DIGITAL DATABASE DEVELOPMENT AND SEISMIC CHARACTERIZATION AND CALIBRATION FOR THE MIDDLE EAST AND NORTH AFRICA

Muawia Barazangi
Dogan Seber
Eric Sandvol
David Steer
Marisa Vallve
Christine Orgren
Alex Calvert
Graham Brew
Francisco Gomez
Dan Plafcan

Cornell University
Institute for the Study of the Continents (INSTOC)
Snee Hall
Ithaca, NY 14853 -1504

Report Date: 24 February 1998

Abstract

It is essential for the CTBT monitoring efforts that multidisciplinary information on any given region be readily available and accessible in a digital, on-line format via electronic networks for use by concerned researchers and decision makers. We collected and organized available seismological, geophysical, and geological data sets for the Middle East and North Africa into a comprehensive Geographic Information System (GIS). In addition, we produced original results, such as crustal structure beneath available broadband seismic stations in the Middle East and North Africa region, and basement depth values in the northern Arabian plate. In addition to the GIS databases and tools, we developed a special World Wide Web (WWW) site to allow restricted access to our databases. All the data sets in our GIS system were documented with a standard metadata format in order to explain the source and nature of the data, their resolution, and their accuracy. The developed system and its efficiency in using and analyzing information will help CTBT researchers and decision makers to fuse and integrate the results of the four established monitoring technologies to reach a conclusion in a very short time. The system also significantly contributes to the better location and calibration of suspect events for any given region. This system will also help in On Site Inspection efforts. Our World Wide Web address for information distribution is **http://atlas.geo.cornell.edu**.

INTRODUCTION

With the signing of a multilateral comprehensive nuclear test ban treaty, it is essential for monitoring efforts that multidisciplinary "reference" information on any given region be readily available and accessible in a digital, on-line format via electronic networks or on host computers used by concerned researchers and decision makers. We have designed and built a digital geophysical and geological information system to help in these efforts. Several essential data sets can be accessed and analyzed with ease and speed within this system. The data sets are complete with "metadata" information allowing users to be familiar with the source, resolution, accuracy, and limitations of the databases. Data access tools are also an important part of the whole system, since it would be very cumbersome to access a specific data set among all types of databases that are kept on the system. This developed system allows a user to search, manipulate, and interact with the databases easily and efficiently. Our GIS system and scientific results are of direct relevance to US efforts in enhancing regional seismic monitoring and discrimination capabilities and to the implementation and operation of the US NDC and monitoring efforts.

The amount of information available for the Middle East and North Africa region is comparatively limited. In order to enrich the content of our database and provide more detailed data sets, we also conducted several seismological studies. It is well known that variations in crustal and lithospheric structure as well as major topographic relief are crucial information for regional event location, understanding seismic wave excitation and the propagation of high-frequency regional seismic phases, verification, and yield estimation of nuclear and chemical explosions. Our research was focused on obtaining this type of information in the Middle East and North Africa region. We obtained crustal depth and velocities beneath broadband seismic stations using receiver function analysis, estimated basement depth in the northern Arabian plate, studied recordings of earthquake and chemical explosion characteristics in Morocco, and relocated some of the earthquakes along the northern Moroccan coast. In addition, we digitized all available crustal scale profiles in the Middle East region. By using these interpretations we produced more detailed and accurate Moho and basement maps which can be used in modeling efforts. We also developed the first digital tectonic map of the Middle East and North Africa region. Finally, we collected significant number of relevant references related to geology and geophysics of the Middle East and North Africa region.

PART I: DEVELOPING A COMPREHENSIVE GIS DATABASE SYSTEM (GEOID – GEOscience Interactive Databases)

GEOID is a Geographic Information System (GIS) with extensive internal data sets as well as data manipulation, analysis, search, and plotting tools. It includes data sets in four different categories: geographic, geophysical, geological, and imagery/grids. The system has been developed over three years, and it continues to grow in size. The target scale of the internal data sets varies, but an average scale of 1:1,000,000 is preserved throughout the entire system. GEOID provides users a unique opportunity to study, search, and analyze several kinds of geophysical, geological, remote sensing and topography data simultaneously. The efficiency and the speed of the system make it more valuable for users who need to access critical information very quickly. The Comprehensive Test Ban community will benefit significantly from this system. Some of the benefits of the GEOID are: better event location, as it provides the most accurate crustal and velocity information on specific regions, providing "ground truth" for better calibration efforts, better understanding of regional seismic phase propagation by providing easy to use tools to extract crustal scale profiles between two arbitrary points, and the ability to interact with any data in the system. GEOID goes far beyond just map making, helping researchers and decision makers obtain considerable information about the geology and geophysics of a region, and helping in efforts before and after an On Site Inspection by providing comprehensive geographical, geological, and imagery information about that region.

GEOID runs on top of a commercially available Arc/Info GIS software. Before installing GEOID, Arc/Info software must be present in the system. Currently, the system is operational only on a UNIX platform. However, the system dependence is quite minimal and with little effort GEOID can run on any platform running Arc/Info software.
Its menu-driven interfaces eliminate the need to know Arc/Info prior to using this system, making it easy to use and attractive to all users at all levels. Almost all the programming in GEOID has been done using Arc/Info's internal Arc Macro Language (AML).

Although the background data sets (i.e., geographic data) in GEOID are global, the geological and geophysical data sets are focused on the Middle East and North Africa region. There are a few global data sets such as seismicity, focal mechanisms of larger events, and a global geology map.

The database format is Arc/Info's coverage and table format. Each data set forms a layer, and it is linked with other data sets either through geographic extent and/or with feature items located in each data set.

1. Installing GEOID

GEOID requires about 6 Gbytes of disk space to install. In the distribution tape there is a README file which details the installation process step by step. You need write access to Arc/Info's home directory, as you need to copy some files there.

2. Running GEOID

Accessing the entire database is done through a series of customized menus. The main control menu is shown in Figure 1. In order to start the program, you need to start Arc/Info and at the Arc: prompt type "GEOID". A global map with oceans highlighted will be plotted and the main menu will be activated (Figure 1). This is the default setting.

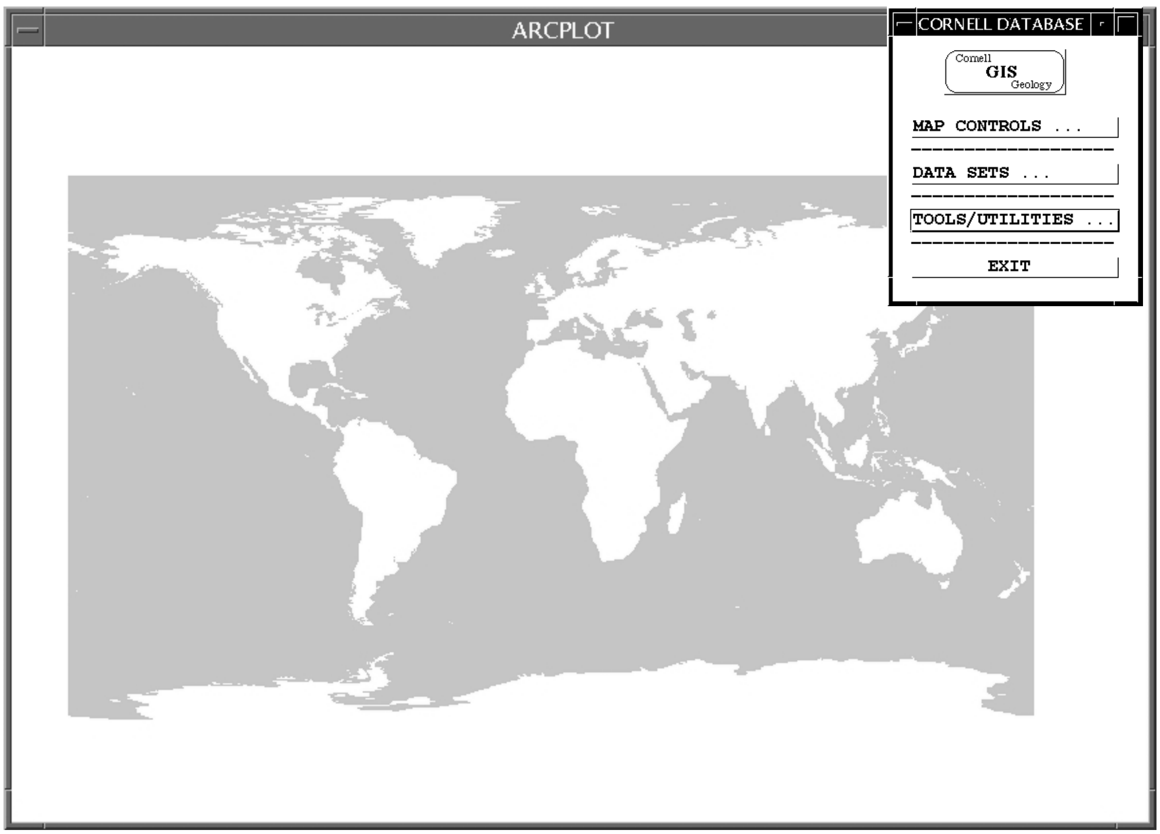

Figure 1. GEOID starts with a main menu and a global map.

2.1. Menu Driven Access

There are two types of buttons used in the menus: check buttons and regular buttons. Check buttons are usually used in displaying any individual data sets and are activated as soon as they are checked. The regular menu buttons are used either for an action or to start up a new sub menu. The main menu includes four buttons, three of which initiate a sub menu, and one, the exit button, quits the entire program. Buttons which start up additional sub menus are indicated by three dots at the end of the function names.

2.1.1. Map Controls

The "Map Controls" menu can be accessed using the button in Figure 1. This button will start up a new sub menu which allows setting the desired map limits and map projection, adding a latitude and longitude grid, adding a legend, and zoom options (Figure 2).

2.1.1.1. Set Maplimits

The set map limits button is used to set up a region of interest. One can choose an already defined region, such as the Middle East and North Africa or North America, or type in latitudes and longitudes bounding the area of interest (Figure 3).

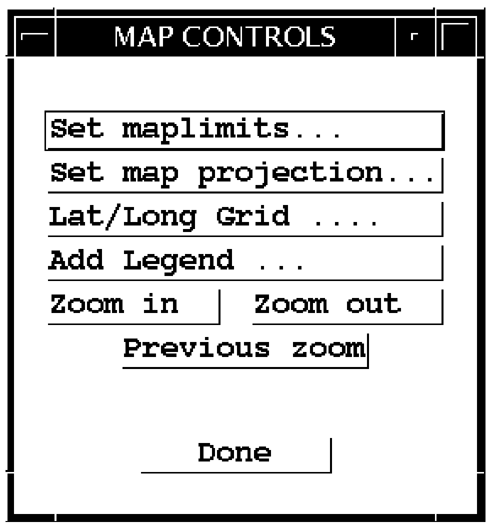

Figure 2. Map controls menu allows users to set essential mapping parameters.

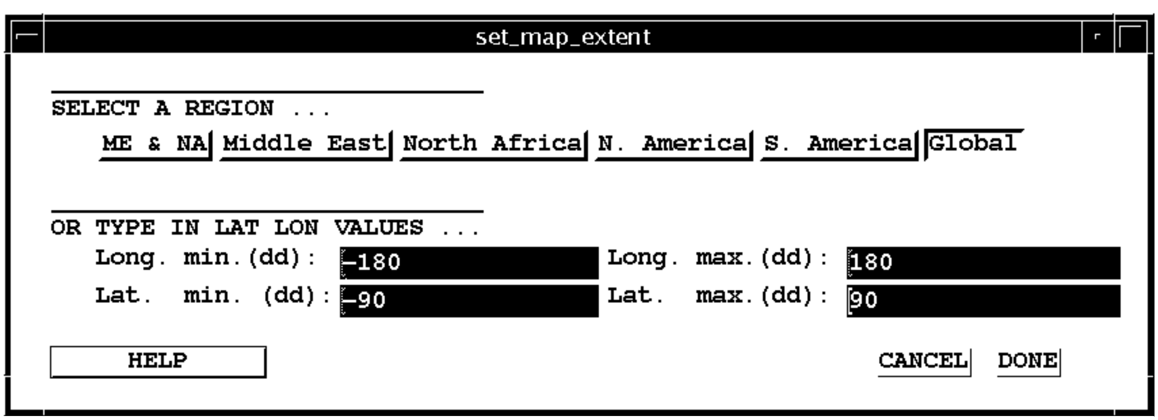

Figure 3. Set map limits menu allows users to set a region of interest either by clicking on a previously defined region or by typing latitude and longitude values bounding a region.

2.1.1.2. Set Map Projection

Map projections in GEOID are done on the fly for all line, polygon, and point type data sets. The grids and images are kept in Equirectangular projection, as projecting any grid will take too long to accomplish on the fly. Using this menu users can set one of the available projections and define the projection's parameters (Figure 4). After this point, until it is changed again, all mapping will use this specified projection. It is possible to change the projection at any time during a session. The default projection is Equirectangular. A warning message will be displayed if a user attempts to display an image file when a different projection is active. In this release there is no option of using other projections. This will be added to the system in future releases.

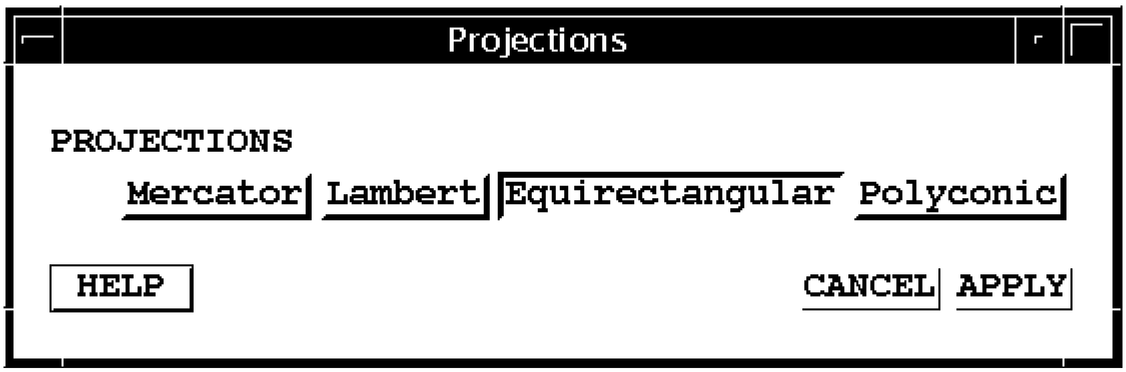

Figure 4. Available map projections in GEOID. In each projection user defined projection parameters can be entered into the system.

2.1.1.3. Lat/Long Grid

This button is used to add a latitude-longitude grid and grid labels to the map. A sub menu allowing a user to choose grid interval, label interval, and their locations appears on the screen (Figure 5). After typing in the desired numbers and checking the "On" button, the grid is displayed once the "Done" button is pressed. It is also possible to set the label format with this menu. Grid label formats are DD, DDM, and DMS representing Decimal Degree, Decimal Degrees - Minutes, and Decimal Degrees - Minutes - Seconds, respectively. Both line and tic (cross) styles are supported in latitude and longitude grids. Labels can be placed on top, bottom, left, or right by highlighting the appropriate button.

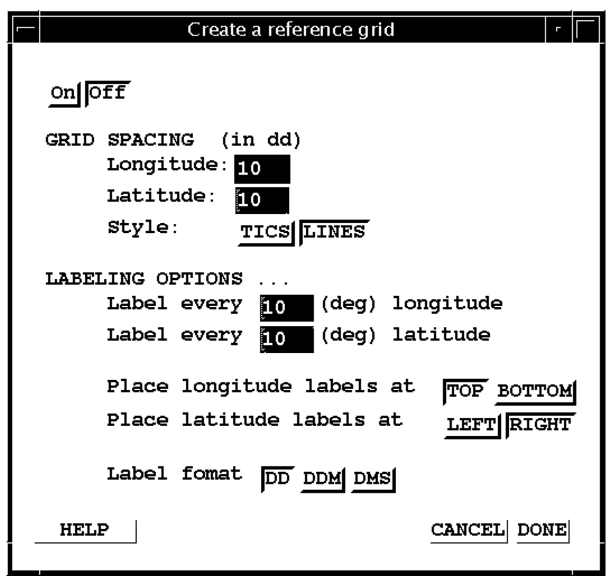

Figure 5. Menu to set up a latitude and longitude grid. Grid interval and label interval must be defined separately as different numbers can be set for each.

2.1.1.4. Add Legend

This button is used to add a legend for the map. GEOID automatically detects which data sets have been activated and generates a legend. The legend's scale (i.e., its size) can be changed by entering a scale factor (Figure 6). The majority of data sets will produce a legend if they are displayed. However, not all data sets can be seen in the legend. It is possible to have items like tectonic units, mine locations, and crustal profile locations, but items like coast lines and country borders will not appear in the legend box. The default legend will appear at the lower right corner of the map. However, it can be moved anywhere on the page by clicking the Move legend button. Once this button is clicked, you need to define the new position and mark the lower left corner on the screen. By clicking the Cancel legend button the legend can be removed from the map.

