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Introduction to TETHYS—an interdisciplinary GIS database for studying continental collisions

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Abstract

The TETHYS GIS database is being developed as a way to integrate relevant geologic, geophysical, geochemical, geochronologic, and remote sensing data bearing on Tethyan continental plate collisions. The project is predicated on a need for actualistic model 'templates' for interpreting the Earth's geologic record. Because of their time-transgressive character, Tethyan collisions offer 'actualistic' models for features such as continental 'escape', collision-induced upper mantle flow magmatism, and marginal basin opening, associated with modern convergent plate margins. Large integrated geochemical and geophysical databases allow for such models to be tested against the geologic record, leading to a better understanding of continental accretion throughout Earth history. The TETHYS database combines digital topographic and geologic information, remote sensing images, sample-based geochemical, geochronologic, and isotopic data (for pre- and post-collision igneous activity), and data for seismic tomography, shear-wave splitting, space geodesy, and information for plate tectonic reconstructions. Here, we report progress on developing such a database and the tools for manipulating and visualizing integrated 2-, 3-, and 4-d data sets with examples of research applications in progress. Based on an Oracle database system, linked with ArcIMS via ArcSDE, the TETHYS project is an evolving resource for researchers, educators, and others interested in studying the role of plate collisions in the process of continental accretion, and will be accessible as a node of the national Geosciences Cyberinfrastructure Network—GEON via the World-Wide Web and ultra-high speed internet2. Interim partial access to the data and metadata is available at: http://geoinfo.geosc.uh.edu/Tethys/ and http://www.esrs.wmich.edu/tethys.htm. We demonstrate the utility of the TETHYS database in building a framework for lithospheric interactions in continental collision and accretion.

Keywords: TETHYS; Continental collision; Remote sensing

1. Introduction

The Tethyan belt extends from the western Mediterranean through Asia Minor and Central Eurasia, to east and southeast Asia, marking the successive closure of Tethyan oceans. Precursors to the modern Mediterranean Sea and Indian Ocean, these oceans, developed during breakup of the Gondwana continent which began in the Late Paleozoic. Northward drift of Gondwana fragments such as Africa–Arabia, India, and Australia produced diachronous (time-transgressive) collisions with accreting Eurasia, a process which continues today. For example, while western China underwent orogenic crustal shortening (Dewey and Burke, 1973; Harrison et al., 1992; Molnar and Tapponnier, 1977), rifting dominated in eastern China and Indochina, accompanied by rapid ocean-ward arc-trench rollback (Tamaki and Honza, 1992; Flower et al., 1998). In western Tethys, the westward escape of Anatolia and opening of the Aegean Sea basin may be linked to the Arabia–Eurasia collision. Pre- and post-collision structures and lithologies in older, exhumed orogen remnants suggest

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that such plate tectonic 'endgames' may be typical of late stages in 'Wilson Cycles' throughout much of the Earth's history.

The development and testing models that explain the evolution of Earth's lithosphere require large, interdisciplinary data sets and the requisite tools for querying and manipulating large complex data sets. Although this approach is handicapped by the chaotic state of relevant databases there is an increased interest among geoscientists in developing digital GIS databases with the necessary tools to exploit the scale and diversity of existing data sets as a basis for regional-scale cross-disciplinary queries. Such initiatives include, but are by no means confined to, projects such as PLATES, Paleomap GERM, Georoc, UNAVCO, ODP, ISES-CI, PetDB/EarthChem, CHRONOS, EARTH-REF (Lehnert et al., 2000, http://georoc.mpch-mainz.gwdg.de/georoc/). National Geosciences Cyberinfrastructure Network—GEON is coordinating such efforts as a seamless accessible resource.

