RESEARCH AND DEVELOPMENT OF A GEOGRAPHICAL INFORMATION SYSTEM (GIS) FOR NUCLEAR TREATY MONITORING

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ABSTRACT

Research and development of a Geographical Information System (GIS) with global and regional coverage is underway at Cornell University. This GIS is being designed to provide essential data and research products required for successful monitoring of the Comprehensive Nuclear-Test-Ban Treaty (CTBT). This system will support the National Data Center (NDC) and the International Monitoring System (IMS) by providing a common frame of reference in which to merge the results of the four monitoring technologies (seismic, hydroacoustic, infrasound, and radionuclide). The GIS under development is intended to improve monitoring capabilities by providing rapid access and visualization of seismic and non-seismic databases in an interactive way. The data and analysis tools will also assist in ongoing calibration and location studies during the implementation of the CTBT and serve the verification readiness objectives of the CTBT.

All available geologic, geophysical, and imagery databases must be fused with bulletins produced from NDC and IMS data to better calibrate a given region and for improved location of events. These complementary data are also essential for verification and discrimination between nuclear explosions and other types of similar events such as mine blasts or collapses, rock bursts, large chemical explosions, or anomalous seismic events. Research and development is focused on creating and evaluating solid earth databases required for calibration and discrimination of events in the Middle East, North Africa, and the United States. A tectonic map of the North Africa region has been finalized and 1:5,000,000 scale or better digital geologic data have been added for Africa, the Middle East, and South Asia. Mosaics of Thematic Mapper imagery for much of North Africa and the Middle East has been assembled from individual scenes, registered, and entered into the database.

An exhaustive review of scientific literature resulted in the most complete database of focal mechanisms available for North Africa and the Middle East, in addition to that available in the Harvard database. Database research and development for the United States has resulted in assembly of all available digital geology. These data include the 1:2,500,000 U.S. Geological Survey digital geology map of the continental U.S. as well as high-resolution geology (1:500,000 scale) for Arizona, Colorado, Idaho, Illinois, Minnesota, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. The entire USGS National Atlas (high-resolution geographic data) was also added to the database.

Research is underway to create an updated, digital map of depth-to-basement for the continental United States and North America. We are also developing and improving the design of menu-driven, custom analysis tools, as well as metadata for all digital data sets. When fully implemented, the GIS will provide a rapid analysis tool to assist in discrimination of nuclear from non-nuclear events. These analyses will be improved by placing suspect events in spatially registered displays of topography, geology, tectonic zones, faults, historical seismicity, focal mechanisms, cultural landmarks, and Landsat imagery. A JAVA-based interactive application program that runs under Web browsers has been developed to access Cornell's GIS system. The CTBT community and other interested researchers can access the application at http://atlas.geo.cornell.edu.

Key Words: GIS, Middle East, North Africa, United States, geophysics, imagery, geology

OBJECTIVE

The main objective of this work is to facilitate and enhance the location and calibration capability of the International Monitoring System (IMS) and to assist the US National Data Center (NDC) by providing digital databases used for monitoring the CTBT. The research and development are focused on the Middle East, North Africa, and the United States. The databases being developed include diversified geological, geophysical, geographical, and imagery information that are pertinent to compliance provisions of the treaty. Regional digital geology and tectonic maps are being added to the system as they become available or are being scanned and digitized at Cornell. Geophysical data such as depth-to-basement, crustal thickness, and crustal and upper-most mantle velocity structure are being derived from compilations of the existing literature. Geographical data of the highest available resolution are also being added to the system to assist in monitoring activities. Digital imagery are being added to assist in locating mines and for geologic interpretations that may provide information pertinent to CTBT monitoring. We are developing and improving the design of menu-driven, custom-made display and analysis tools and the accompanying metadata for all data sets housed in the system. The metadata provide the necessary information about the quality, resolution, accuracy, and techniques used to develop the data. This research and development is critical to both the verification and compliance provisions of the Comprehensive Nuclear-Test-Ban Treaty.

