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**A GEOLOGICAL AND GEOPHYSICAL INFORMATION
SYSTEM FOR EURASIA**

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Table of Contents

Summary	1
Introduction	2
Datasets acquired.....	3
Digital topography.....	3
Crustal structure	4
Network data server	6
Conclusions and recommendations	8
References.....	8
Figures	10

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SUMMARY

The topography and heterogeneous crustal structure along seismic propagation paths and at the source and receiver sites are crucial information to understand the excitation and propagation of regional seismic phases (especially L_g and P_n) and other aspects of the problems of nuclear non-proliferation treaty monitoring. We are collecting and organizing available topographical, geological, and geophysical datasets for Eurasia into a digital information system that can be accessed via network connections to the Center for Seismic Studies (CSS) over the Internet. The work includes assembly of available digital datasets such as topography, satellite imagery, and crustal reflection and refraction profiles and digitization of available geological and geophysical information on sedimentary basins and crustal structure thicknesses. We are cooperating with CSS researchers on the development of an X Window System-based user interface compatible with other CSS systems that provides effective access to these three-dimensional datasets.

We are expanding the scope of our information system to include data on the Middle East and North Africa. Under the auspices of several other ongoing projects at Cornell we have collected a very large literature collection, satellite imagery and some detailed datasets, especially in Syria and Morocco. In Syria, data include DSS and industry seismic reflection profiles, drill hole analyses, magnetic and gravity measurements, and possibly the data from a 20 station digital seismograph network to be installed soon with the help of Cornell scientists. For Morocco, data include seismic reflection profiles with drill hole tie points, gravity measurements, and many digital records from a network of about 30 seismograph stations that we helped to establish. For both Syria and Morocco, we have complete coverage of digital Landsat MSS (Multispectral Scanner) scenes, complete sets of geologic maps, and all available high-resolution digital topographic data.

Work in progress has realized useful datasets for Eurasia, including new maps of depth to Moho beneath Europe and Scandinavia. We have created regularly spaced grids of the crustal thickness values from these maps that can be used to create profiles of crustal structure. These profiles can be compared by an analyst or an automatic program with the crustal seismic phases received along the propagation path to better understand and predict the path effects on phase

amplitudes, a key to estimating magnitudes and yields, and for understanding variations in travel-time delays for phases such as P_n , important for improving regional event locations. The gridded data could also be used to model propagation of crustal phases in three dimensions. In the near future, we will be making new databases from the Middle East and North Africa available via the Internet. We encourage ARPA and Air Force researchers to contact us about gaining access to our databases at these computer mail addresses: "eric@geology.cornell.edu" -or- "fielding@seismo.css.gov".

INTRODUCTION

Topography and variations in crustal structure along seismic propagation paths and at the source and receiver sites are crucial information to understand the excitation and propagation of regional seismic phases and other aspects of the problems of detection, verification, and estimation of the yield of nuclear explosions. Our objective is to collect and organize available topographical, remote-sensing, geological, and geophysical datasets for Eurasia, North Africa, and the Middle East into a digital information system that can be accessed by display programs running at the Center for Seismic Studies (CSS) and by other ARPA researchers. We are expanding the area of data coverage to include China, the Middle East and North Africa in addition to continuing our work in Europe and Central Asia. We store the data in an information system (GIS) with a network-accessible server to which can connect X Window System client modules of future versions of the Intelligent Monitoring System (IMS) running at CSS and other ARPA researchers. The information system is organized to extract and usefully display the information most relevant to verification and detection, such as maps and profiles of crustal thickness and depth to basement. The work includes assembly of available digital datasets such as topography, satellite imagery, and crustal reflection and refraction profiles and digitization of available geological and geophysical map information on sedimentary basins and crustal thicknesses and other details of crustal structure.