GIS capabilities for spatial resolution, manipulation, and dissemination of diverse data categories can enhance our capacity for project design and global-scale interdisciplinary research. Moreover, the advent of Internet-based interfaces to GIS datasets, which combine GIS's massive potential for data integration, visualization, and modeling with the Internet's ability to widely disseminate data, provides new opportunities to geoscientists. We are building a GIS relational database ('TETHYS') as an aid to interdisciplinary research on the Earth's largest active collision belt. Recording multistage closure of Paleozoic and Mesozoic oceans, today's 'Tethyan belt' may include the circum-Mediterranean region, Asia Minor, the Mid-East, central and southeastern Asia, and western Pacific marginal seas, representing the Earth's single-most active zone of seismicity and volcanism. Upon completion, the database will act as a tool for researchers, educators, and students studying continental plate collisions and a means to better characterize natural hazards in one of the world's most densely populated regions.

2. Why the Tethyan collisional belt?

The Tethys collisional belt offers a natural laboratory in which all stages of continental collision and growth can be studied. These stages include mature collisional belt (e.g. Tibet and Himalaya), young Continent–Continent collision (e.g. Zagros Mountains and eastern Anatolian plateau), and the later stages of subduction (e.g. Hellenic and Cyprean arcs). Furthermore, collisions of the African–Arabian, Indian, and Australian plates provide opportunities for studying the responses of both ductile mantle and brittle lithosphere to plate collisions, and exploring how these are linked to seismicity and volcanic activity. As an effort to better understand the underlying causes of the latter, IGCP 430 (a 5-year renewable UNESCO-IUGS-sponsored program) (Flower et al., 2000) is attempting to develop response models, testable against the Tethyan geologic record, on the basis of processes observed in the Mediterranean and western Pacific marginal seas. These models use, and in many cases combine, results from space geodesy, remote sensing, thermochronology, geochronology, paleomagnetism, seismology, isotope geochemistry, and geological field studies, in the context of numerical and experimental models.

Our long-term objectives with regard to database development include interfacing with the 'earth reference model' and other research-oriented databases (e.g. REM, GERM, UNAVCO, Digital Earth, ODP), developing TETHYS as a node of the Geoinformatics initiative, and enhancing the scientific utility and cost-effectiveness of data acquisition.

3. Our strategy

1. Acquire and set up datasets; remote sensing, sample-related (igneous and metamorphic) geochemical, seismic s-wave, tomographic, magnetic, gravity, heat flow, digital geology, neotectonic structures, etc. in an integrated database
2. Refine and develop discipline-specific and 'integrated' tools
3. Provide restricted 'within-group' web access for testing application and manipulation of integrated data sets in interdisciplinary continent-scale geodynamic projects, and advanced visualization capabilities
4. Provide community-wide web access–pending verification of metadata, tool functioning–after a 2-year start-up phase and integration as a 'GEON' node
5. Develop actualistic models for continental 'escape', pre- and post-collision magmatism, marginal basin formation, arc-trench rollback, and collision-induced asthenosphere displacement. These models include:
    (a) arc-trench rollback in the Izu-Bonin-Mariana subduction factory, presenting a natural laboratory for ophiolite genesis
    (b) convergence of Africa with Anatolia, depicting evolution and significance of the Isparta Angle
    (c) Carpathian arc rollback and collision with the European Platform, representing subduction, delamination, tectonic erosion, etc.
    (d) integrated tests of mantle extrusion hypothesis: India–Asia collision responses in southeast Asia.

The relational database includes geological, geochemical, geophysical, and remote sensing data for the Tethyan tectonic belt. Until completion of the start-up phase, the database is being developed at our four institutions. University of Houston is primarily putting together geological and digital maps and tools for displaying and querying the integrated data (e.g. Gryc, 1992; Hamilton and Fisher, 1978;