RESEARCH ACCOMPLISHED

Middle East and North Africa Databases

Research and development of databases for the Middle East and North Africa resulted in a regional tectonic map, a study of focal mechanism solutions, and registration of a large volume of imagery data. The regional tectonic map of North Africa (Figure 1) was completed by digitizing, registering, and adding attributes to maps of Algeria, Tunisia, Egypt, Libya, and Morocco. These data are important for placing an event in its proper tectonic setting during analysis. Digital geologic data that cover all of Africa, the Middle East, and South Asia were acquired from the USGS (USGS 470 series data), simplified, and added to the GIS database. The data for Africa (Persits et al., 1997) that cover the entire African continent were synthesized from UNESCO maps of approximately 1:5 million scale. Data for the Arabian Peninsula (Pollastro et al., 1998) were compiled from UNESCO 1:5 million and 1:2 million USGS maps. The digital database for South Asia (Wandrey and Law, 1998) was compiled from 1:5 and 1:10 million scale UNESCO maps. Geologic data for the Asia Pacific (Steinshouer et al., 1999) region were derived from regional 1:5 million scale maps and data for the Former Soviet Union (Persits et al., 1998) were derived from 1:7.5 million maps. These data are accurate to approximately 5000 meters (based on a 1:5 million scale map) and provide essential information about the surface geology that is needed when rapidly researching an area of interest. References that describe seismic events with focal mechanism solutions for the Middle East and North Africa were located. A total of ~800 events, primarily with magnitudes between 4-5.5, were added to the database (Figure 2). This database expands on the global Harvard CMT focal mechanism database and provides another important resource for analyzing regional events.