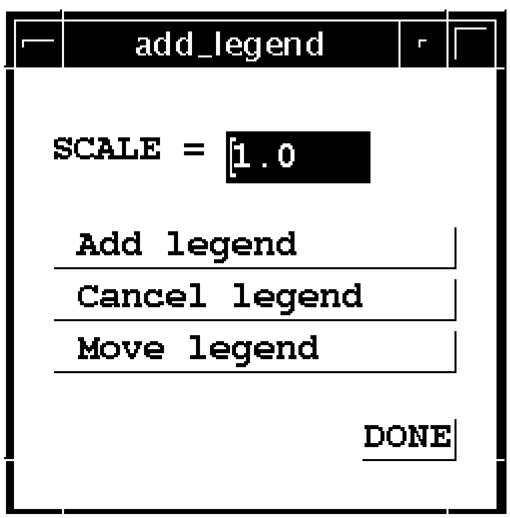

Figure 6. Menu used to place a legend on the map.

2.1.1.5. Zoom in, Zoom out, and Previous zoom

These three buttons are used to set a zoom level. Instead of using the Set map limits option described above, one can use the zoom in button to zoom in on a region of interest directly from the screen. Once the Zoom in button is pressed, two corners of the area of interest must be marked on the screen. You can mark the corners in any order. The new map area will be redrawn when two points are marked in the screen. The Zoom out button zooms back to initial map limits. The Previous zoom option allows going back one step in zoom level.

2.1.2. Data Sets

The data sets menu button (see Figure 1 inset) is the button through which all the data in the system can be accessed. Clicking on this button will activate the "Datasets" menu with four options representing our four categories of data classes: Geographic, geophysical, geological, and images/grids (Figure 7). For data sources and quality refer to the Metadata section. The following sections highlight all the data sets and related access tools.

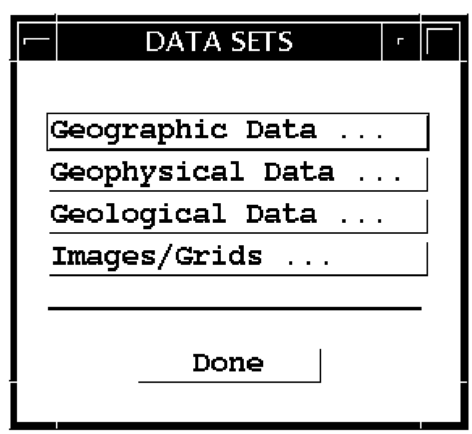

Figure 7. The Data sets menu allows the access to all data sets in GBASE.

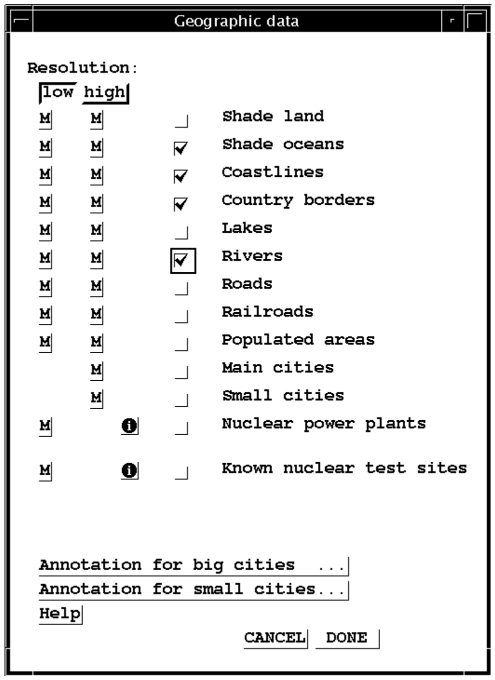

Figure 8. Menu with available geographic data sets. In addition, global data sets of nuclear power plant locations and known nuclear test sites can also be accessed via this menu.

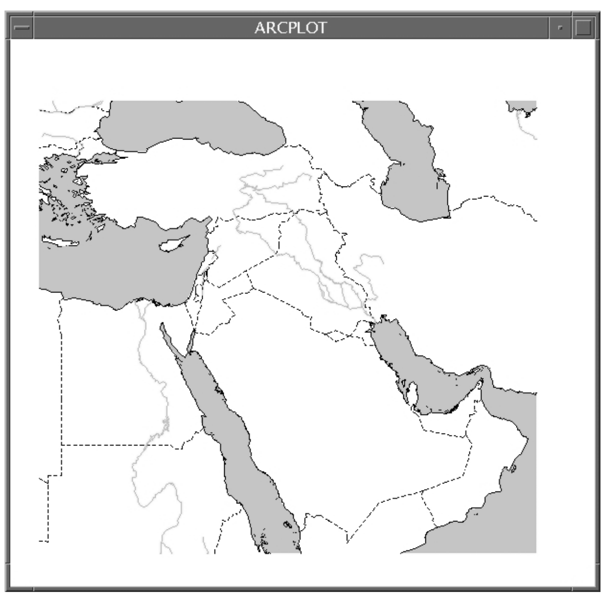

Figure 9. Map obtained after the selection in Figure 8 is made.

2.1.2.1. Geographic Data

Geographic data sets are kept and accessed through this button. All essential geographic information such as coastlines, country borders, city locations, etc., are available. All available data sets can be viewed once this button is checked (Figure 8). All geographic data were extracted from the Digital Chart of the World. The original data sources are maps of 1,000,000 scale. Hence, this represents the resolution level at which these data

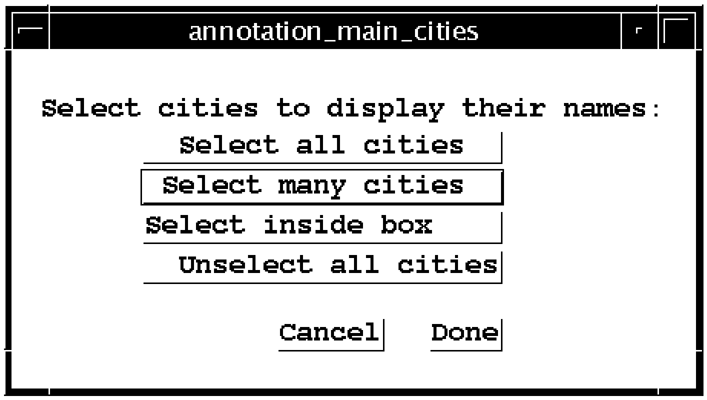

Figure 10a. Menu to label the city names.

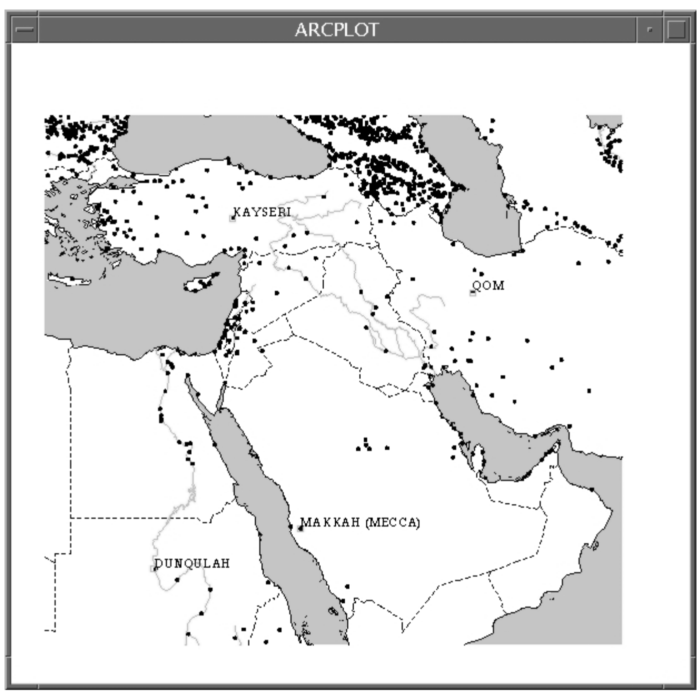

Figure 10b. Map showing the main city location data set. Four cities selected and labeled using the menu shown in Figure 10a.

sets should be used. In order to speed up the plotting process when much smaller scale maps are requested, a resampled low resolution data set is plotted. The low resolution

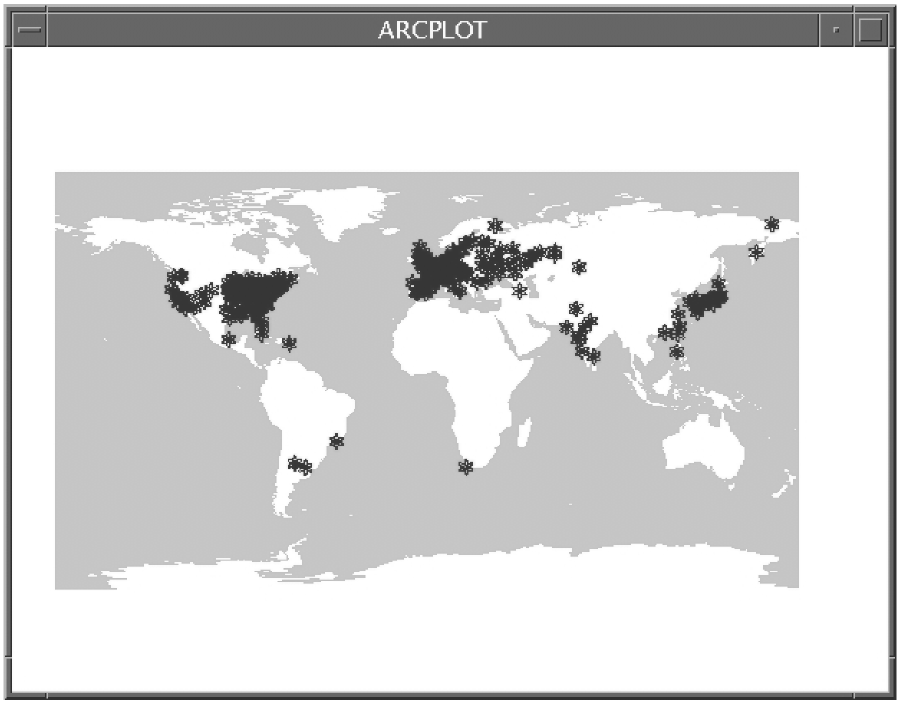

Figure 11. Nuclear power plant locations in the world.

data are the default. The selection criterion above the geographic data sets menu labeled as "low" and "high" must be changed to high, if the user wishes to have the high resolution data sets.
All geographic data can be accessed through check buttons next to their names. As soon as any data set is checked, it is plotted. Figure 9 shows an example of output with selections shown in Figure 8 after zooming on the Middle East region.

The two buttons at the end of the menu ("Annotation for big cities" and "Annotation for small cities") are used to label cities. An example is shown in Figures 10a and 10b. It is possible either to choose all the cities and label them or choose a few cities and just label the chosen ones. Selecting all the cities usually gives overlapping labels due to the large number of cities being selected. In order to prevent this problem, it is better to select a few cities using the "Select many cities" button and mark the city locations that need to be labeled. As many cities as necessary can be selected. Once the selection is made, the 9 key on the keyboard stops the selection process and the selected cities are labeled. The same selection criteria can also be applied to smaller cities. In order to remove the city labels, the "Unselect all cities" button must be clicked. This removes all of the selections from the selection file.

Other data sets that are kept within the geographic data sets menu are nuclear power plant locations and nuclear test sites. Both of these data sets are global. Figures 11 and 12 show these data sets.

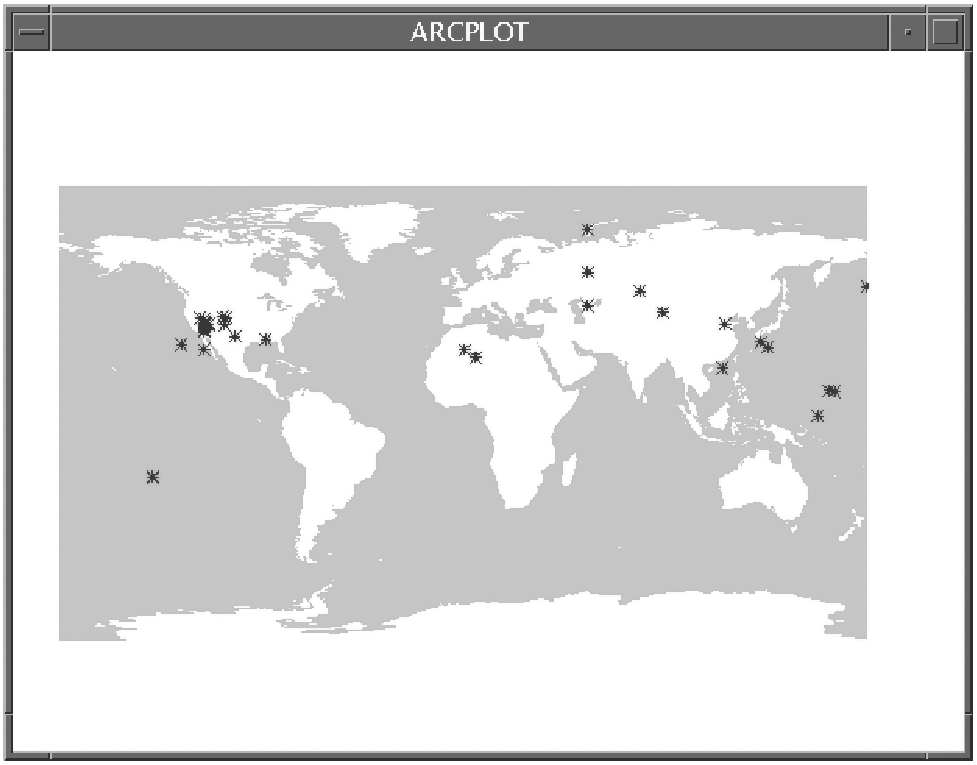

Figure 12. Map showing known nuclear test site locations.

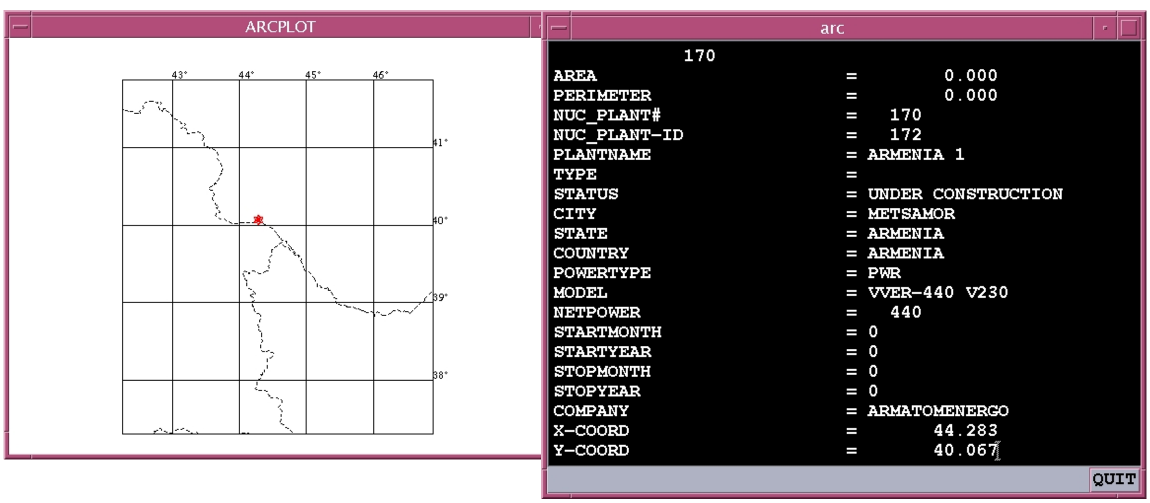

Figure 13. Map showing the Turkish and Armenian border and the nuclear power plant in the region (left). Once the identify button is clicked, the “i” button in Figure 8, and this power plant is selected from the screen, information regarding the power plant is displayed in an adjacent new window.

In the geographic data sets menu as well as in all other data set menus there are icons named "i". These icons indicate that features in these data sets can be identified, and all the items assigned to each feature can be viewed from the screen. For example, in order to identify one of the power plants in the Middle East, after zooming in on that region, one needs to click on the icon "i" next to this data set. This will initiate an interactive search. Going to the map and clicking on any of these nuclear power plants will give information and attributes about the selected feature. An example is shown in Figures 13. After zooming on the Turkish – Armenian border, selecting the "i" next to the nuclear power plants data set, and clicking on the nuclear power plant symbol on the map, a new window will pop up on the screen showing all the attributes available for that data point. This option is quite useful throughout the GEOID environment. It makes maps dynamic, and allows users to obtain information about any data point on the screen.

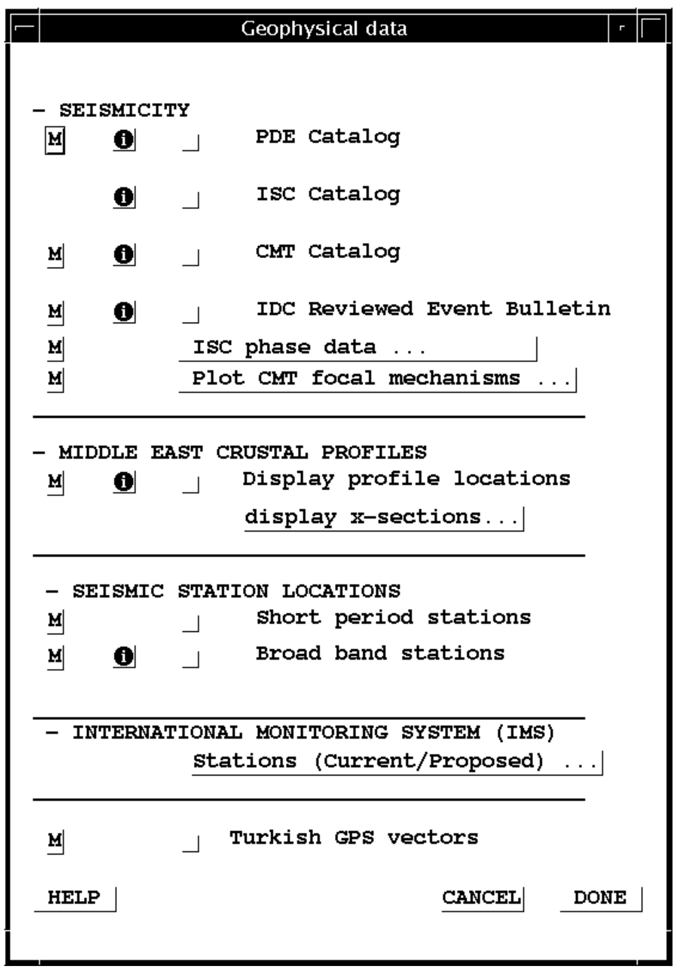

Figure 14. Geophysical data sets menu. Remaining geophysical data sets are included in the Grids/Images menu.