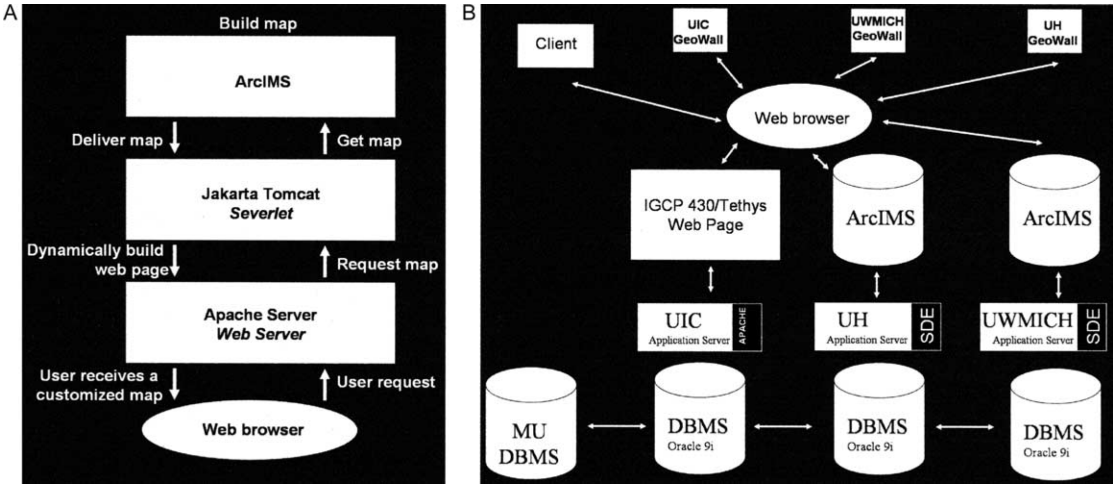


Fig. 1. (A) Database architecture for TETHYS. The database system is integrated with ArcIMS (ARC Internet Map Server) via ArcSDE. ArcSDE is a GIS gateway that facilitates management of spatial data in relational database management systems, whereas ArcIMS is currently widely utilized in the integration of local GIS data sources with Internet data sources for display, query, and analysis using a web browser (Koeppel, 2001). Visualization will be made available through ArcIMS to GEOWALL. (B) Flow chart explaining process of making customized maps via web browser.

Hearn et al., 2001a,b, 2003a,b; Weittekindt and Weippert, 1973). University of Western Michigan is compiling remote sensing data and developing tools for raster data manipulation on the Internet. UIC is assembling sample-based (igneous and metamorphic) geochemical data for collision-related igneous activity, with relevant metadata. UMC is compiling seismic shear-wave, tomographic, magnetic, gravity, and heat flow data. At UH and University of Western Michigan the Oracle 9i database system is integrated with ArcIMS (ARC Internet Map Server) via ArcSDE (ARC Spatial Database Engine). ArcSDE is a GIS gateway that facilitates management of spatial data in relational database management systems, whereas, ArcIMS is widely utilized in the integration of local GIS data sources with Internet sources for display, query, and analysis using a web browser. Completing the database, i.e. integrating all datasets, metadata, and tools for data integration, manipulation, and visualization, is the responsibility of UH (Fig. 1). Current access to the database is via UH and University of western Michigan at the following sites: http://geoinfo.geosc.uh.edu/Tethys, http://ims.esrs.wmich.edu/website/Tethys/. However, public access to some data is restricted to project participants pending verification of metadata and testing tool applications in our ongoing research projects. At present, users can log in contemporaneously to the University of Houston and University of Western Michigan to avoid replication of data sets at both sites.

Our initial Oracle database contains several tables each containing primary key (PK) and foreign keys (PFK) which serve as a basis to logically relate different tables in the database. The primary and foreign keys are the most basic components on which relational database theory is based. The primary key of a relational table uniquely identifies each record in the table and it can either be a normal attribute that is guaranteed to be unique, e.g. Social Security Number in a table with no more than one record per person or be generated by the DBMS for example, a globally unique identifier (Date, 1981). Primary keys enforce entity integrity by uniquely identifying entity instances. A foreign key is a field in a relational table that matches the primary key column of another table. The foreign key can be used to cross-reference tables (Date, 1981). Foreign keys enforce referential integrity by completing an association between two entities. Fig. 2 shows the logical relationship among tables. For instance ophiolite table is related to the geochemistry table by *OphID* which is a primary key in the ophiolite table and foreign key in the geochemistry table.