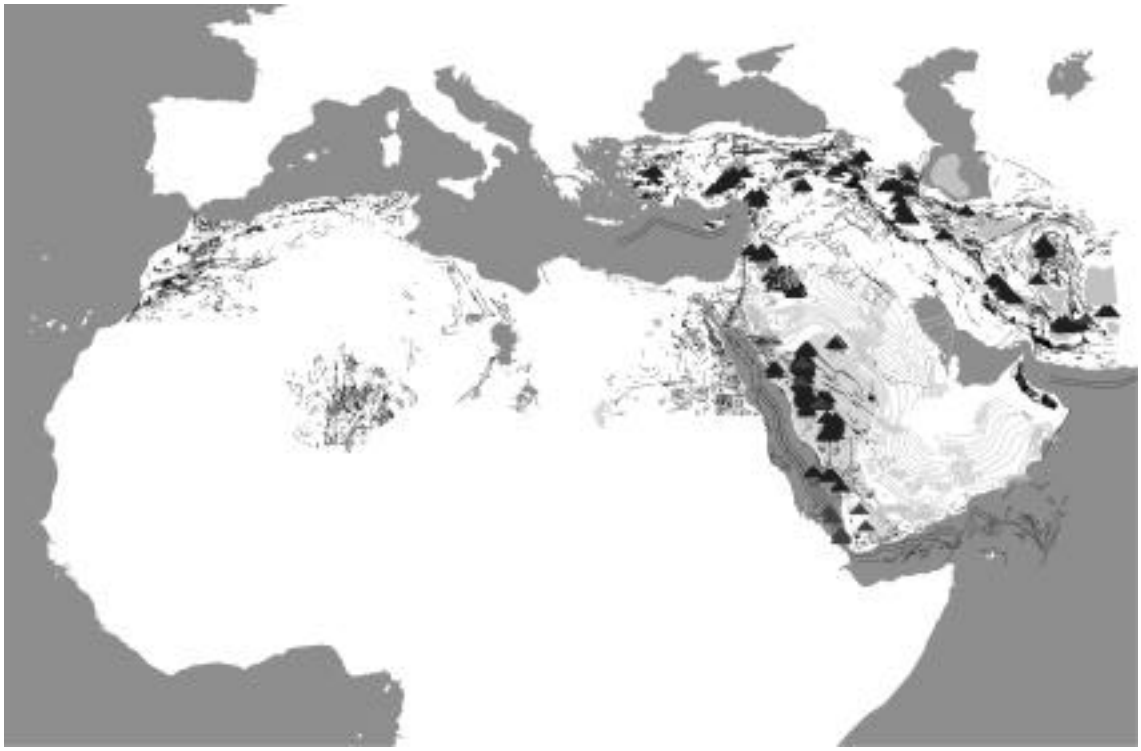

Figure 1. Tectonic map of the Middle East and North Africa compiled from detailed research of the literature and original research completed at Cornell University.

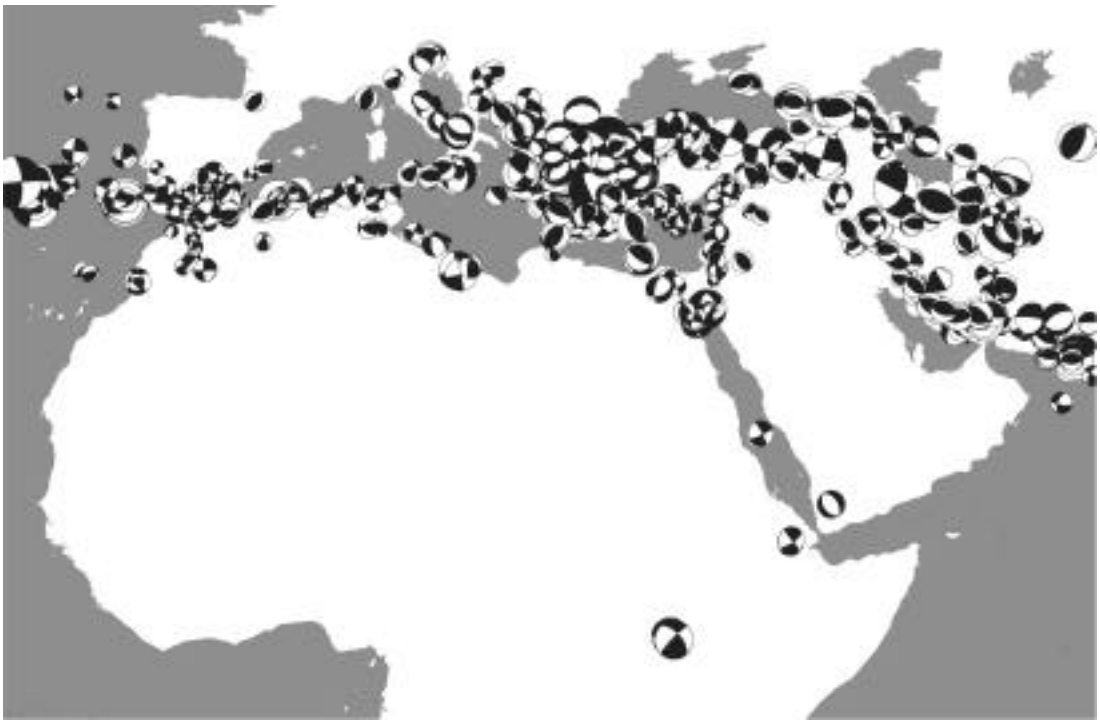

Figure 2. Focal mechanism solutions for the Middle East and North Africa as derived from a search of the scientific literature. These solutions are in addition to those found in the global Harvard CMT focal mechanisms database.

A revised Bouguer gravity anomaly map for the entire Middle East and most of the African continent was developed using new data obtained from the Defense Mapping Agency. These data can be used to model crustal structure when analyzing a specific path of interest. Cornell also expanded the library of Thematic Mapper imagery available for the Middle East and North Africa. The data span Northwest Africa and most of the Middle East including Israel, Palestine, Lebanon, Syria, eastern Turkey and most of Iran and Iraq (Figure 3). These data are being used to locate possible active mine locations and for geologic interpretations of the Middle East and North Africa.

