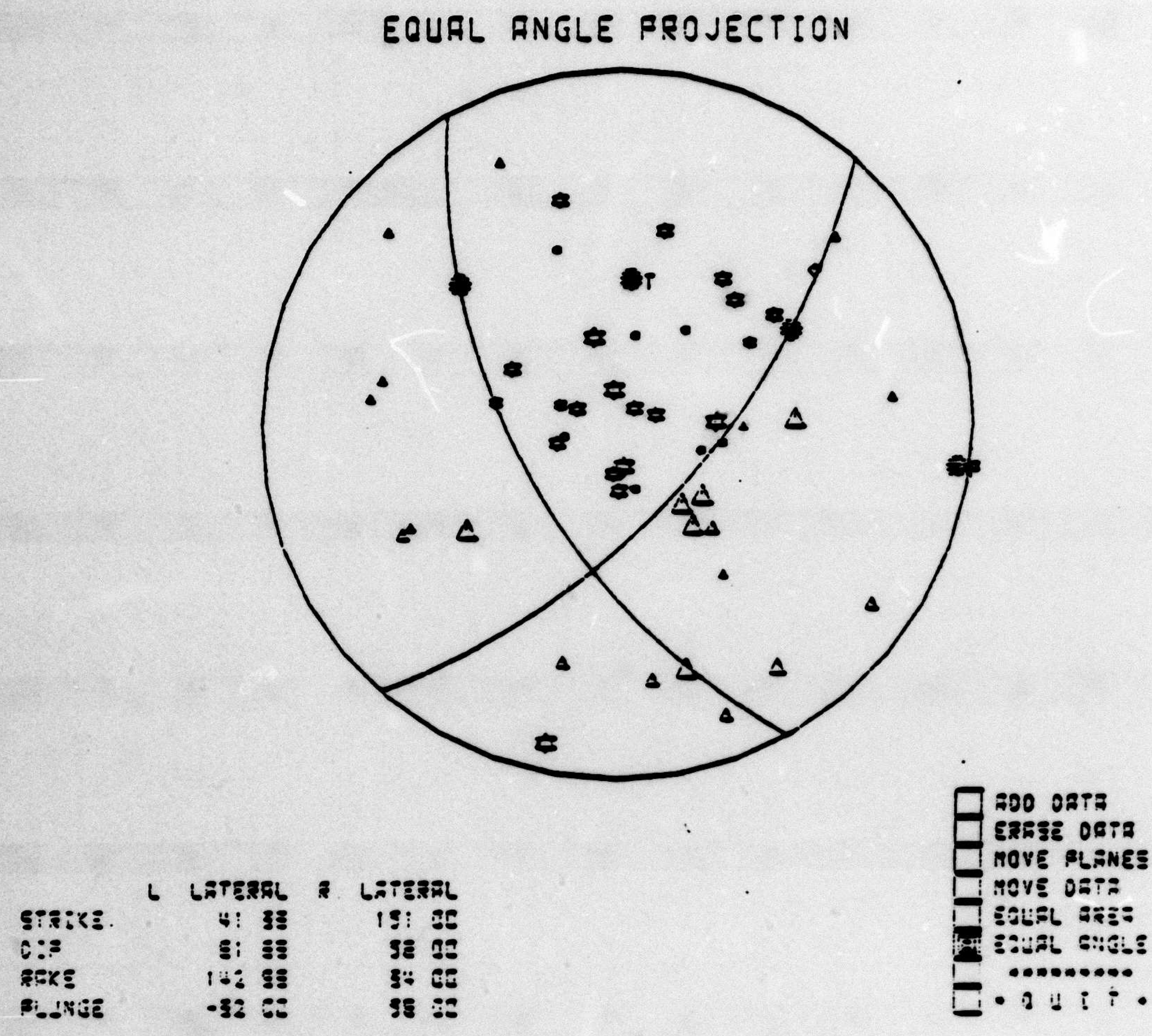

Figure 7. Equal angles (Lambert-Schmidt) projection of the focal sphere.

IV. THREE-DIMENSIONAL GEOGRAPHICAL, TECTONIC, AND SEISMOLOGICAL DISPLAYS

In the process of analyzing seismic data, seismologists repeatedly need to refer to geological and geographical information. As an example, it is often important to know which proportion of a great circle path crosses oceanic structures versus shields or orogenic crust and upper mantle structure.