The buttons labeled "M" in this menu as well as in the others represent the metadata access tools. Each data set contains metadata which provides information about the resolution, accuracy, source, and attributes about the data set. In a later chapter the metadata will be discussed in more detail.

2.1.2.2. Geophysical Data

Although some of the geophysical data sets are placed under the images/Grids menu option, all non-grid type data sets are accessed through this menu button. Figure 14 shows the content of the "Geophysical Data" menu. The data sets include: Seismicity catalogs, focal mechanisms, crustal scale refraction and gravity profile locations and their interpreted depth sections in the Middle East region, local seismic station locations in the Middle East and North Africa, broadband station locations in the Middle East and North Africa, International Monitoring System station locations, and displacement vectors obtained by GPS in the eastern Mediterranean.

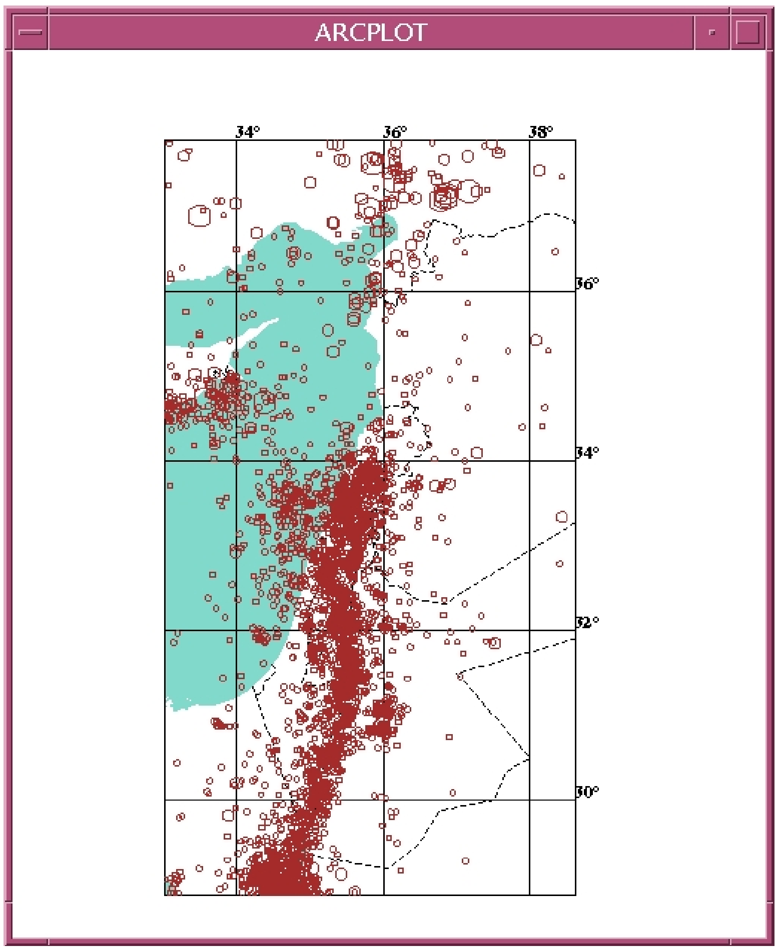

Figure 15. Seismicity along the Dead Sea fault system from the ISC catalog. This map is obtained by first zooming in on this region and then checking the ISC check button in the geophysical data sets menu.

Earthquake Catalogs

We collected all available and reliable seismic catalogs and placed them in GEOID.

These data catalogs include: the USGS, the International Seismological Centre (ISC), Centroid Moment Tensor locations and solutions from Harvard University, and the International Data Centre's reviewed event bulletins. Among these catalogs, only the ISC's catalog is global and is complete with all related phase data. The other catalogs include only the locations and primary information such as magnitude, depth, and origin time.

The USGS catalog covers the period from 1964 to 1992. This data set is only for the Middle East and North Africa region. The ISC catalog covers the period from 1964 to 1994. It is global in nature and complete with all the phase information. The CMT catalog is global, and most useful when events with focal mechanisms need to be analyzed. The catalog covers a time period of 1977 to 1996. The magnitudes of the earthquakes in this catalog are 5.5 or higher. All the events are complete with their attributes as provided by the Harvard group. The IDC catalog covers a much shorter time period (1996 - Sept, 1997), as the IDC is a new organization. The IDC events include magnitude, depth and origin time information.

Figure 15 shows earthquakes from the ISC catalog along the Dead Sea fault system in the Middle East. This map can be obtained by zooming in on the region using the "Zoom in" button, then checking the ISC catalog check button in this menu. The events are plotted with varying symbol sizes related to their magnitudes.

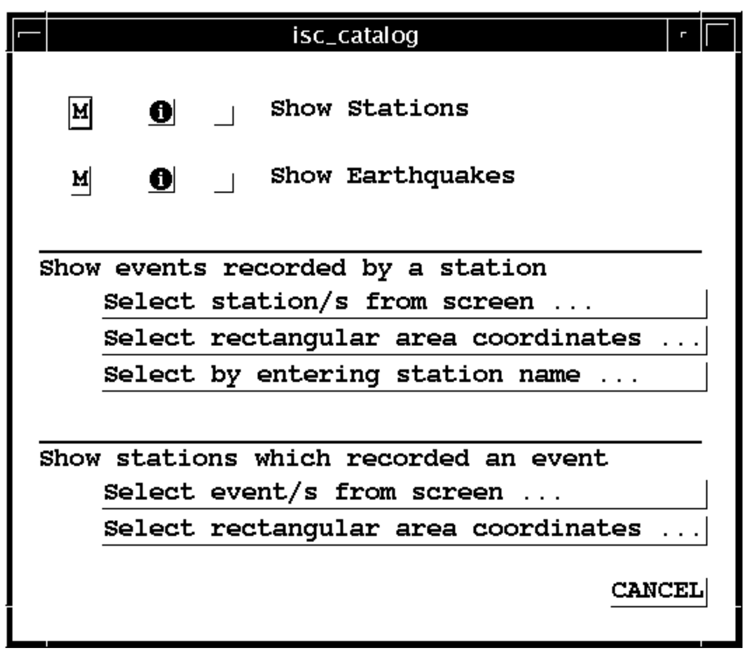

Figure 16. ISC phase data selection tool. Either station or event based searches can be conducted.

ISC Phase Data Selection and Analysis Tools

The "ISC phase data" button can be used to start up new tools for further analysis and selection of the ISC phase data (Figure 16). One can search the ISC data set by either station or event attributes. In either case, the search can be done for a single station/event or a group of stations/events located in an area defined by a box. Selecting a single station can be done either by station name or by simply clicking on any station on screen. One can also click on an event to select it from the screen. There are further selection criteria based on date, depth of event, and azimuth of arrival. For example, if one decides to select all events recorded (and reported to the ISC) by station TAB in Iran, he/she first clicks the "select by entering station name" button. This will initiate a secondary menu shown in Figure 17. In this menu, the station name "TAB" is entered in the text input area on top. Then any other selection criteria such as event depth, date, distance range of events, and azimuths can be entered. In this example, if we select a distance range of 0 to 10 degrees we need to modify the default distance variables, then click on the "Start search" button. This search will return all the events in the range of 0–10 degrees from the station "TAB" between the years 1964 - 1994. The output on the screen is shown in Figure 18a. A further step would be either to export the selection as an ascii file or to view the travel time plots of the selected data. If one would like to see

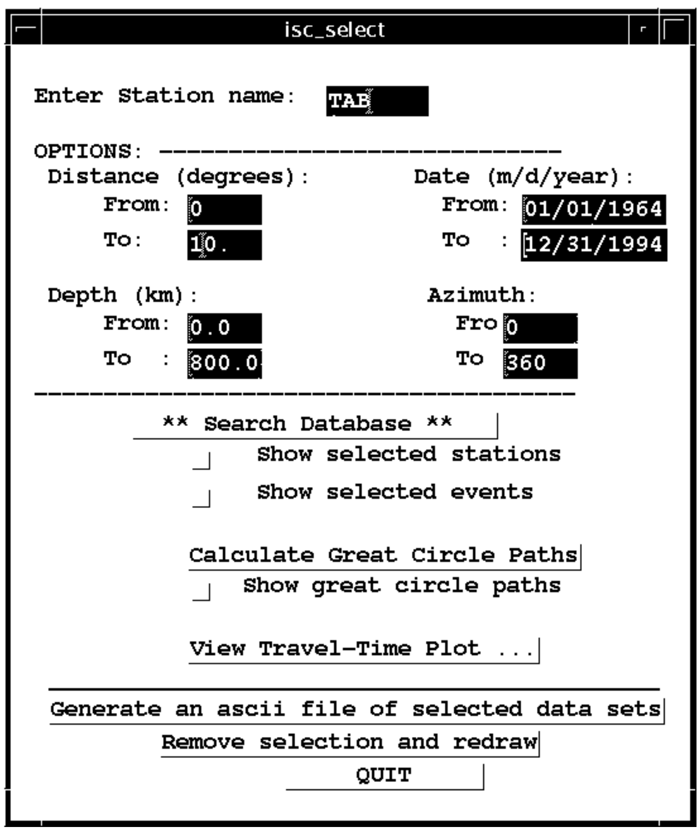

Figure 17. One of the sub menus used in selecting ISC phases by station name.

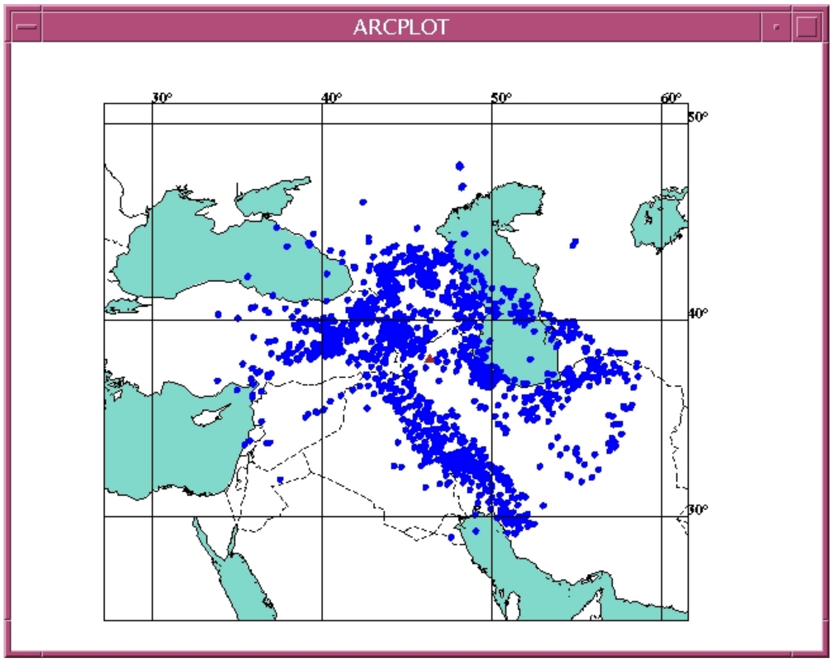

Figure 18a. Station TAB in Iran and recorded earthquakes between 0 and 10 degrees from the station**.**

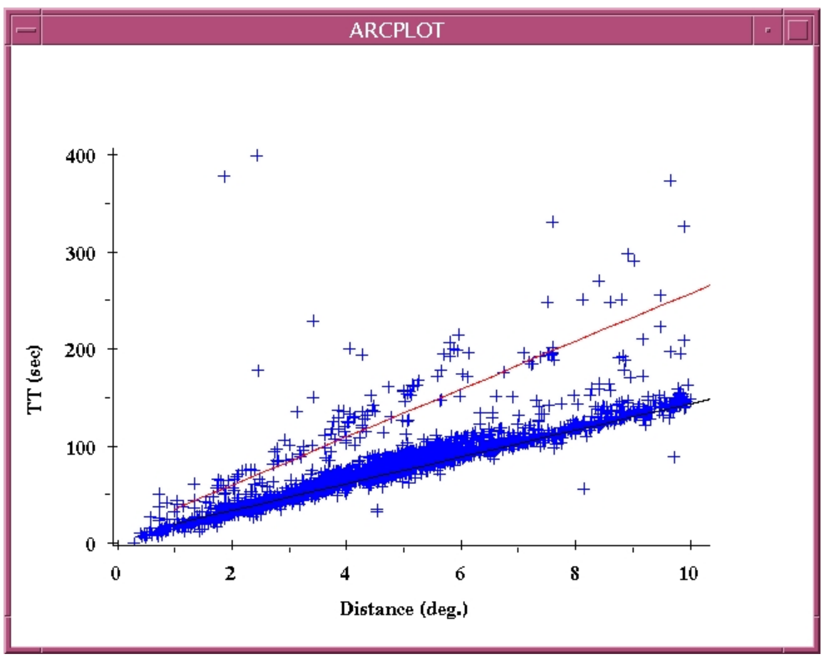

Figure 18b. Travel time plot of selected events in Figure 18a. Theoretical Pn and Sn curves are also plotted as lines.

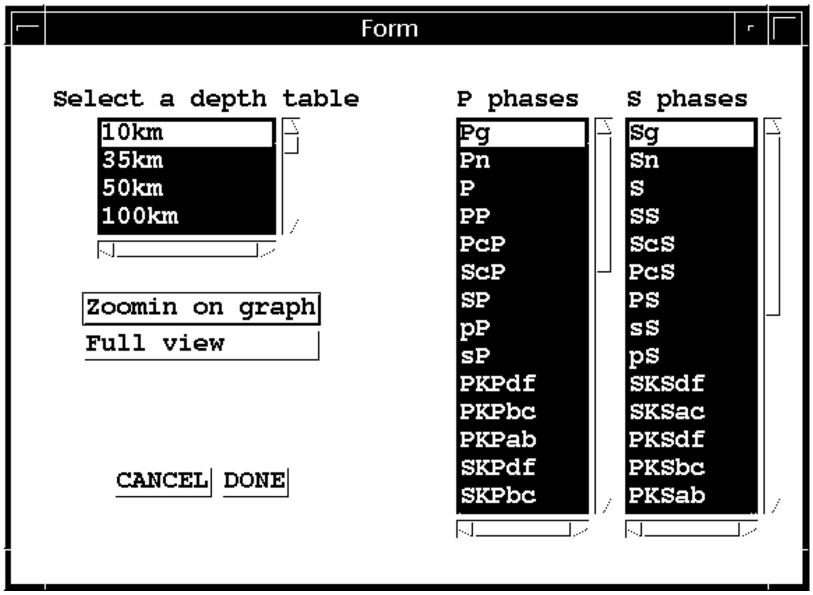

Figure 19. IASPEI-91 travel times are included in GEOID, and theoretical travel times of each of the available phases can be plotted with the selected ISC phases.

the travel time data, a click on the "View Travel-Time Curve" button will initiate a new sub menu (Figure 19) and the travel time plot will be displayed on the screen. In this menu there are options as well. GEOID includes IASPEI-91 travel-time tables. Certain phases from this travel-time table can be plotted on top of the observed phase arrivals. First a depth range needs to be selected. The default value is 10km. This value can be changed by simply clicking on the appropriate depth value. Then, any desired phase can be selected from the list in the window. Figure 18b shows the phase readings and theoretical Pn and Sn phase arrivals. It is also possible to zoom in on a region in the travel-time plot using the zoom in button.

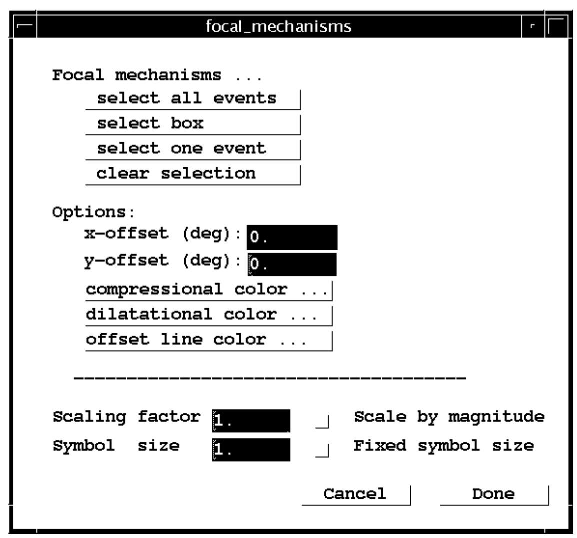

Figure 20. Focal mechanism plotting menu. Events can be plotted after a selection is made, and one of the check buttons is checked.