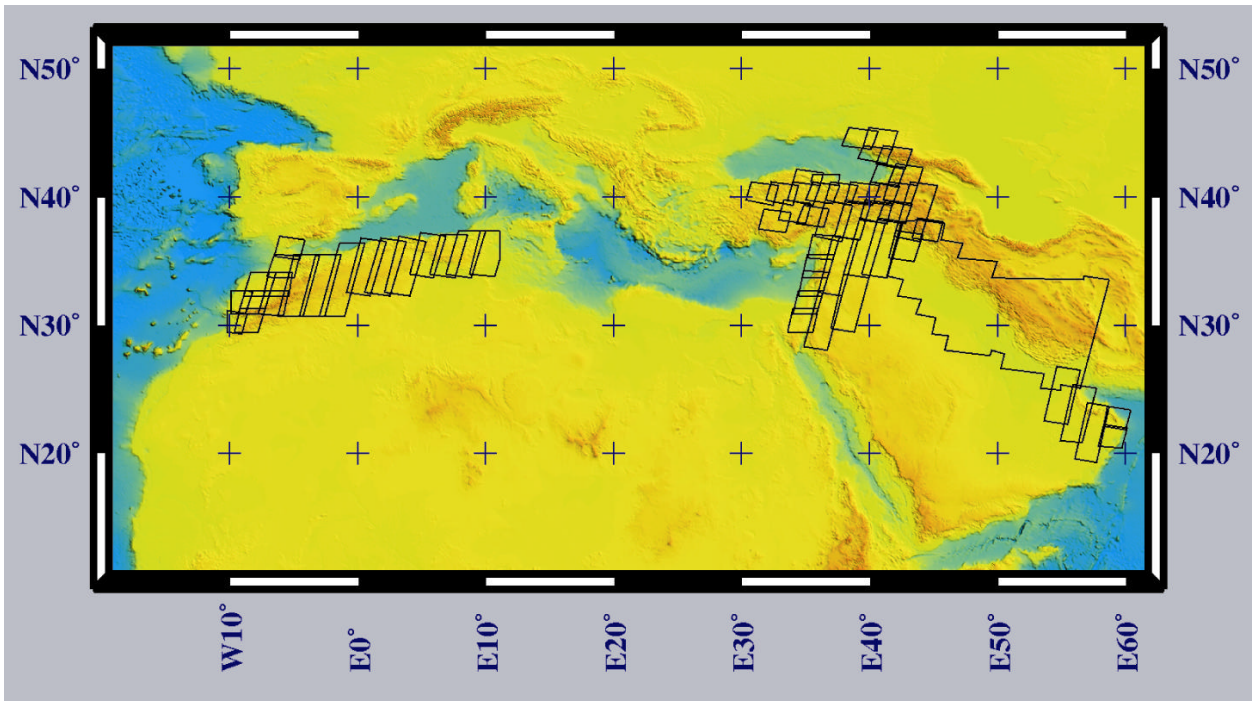

Figure 3. Map showing Landsat Thematic Mapper imagery that are processed, geographically registered and available at Cornell

United States Databases

High-resolution digital geophysical and geological databases for the United States were researched, downloaded, and reformatted for inclusion to the Cornell database. Detailed geology and fault data were obtained from the USGS or state geologic surveys for *Arizona*, *Arkansas*, Colorado, *Idaho*, *Illinois*, *Kentucky*, *Minnesota*, Montana, *Nevada*, New Mexico, *Oregon*, Utah, *Washington*, and Wyoming (states in italics include fault data). Additionally, regional geologic data were located and downloaded for the Lake Superior, Northwest, and Pacific Northwest regions. These data are at 1:500,000 scale with a variety of projections. Due to the complexity of the geology represented by these data, a time period attribute is added to each data set and the data are then projected to geographic coordinates. This allows all the detailed data to be displayed simultaneously with correct, uniform geologic color symbology while retaining all detailed information. Other geologic information pertinent to analyzing an event in the United States include the mine database from the former US Bureau of Mines. This global database includes over 220,000 mines with over 70 attributes for each mine.