4. Datasets

The preliminary Tethys database include the following:

1. Digital maps database
2. Geochemical majors and trace elements, Sr, Nd, Pb, Hf, Os (etc.), radiometric ages, stable isotopes, metadata
3. Remote sensing data
4. Geophysical data

4.1. Digital maps

The database for digital maps includes geological, structural, earthquake epicenter and volcanoes data.

4.1.1. Geological and structural maps

We have compiled general geology and structural maps for the Tethyan region utilizing the following three digital resources:

1. *USGS and AGI Global GIS Database*: The American Geological Institute (AGI) in collaboration with USGS

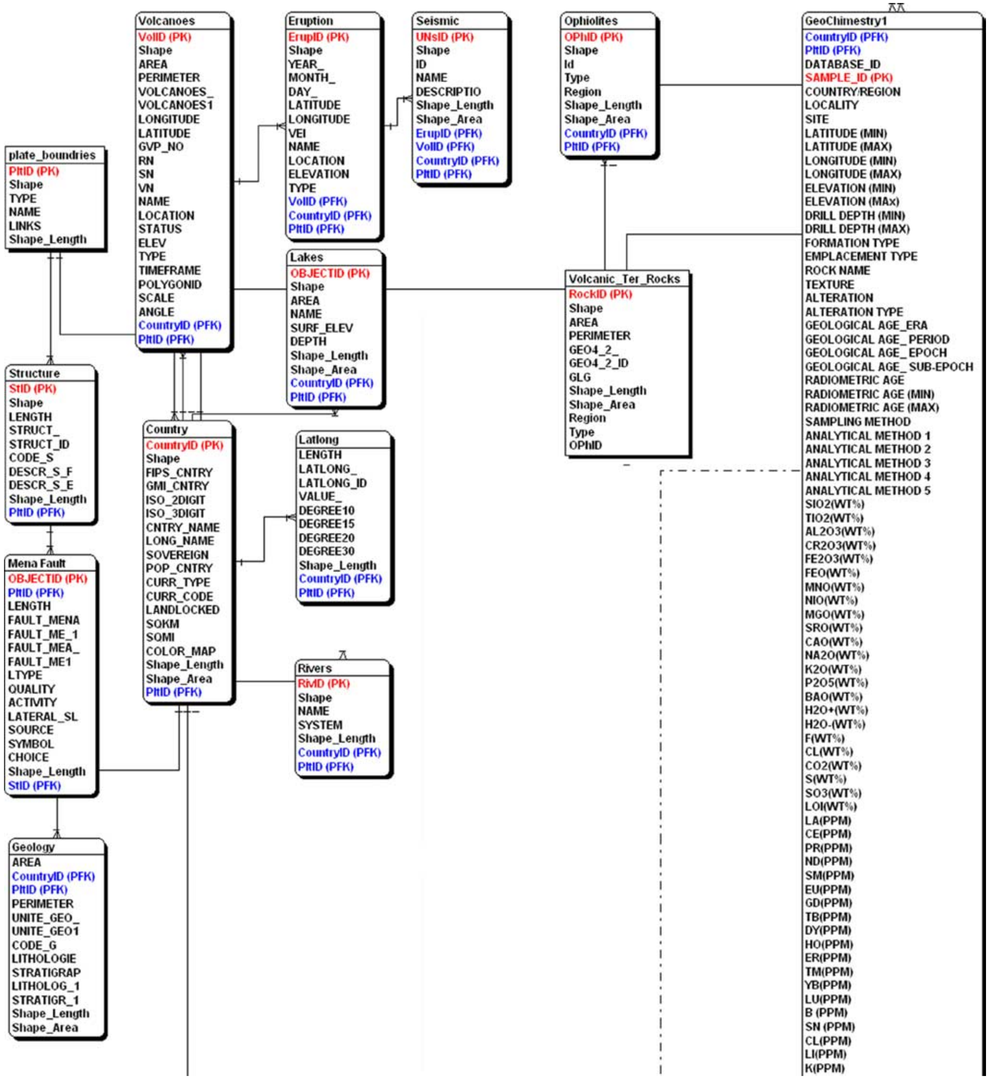


Fig. 2. Diagram illustrating the relationship among different tables in Tethys database. Primary Keys (PK) are shown in red; Foreign Key (FK) is shown as blue. Line with arrows indicate one to many relationships. (For interpretation of references to color in this figure legend, the reader is referred to the web version of the article).

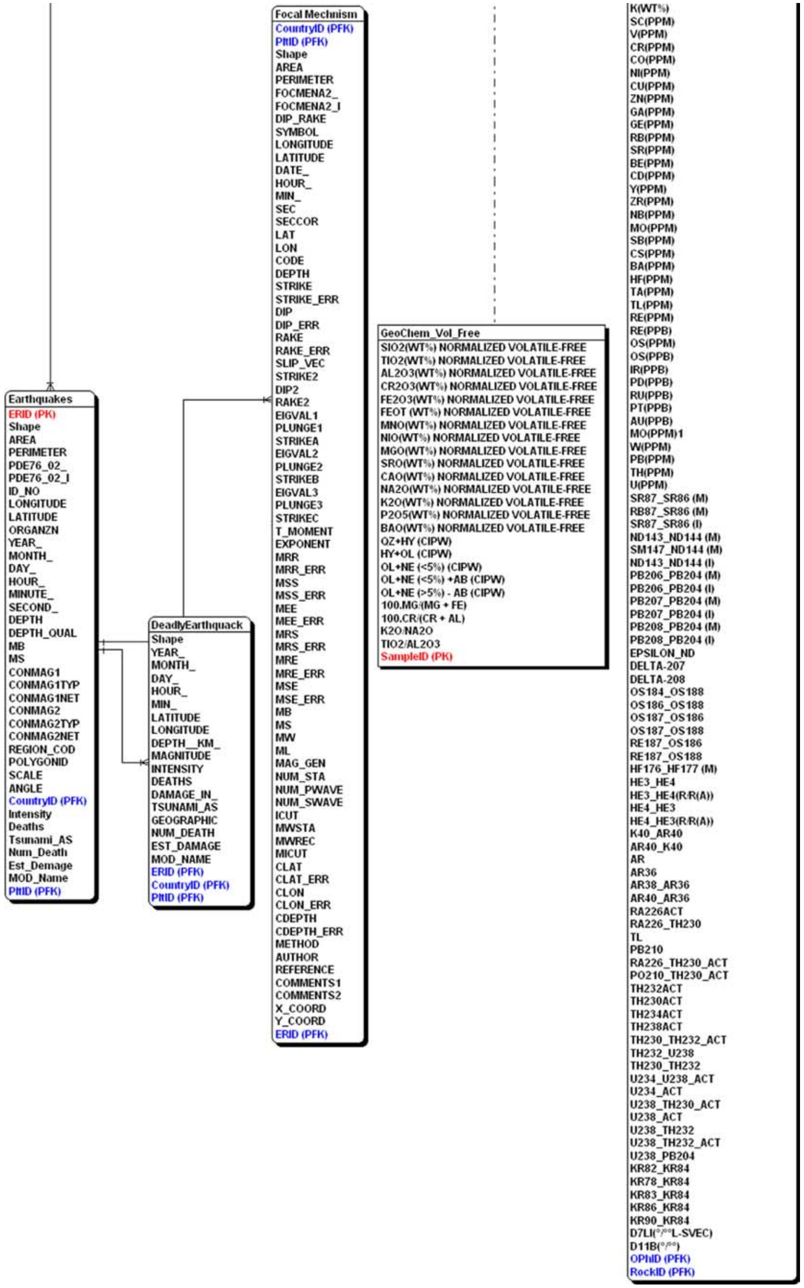


Fig. 2 (*continued*)