The three-dimensional display package developed at S-CUBED, constitutes a first step toward making such decisions in a convenient, computer-oriented environment. It is a menu-driven interactive program designed to display and manipulate geological, geographical and geophysical information, and to place this information at the analyst's fingertips. It is implemented on a VAX 11-780 computer under the UNIX operating system, but is written in Standard FORTRAN 77, so as to be as transportable as possible. The output device is a MEGATEK 7250 intelligent color graphics terminal, equipped with keyboard, key pad and joystick peripherals.

The basic graphics software used in this code is the WAND graphics package, modified for operation under UNIX. The current version of the program is designed for terminals equipped with an RS-232 serial interface. The only significant impact of this configuration from a user's point of view is that program initialization is speed-limited by the serial interface and takes from one to two minutes, depending on the user load on the host computer.

Figure 8 summarizes the features of the software module. Figure 9 shows an example of screen display which can be constructed using this program. Manipulation of this display can be performed using the menu selection shown on Figure 10.

SEISMIC ANALYSIS STATION
THREE-DIMENSIONAL DISPLAY OF THE EARTH

- Three-Dimensional Interactive Display.
    - Joystick - Controlled Rotation and Zoom.
    - Interactive Handling of Up to 20 Lat-Lon Pairs (Pick-List).
- Geographical Information (Coastlines).
- Regionalized Tectonic Map (Jordan, 1981).
- Overlays.
    - Markers at Points Selected from Pick-List.
    - Display Event and Recording Stations.
    - Seismicity Catalogues.
    - Great Circle Paths.

Figure 8.