We are expanding the scope of our information system to include data on the Middle East and North Africa. Under the auspices of several other ongoing projects at Cornell we have collected a very large literature collection, satellite imagery and some detailed datasets, especially in Syria and Morocco. In Syria, data include DSS and industry seismic reflection profiles, drill hole analyses, mag-

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DATASETS ACQUIRED

Work in progress has now realized useful datasets for Eurasia, including a vast digital topographic database and digitization of several sets of crustal seismic structure maps, at scales from 1:15,000,000 for the entire continent to 1:500,000 for selected areas. These include maps of crustal thicknesses (depth to Moho) and sedimentary basin depths (depth to seismic or "metamorphic" basement). We have created regularly spaced grids of the crustal and sediment thickness values from these maps that can be used to create profiles of crustal structure. These profiles can be compared with the crustal seismic phases received along the propagation path to better understand and predict the path effects on phase amplitudes, predominant frequencies, and delay times, which are keys to estimating event magnitudes and yields. The gridded data could also be used to model propagation of crustal phases in three dimensions.

Digital topography

We continue to expand our database of digital topography for Eurasia, North Africa, and the Middle East. We have processed and analyzed a huge volume, nearly 15 gigabytes (GB), of high-resolution Digital Terrain Elevation Data (DTED—Level 1) that we have received for Asia, Europe, the Middle East and North Africa (Figure 1). Coverage is complete for Europe, central and southern Asia, and most of the Middle East and North Africa. The basic processing of the raw DTED into an accessible format included the creation of mosaics of the full resolution data for each 5° by 5° block, a file of manageable size for manipulation on a workstation and storage on optical media.

All of our topography, including both the reduced resolution mosaics and the full resolution topography blocks, and other archived datasets are being stored in our Epoch-1. The network-based Epoch file server includes an optical disk jukebox system with a library unit that contains 60 GB of "semi-online" storage and unlimited off-line storage of rewritable optical cartridges. The Epoch-1 provides unattended access, usually within less than a minute to any of the disks in the library unit. Our server program is able to load any part of the dataset in a short time, when the necessary optical cartridges are available inside the jukebox.

The digital topography is stored with "georeferencing" or geographic coordinates, and can be easily projected into a map projection and overlain with other datasets, such as seismic events. Figure 2 shows the full resolution DTED for the nuclear test site at Matochkin Shar, central Novaya Zemlya, portrayed as shaded relief, overlain with the locations of known nuclear tests as 250m radius circles and the 95% confidence error ellipse of an event that occurred on 92/12/31(both obtained courtesy of Dr. Hans Israelsson at CSS). The "New Year's Eve" anomalous event is clearly located across the Matochkin Shar from the test site.

To enhance access to the voluminous database, we have written a subroutine library to easily read and write files in the image format with their accompanying text georeferencing files. Building on this subroutine library, we have created a program that will "cut out" a patch of topography given the latitude-longitude limits of the area required. We have already used this program to supply areas of topographic data to ARPA researchers at the CSS, USGS, Lamont, University of Wisconsin, and SUNY Binghamton. We have enhanced the extraction program to use averaging to reduce the resolution of a patch as it is extracted. Again, any ARPA researchers are welcome to request patches of topographic data for their research from us. The subroutine library is also available upon request.

Crustal structure

We began our digitization of lithospheric structure with a set of crustal seismic structure maps of Eurasia. These include 1:15,000,000 maps of depth to Moho and depth to seismic (metamorphic) basement (Kunin and others, 1987). These maps provide a first-order database of crustal structure for all of Eurasia at a moderate resolution, but the data may not be correct in detail for every area.

To improve our datasets, we have begun digitizing more detailed maps of crustal structure that are available in some areas, beginning in Europe, where the most detail is available. Using the attributes capability of the Arc/Info GIS, we can record which contours are dashed (inferred or interpolated) and which are solid, or record other information about the data reliability from the maps such as the locations of the seismic refraction and reflection lines used, if they are recorded. Arc/Info was used to edit the resulting databases and project the data from each map's projection into latitude-longitude coordinates. Some maps have "faults" or discontinuities in the Moho, and these are digitized as well. We then created regularly spaced grids of the crustal and sediment thickness values from each of these digitized maps, including the offsets of "faults".

A map of a new gridded dataset of depths to Moho for the Baltic area is shown in Figure 3. This map is the result of a collaboration with Dr. Vlad Ryaboy at CSS. We digitized two previously published Moho maps of area around the Baltic (Kinck and others, 1992; Sharov, 1991) and then plotted them at the same scale and map projection. Vlad then used these two maps and other info (Ryaboy, 1990; BABEL, 1993) to produce a new combined map that we digitized and converted into a gridded database. These gridded data can then be used to calculate grids of source-specific station corrections for P_n travel times using an empirical equation relating travel-time delays to the depth to Moho beneath the source (at each point of the grid) and the receiver (each of the three arrays NORESS, ARCESS, and FINESA) as described by Suteau-Henson and others (1993, this volume). The locations of the arrays are marked. These kinds of travel-time corrections may greatly improve the locations of regional events. This and all of our completed crustal structure datasets are available over the network from our raster server and via ftp.