Focal Mechanisms

Harvard Centroid Moment Tensor (CMT) solutions are included in GEOID. In order to display the focal mechanisms, the "Plot CMT Focal Mechanisms" button needs to be clicked (Figure 14). This initiates a new window with several options (Figure 20). In this menu one can select all the events or select a single event from screen or events located in a region. A linear offset can be applied to selected focal mechanisms. Focal mechanisms can be plotted with varying sizes relative to their magnitudes or they can be plotted at a fixed size. Once the selection is done, clicking on one of the checkbuttons at the bottom of the window plots the focal mechanisms. Figure 21 shows an example plot showing earthquake locations and a few focal mechanisms in Eastern Turkey. The focal mechanism data set is global. Hence, a similar map can be done on any region on earth.

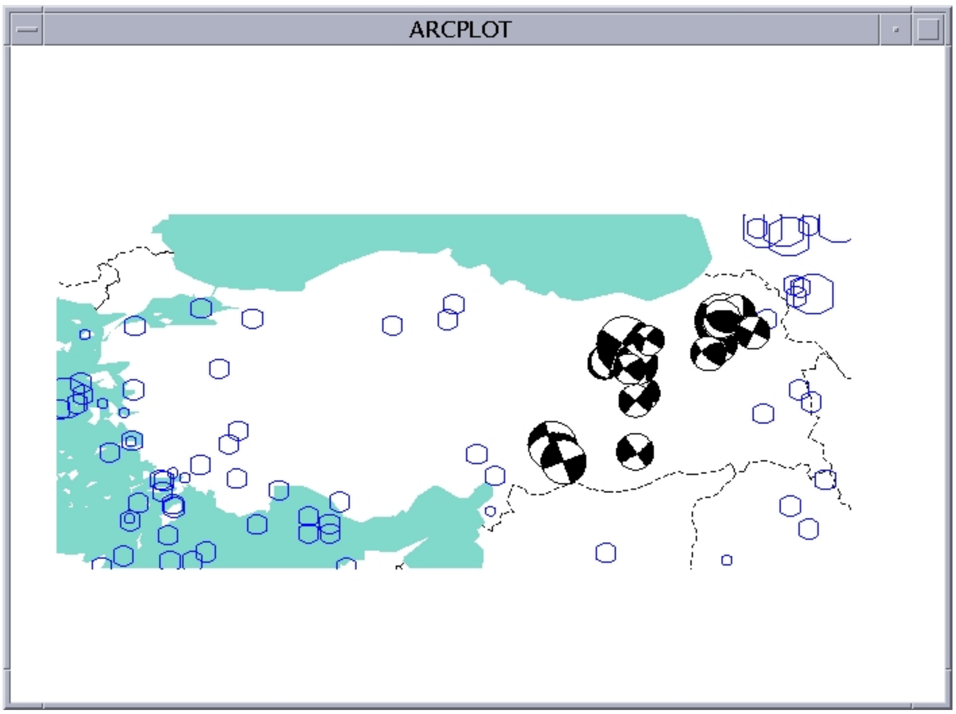

Figure 21. Focal Mechanisms of a few selected events in eastern Turkey. The focal mechanism data set is global.

Middle East Crustal Profiles

We have collected from the literature over 60 crustal scale cross sections in the Middle East region. All profile locations as well as their interpretations have been digitized and added into GEOID. Figure 22a shows the locations of these profiles. A similar map can be obtained by simply checking the data set labeled "Display profile locations" (Figure 14). In order to see the interpreted sections, a new menu is initiated by clicking on the "Display x-sections" button. This will erase the current screen and plot a map of the Middle East region with all available profile locations in the upper left corner of the screen. The remaining area is used to draw the cross sections (Figure 22b). Up to three profiles can be displayed on the screen at a time. In order to display one of the profiles, one of the "select profile" buttons need to be pressed and the desired profile must be selected from the map on the screen by clicking on the profile. Once a profile is selected, it will be displayed in the reserved area on the screen. The interpreted basement is drawn in red and the Moho is in blue. These values were used in obtaining the Cornell

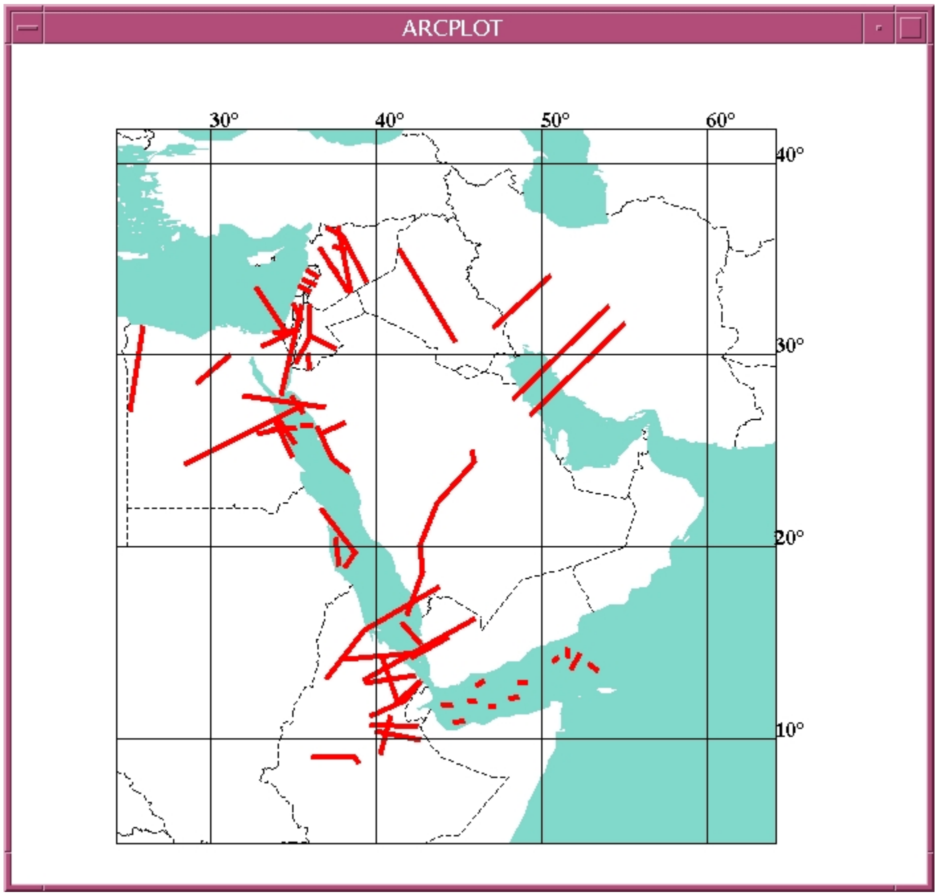

Figure 22a. Locations of collected crustal scale profile locations (thick gray lines).

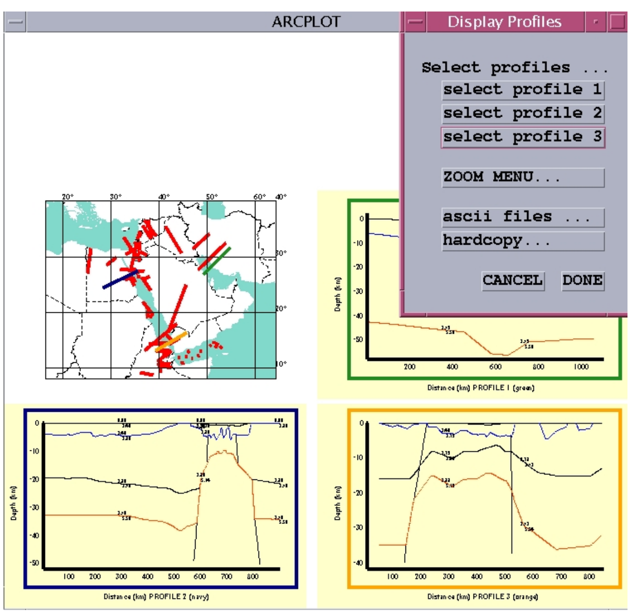

Figure 22b. Up to three cross sections can be displayed on the screen. The menu shown in the upper right corner allows selecting the profiles from the map shown in the upper left corner.

basement and Cornell Moho data sets discussed later in this report. Information about each profile can be downloaded into an ascii file by clicking the “ascii files” menu button. This opens up a new window. A directory path and a file name for each profile must be entered. Once the “Done” button is clicked, an ascii file containing all relevant information, such as publication information, type of data set, etc., is written. Using the zoom menu button, any segment of the map or profiles can be zoomed in, once they are displayed on the screen. In order to create a hardcopy map of the location map and/or profiles, the “hardcopy” button is pressed and file names are typed. An output format can be selected by choosing one of three options: Postscript, Illustrator, and CGM.

Seismic Station Locations

Data for all broadband stations and for short period stations from some of the countries of the Middle East were collected and entered into the GEOID system. The broadband stations are complete with attribute information such as the operating agency of the station, operation period, and instrument type. The short period station locations are not complete for the Middle East and North Africa region. However, the station locations under the ISC phase data coverage are more complete and can be used to replace these station locations.

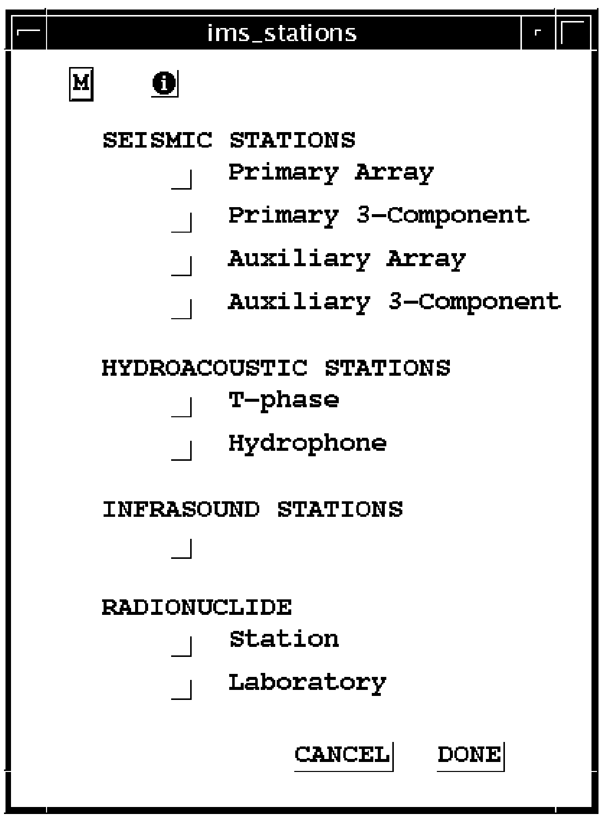

Figure 23a. Menu to display the IMS stations.

International Monitoring Station Locations

We entered all the International Monitoring System (IMS) locations into the GEOID system. A menu to access these data sets can be initialized by clicking on the "International Monitoring System" stations menu (Figure 23a). The locations of the stations were taken from the signed Comprehensive Test Ban Treaty agreement. The stations are divided into four different categories: Seismic, hydroacoustic, infrasound, and radionuclide. A map of these stations can be obtained by marking the check mark areas. Using the "i" button located on top of the window, more information about each site can be obtained. First clicking on the "i" button and then on the desired station location would give the station attributes in a popup window. Figure 23b shows all the stations located in the Middle East and North Africa region.

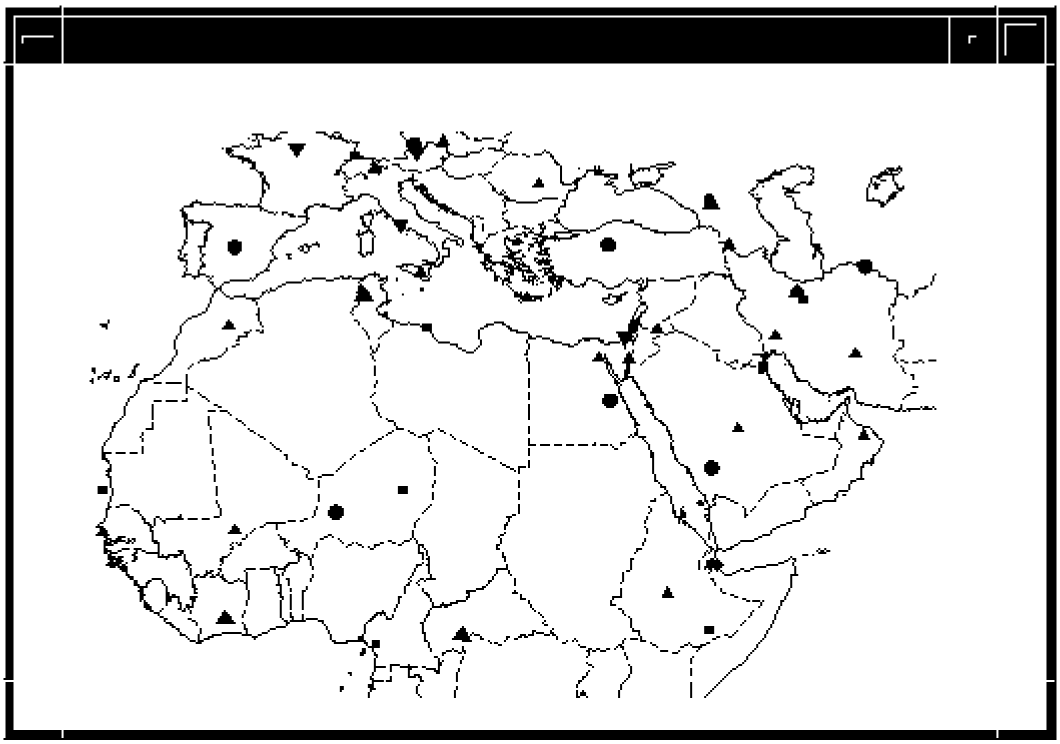

Figure 23b. IMS Stations in the Middle East and North Africa region. Circles and upright triangles are seismic stations; squares and upside-down triangles are radionuclide stations; diamonds are infrasound stations.

Turkish GPS vectors

These continental motion vectors show relative surface motion in the Eastern Mediterranean region, mainly in Turkey. Figure 24 shows available vector locations and their motions relative to Eurasia.

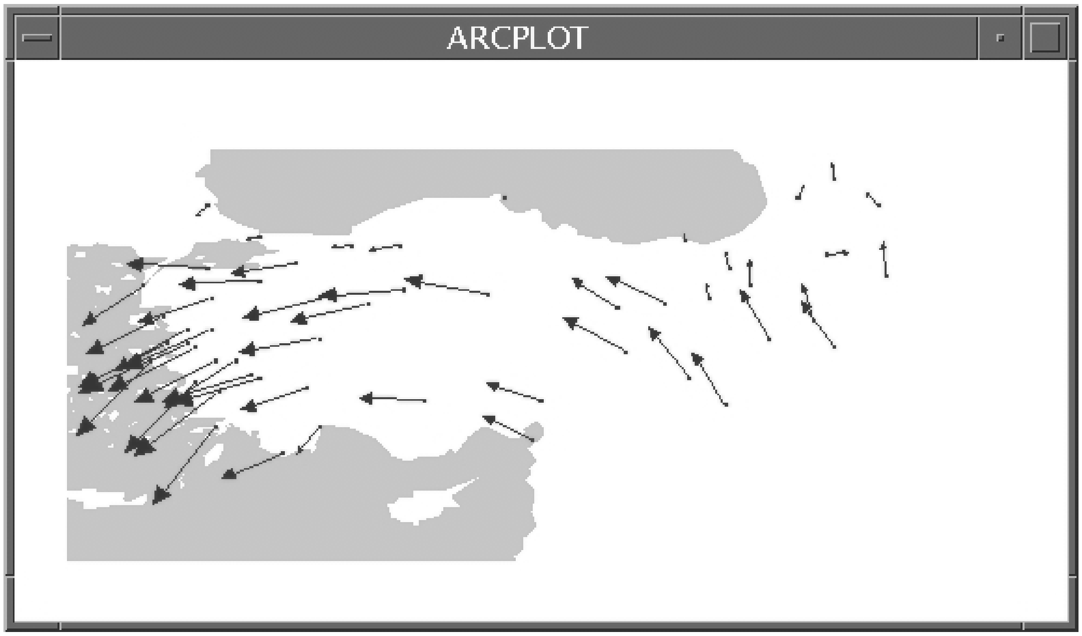

Figure 24. GPS vectors in the Eastern Mediterranean region.