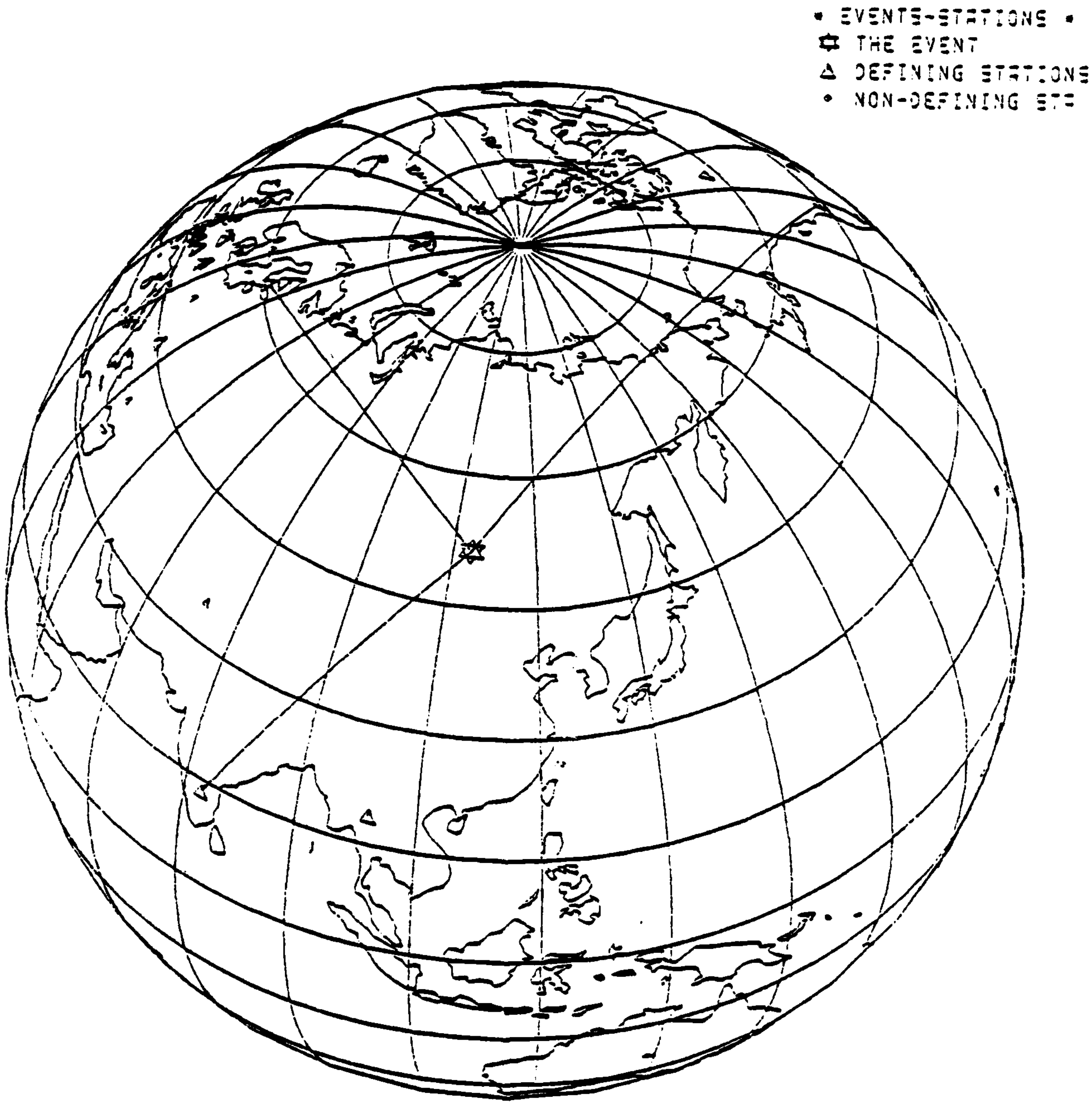

Figure 9. Screen display of the globe showing geographical information, as well as surface wave paths from a seismic event to various seismic stations.

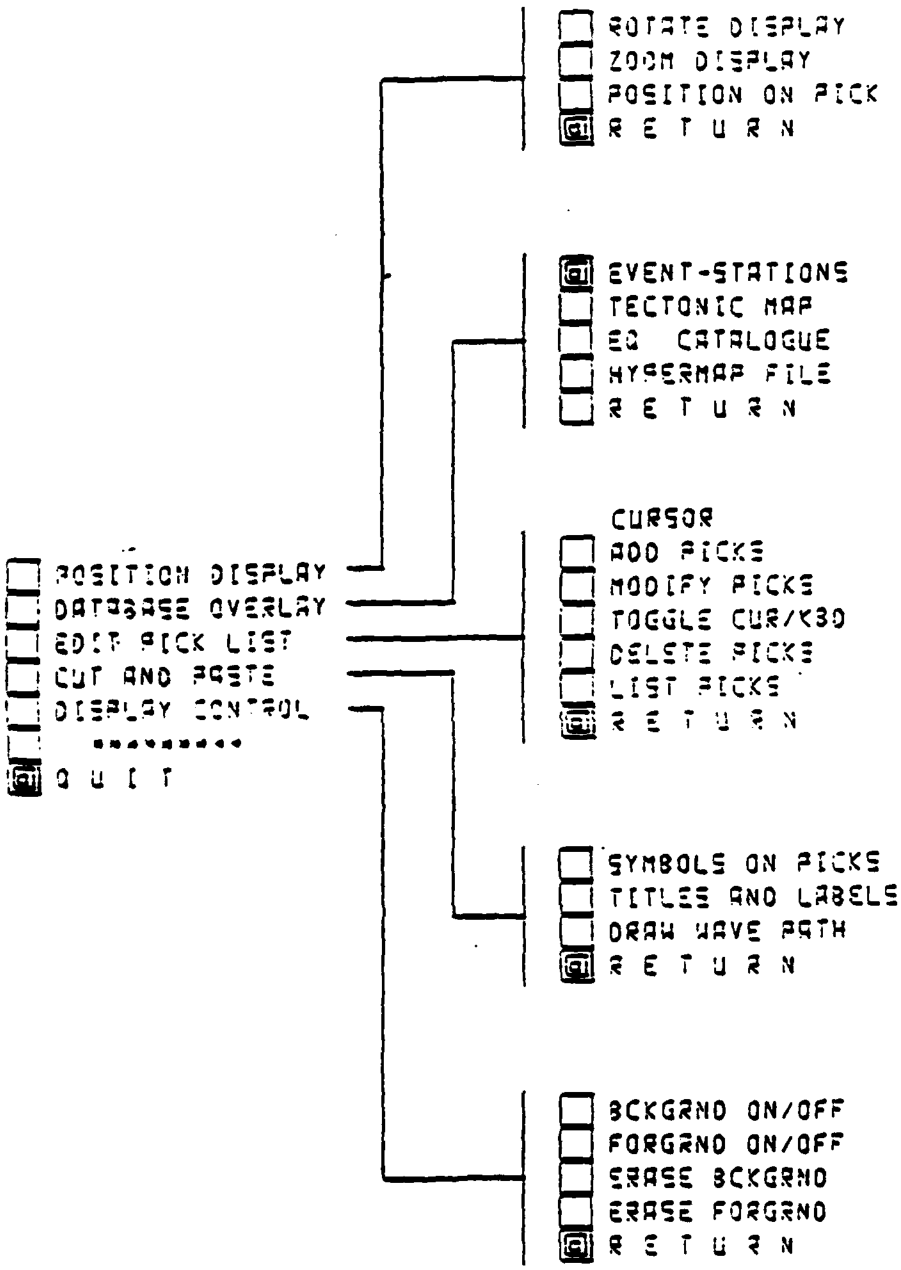

Figure 10. Menu Tree illustrating the range of interactive capabilities available for three-dimensional displays.

