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INSIDE

Middle East Tectonics: Applications of Geographic Information Systems (GIS)

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ABSTRACT

The Middle East region incorporates all known types of major plate boundaries in its territory as well as significant active intraplate deformation. Until recently, understanding the tectonics in this complex region has been hindered by a relative lack of data and the complexity of the geologic and tectonic problems. Even with the increase in the amount of data in the past decade or so, the complexities of the region require a multidisciplinary approach to understand the geology and tectonics. In order to handle large, multidisciplinary data sets with varying quality and resolution, we have adopted a Geographic Information System (GIS) approach for construction of a multipurpose database to look at these problems in a comprehensive and unconventional way. Here, we present new compilation maps of surficial tectonic features and depth to the Moho for the Middle East, and describe a cross-section tool to work with data in a GIS format. These maps are available at our web site at http://atlas.geo.cornell.edu.

INTRODUCTION

At present, the earth sciences are undergoing a revolution. Evidence comes from collection to analysis of data, interpretation, and publication. Classical approaches are being increasingly supplemented by digital techniques, i.e., analog maps by digital counterparts, air photos by high-resolution satellite imagery, hand-collection of field data by GPS receivers and laptop computers, simple modeling by computer using sophisticated software, and electronic publication of results. This development is an inevitable outcome of modern technology. However, this technological revolution is not without problems. Already, somewhat chaotically organized databases are appearing in the digital world owing to problems like data accessibility and formats. Geographic Information Systems (GIS) provide a means to eliminate these problems and to keep data in an organized and centralized system (see also Walker et al., 1996). Structured properly, well-engineered databases are easy to use, update, modify, manage, distribute, and exchange.