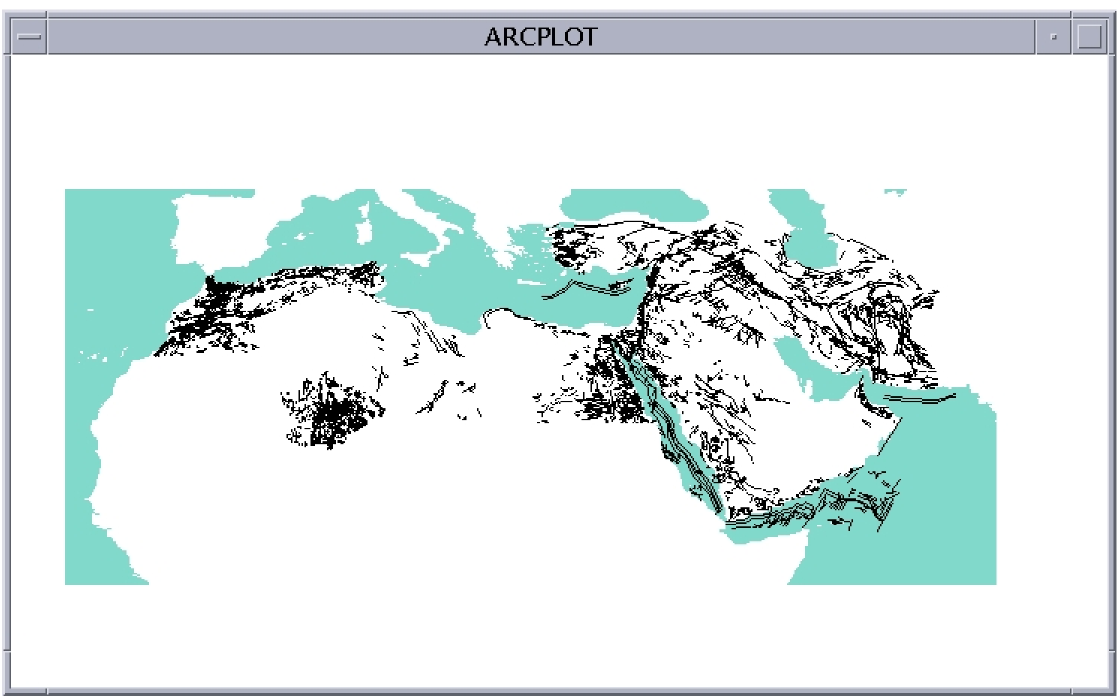

Figure 25. Digitized faults of the Middle East and North Africa region. These faults are parts of the Middle East and North Africa tectonic map that is available in GEOID.

2.1.2.3. Geological Data Sets

Several geological data sets have been included in the GEOID environment. These data sets include a new tectonic map of the Middle East and North Africa region, a low resolution global geology map, a detailed geology map of the United States, and additional data sets such as mine locations in the Middle Eastern and North African countries, world stress map, and historically active volcanoes of the world.

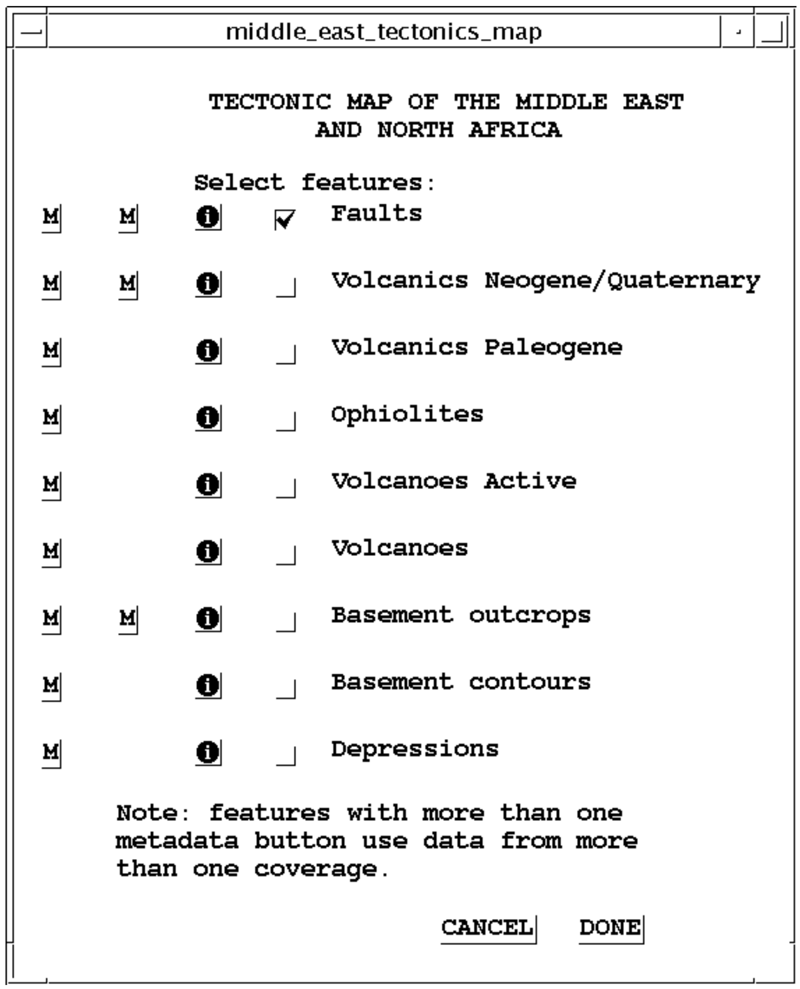

Figure 26. Menu designed for the Middle East and North Africa tectonic map.

Tectonic Map of the Middle East and North Africa
Several tectonic and geology maps in the Middle East and North Africa have been digitized and merged to create a uniform scale tectonic map of this region. This data set includes features like faults, volcanics, basement outcrops, and ophiolites. Most features in the tectonic map have also been supplemented with related information, such as the

activity of faults, detailed age information, etc. Figure 25 shows all the faults in the region. These data sets can be accessed through the "Tectonic Maps" button under the "Geological Data Sets", and then under the "Middle East and North Africa Tectonic Map" button (Figure 26). Using this menu, any of the tectonic features can be selected and displayed, and features in the map can be identified.

Mine Locations

Mine locations in most of the Middle East and North African countries have been entered into the system (Figure 27). The data are organized by country and can be accessed through the menu button available in the "Geological Data Sets" menu. Detailed information exists for Algeria, Egypt, Iran, Iraq, Israel, Jordan, Libya, Syria, Tunisia, Turkey, and Morocco mines. In addition, less detailed mine locations from the USGS, DCW, and US Bureau of Mines sources have been added. Figure 28 shows the producing mine locations in the Middle East and North Africa region. Each of the locations are complete with attributes such as commodity, mine type, activity, etc.

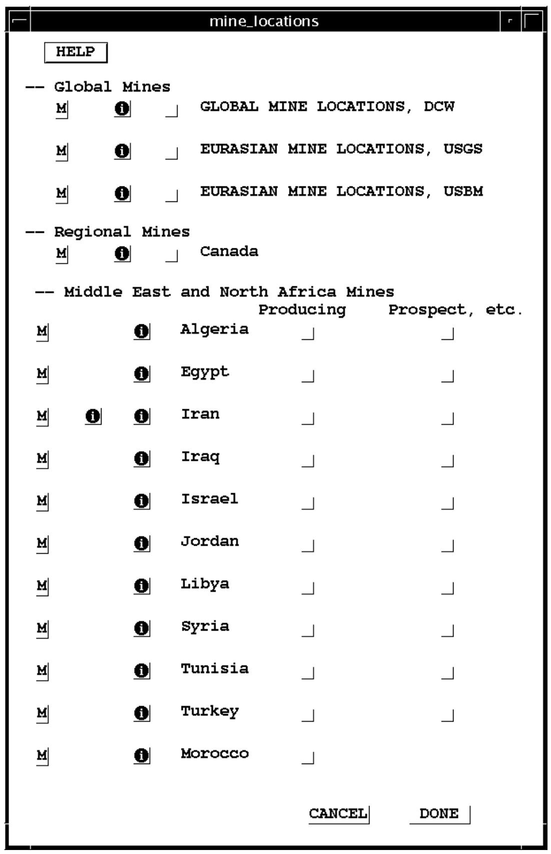

Figure 27. Mine locations for most countries in the Middle East and North Africa have been entered and added into the database system.

World Stress Map

World stress data compiled by several organizations have recently been made available. We copied these data and placed them in GEOID with all their attributes. This data set

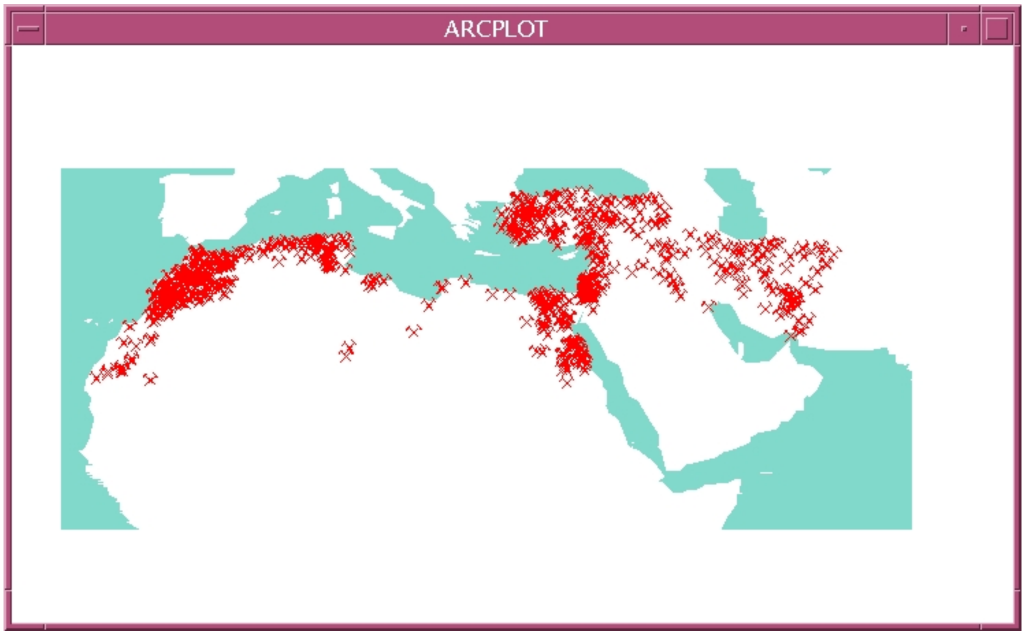

Figure 28. Producing mine locations in the Middle East and North Africa region.

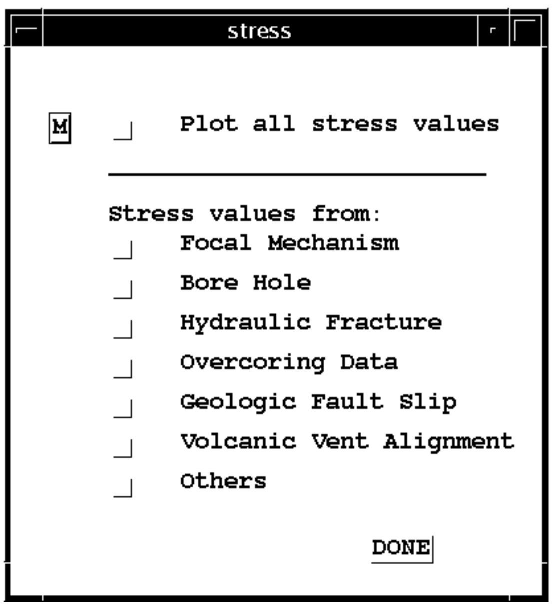

Figure 29. World Stress map menu available under the geological data sets.

includes stress direction estimated from earthquake focal mechanisms, borehole measurements, and field data. This data set is available through the "World Stress Map" button under the geology data sets (Figure 29). A small region near the southern Dead Sea fault is shown with available stress measurements in Figure 30.

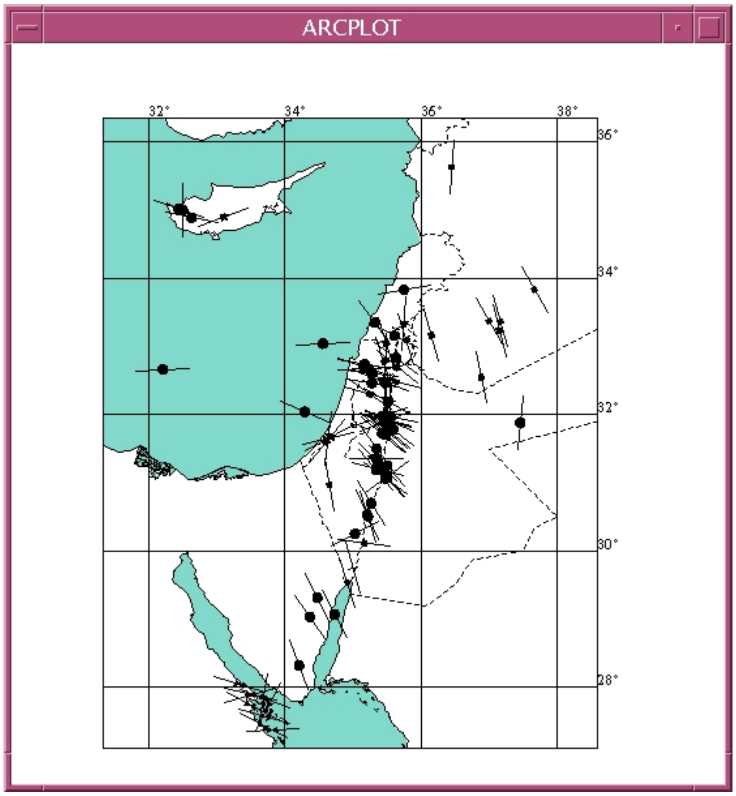

Figure 30. Stress directions in the southern Dead Sea fault region

Holocene Volcanoes
Holocene volcano locations are a comprehensive list of historically active volcano locations (Figure 31). This data set is available for the entire world. The volcanoes data set can be accessed through the “Holocene Volcano Locations” button. There are four different categories: Erupted between 1900 – 1993, Erupted 1 – 1900, Erupted B.C. and/or undated, and thermal activity/uncertain.

World Geology Map
In addition to the data sets mentioned above, there is a global geology map of the world. This map has lower resolution information, and it should be used with regional or continental scale applications. Figure 32 shows this data set in the Middle East and North Africa region.

2.1.2.4 Images/Grids

The grids and images comprise a significant volume of the data sets within the GEOID environment. Several of these data sets were collected as images. Others were gridded for easier use. The cell size in each data set was determined by either data point density or final disk space usage. All the data sets in this category are projected. Projecting them

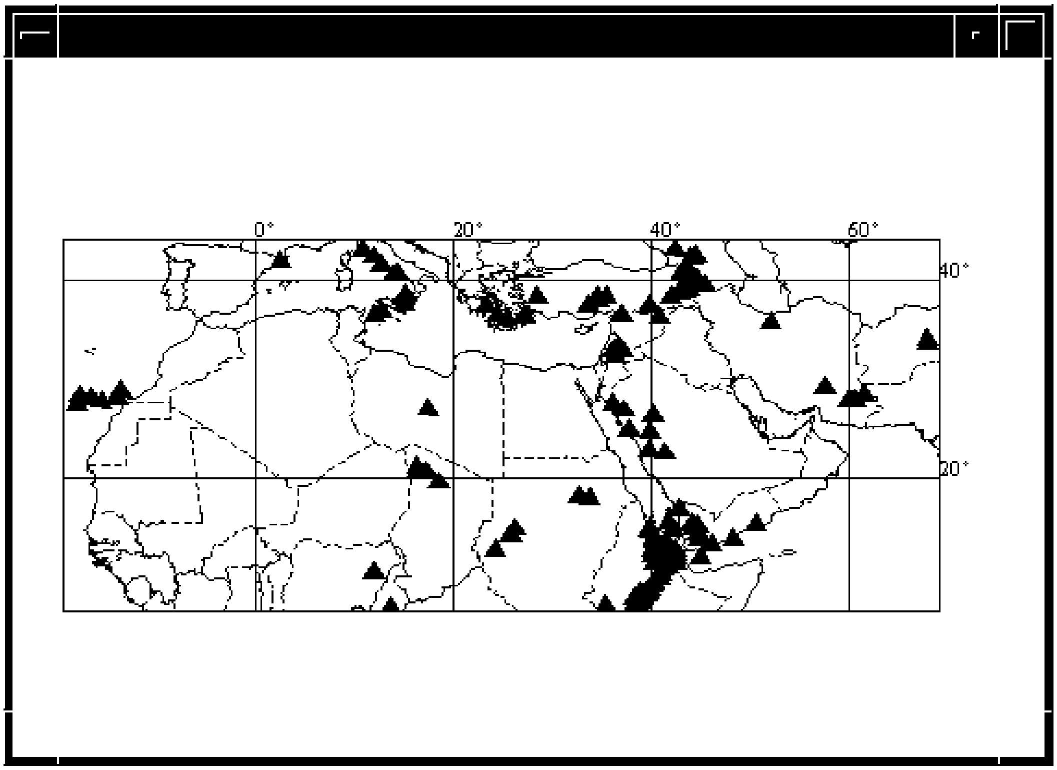

Figure 31. Holocene volcano locations in the Middle East and North Africa.