V. TWO-DIMENSIONAL MAP CONSTRUCTION

The program which draws static map projections on the MEGATEK 7250 is an adaptation of a program called SUPERMAP which originated with Dr. Robert L. Parker at the University of California, San Diego. Many different versions of this software have found their way onto various computer systems around the seismic community, notably an interactive implementation due to Carl Johnson on the CAL-TECH PRIME. Many of the commands available in this latter version have been retained, and some new ones which facilitate special features of the UNIX/MEGATEK environment have been added. The user interface has been reworked for UNIX/FORTRAN 77 compatibility and, where practical, format-free input has been substituted for the old columnated form. The command syntax is nearly identical to the original, which acted on the first four characters of the first word in each command line and used the remaining words as arguments to the command.

In this version, commands need not begin in the first character position since the scan of the command line begins at the first nonblank character. Blanks and commas are treated as delimiters and any extra blanks between words are ignored. Arguments to commands are words which appear after the command word of which the first six characters are retained, the remainder being discarded. One essential feature of the current version of SUPERMAP resides in its capability to take input from a script. Switching between script input and interactive input offers a convenient way for the routine user to construct complicated maps interactively, by relying on scripts to produce a base map, and by relying on interactive inputs to produce and display information which is specific to the current task. Furthermore, the code makes use of the hardware capabilities of the MEGATEK 7250 by allowing the user to "zoom and pan" the display and focus his attention on a portion of the map which is particularly relevant to the task at hand. The capabilities of this mapping package are summarized in Figure 11., and Figure 12 shows an example of the types of displays which can be generated interactively on the screen using this software module.

SEISMIC ANALYSIS STATION

TWO-DIMENSIONAL INTERACTIVE MAP CONSTRUCTION

- Interactive, Command-Driven Two-Dimensional Mapping Program (Parker, 1967).
    - Concatenation of Keyboard Input and Command Files Permits Convenient Construction of Maps in Any of Eleven Different Projections.
    - Specialized Commands for Display of Seismicity Catalogues. Event and Stations and Labeling.
    - Fifteen Colors Available.
- MEGATEK - Specific Features: Zoom and Translation.
    - Joystick and Keypad Interactive Control.

Figure 11.