has compiled geological datasets which are readily available in digital form, either via the Internet or on CD-ROM. The database is built from relatively small scale data (1:1 million scale or 1 km resolution) and put on seven CDROMs organized by regions of the world. Each CD-ROM integrates data for a given region at a scale of 1:1,000,000 scale and includes a user-friendly GIS viewer (Hearn et al., 2001a,b, 2003a,b).

2. *Commission for the Geological Map of the World (CGMW)*: The CGMW is one of the Commissions of the International Geological Congress (IGC), and is affiliated to the International Union of Geological Sciences (IUGS). CGMW, in collaboration with UNESCO, published a digital geological map of the world at 1:25,000,000 in the summer of 2000 (Mercator projection) (CGMW and UNESCO, 2000). This map shows geology of the continents as well as oceans.
3. *Geotectonic map of the East and Southeast Asia*: The second edition of the geotectonic map of the East and Southeast Asia was released in 2002 by the Coordinating Committee for Coastal and Offshore Geosciences Programs in East and Southeast Asia (CCOP) of the Geological Survey of Japan (CCOP, 2002). The map covers part of East and Southeast Asia, including Shikhote Alin, Korean Peninsula, Japanese Islands, part of China, Vietnam, Laos, Cambodia, Thailand, Myanmar, Peninsular Malaysia as well as Western Pacific and Northeastern Indian Oceans. The map includes basic tectonic information such as tectonic provinces, major tectonic domains (continental, oceanic and continental margin), tectonic nature of map units (age of constituent units, age and nature of tectonic deformations, attitude of structural features like faults and fold, types of igneous rocks, sediment isopachs, sedimentary basins, volcanoes, paleomagnetic anomalies, earthquake epicenters, and many others). The electronic maps are written by a GIS software, TNTmips®. It is readable only by the viewer software, TNTatlas®. The editing of the maps is impossible unless TNTmips is available.

We created a geologic database in Oracle and included general geology of the whole Tethyan region with major lithologic units like sedimentary rocks, volcanic rocks, flood basalts (i.e. Decan Trap, etc.) and plutonic rocks. In offshore arcs, seamounts and ocean floor, etc. are included. This dataset also includes stratigraphic information with major formation names and ages ranging from Archean to Quaternary. This table can be seen via ArcIMS as shape file with geographic WGS 1984 projection system.

Ophiolites provide clues for the pre-collisional history, whereas, Quaternary and Tertiary Volcanic rocks (QTV) carry post- and syn-collision information in the Tethyan region. Therefore, we focused on these two major units and created maps and data tables. We have compiled a regional map for ophiolites (Fig. 3). In order to create Tethys scale map for ophiolites the following maps were digitized using HP 42″ wide scanner at the University of Houston.