Another map of depth to Moho has been recently published as part of the European GeoTraverse (EGT). We have completed the digitization of this map which runs from the Arctic Ocean across central Europe to Tunisia, shown in Figure 4 below. The map includes several "faults" or discontinuities in the Moho, in the Alps and Apennines of Italy, where the Moho changes depth by up to 20 km over distances of a few dozen km horizontally, marked on the map. Several of these faults can be also seen in the cross-section of Figure 5 below. We are now digitizing the locations of the seismic refraction and reflection lines that were in-

interpreted to make this EGT map, as recorded on the back of the map. The gridded version of this dataset has a point spacing of about 10 km.

These gridded datasets can be used to extract the crustal structure profile along a given propagation path. An example is shown in Figure 5, which shows the depth to Moho profile from the GERESS array towards the south. This type of profile of crustal structure can be compared by an analyst or an automatic program with the crustal seismic phases received along the propagation path to better understand and predict the path effects. The Xgbm (v. 1.1) program can connect to our raster database server over the network, extract the depths of the Moho and seismic basement along a great circle, and then use this type of profile as the basis for ray tracing of seismic phases and gaussian beam approximation of the seismic waveforms (Davis and Henson, 1992; 1993).

Harjes and others (1992) have described a lack of significant L_g energy at the GERESS array from distances greater than 500 km for propagation paths in most directions, and this effect is especially strong for events to the south and southwest. They also observe a corresponding increase in S_n energy starting at about an epicentral distance of 350 km in the same direction. The extreme variations in depth to Moho shown in Figure 5 beneath the Alps and Apennines at distances of 300–700 km from GERESS are likely to be the cause of these major disruptions of regional phase propagation. The deep Moho root of the Alps may also explain an azimuthal bias or secondary arrivals and other anomalies of events in the eastern Mediterranean received at GERESS (Jenkins and others, 1992; Harjes and others, 1992).

NETWORK DATA SERVER

We are utilizing the rapidly accelerating Internet (formerly ARPAnet) network to share datasets with CSS and other ARPA researchers. We have developed a "server" system at Cornell to allow "client" modules of the IMS to directly connect to databases that we are generating and improving. This allows IMS users to utilize data as soon as it is available. Our network "raster server" program that allows "client" programs, such as the "Xgbm" program (Davis and Henson, 1992; 1993) to access our crustal structure datasets over the Internet, extracting a profile along a great circle path and then using the structure for seismic propagation modeling. Datasets are also available via the time-honored

method of "anonymous ftp" from Cornell. We encourage researchers to contact us about gaining access to our databases at the computer mail addresses listed on the first page of this paper. Due to data access restrictions imposed by the DMA, we are not able to provide network access to our digital topography databases, but we encourage ARPA and Air Force researchers to contact us about access to processed versions of the topography for use in their seismic research.

A concern has been raised about unlimited access to topographic data and other proprietary or copyrighted data, so we are studying a modification to the raster-server protocol that would require a user validation procedure (username and password) for access to such databases. This would not restrict access to other databases, such as our crustal structure databases and the public domain ETOPO5 topography, which would continue under the existing protocol. In addition, while implementing our server, we have found that some modifications of the protocol would greatly increase the efficiency of access to high-resolution raster data, such as the ability to request data for an area smaller than a square degree. Another apparently popular function that could be made part of the server protocol is the extraction of the lithospheric structure along a great circle path from the our raster datasets. We will propose a "second-generation" version of the raster view-server protocol, with the user validation and other modifications, when the needs are clarified.

We continue to work closely with CSS researchers and programmers on the interfaces to display and utilize information from our databases over network connections. The client display programs are built upon "widgets" from the Motif toolkit and the X Window System to create a user interface that is compatible with existing programs at CSS. The interface is intended to be easy to use and easy to modify, similar to the "Geotool" program developed at CSS by Ivan Henson and John Coyne. The prototype client program can connect to the database servers at Cornell and elsewhere and display raster data obtained from the server. We have written and tested a subroutine for the client program to allow the user to "save" a dataset or portion of a dataset to their local machine in a choice of formats, and this routine should be incorporated in the next major revision of the client program.