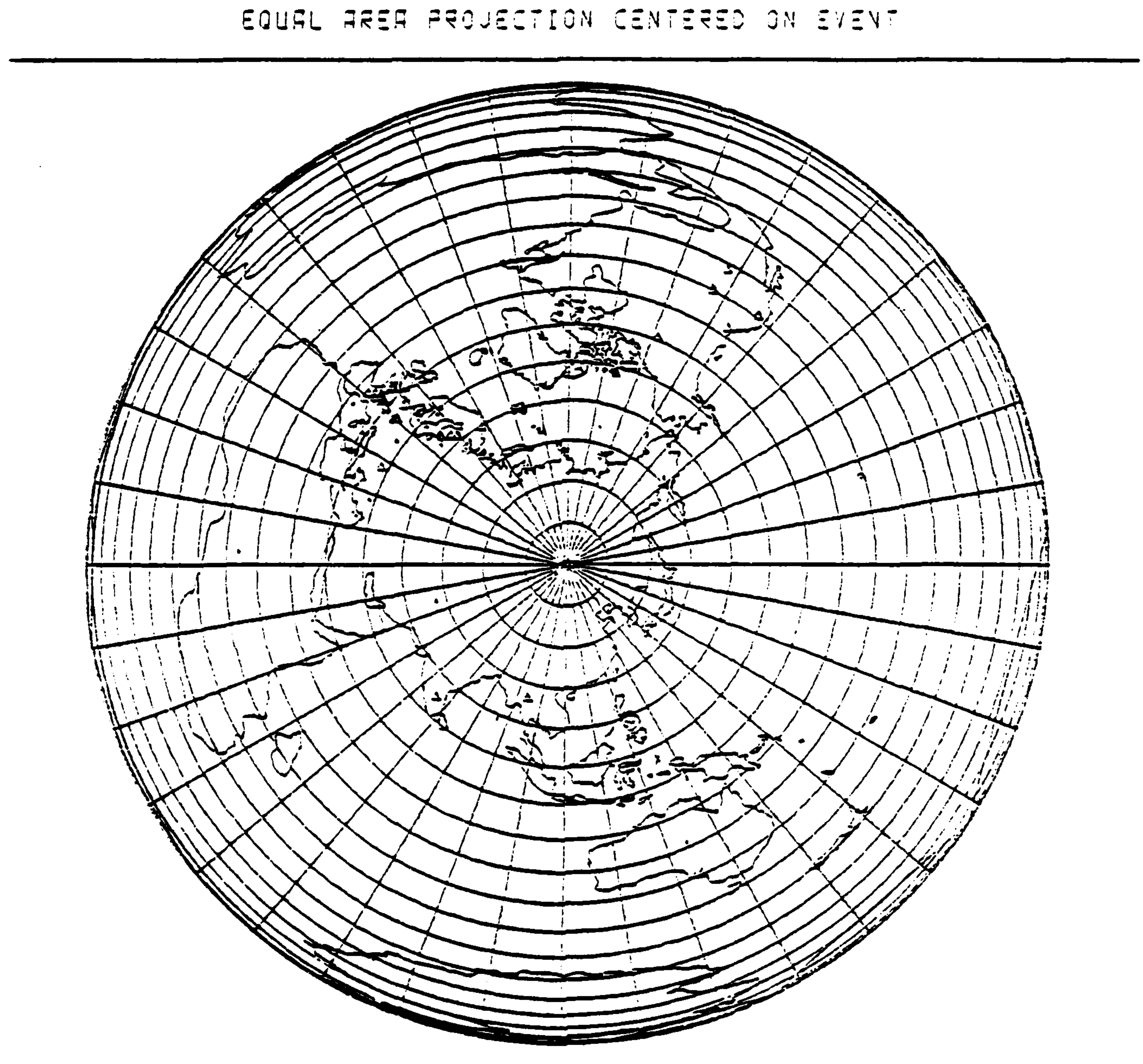

Figure 12. Example of a two-dimensional equal-area map projection centered on a seismic event. This type of projection is particularly useful for the study of station coverage used in locating the hypocenter.

VI. TWO-DIMENSIONAL RAY-TRACING IN A SPHERICALLY SYMMETRIC EARTH MODEL

This package invokes a system that calculates ray paths and travel times of various body wave phases and provides an interactive system for displaying the results graphically. The earth model used for the calculations has a simple, free-form format that is easy to generate or modify. The current implementation of the program uses spherically symmetric earth models. The numerical results of the calculations are written in a line-image file which can be printed as it stands (e.g., in the form of travel-time tables) or read for further processing by other parts of the system.

As it performs its calculations, the program generates a set of five graphic displays which can be brought up for presentation in any sequence desired by the user. The five displays are:

1. The earth-model, in which the P-wave velocity, the S-wave velocity, and the density are plotted as a function of depth (or radius).

2. Ray paths, which are plotted on a cross-section of the earth. Tick marks at 60 second intervals indicate elapsed time along the path and also given an indication of wave-front shapes.

3. Tau versus p, which is a plot of intercept time, tau, in seconds as ordinate versus ray parameter p in seconds/degree.

4. p versus delta, which is a plot of ray parameter p in seconds/degree versus range, delta, in degrees.

5. Travel-time, which is a plot of reduced travel-time t-u* delta in seconds versus range delta in degrees. The reducing slowness u in seconds per degree is adjustable.

The system maintains a list of phases which the user can specify. Phase-names are composed of characters from the reduced alphabet P, S, I, J, K, p, s, i, c. We do not give the syntax for writing acceptable phase-names; suffice it to say that no leading or imbedded blanks are allowed and that most simple sequences obeying the standard conventions will pass the test. As presently configured, the system can accommodate 12 different phases at a time and as many as 100 rays per phase.

The most important restriction currently imposed on phase names is that the system will reorganize the ray sequence so as to minimize the number of conversions. For instance, PSPSPS is calculated as PPPSSS, which gives the wrong ray path, but the correct travel-time curve.

The plot of the earth model stands by itself in that it is not directly related to other plots. In all other displays, a color-coded list of phases is presented in the lower left area of the screen. Each phase is assigned a unique color which is used in listing its name and for any graphic element such as a ray or a curve associated with that phase.