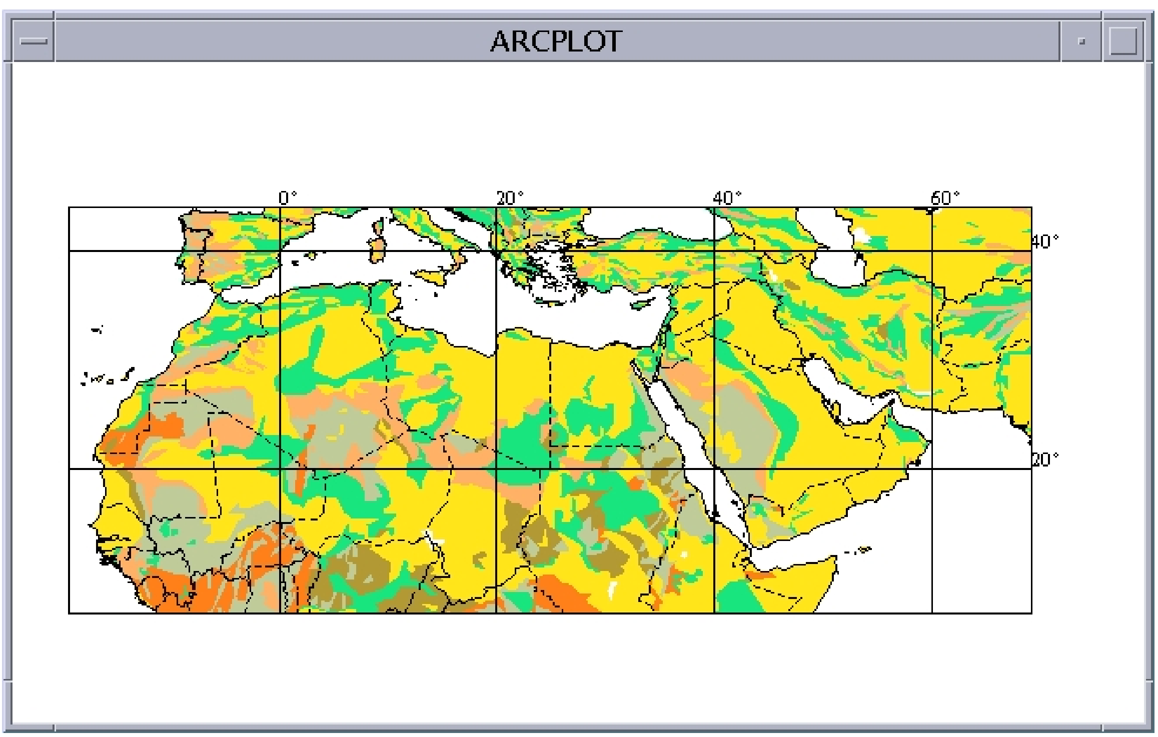

Figure 32. Geology map of the Middle East and North Africa. This is a global data set.

on the fly would take too long to display. The selected projection is Equirectangular, which is also the default projection in GEOID. The data sets can be accessed from the main menu by pressing the "Images/Grids" button. The projection is set to Equirectangular automatically; if it has been set to some other projection by the user, a warning message is displayed. Figure 33 shows the Images/Grids menu.

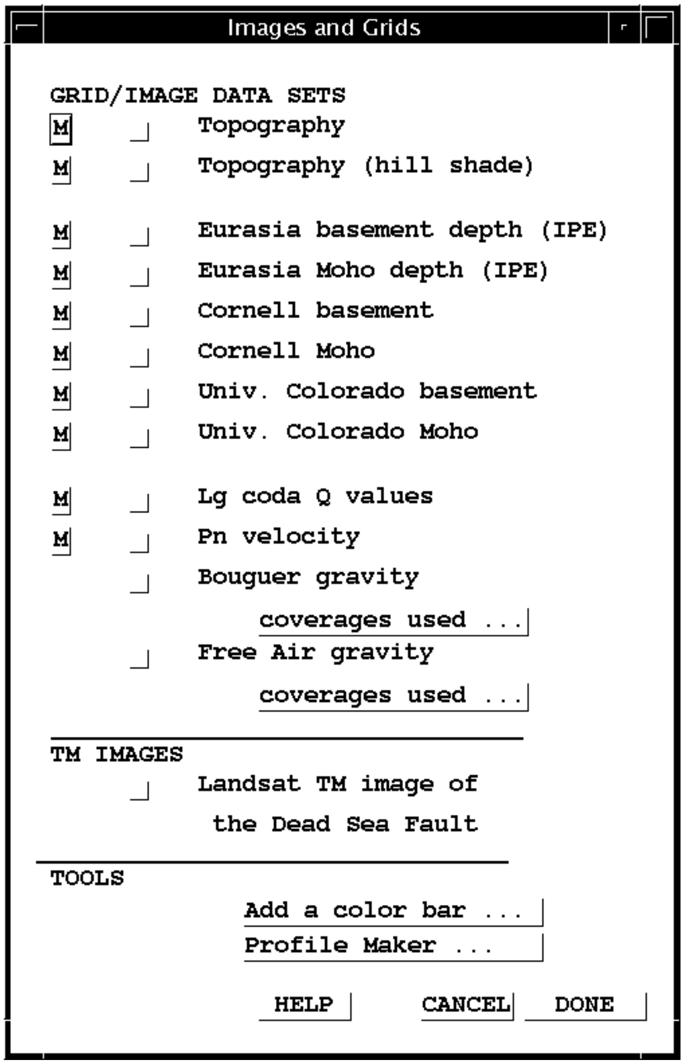

Figure 33. Images/Grids menu and available data sets

Topography

At the top of the list are the topography data, which include submarine bathymetry as well. The cell size of this data set is 2 km. However, the original topography data had a resolution of 1 km. The bathymetry data came from two different data sets, one with about 3 km cell size beneath most of the oceans, and the other with 10 km cell size covering the polar regions. We merged all these data sets and generated a 2 km cell sized data set, hence subsampling the land areas and over sampling the bathymetry. Figure

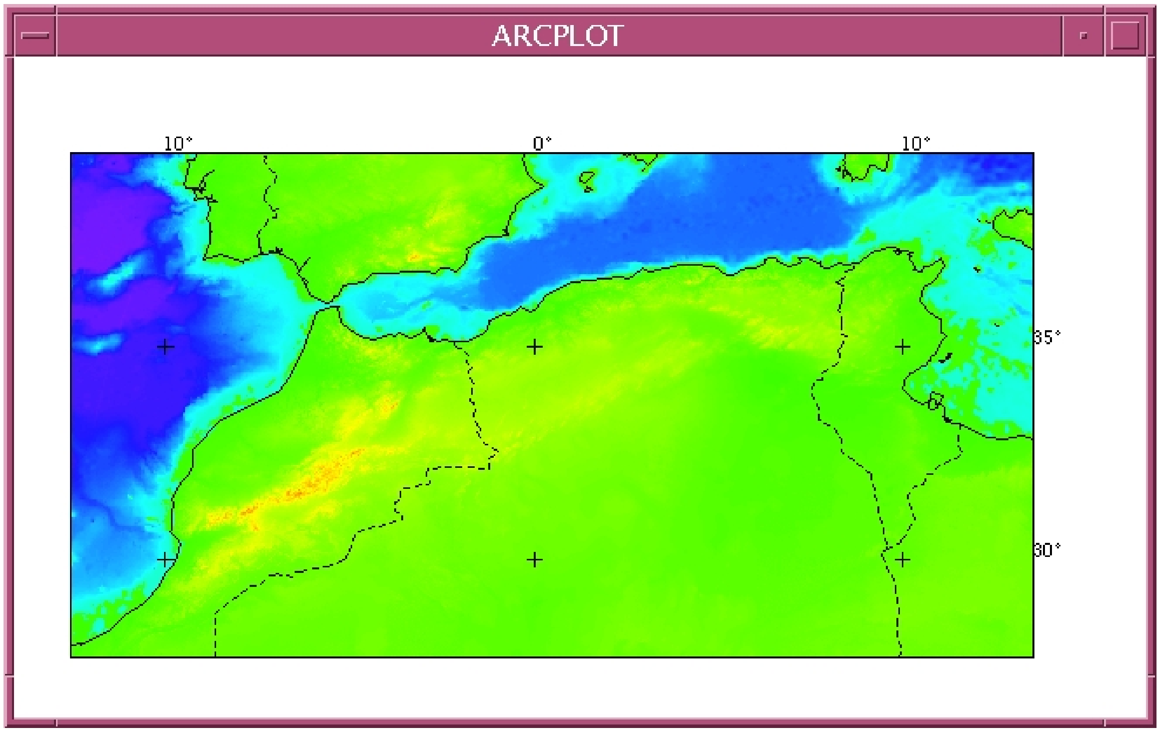

Figure 34a. Topography and bathymetry data of the Atlas mountains in northwestern Africa.

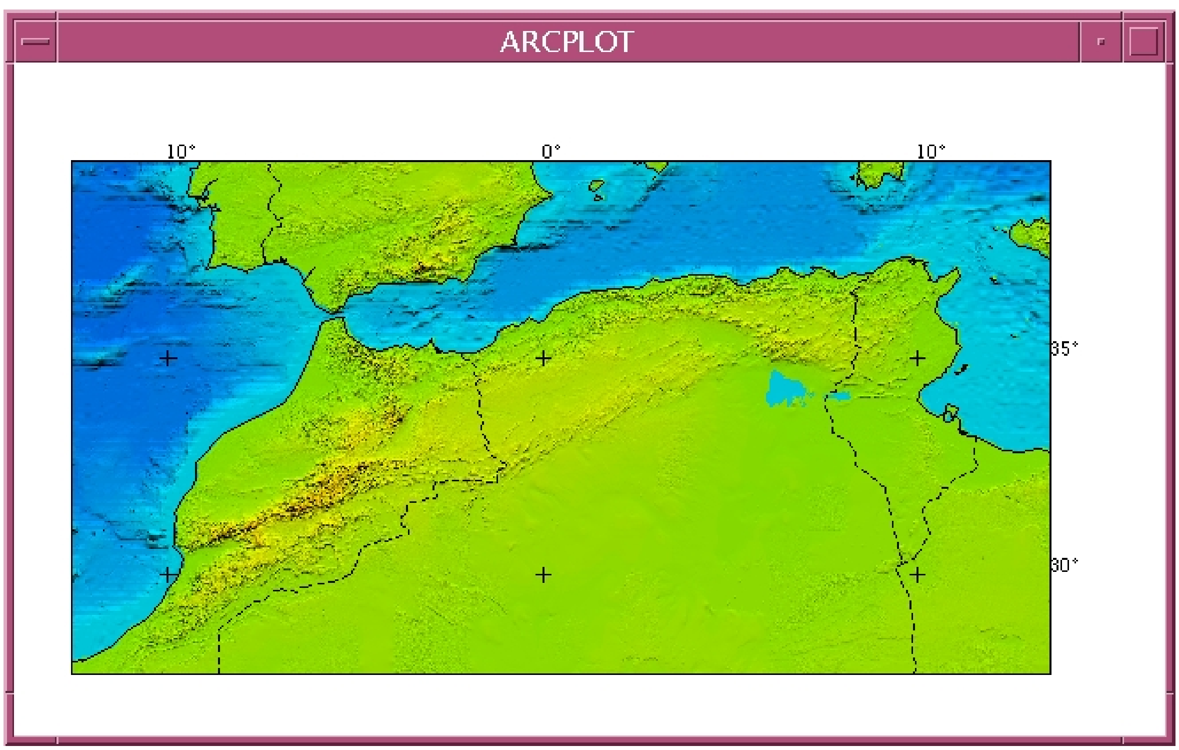

Figure 34b. Hill shaded topography of the same area shown in Figure 34a.

34a shows part of this data set in the Atlas mountains in North Africa. We also created a hill-shaded representation of the topography. This representation allows the relief to be highlighted, and it is convenient for display purposes. Figure 34b shows the same area as Figure 34a with shaded relief option.

Eurasia Basement Map

The Eurasia basement map covers, as its name implies, most of Eurasia. It is taken from the former Soviet Union's IPE (Institute for the Physics of the Earth) maps. The data were gridded to a cell size of 10km. Figure 35 shows part of this data set in the Middle East and North Africa region.

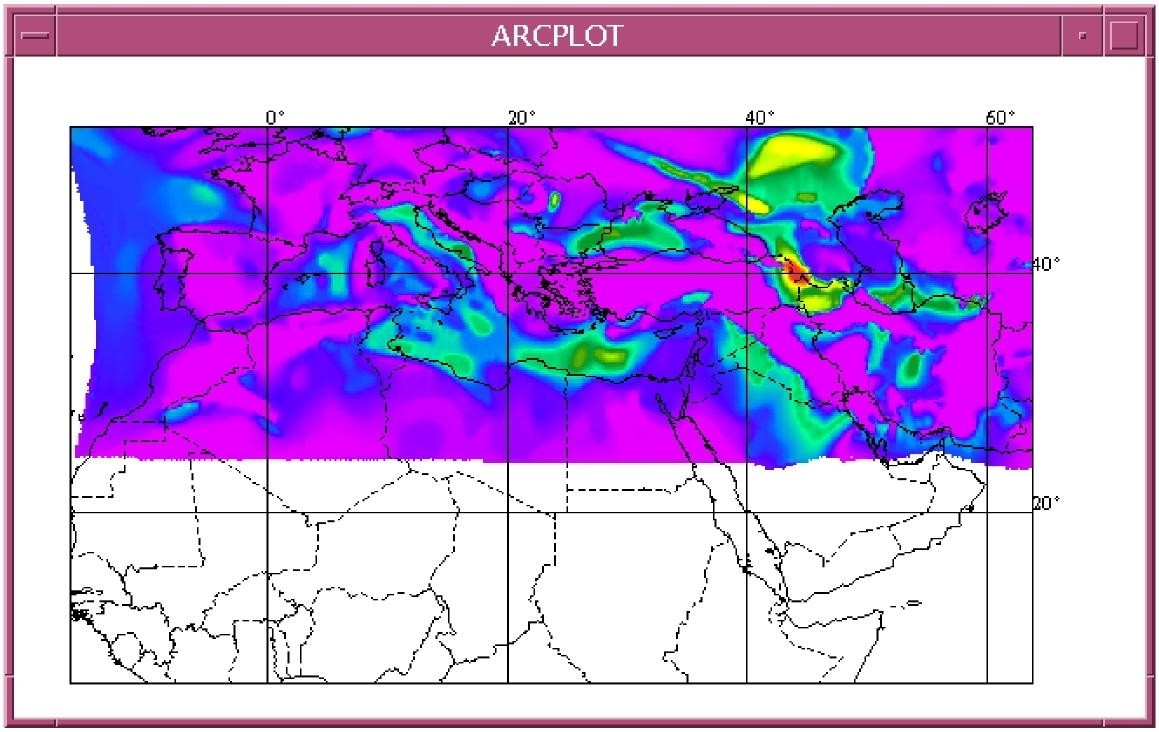

Figure 35. The Eurasia basement map covers parts of the Middle East and North Africa.

Eurasia Moho Map

The Eurasia Moho map is similar to the Eurasia basement map in its source, spatial extent and cell size. Both the basement and Moho maps can be used for continental scale applications. Using them in regional and local studies may be misleading due to their nature. They are averaged and simplified and there is not an independent way of checking the quality of the reported values. Figure 36 shows the Moho values in the Middle East and North Africa region.

Cornell basement

This data set was developed entirely at Cornell for the Middle East region. Results from

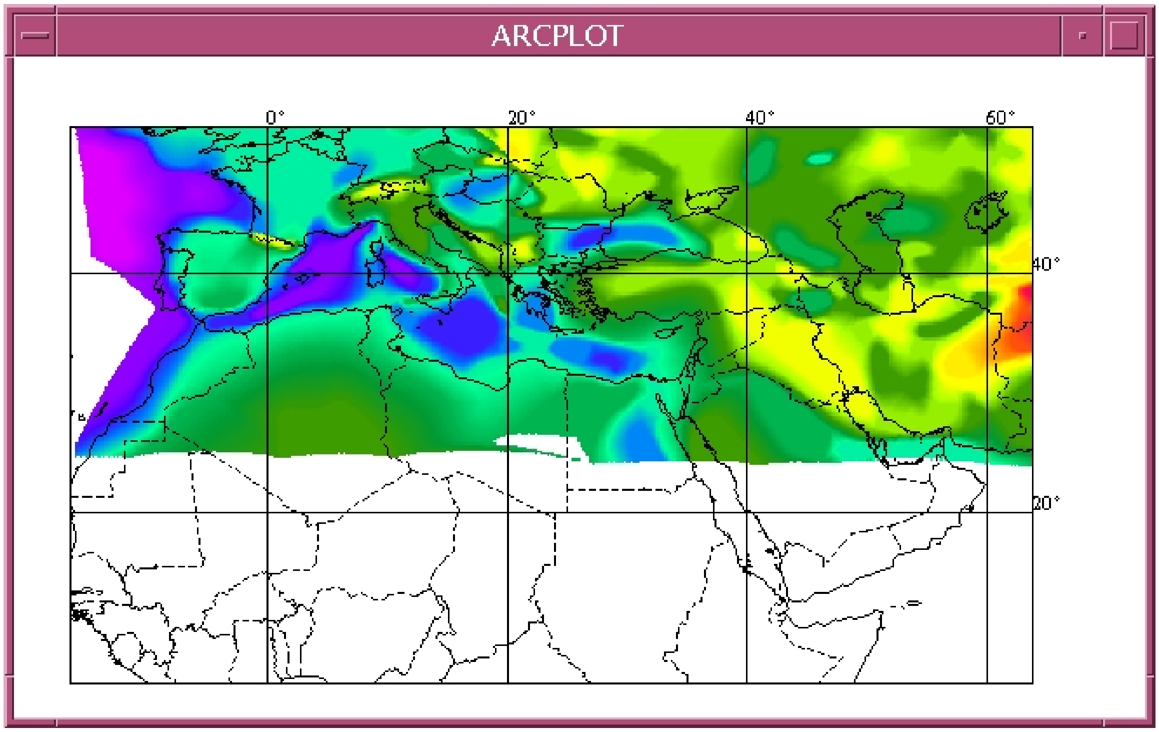

Figure 36. Eurasia Moho map covers parts of the Middle East and North Africa.

several published studies as well as original work in Syria were used in generating this data set. The refraction and gravity profiles taken from the literature are shown in Figure 22a. Figure 37 shows the basement values and geographic extent of the data set.

Cornell Moho

The Cornell Moho data set is also entirely developed at Cornell using several data sets including the profiles shown in Figure 22a, gravity maps, surface wave tomography results, and receiver function studies. Figure 38 shows the Moho values and the geographic extent of the data set. This is the most reliable Moho map in this region. The values can be confirmed with published data sets and other studies.