CONCLUSIONS AND RECOMMENDATIONS

We are happy to report that numerous CSS, ARPA and Air Force researchers are already using our databases in their ongoing studies. We have supplied datasets and maps made from our datasets to CSS, SAIC, ENSCO, Phillips Lab, SUNY Binghamton, Univ. of Conn., Harvard, and ARPA scientists in the last year.

Geophysical and geological datasets can provide important ancillary information on the propagation of seismic phases through the continental lithosphere. In turn, this bears on the detection, discrimination, and yield estimation of nuclear explosions. The rapidly changing geopolitical situations in Eurasia, North Africa, and the Middle East make it imperative that databases are extended to areas outside the former Soviet test sites. The types of datasets that we are compiling can be used to compare well studied propagation paths, such as within Europe, with paths to events in other locations that have not been studied in great detail to enhance the monitoring of nonproliferation treaties.

These datasets of digital geological and geophysical information can now be incorporated into modules of the IMS at the CSS and will be extremely useful for the interpretations of seismic data. We will continue to make our databases available via Internet to ARPA and AFOSR researchers. We have proposed some modifications to the protocol of the raster server to make some data types more accessible, especially high-resolution satellite imagery and lithospheric structure along great circle paths. The direct connection of Cornell to the NSFnet (T3 backbone) makes communication between Cornell and the Internet especially rapid. As described above, we are making the processed topography data available, beginning with the reduced resolution mosaics that will be most useful for seismic researchers.

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FIGURES

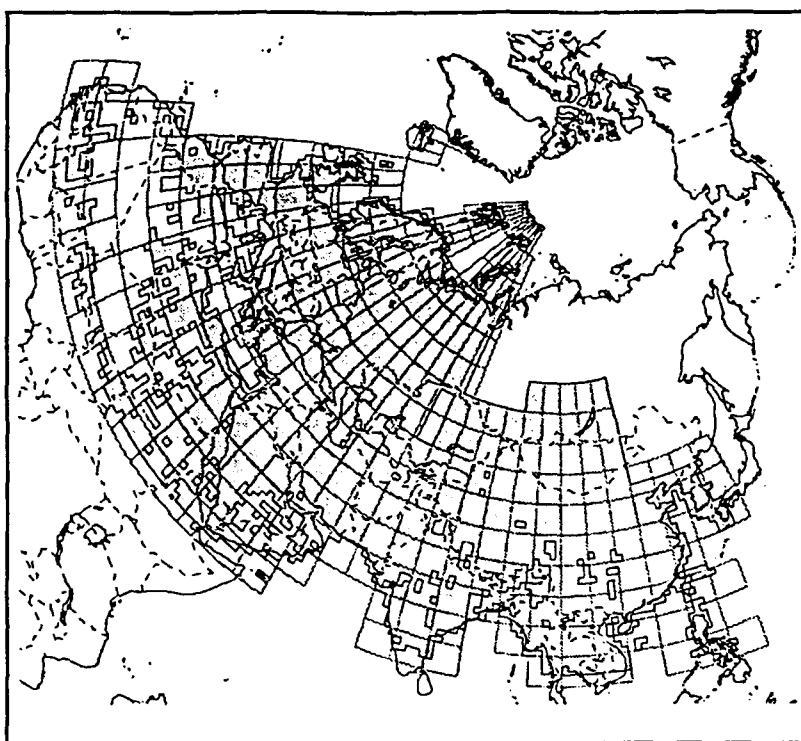


Figure 1: Map of Eurasia, the Middle East and North Africa showing area covered by our present databases of digital topography. Coastlines of oceans, seas, and major lakes are *solid lines* and country borders are *dashed lines*. Acquired and processed DTED cells are *filled light gray* and outlined with a *black line*. Missing and "unavailable" cells are *irregular white holes*. Blocks 5° by 5° of DTED are outlined with *dark gray lines*. Map is an azimuthal equidistant projection centered in north central Eurasia.