In order to assist in ongoing calibration efforts in the United States, the 1:2,500,000 basement maps for the central United States of Sims et al. (1991) and Sims (1990) were merged. These data were converted to three-dimensional grids (Figure 4) with an associated statistical confidence interval using the kriging technique. Additional data covering other regions of the United States were identified, digitized and are

being combined with other data to complete a basement map of the United States. Analog maps of basement contours for the Pacific margin of the United States (Gardner et al., 1993) were located and digitized. These data were combined with previously entered data for the Great Valley and Sierra Nevada (Wentworth et al., 1995). For other areas of California, the Smith (1964) map of basement exposures was digitized. Similar maps of basement exposures were located for portions of Texas (Vlissides, 1964) and the Appalachians (Drake et al., 1988).

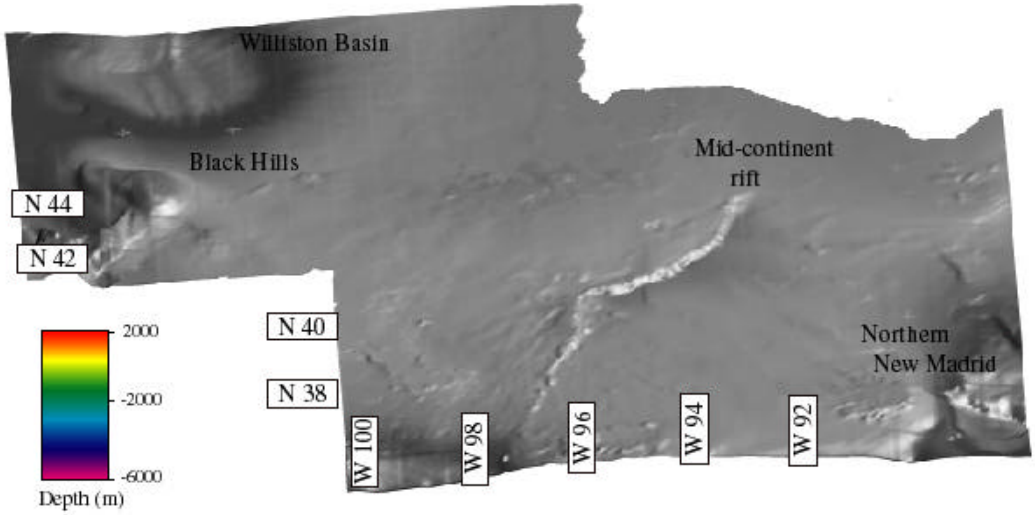

Figure 4. A perspective view of the depth-to-basement grid of the US mid-continent region. This grid was generated using the kriging interpolation technique. Contour data were digitized from regional maps, converted to point data and then interpolated.

Other data added to the Cornell database include seismic event locations and geographic data. The complete Center for a National Seismic System (CNSS) seismic database was added to the Cornell database. The CNSS composite catalog is created and stored at the Northern California Earthquake Data Center (NCEDC). This is a global database that includes over 700,000 events (1940-present). Contributions to the CNSS catalog are made on a regional basis and include many very small events (magnitude 1-2) that are not reported in any other catalog. Each seismic network that contributes catalog data to the CNSS composite catalog is assigned a geographic region where that network's solution (location and magnitude) is considered authoritative. If more than one network supplies a solution for the same earthquake, only one solution for that earthquake is included in the composite catalog. The complete USGS digital National Atlas database was identified and downloaded for inclusion to the database. This large database contains detailed geographic

data for the continental Unites States. It includes airport locations, aquifers, cities and urban areas, counties, federally protected land and watershed boundaries, hydrologic data, roads, and railroads.