1. Geological and structural map of the Eastern Asia (Letouzey and Sage, 1988)

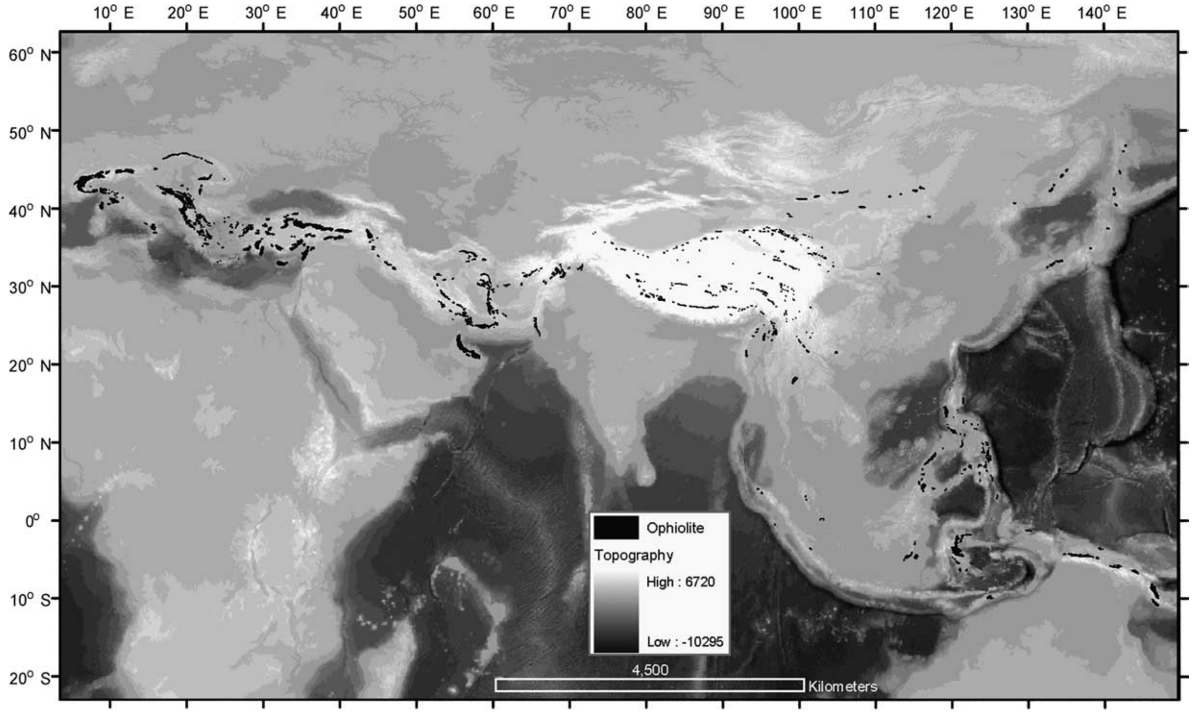


Fig. 3. Ophiolite map for the Tethys region. This GIS map (ESRI shape file) is created by digitizing several paper maps listed in the text and is linked to Tethys Oracle database.