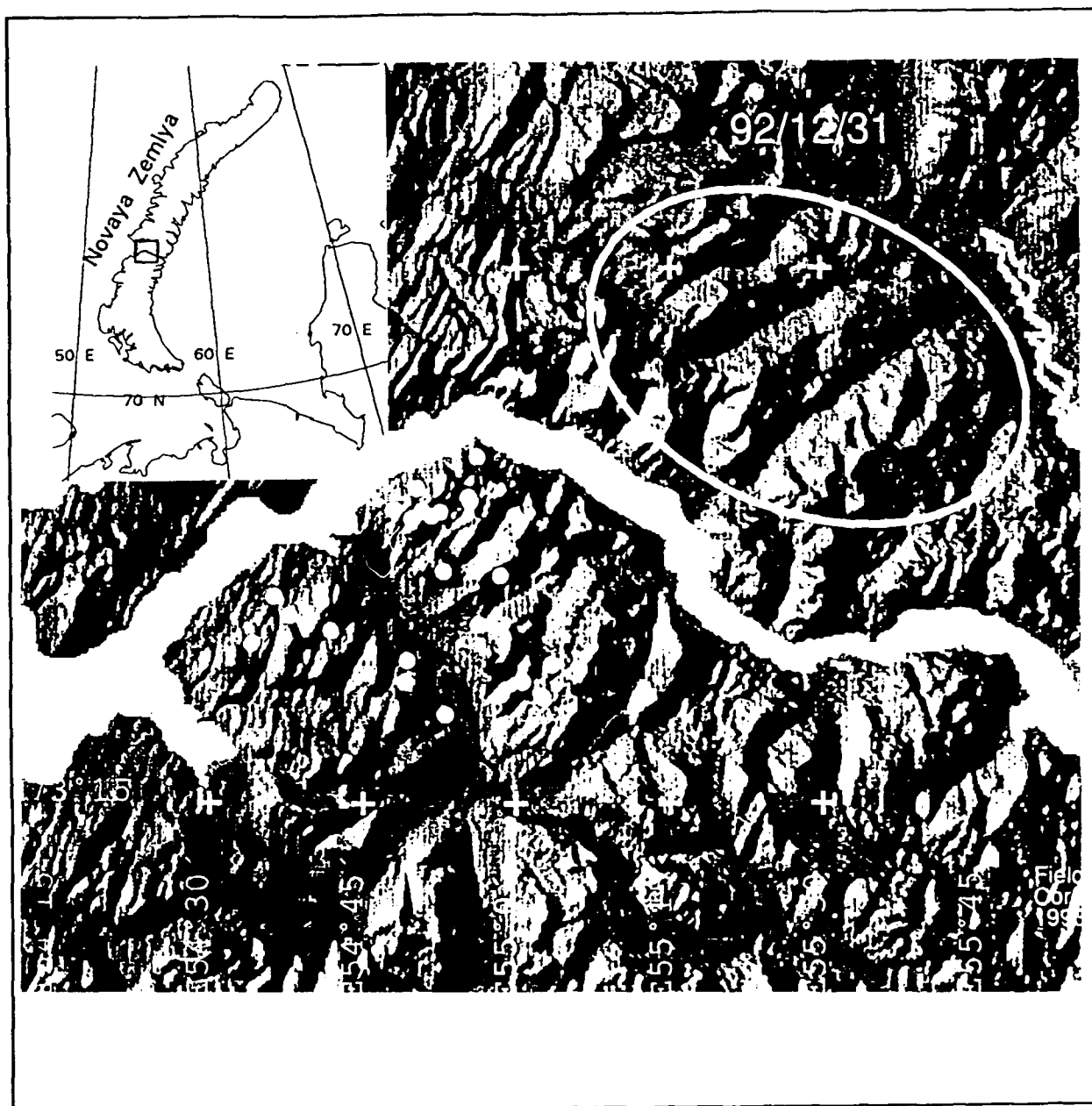


Figure 2: Shaded relief map of the central Novaya Zemlya nuclear test site showing locations of known tests and an enigmatic event on 92/12/31. Known nuclear test locations are shown as *small white circles*, and the error ellipse of the "New Year's Eve" event is shown as a *white outline*. The full resolution topography was shaded with a light from the west-northwest. *White crosses* mark 15 minute latitude and longitude ticks. Water of ocean and Matochkin Shar is shown in *white*. Map is in an azimuthal equidistant projection centered on 73°N and 55°N. Inset map shows location *box* of image.