One of the common misconceptions about GIS database development is that it

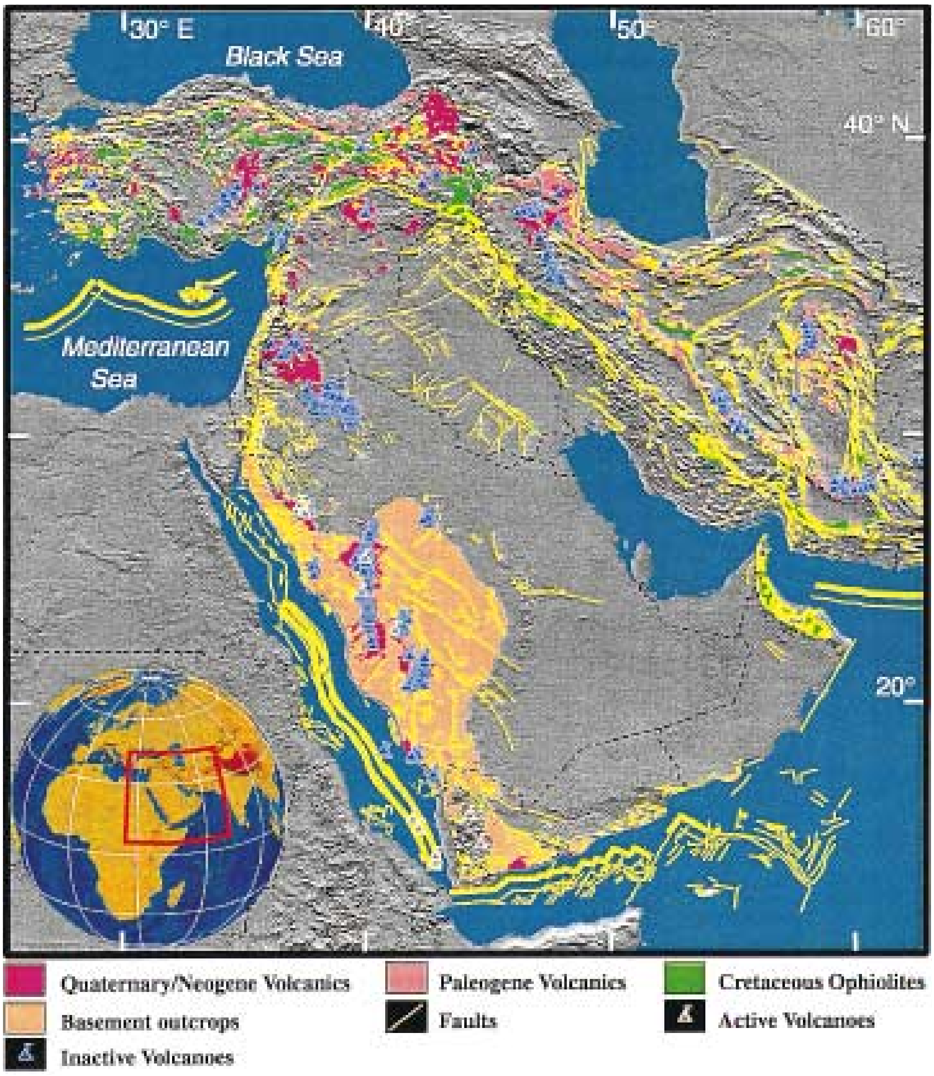

Figure 1. New map of the Middle East region showing locations of oceanic trenches, rift zones and major faults (thick yellow lines; see names in Figure 2), secondary faults, ophiolites, regions of basement outcrop, and principal areas of volcanism. This map is compiled from GIS data set that includes tectonic and geologic maps of various scales from the different countries in the region. See Figure 2 for tectonic interpretation. The gray background image is the shaded topographic relief map, illuminated from the north (shown in more detail in Figure 3). A clear correlation between topographic features and faults suggests that most of the faults shown on the map are still active.

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Bedford, Texas
December 7, 1996

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Whittier, California
January 3, 1995

Herbert E. Hawkes
Hanover, New Hampshire
December 4, 1996

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is primarily a mapping tool. Although the output is commonly in map form, the main use of GIS is to analyze, search, manipulate, and select databases for a specific purpose. The use of GIS systems opens new avenues for comprehensive studies and solving complex problems related to integrated and dynamic earth systems. Earth sciences, by their very nature, are among the most suitable disciplines for GIS applications.

BUILDING A COMPREHENSIVE DATABASE FOR THE MIDDLE EAST

In this paper, we apply GIS technology to regional-scale tectonic problems of the Middle East. To do this, we are developing a comprehensive database at a resolution of 1:1,000,000 scale which can be used as both a scientific and educational tool. Developing such a database system for multiple users is most advantageous, if easy-to-use tools for accessing and manipulating data sets are built into the system so that scientists can use the database in innovative ways to make research advances. The principal reasons for constructing this database in the Middle East are to help in the monitoring and verification of the recently signed global Comprehensive Test Ban Treaty (CTBT) (see Barazangi et al., 1996) and to study the complex tectonic and geologic problems of the region. This database will also have an impact in natural hazard evaluation, particularly in understanding the earthquake occurrences in the region and seismic risk assessment. The data set can also be used in classrooms as an educational tool.