The graphics display is controlled by menu selection. A list of all menu items is supplied in Figure 13. As indicated there, most options are available from three or four displays. When a blinking cursor appears in a menu area, it indicates that the system is idle and waiting for the user to make a selection. To make a selection, the user maneuvers the cursor by means of the joystick. When the cursor is in the box associated with the desired operation, he presses the button on the end of the joystick. A summary of the features afforded by this package is provided in Figure 14. Figure 15 depicts the screen image resulting from the menu selection requesting the earth model. Figure 16 shows ray paths for three families of compressional wave arrivals, as well as illustrates the available menu selection. Reduced travel time curves for the same rays are shown on Figure 17.

	earth model	ray-plot	τ vs delta	delta vs p	travel-time
plot model		X	X	X	X
plot rays	x		x	x	x
plot tau vs p	X	X		X	X
plot p vs x	X	X	X		X
plot tot	X	X	X	X	
SHIFT	X		X	X	X
ZOOM	X		X	X	X
LOCATOR	X		X	X	X
BLANKING		X	X	X	X
NEW PHASE		X			
CHANGE U					X
RETURN	X	X	X	X	X

Figure 13. List of available menu items for two-dimensional ray-tracing package.

SEISMIC ANALYSIS STATION
TWO-DIMENSIONAL SEISMIC RAY CALCULATIONS

- Ray-Tracing in Spherical Earth Model.
  - Command (Keyboard) and Menu (Joystick) Driven.
- User Specified Earth Model and Source Depth.
- Ray Selection by Phase Name.
- Color Coded Displays.
  - Earth Model.
  - Ray Paths.
  - Travel-Time Curves with Controllable Reduction Velocity.
  - $p - \tau$ Diagrams.
  - $p - \Delta$ Curves.
- All Displays Individually Controlled Including Rescaling and Translation.
- Construction of Travel-Time Tables.

Figure 14.