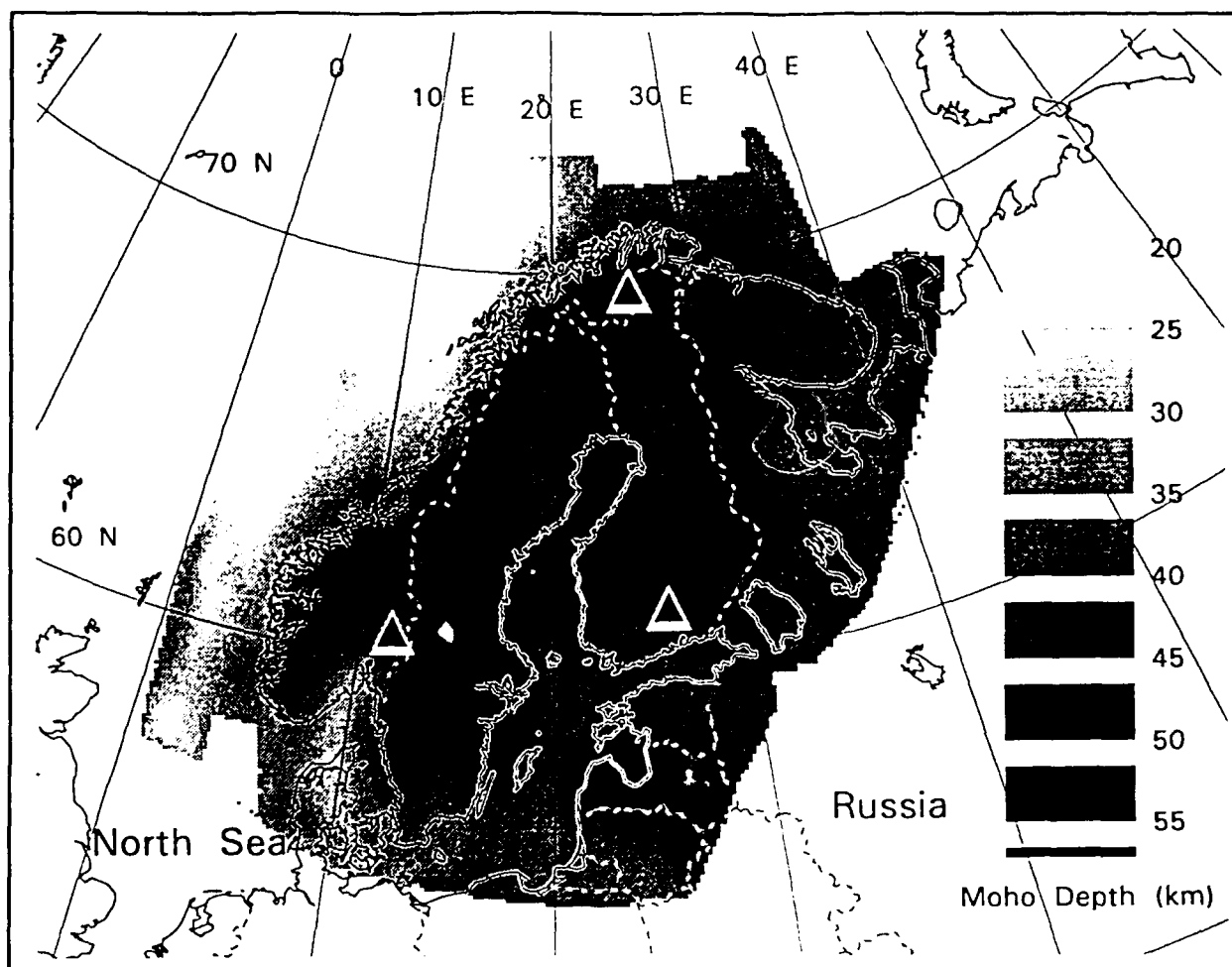


Figure 3: Map of the gridded database of depth to Moho beneath Baltic area. Dataset was digitized from a combination of maps (see text). *Gray scale* shows depth in km. This gridded dataset, along with similar datasets of depth of sedimentary section can be used for two- and three-dimensional modeling of crustal phase propagation and P_n travel time delays. *Solid black lines* mark coastlines and major lakes. *Dashed lines* mark country boundaries. Locations of NORESS, ARCESS, and FINESA arrays are marked by *black triangles with white borders*. Map projection is Lambert Conformal Conic.