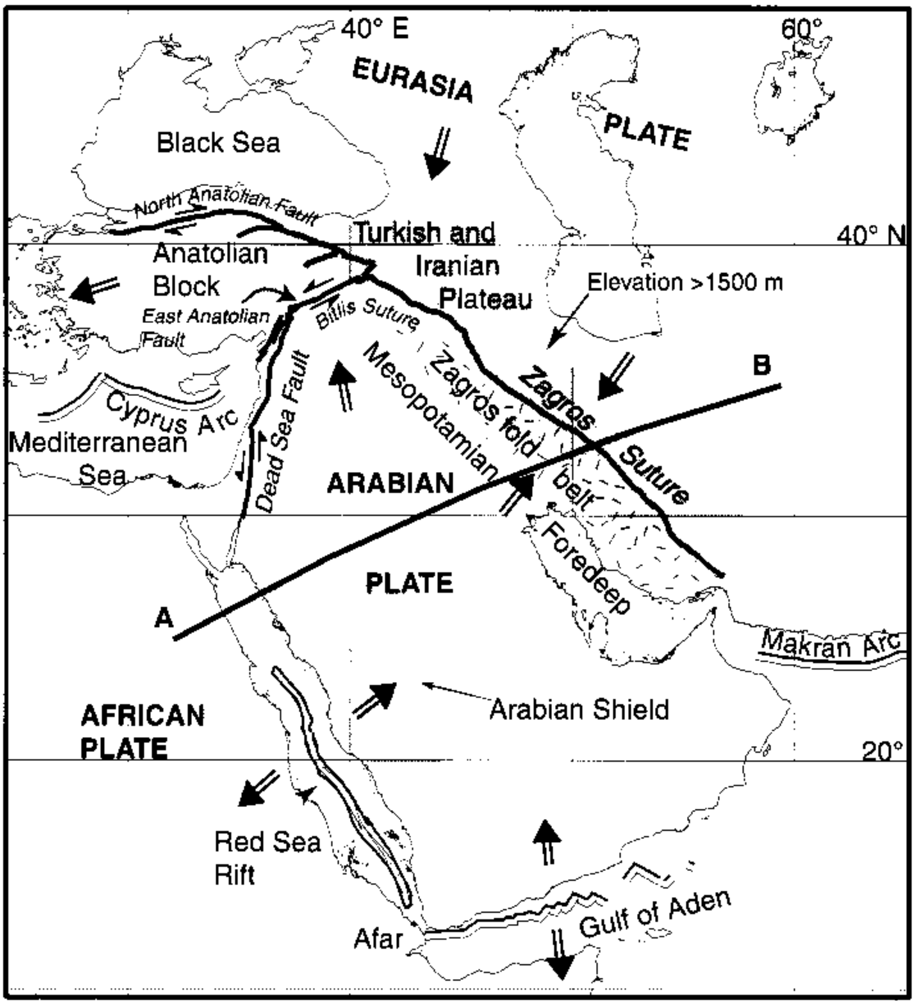

Figure 2. Simplified tectonic map of the Middle East showing types of plate boundaries surrounding the Arabian plate, features within the Arabian plate, and location of profile A-B in Figure 5. Modifications from previous regional tectonic maps include the boundaries of the Turkish and Iranian plateau and the exact locations of the North and East Anatolian faults. See discussion in the text.

GIS Data and an Improved Middle East Tectonic Map

A tectonic map made from our GIS data set showing the major plate boundaries and surface features of the Middle East is shown in Figure 1. The background for the map is a high-resolution (~90 m) digital topographic map of the Middle East obtained from the Defense Mapping Agency (DMA). Information on the map includes locations of trenches, rifts, secondary faults, volcanic rock and ophiolite distributions, basement outcrops, and basins. The features have been compiled from regional tectonic and geologic maps among which the most important are the Geological Survey of Iran *Seismotectonic Map of the Middle East,* the Syrian Arab Republic Ministry of Petroleum and Mineral Resources *Geologic Map of Syria,* and the General Directorate of Mineral Research and Exploration of Turkey *Active Fault Map of Turkey.* In the GIS database, geologic features on the maps have all been assigned attributes defining their properties.

Using the Middle East GIS data system, one can display any set of data needed for a particular study. For example, faults longer or shorter than any given length can be selected, or active faults and volcanoes can be displayed. High-resolution satellite imagery and field geology data can be incorporated in the database system for special studies such as the effects of erosion on topography. Among important problems for study in the Middle East are reasons for volcanic activity in both tectonically active and platformlike environments, for the complex patterns of seismicity, and for variations in crustal structure.

The map shown in Figure 2 has been modified from previous versions through the use of our GIS database. Particularly important in this modification was the use of the high-resolution (~90 m) digital topographic map shown in the background of Figure 1 and in Figure 3. Digital Elevation Models (DEMs) like this provide highly accurate elevation information that can be used as a guide in defining boundaries of tectonic units, especially those related to young (i.e., Quaternary) deformation. Using the DEM with our database, we have found first-order correlations between topography, faults, and seismicity that indicate that most of the major faults in Figure 1 are still active and that the topography is in large part shaped by active tectonic processes. Taking advantage of this correlation, we have refined the positions of the North and East Anatolian faults and defined a new boundary for the Turkish-Iranian plateau.

Figures 1 and 2 can be used as a guide for a tutorial on the major tectonic features of the Middle East. As shown, the region incorporates all known types of major plate boundaries around the borders of the Arabian plate (e.g., Dewey and Şengör, 1979). To the south along the Red Sea and the Gulf of Aden, new oceans are opening (see Cochran, 1983; Le Pichon and Francheteau, 1978). To the north and east, continental collision is occurring along the Bitlis suture zone in southern Turkey (Şengör and Kidd, 1979; Şengör et al., 1985) and the Zagros suture zone in western Iran (Snyder and Barazangi, 1986; Ni and Barazangi, 1986). The current counterclockwise rotation and northward motion of the Arabian plate relative to Eurasia are accommodated along these collision zones. Well-developed arc volcanoes and a foreland basin along the entire Zagros mountain system indicate Neogene subduction in this region. Although a similar volcanic arc and foreland basin are not easily identified along the Bitlis suture, a Neogene subduction zone is also inferred in this region, especially in southeast Turkey. To the northwest, the Dead Sea fault system manifests itself as a left-lateral strike-slip plate boundary that extends approximately 900 km along the boundary between the Arabian and African-Levantine plates (Garfunkel, 1981; Girdler, 1990; Chaimov et al., 1990). Other major strike-slip zones are the right-lateral North Anatolian fault in northern Turkey and the left-lateral East Anatolian fault in eastern Turkey, which form respectively the northern and eastern boundaries of the