University of Colorado Basement

This data set was obtained from surface wave tomography studies by the University of Colorado group. The data set covers much of Asia including parts of the Middle East. Figure 39 shows this data set and its geographic extent.

University of Colorado Moho

This is also a data set obtained from surface wave tomography by the University of Colorado group. The data set also covers an area in Asia with some Middle Eastern coverage. Figure 40 shows this data set.

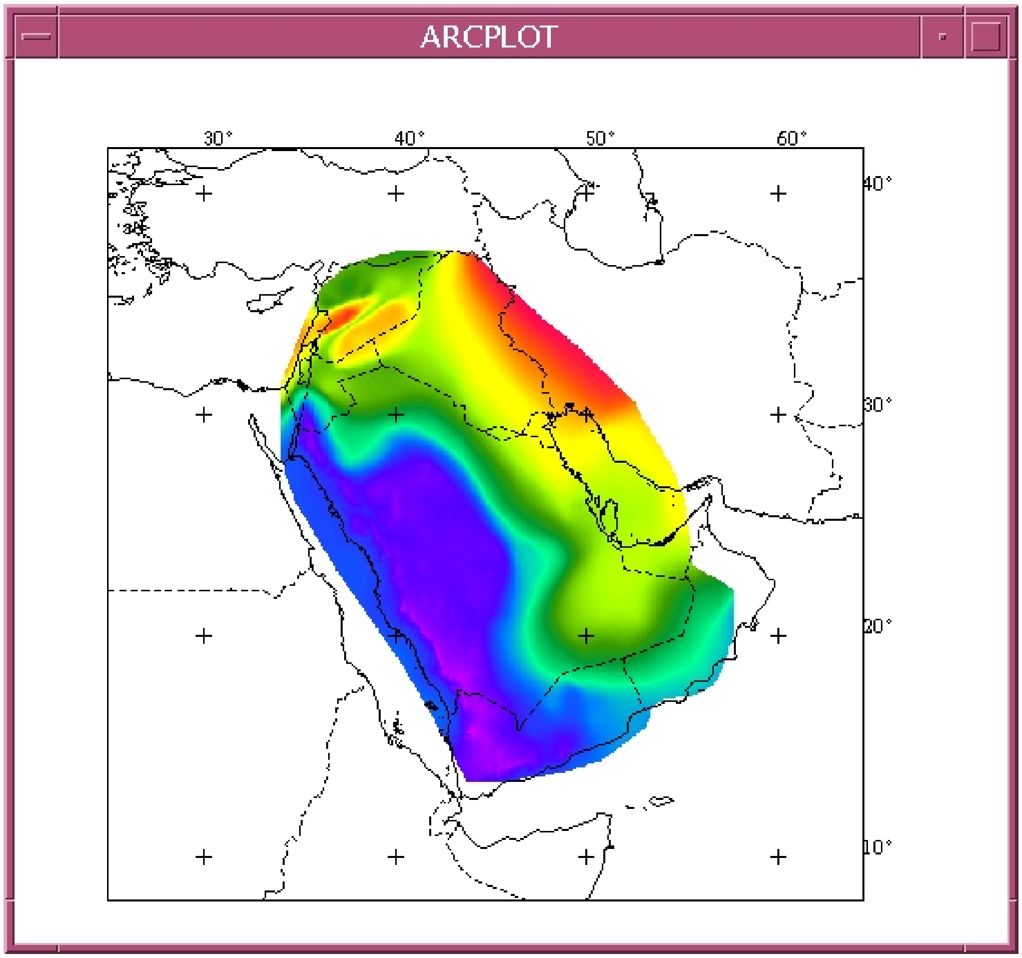

Figure 37. Cornell basement map of the Middle East.

Lg Coda Q Values.
Lg coda Q values were computed for Eurasia by the St. Louis University research group. The values were obtained from a tomographic inversion. The coda Q values represent the efficiency of Lg wave propagation in the crust. Figure 41 shows the Lg coda Q values in the Middle East region.

Pn Velocity
Seismic Pn phase velocities were obtained from the New Mexico State University research group. The data set was obtained using a Pn tomography technique in the Middle East region. The values represent variations from a base velocity of 8.0 km/s. Figure 42 shows the data set and its geographic extent.

Bouguer Gravity Data
These Bouguer gravity data were obtained by gridding the point data provided to us by the Defense Mapping Agency. We are not at liberty to disclose the locations that were used in gridding. However, a secondary data set is provided under the Metadata section to

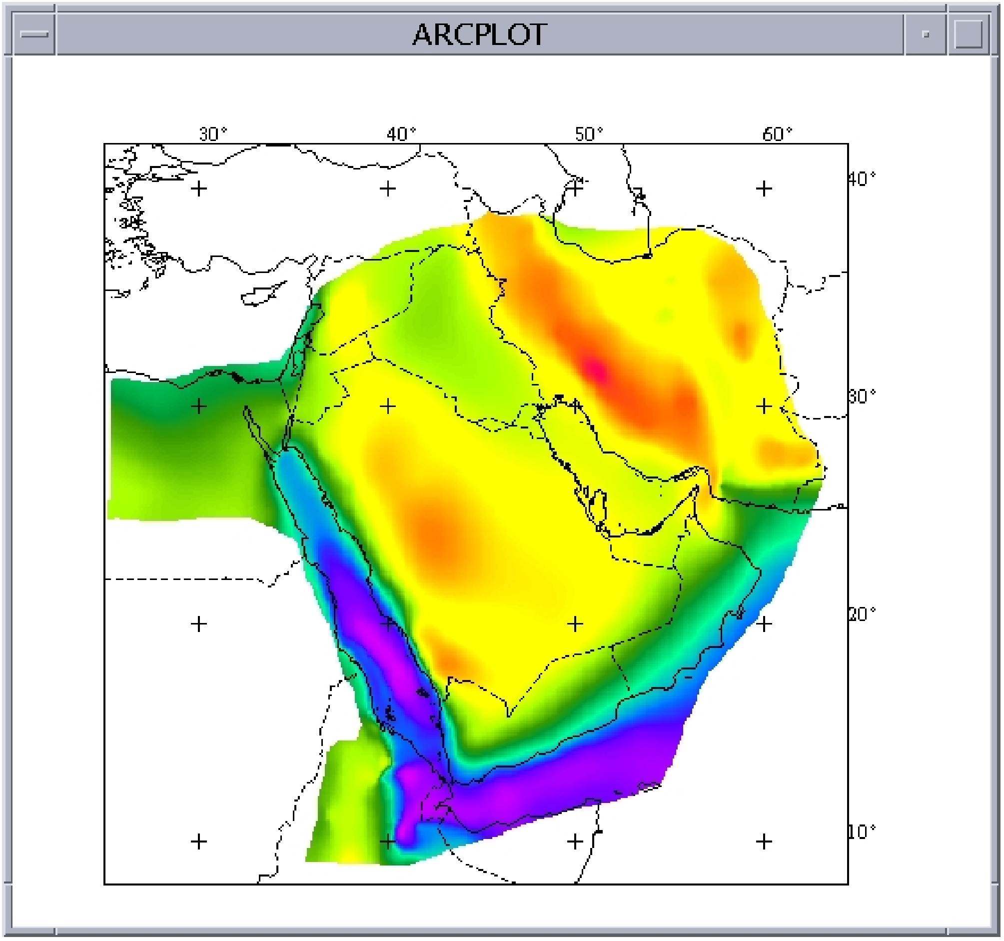

Figure 38. Cornell Moho map of the Middle East

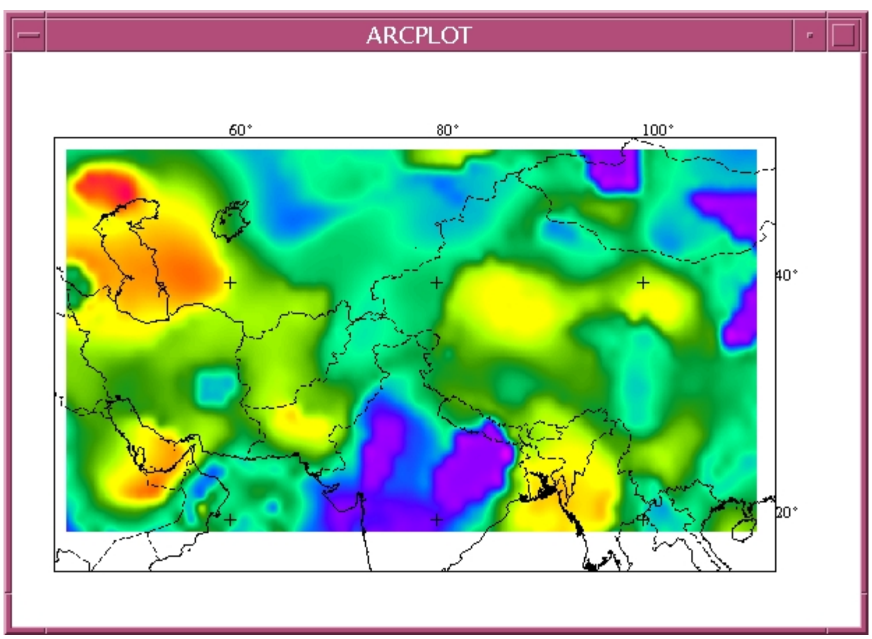

Figure 39. University of Colorado Basement map.

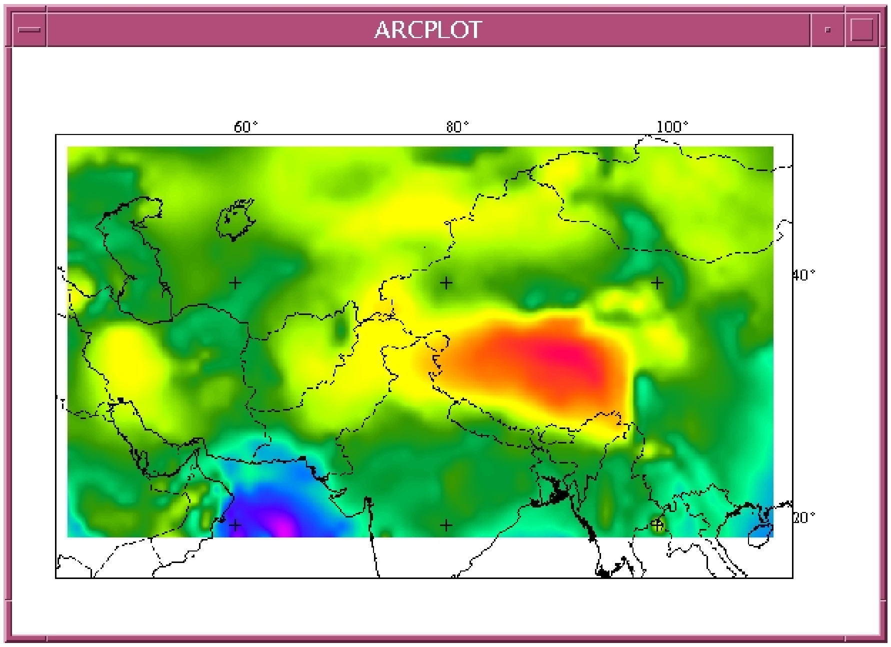

Figure 40. University of Colorado Moho map.

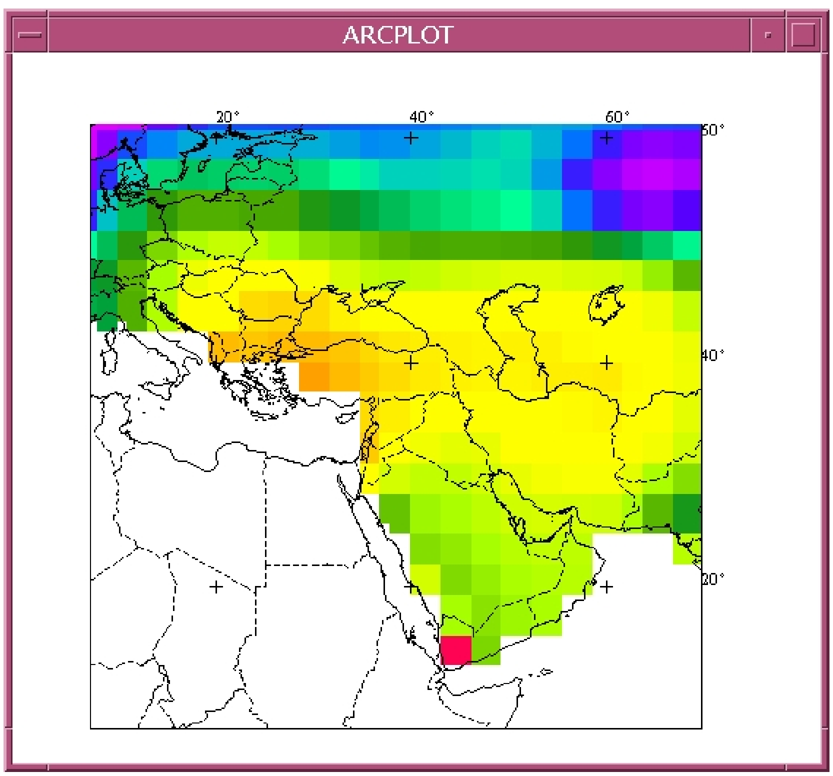

Figure 41. Lg Coda Q values obtained from St. Louis University.

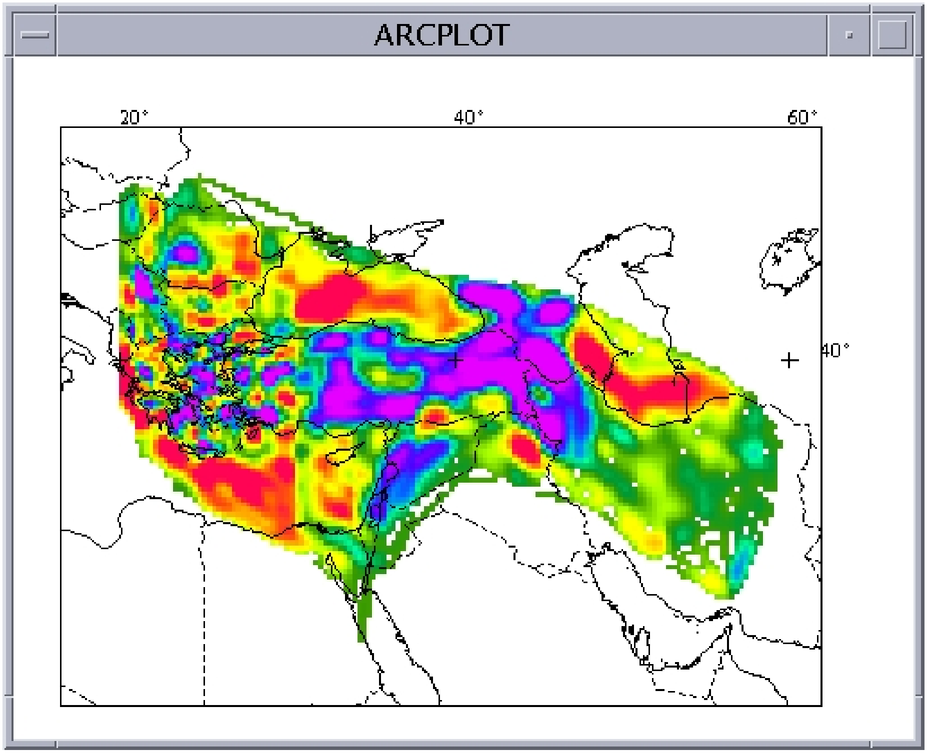

Figure 42. Pn velocity variations in the Middle East obtained from the New Mexico State University group.

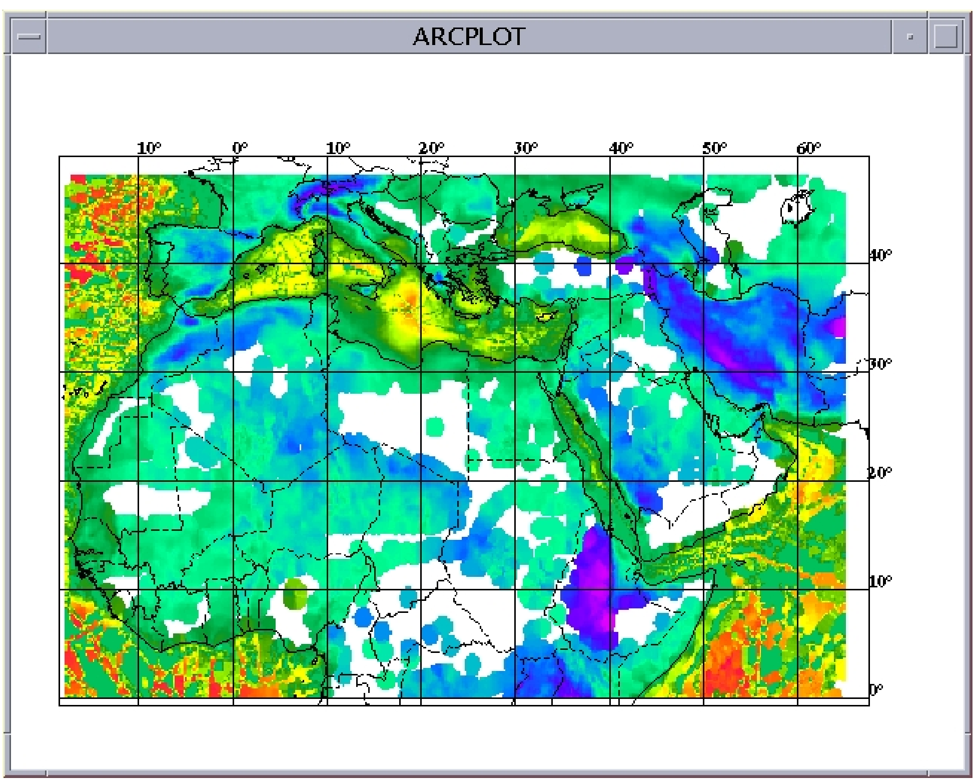

Figure 43. Bouguer gravity data in the Middle East and North Africa.

represent the variance of the grid provided. Figure 43 shows the Bouguer gravity map.