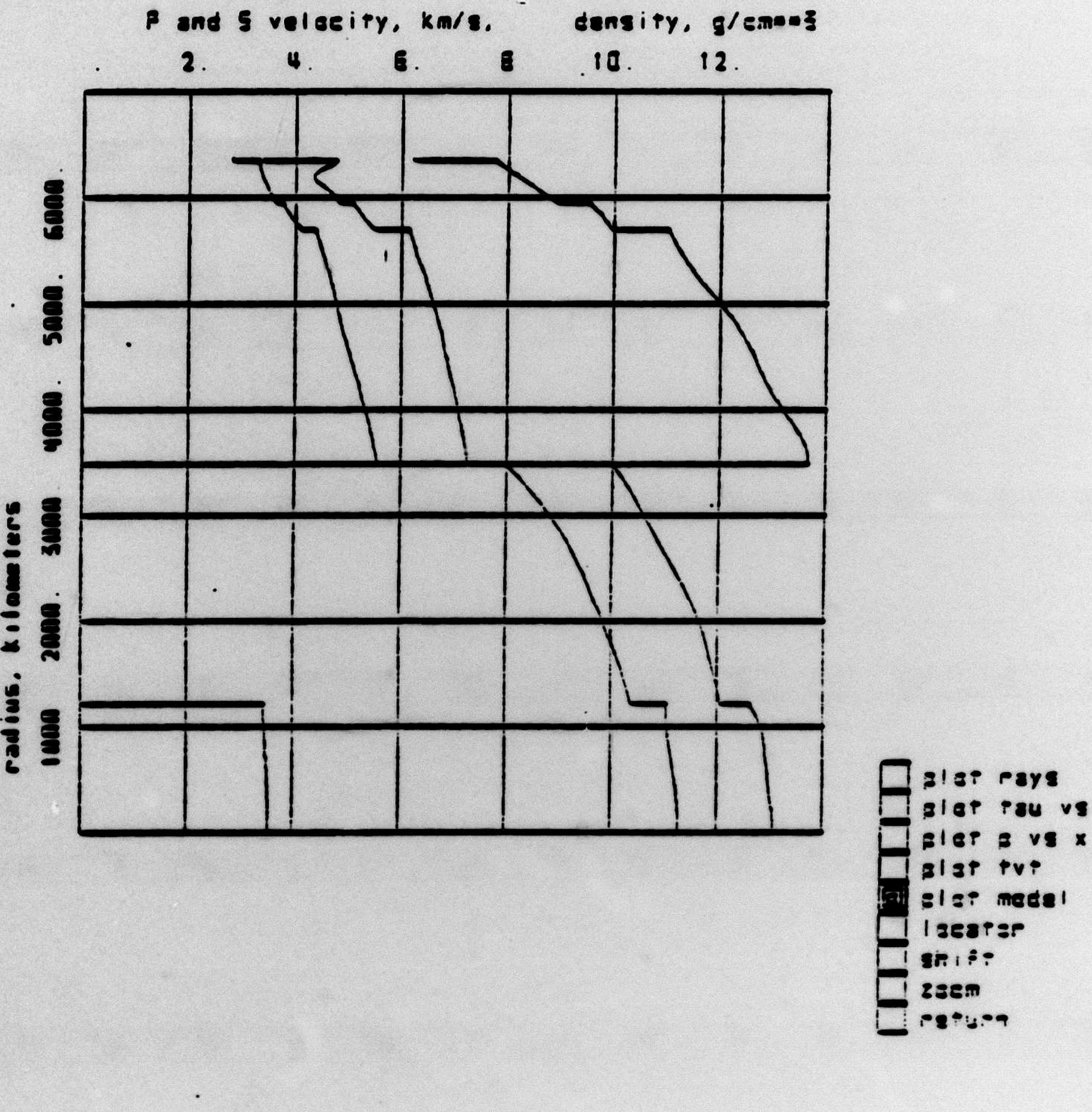

Figure 15. Earth model for ray-tracing. The radial variations of seismic velocities and density are displayed interactively on the screen in response to a menu-selection.

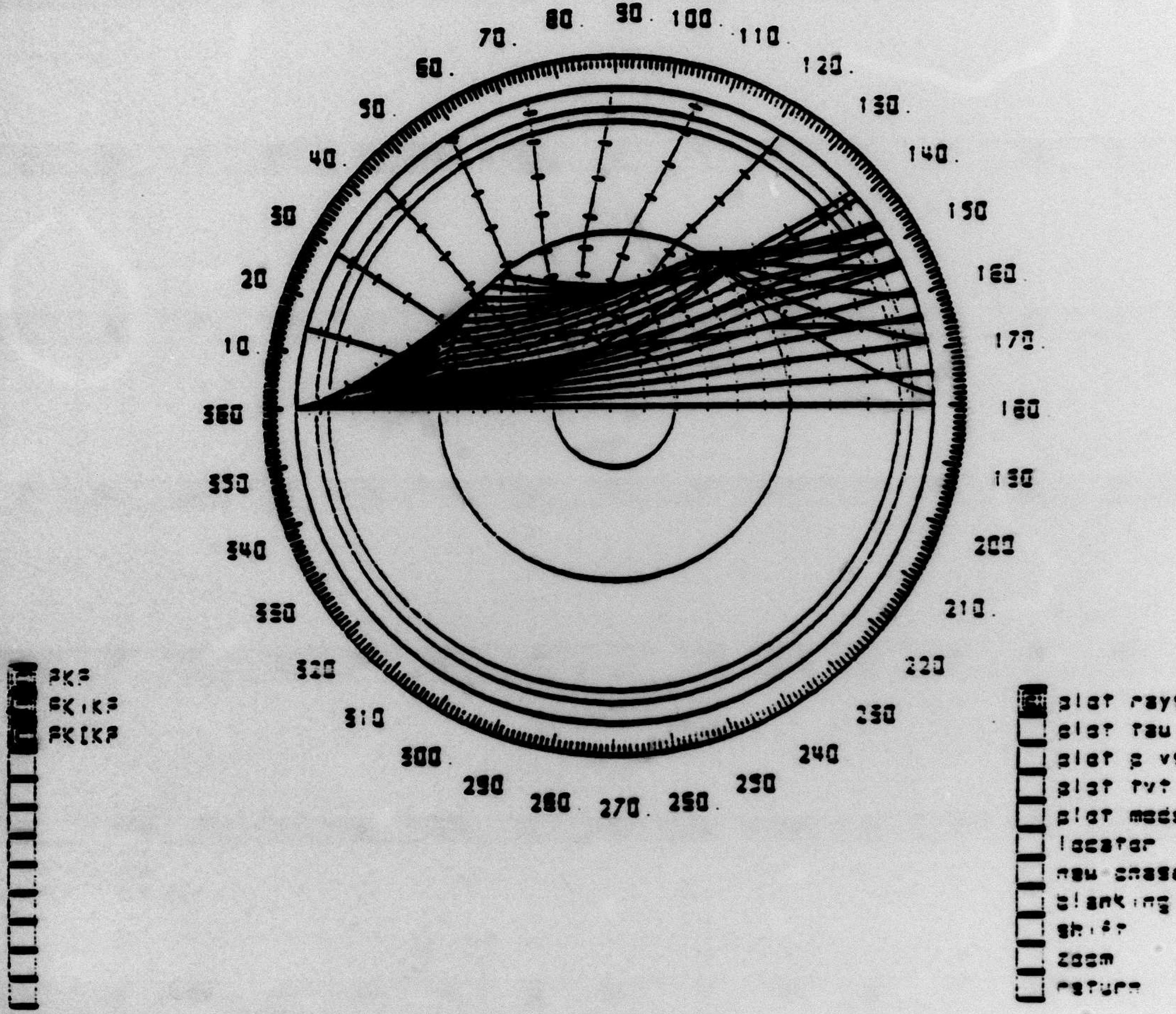

Figure 16. Selected ray paths for three families of compressional seismic phases. The menu and the display are color-coded on the screen for convenience.