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Anatolian block. These faults developed to accommodate escape of the Anatolian block toward the west in response to the collision of Arabia and Asia (Şengör et al., 1985).

A consequence of the collision between the Arabian and Eurasian plates was the development of the high Turkish and Iranian plateau in eastern Turkey and northwestern Iran. This plateau covers a wide region behind the main Zagros and Bitlis suture zones. By following the 1500 m elevation contour on the high-resolution topographic image, we have been able to map the boundary of this plateau. This contour represents the maximum elevation or base level of the plateau that defines a continuous elevated surface over the entire region. Although the mechanism that holds up this high plateau is not well understood, extensive volcanism and strong seismic shear wave attenuation in the mantle lithosphere beneath the plateau (e.g., Kadinsky-Cade et al., 1981) suggest that a thermal component is required. Further work is needed to fully understand the crustal and upper mantle structures of this region.

The western part of the Arabian platform, east of the Red Sea, has a large region called the Arabian shield where Precambrian crystalline rocks are exposed (Fig. 2). Unlike other shields, which by definition are regions of long-term tectonic stability, the Arabian shield has been subjected to recent tectonic activity. In particular, the continuing rifting process that formed the Red Sea has affected the region. The presence of Cenozoic volcanic activity within the Arabian shield area shows a real departure from a typical shield environment (e.g., Camp and Roobol, 1992). The very low seismic crustal Q values of the Arabian shield (Seber and Mitchell, 1992), which are atypical of shield regions, reflect this tectonic and magmatic activity.