Metadata

To provide consistency for users with datasets from other sources, the Federal Geographic Data Committee (FGDC) Content Standard for Digital Geospatial Metadata is being applied to all data that are entered into the Cornell GIS system. Metadata standards facilitate data sharing through time and space. The standard specifies the information content of metadata for digital geospatial data; its purpose is to provide a common set of terminology and definitions for documentation related to these metadata. The standard establishes the names of data elements and groups of data elements, the definitions of these data elements and groups, and information about the values that are to be provided for the data elements.

The FGDC data elements are as follows: Identification Information - this is the basic information about the data set. Examples include the title, the geographic area covered, vintage, and rules for acquiring or using the data. Data Quality Information - this is the assessment of the quality of the data set. Examples include the positional and attribute accuracy, completeness, consistency, the sources of information, and methods used to produce the data. Spatial Data Organization Information - this is the mechanism used to represent spatial information in the data set. Examples include the method used to represent spatial positions directly (such as raster or vector) and the number of spatial objects in the data set. Spatial Reference Information - this attribute is a description of the reference frame, means of encoding, and coordinates of the data set. Examples include the name of and parameters for map projections or grid coordinate systems, horizontal and vertical datum, and the coordinate system resolution. Entity and Attribute Information - this is information about the content of the data set, including the entity types, their attributes and the domains from which attribute values may be assigned. Examples include the names and definitions of features, attributes, and attribute values. Distribution Information - this contains information about obtaining the data set. Examples include a contact for the distributor, available formats, information about how to obtain data sets online or on physical media (such as cartridge tape or CD-ROM), and fees for the data. Metadata Reference Information - this is information on the vintage of the metadata information and the responsible party. Examples include update data and information about the organization that provided the metadata.

Development of New Web Site

A new, sophisticated web site that is interactive, easy-to-use, and gives complete access to data sets available at Cornell University is now operational. The application is written using the Java language. The Java applet acts as an interface to our ArcInfo data sets that are kept on the server side. ArcInfo is a Geographic Information System software package from Environmental Systems Research Inc. Once a user selects data and/or entries and click on the "Submit Request ..." button, a URI is sent within Java to the server, which is received by a CGI script that creates Arc Macro Language (AML) files that are run in ArcInfo. The resultant map is then served back to the client and registered with the application so that the user can get latitude and longitude information. Once a new map is displayed, a user can download postscript or jpeg versions of the maps within the application. The projection used in all mapping applications is Equirectangular centered at 30 degree North (or South) latitudes. Equirectangular is a simple projection that allows displaying data sets in both local and global scales. The web site now allows users to enter their own data as well the ability to query existing databases. The interactive site includes a graphical user interface that permits the user to zoom and change display properties. This resource is now available for the entire CTBT research community to assist in their research and development efforts. The site includes all metadata and a comprehensive users manual and is located at **http://atlas.geo.cornell.edu**.

CONCLUSIONS AND RECOMMENDATIONS

The geology, geophysical, geographic and imagery data contained in the Cornell GIS database are essential for CTBT monitoring and compliance. The data contained in the system provide ancillary information essential for regional calibration and discrimination studies as well as for possible On-Site Inspections.

Research and development of GIS databases to support compliance and verification provisions of the CTBT must continue. Though much work has been accomplished in acquiring, researching, and evaluating data for the Middle East, North Africa, and the United States, much remains to be completed. Existing databases must routinely be updated and new regions must be added as information becomes available. Metadata, though time consuming to create, are an essential element of the database and must be created for those databases added to the system or updated as needed. In order to disseminate CTBT research results to the broader scientific community, Cornell will continue to provide public access to data through an open web site. With cooperation from contributing scientists, data and results of research can be added to the system such that signatories to the treaty, researchers, and interested scientists can view the data, make maps, and compare results. Cornell will also continue to develop new components to its GIS that will provide additional analysis tools and simpler access to the data.

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