TM Images

We currently hold a data set of about 100 TM scenes in the Middle East and North Africa region. A selection of these scenes is now available in GEOID. The original TM scenes are about 30 m resolution. The data sets in GEOID are subsampled versions of these data sets. The new cell size is 285 m. The scenes were registered and a mosaic was formed. The scenes cover two regions: one in the Atlas mountains of North Africa, and the other in the Northern Arabian plate. Figure 44 shows the mosaic over the Middle East region. The other scenes are being processed and registered.

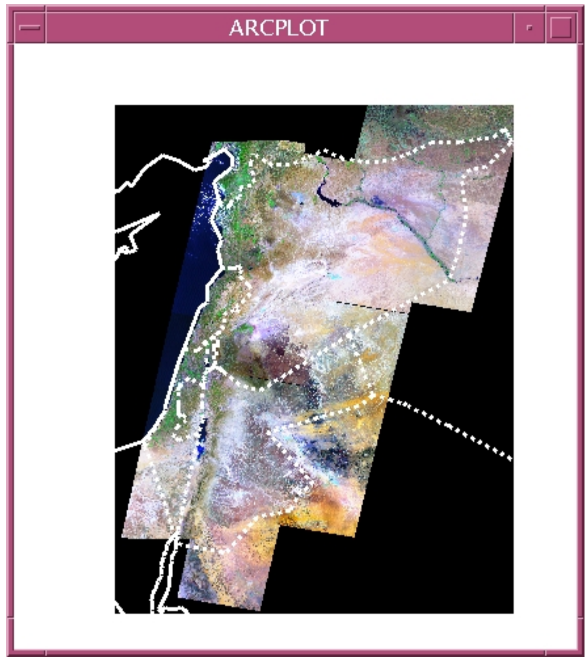

Figure 44. TM mosaic of the Northern Arabian plate.

There are two other "tools" that are provided at the bottom of the "Images/Grids" menu. One of these is used to add a scale bar for the grids, and the other one is used in profile making. The Profile Maker will be discussed in the next section.

The Profile Maker

The profile maker is a tool developed at Cornell to extract profiles or cross sections from the gridded data sets. The profile maker can be used to extract cell values along a transect, or it can be used to construct crustal scale cross sections including topography, basement, and Moho values. Clicking on the "Profile Maker" button initiates a new sub menu and redraws the screen. The screen is divided into two sections: one to plot the map and the other to view the profile (or cross section) values. In the Profile Maker menu first the grids need to be selected from the "Select the grids" menu (Figure 45). Then two point locations representing the beginning and end points of the profile need to be entered. This can be done by either entering the values in the text entry locations or by selecting the "Select 2 points from the screen" button and marking two points on the screen. Following this, pressing on the "apply" button would extract the requested profile or cross section. Figure 46 shows a sample output of a cross section obtained using topography, basement, and Moho values. A great circle path approximation is applied, so that the distance along the profile is the minimal distance between the end points. The extracted profile can be saved in an ascii file or plots of the map and the cross section can be made using the hardcopy button.

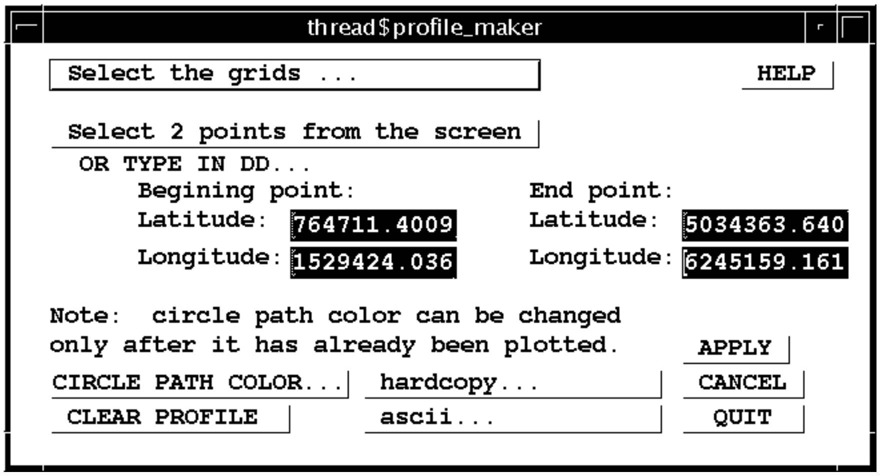

Figure 45. The Profile Maker menu. First the grids need to be selected. Then marking two points on the map or just entering the transect's end coordinate values enables the profile to be extracted by selecting the apply button.

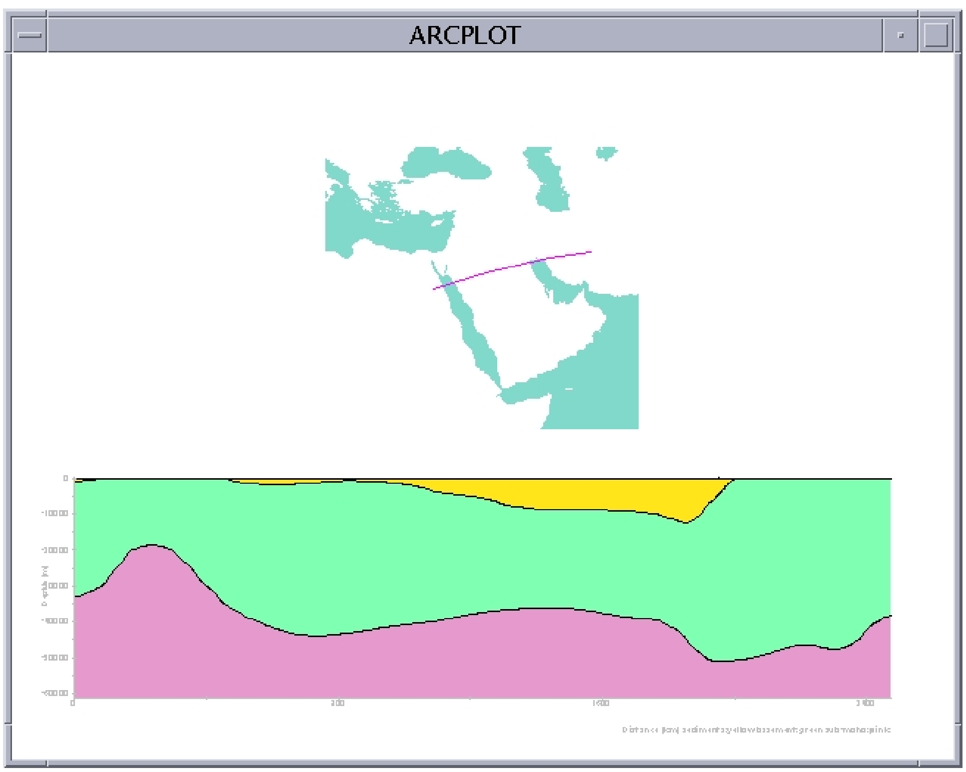

Figure 46. An output from the Profile Maker. Three grids are selected for this cross section: Topography, basement, and Moho.

2.1.3. Tools and Utilities in GEOID

GEOID is developed with certain tools and utilities. As discussed in section 2.1.1 some of the map creation tools are kept under that section. However, we developed several other tools that can help users in their data analysis and mapping. In the next section we will explain other available tools shown in Figure 47.

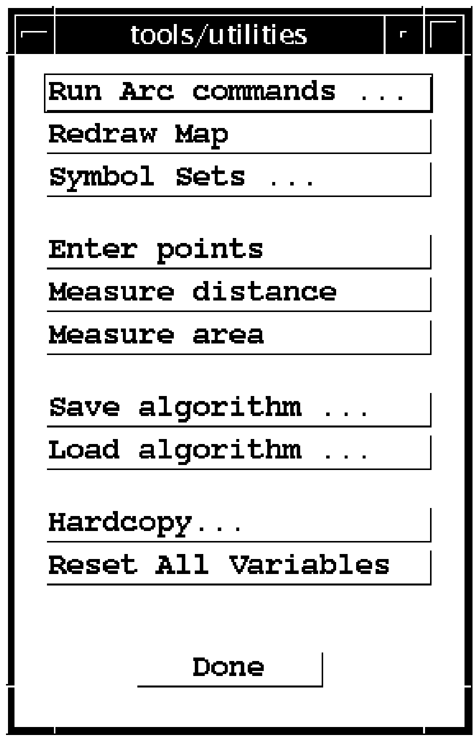

Figure 47. Tools and Utilities menu.

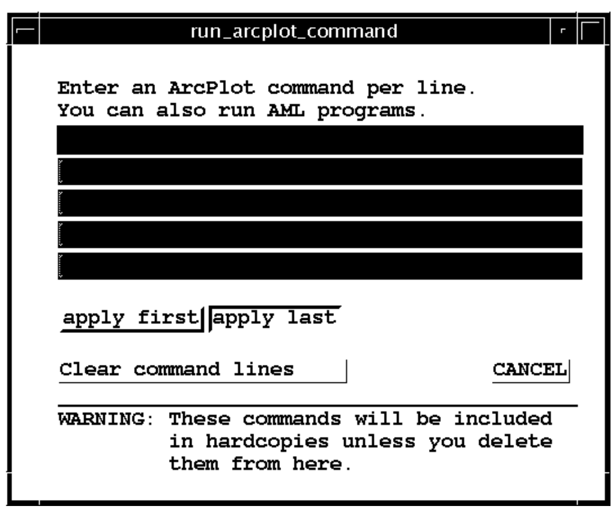

Figure 48. Arc/Info commands can be entered through this menu. This allows users to add their own data sets as external inputs to GEOID. The external data sets become part of the GEOID environment and all the projection, hardcopy, and other options are applied to them directly as if they were internal data sets.

Run Arc Plot Command
This Arc/Info command access tool (Figure 48) is developed for users who are familiar with Arc/Info. Using this tool one can extract information from the system or plot one's own external data and make it part of the GEOID system. For example, if a user has his/her own data set that he/she would like to display with the data sets in GEOID, all the user has to do is type the regular Arc/Info commands that would plot the ArcInfo coverage in one of the five entry lines given in the Arc Plot Command menu. This would make the new data set an external part of the GEOID system. All the zoom, map projections and printing option would work with this external data set. This makes the GEOID system quite powerful for expansion. Similarly, if the user has multiple data or they require selection and definitions, then the user can create an AML program and run it from these command lines. This is quite a useful tool for those who wish to add their data into GEOID and take advantage of GEOID's structure.

Redraw Map
The Redraw Map button is used when some of the mapping parameters are changed. In order to erase the screen and redraw the modified selections this button needs to be pressed. It will redisplay all the selected items in the right order (i.e., polygons would not overlay point or line data sets).

Symbol Sets
Each data set in GEOID is plotted with a default symbol type and color. However, using the symbol sets menu, one can overwrite the default parameters. The "Symbol Sets"

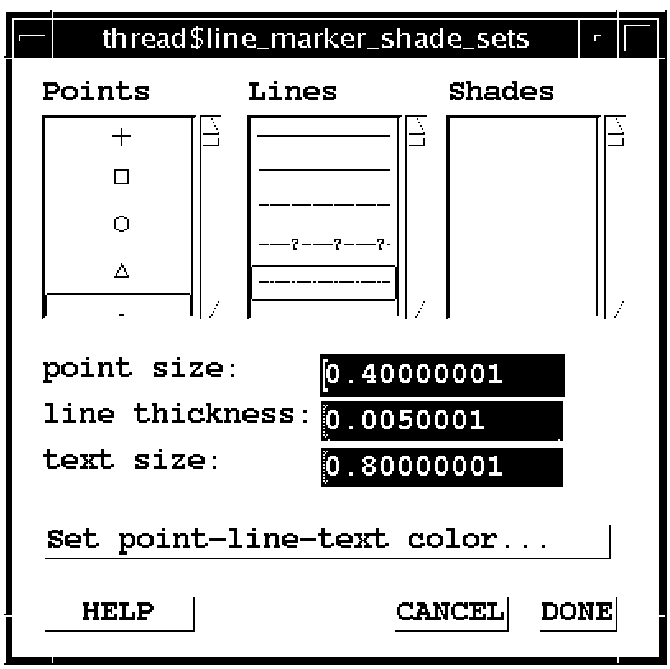

Figure 49. Symbol Sets menu allows changing default symbol types for each data set.

menu (Figure 49) allows one to change line, marker and shade colors as well as size of the symbols. For example, earthquakes are plotted with circles as default. If one wants to plot them as pluses, the plus symbol from the "Symbol Sets" menu needs to be selected. Following that step, the earthquake data set must be re-checked in order for the change to take effect. Once changed the new symbol stays changed until the session is closed. Similarly, all the line and shade types can be changed. The "Set point-line-textcolor" button allows the user to a new color for these items.

Enter Points
This is also a window for user input. If the user has a few points (lat, long pairs) that he/she wishes to display in GEOID with its data sets without creating Arc/Info files, this menu provides an easy solution (Figure 50). Typing longitude and latitude pairs in the text area in this menu would display them in GEOID. The typed values remain there until they are cleared by pressing the "clear all values" button in this menu.

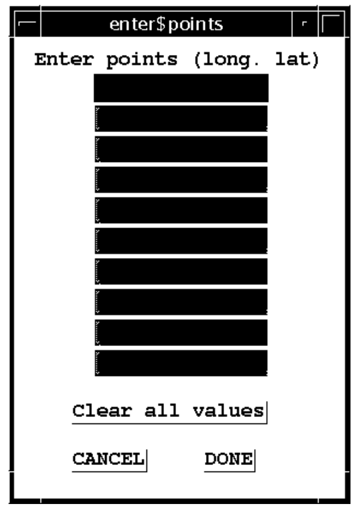

Figure 50. The "Enter Points" menu allows users to define points manually. These points are plotted on the map.

Measure Distance
The Measure Distance button is a simple tool to measure a line distance between two or more points. Once this button is clicked, the user must mark points on the map. A minimum of two points is required. However, as many number of points as necessary can be entered. The entry should end by hitting the "9" key from the keyboard. This will produce an output in the terminal window giving the distance obtained by connecting the points in inches and in map units (usually in meters).

Measure Area
Measuring area is very similar to the "Measure Distance" tool. The only difference is that a minimum of three points is needed to define an area. When the selection of the area on the screen is done, the "9" key will quit the area definition and the output will be written in the terminal window.

Save Algorithm/Load Algorithm

These two tools allow users to save the environment that they are in (such as the map extent area, displayed data sets, symbols, etc.) and restores back to that environment upon loading the algorithm. Within a session, all changed symbol sets or selected data sets will be saved and restored. Once the session is exited, all this information is lost. These algorithm buttons are used to restore the saved environment quickly.

Hardcopy

This is a tool used in obtaining a hardcopy of the screen output (Figure 51). The user can set a map scale, a page size, page layout, and an output file format. The default output format is postscript. An extension is added to the output file name.

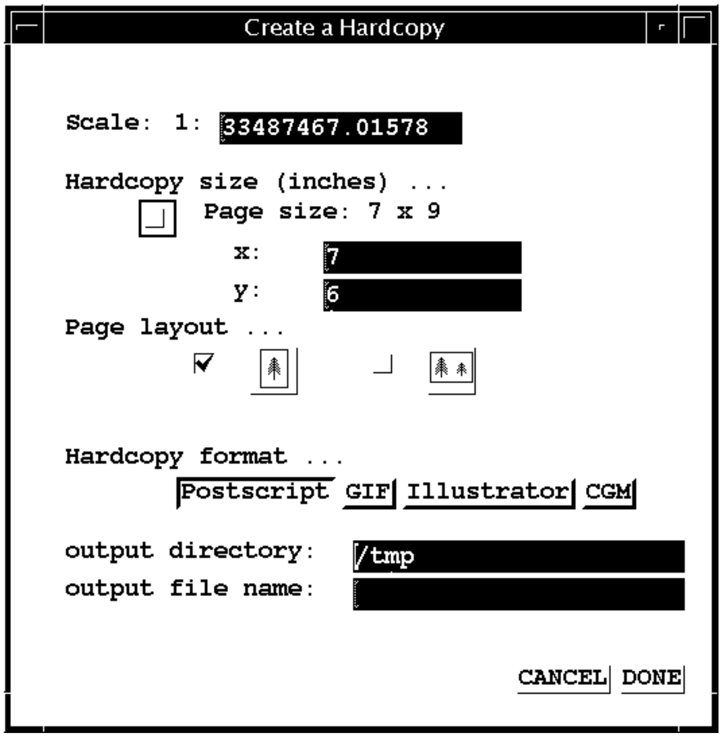

Figure 51. Hard copy menu allows users to create a hardcopy of the map on screen.

Reset All Variables

This button resets all the variables already changed and returns to the beginning environment.