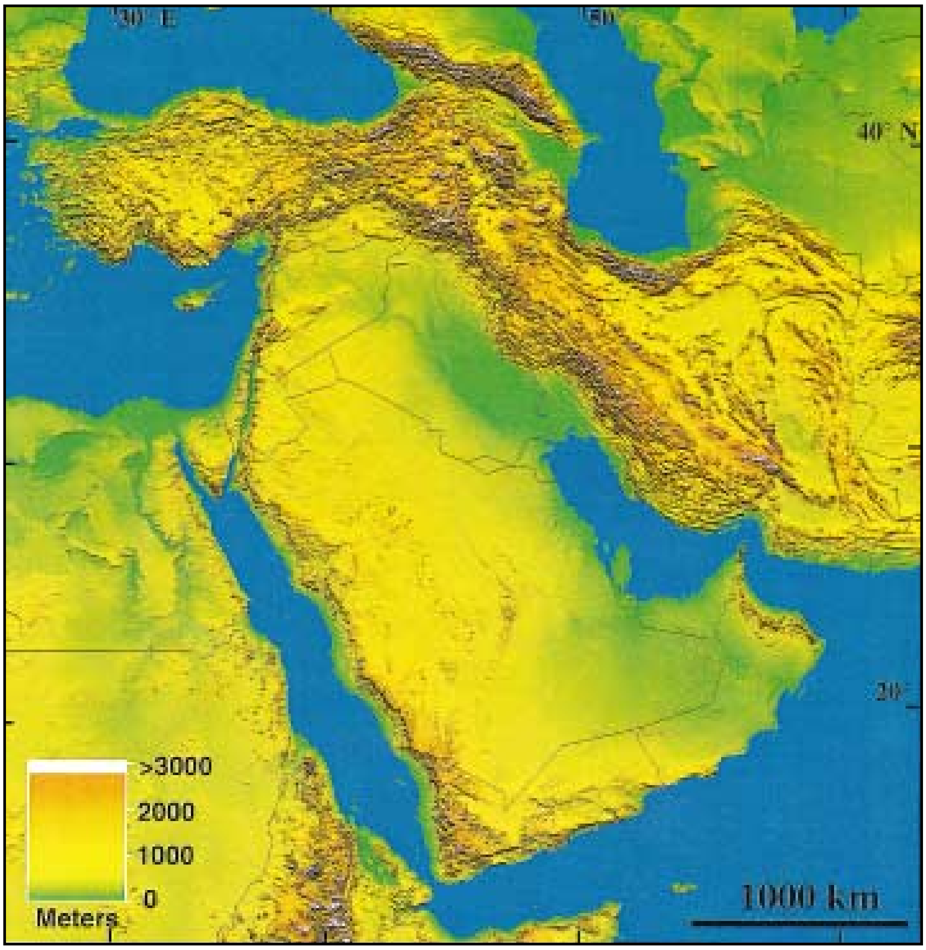

Figure 3. Shaded topographic relief map for the Middle East created from Defense Mapping Agency data and the 1 km global elevation model from the U.S. Geological Survey. Elevations range from sea level to over 6000 m in some localized peaks. See Figure 2 for names of tectonic units and Figure 4 for geographic names.

New Moho Map and Crustal Cross Section of the Middle East

One of the least known geological features in the Middle East region is the thickness of the continental crust—that is, the depth to the crust-mantle boundary or Moho. To constrain Moho depth in this region, we have digitized more than 50 interpreted crustal-scale refraction and gravity profiles (Fig. 4) from the published literature. All boundaries have been assigned specific attribute names like "basement" and "Moho." To this database, we have added Moho depth estimates obtained using a single-station technique (Sandvol et al., 1996). Moho depth values from surface-wave tomographic studies (Ghalib, 1992) and interpretations of Bouguer gravity data in Iran (Dehghani, 1981) were also incorporated. The Moho map in Figure 4 was made by selecting and gridding all of the Moho depth values in the database. In regions where data were limited, Moho depth was determined by interpolating from the nearest data points.

Examination of the map in Figure 4 points to several first-order crustal characteristics in the Arabian plate region. First, the thickest crust occurs beneath the Zagros Mountains in Iran where continental collision is taking place. Second, the thinnest crust occurs beneath the southern Red Sea where new oceanic crust is forming. Third, the crustal thickness beneath the Arabian shield appears to be mostly around 40–45 km. This result is constrained by a single profile, and should be taken cautiously. However, seismological data recently collected by Scripps Institution of Oceanography and Saudi scientists will soon allow us to provide additional constraints in Moho depth in this region. Fourth, the crust is very thin (~8 km) beneath the Afar triangle of Africa, just west of the southern Red Sea. This region is thought to be underlain by either an oceanic crust or stretched continental crust heavily injected by magmatic rocks (e.g., Mohr, 1989).

A tool called Profile Maker that we have developed for use with gridded databases is useful in detailed studies of crustal variations. This tool extracts and draws two-dimensional crustal scale cross sections between any two points within the area of data coverage. Any combination of topographic, basement depth, crustal thickness, seismic velocity, gravity, and any other available data can be incorporated. These profiles can be used for multiple research purposes such as seismic waveform or gravity modeling, or for teaching.

A cross section made with this tool which incorporates topography, depth to crystalline basement, and total crustal thickness (Fig. 5) illustrates the thin crust in the Red Sea and the thick crust beneath the Zagros Mountains in comparison with the rest of the Arabian platform. The Mesopotamian foredeep is identifiable by the thickening of sedimentary rock toward the Zagros collision zone.