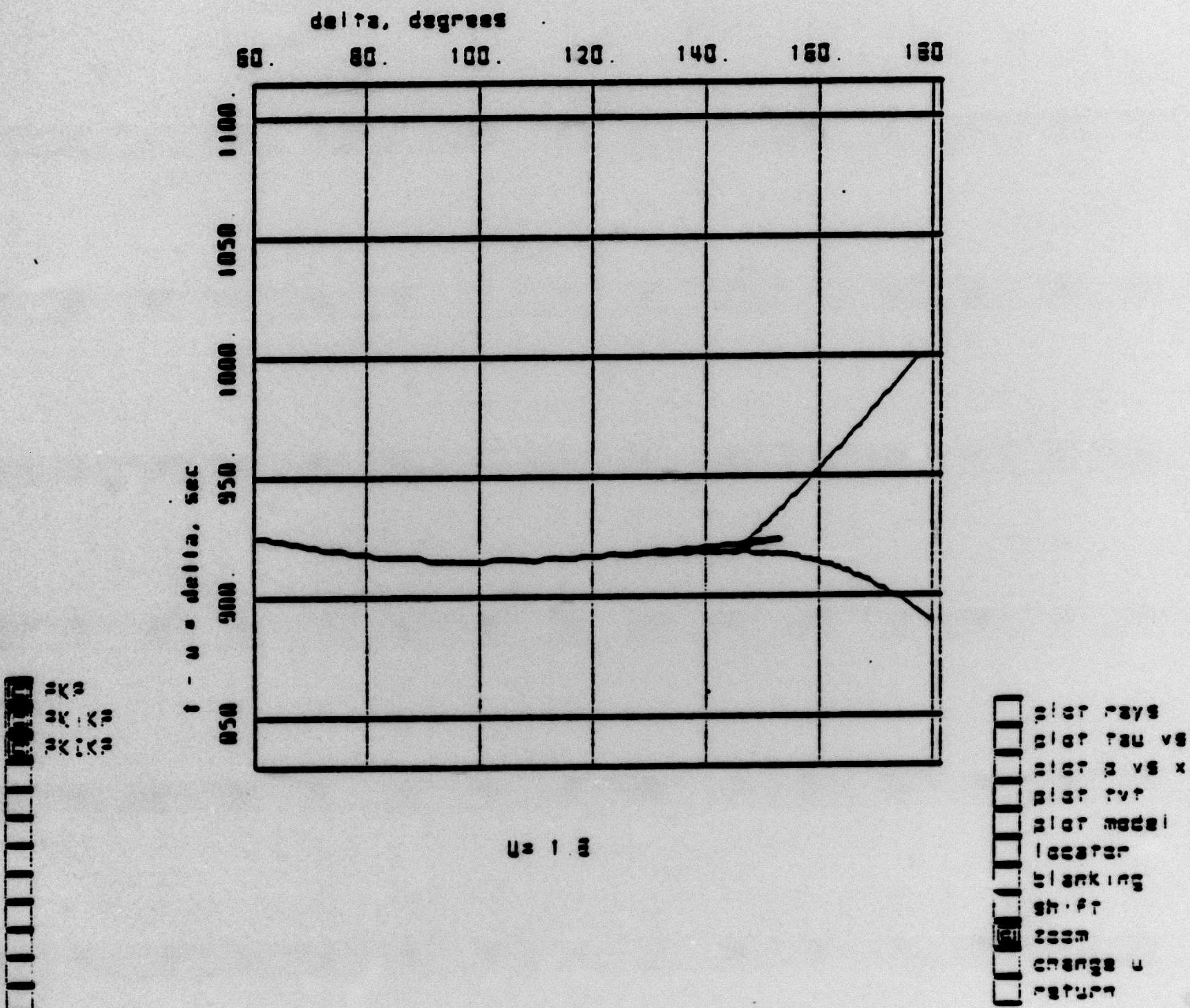

Figure 17. Reduced travel-time curves for the rays shown in Figure 15. The actual screen display is color-coded for viewing clarity.