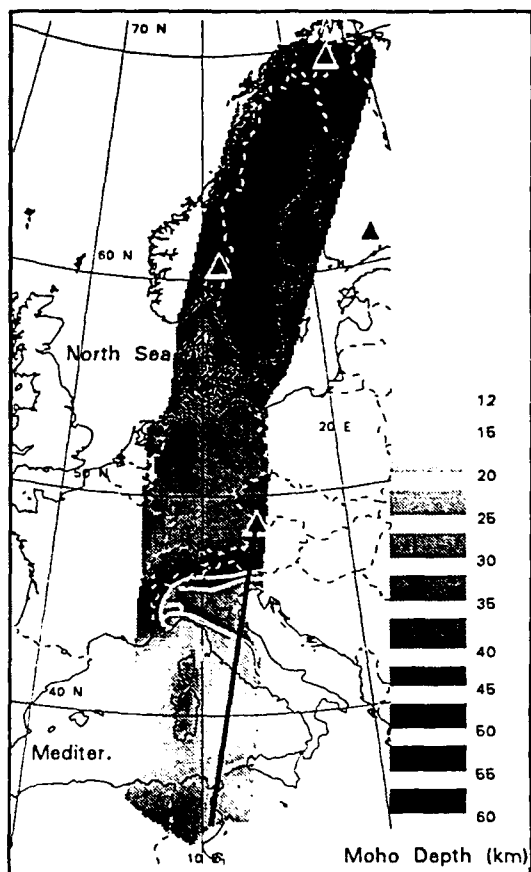


Figure 4: Map of depth to Moho from European Geotraverse. *Gray scale* shows depth in km. This gridded dataset, along with similar datasets of depth of sedimentary section can be used for two- and three-dimensional modeling of crustal phase (L_g) propagation and P_n travel time delays. *Solid black lines* mark coastlines and major lakes. *Dashed lines* mark country boundaries. *White lines* mark "faults" in Moho. Locations of NORESS, ARCESS, GERESS, and FINESA are marked by *black triangles with white borders*. *Thick black line* shows location of profile of Figure 5. Map projection is Lambert Conformal Conic.

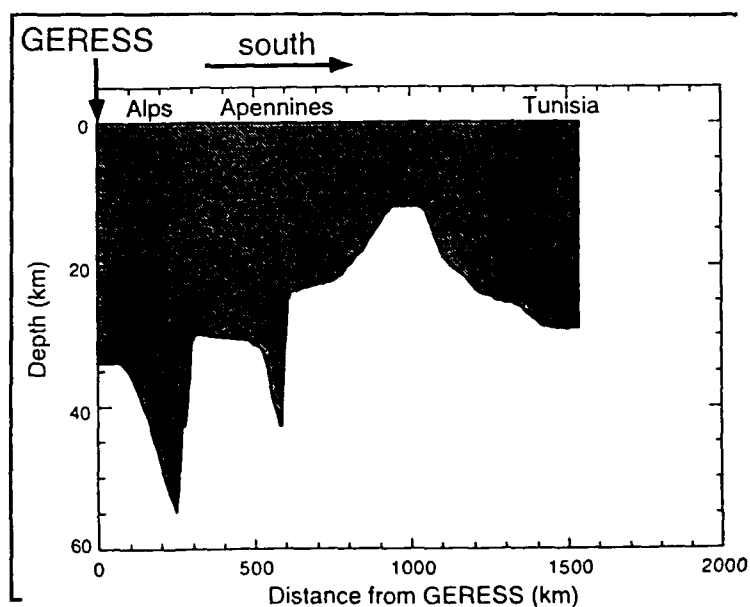


Figure 5: Profiles of Moho database along great circle path from GERESS towards the south. Note the extreme variations in crustal thickness that will affect the propagation of crustal phases, such as L_g . No L_g is observed for events more than 500 km from the GERESS array in this direction (Harjes and others, 1992). Location of profile shown on Figure 4.