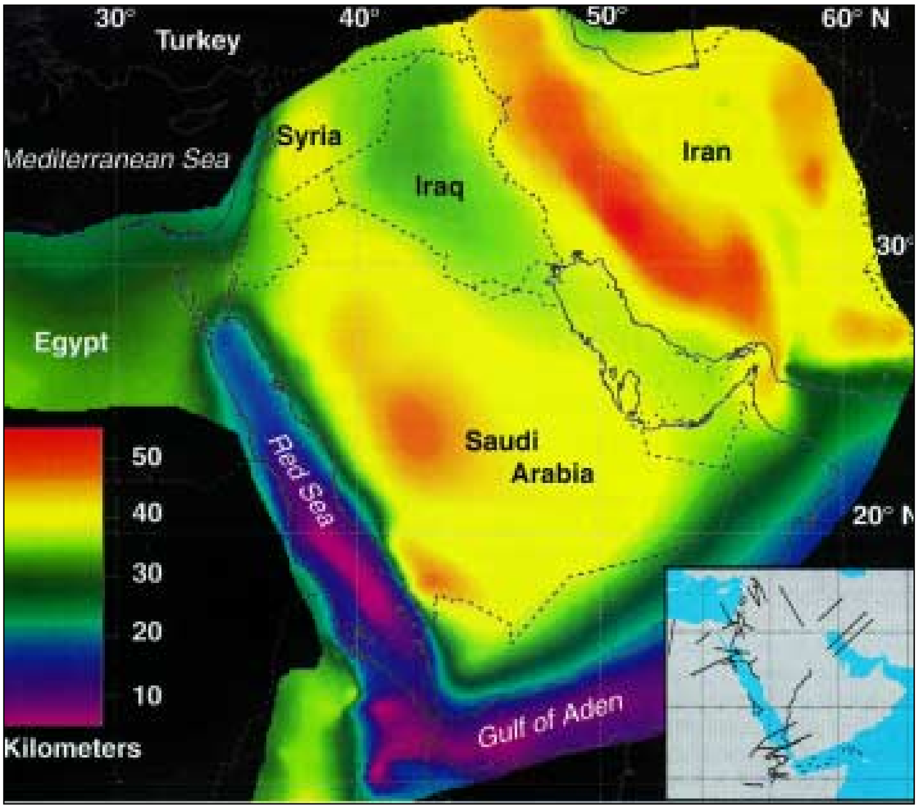

Figure 4. New compilation map for depth to the Moho in the Middle East made by merging more than 50 crustal scale profiles with other geophysical information (see text). The deepest Moho occurs beneath western Iran, whereas the shallowest Moho is under the southern part of the Red Sea. Moho depths are near 40 km in most of the Arabian plate. The inset map shows locations of published profiles used in the compilation.

CONCLUSIONS

As we progress into the digital technology age, efficient ways of capturing, storing, organizing, manipulating, and updating data sets are needed so that we are not overwhelmed by the amount, diversity, and heterogeneity of the data. Clearly, GIS provides a convenient platform for data collection, organization, and research with multidisciplinary data sets. As more groups adopt GIS applications, the earth sciences community will be in a position to prepare a unified global database for more efficient, productive, and rewarding research. Such a database platform will significantly affect the way we conduct research, teach, and educate future generations of earth scientists. This study shows that there are significant scientific returns for the effort required in putting together a GIS database. With our GIS database we are developing a better understanding of the tectonics and crustal structure of the Middle East. More information on our Middle East GIS database, as well as access to the databases and profile tool discussed in this article, can be found on the Internet at http://atlas.geo.cornell.edu.

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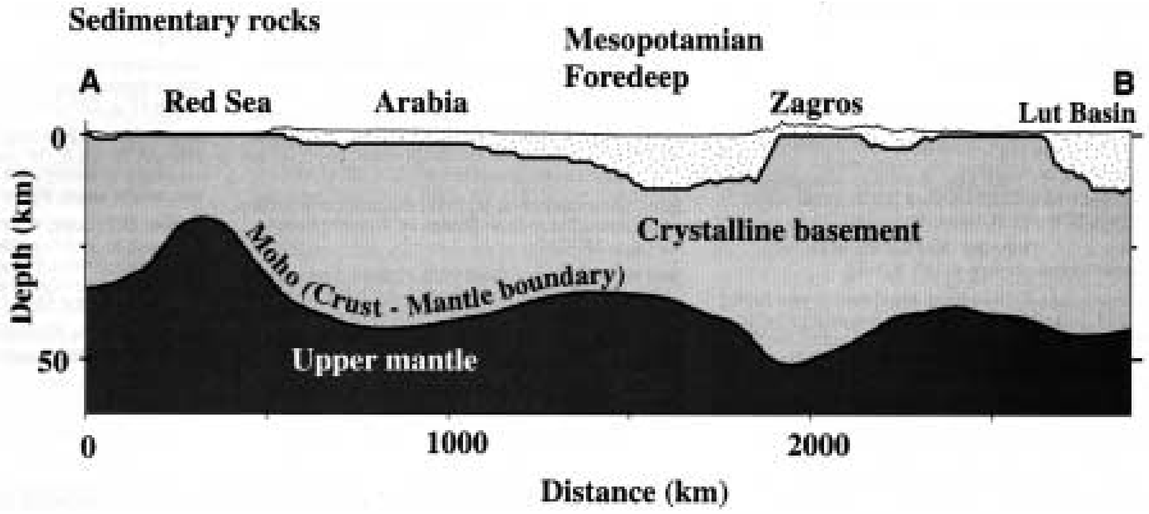

Figure 5. Crustal scale profile showing how the crust-mantle boundary and the thickness of sedimentary cover change on a southwest-to-northeast profile (line A-B in Fig. 2) across the Red Sea, the Arabian plate, and the Zagros suture. The profile was made by the profile tool in our GIS database by using basement depths in the database and information shown in Figures 3 and 4. Depth to the MOHO or base of the crust is largely based on seismic velocity information. The boundary between sedimentary cover and crystalline basement is set where seismic P-wave velocities reach 6 km/s when based on seismic data. Note the effects of rifting and thinning of the crust in the Red Sea, and the thickening of foredeep sediments and crust beneath the Zagros collision zone.

WASHINGTON REPORT

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Washington Report provides the GSA membership with a window on the activities of the federal agencies, Congress and the legislative process, and international interactions that could impact the geoscience community. In future issues, Washington Report will present summaries of agency and interagency programs, track legislation, and present insights into Washington, D.C., geopolitics as they pertain to the geosciences.

WIPPing the Problem of Nuclear Waste

> *"Scientific analyses indicate that the WIPP repository has the ability to isolate transuranic waste for more than 10,000 years, provided it remains undisturbed by human activity."*
>
> — Charles Fairhurst,
> Professor of Mining Engineering and Rock Mechanics
> University of Minnesota

A newly released National Research Council (NRC) report indicates that human exposure to radiation from nuclear waste that would be stored in an already constructed, underground disposal site in southeastern New Mexico is "likely to be low," not exceeding U.S. and international radiation protection standards. The report, "The Waste Isolation Pilot Plant: A Potential Solution for the Disposal of Transuranic Waste," was prepared by a 13-member committee that included Stanford University geochemist Konrad B. Krauskopf and U.S. Geological Survey hydrologist Leonard F. Konikow. The committee's report is one of a series prepared by the NRC since 1978 in response to a request from the U.S. Department of Energy (DOE), for an independent review of scientific and technical issues related to designing, constructing, and operating a pilot plant for isolating radioactive wastes from the biosphere. The NRC is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering. It is a private, nonprofit institution that provides science and technology advice under a congressional charter.

The Waste Isolation Pilot Plant (WIPP) is a network of underground excavations, chambers, and tunnels cut in a layer of "geologically stable," Permian age Salado Formation salt, 2,160 ft (658 m) below the desert surface, 25 mi (40 km) east of Carlsbad, New Mexico. The WIPP is designed to be a permanent repository for a category of intermediate-level, defense-related, radioactive waste known as transuranic (TRU), waste containing radionuclides with atomic numbers greater than uranium (atomic number 92), which results chiefly from the production of nuclear weapons from plutonium and enriched uranium.

The WIPP is the first geological repository in the nation for which an application to begin permanent geologic isolation of TRU waste has been submitted for a regulatory decision. If approved, the WIPP site will be the deepest intermediate waste repository in the world. (An intermediate-level waste repository in Olkiluoto, Finland, is about 400 ft (125 m) below the surface.)

The WIPP is designed to store 175,580 cubic meters of TRU waste. It is anticipated that 137,000 cubic meters of TRU waste with an activity of 7,900,000 Ci will eventually be stored at the facility. The TRU waste consists of contaminated materials from laboratory and production operations, including discarded protective clothing, laboratory reagents and test equipment, solidified sludge, and machine components. This waste has been stored for as much as 50 years in 55-gallon steel drums and wooden boxes at locations around the country. Additional TRU waste will result from the future clean-up of U.S. weapons sites (see January 1997 Washington Report).

The objective of the U.S. nuclear waste disposal program is to place waste in a location where "harmful quantities cannot return to the biosphere by any foreseeable process." According to the report, unless the site is breached by humans sometime in the future, there is no credible, probable mechanism for release of radioactive material into the surrounding environment. Committee chair Charles Fairhurst stated, "There are ways to engineer the facility—should studies now in

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