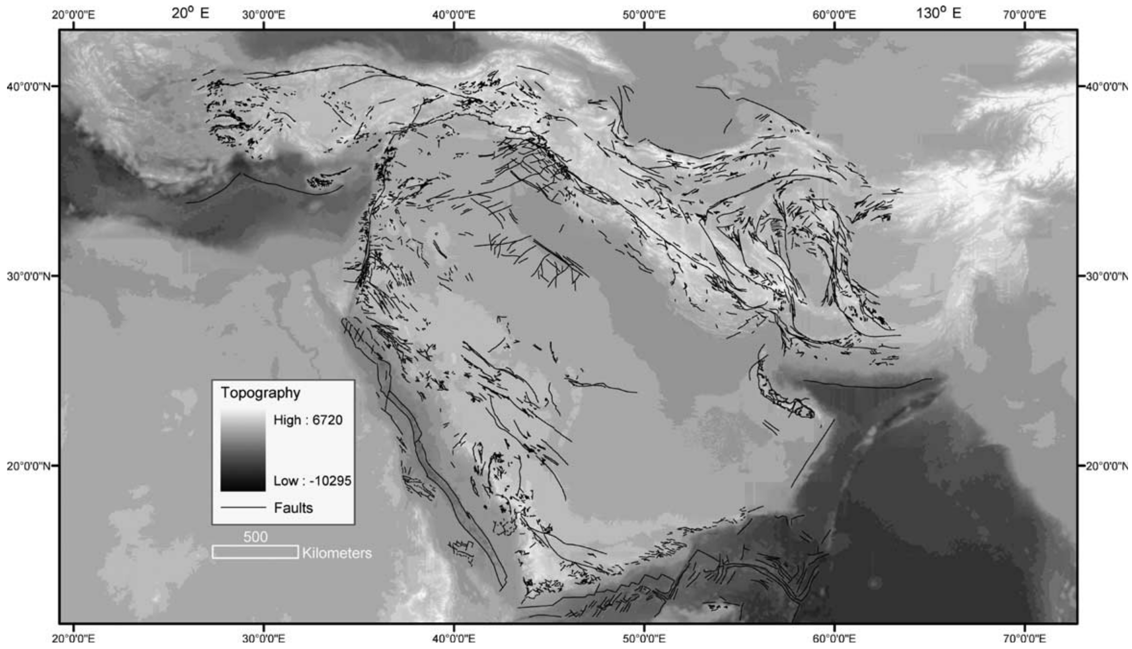


Fig. 4. Map of Arabia showing major structures and plate boundaries.

2. International Atlas of Ophiolites, Ophiolitic Belts of Central Mediterranean (Dietrich, 1978)
3. Tectonic Map of the Indonesian Region (Hamilton and Fisher, 1978)
4. Energy Resources map of the Circum-Pacific Region (Gryc, 1992)
5. Geological map of the Central and Southern Afghanistan (Weittekindt and Weippert, 1973)
6. Geological Map of the Tibetan Plateau and Surrounding Areas (Chengdu Institute, 1988)
7. Regional map of the Eastern Mediterranean Region (Robertson, 2002).

The raster images were digitized in Arc Editor of ESRI ArcGIS package. Currently we are refining our ophiolite map using some new resources. We have also created a map and a dataset for QTV.

Major plate boundaries and structures such as faults are also included in our database. We used digital data sources as described above. We also acquired University of Texas Institute for Geophysics plate boundaries data that depict the world's plates (UTIG; http://www.ig.utexas.edu/research/projects/plates/plates.htm), and included commonly used name of each plate, percent of the Earth's surface covered by the plate and type of plate boundaries. We are in the process of adding detailed structural data, for example, we have included a dataset which contains faults, flexures, fissures, and plate boundaries of the Middle East. Faults are described in terms of type, length, level of activity, and quality of data.

Table (Mena) which shows the main structural elements of the Arabian Shield, mainly earlier N–S and NE trending elements that developed during the accretion of volcano-sedimentary arc terrains of the Arabian Shield. Many of these accretionary features were reoriented in a NW-trending direction through brittle and ductile deformation associated with the Najd transcurrent fault system, the Najd system that crosscuts the entire Arabian Shield (Fig. 4).

4.1.2. Earthquake and volcano data

The earthquakes and volcano are included in our database as geospatially referenced point data containing numerous attributes regarding each event/volcano. This point data set contains all earthquake events, worldwide, from the (PDE) Preliminary Determinations of Epicenters, Monthly Listing. This list is the most complete computation of hypocenters and magnitudes done by the United States Geological Survey (USGS) National Earthquake Information Center (NEIC). It is normally produced a few months after the events occur. The publication is called 'Preliminary' because the 'final' computation of hypocenters for the world is considered to be in the Bulletin of the International Seismological Centre (ISC), which is produced about 2 years after the earthquakes occur. The NEIC PDE program contributes about one-third of all data used by the ISC.

Volcano and eruption tables are created from the Smithsonian Institution's Global Volcanism Program database, Volcanoes of the World (Jones et al., 2002). This database contains basic geographic and geologic information for volcanoes thought to have been active in the last 10,000 years (Holocene). The data can be used to locate active volcanoes and read one-line summaries of them.

'Volcanoes of the World' (Simkin and Siebert, 1994) provides a discussion of the many 'cautions' that are so easily stripped away from an electronic database, such as the incomplete and uneven nature of the historical record, even in this century, and the large uncertainties surrounding many older eruption dates. The accuracy of the record varies enormously from one region to another (and one century to another), and the sea-floor volcanism that dominates our planetary magma budget is scarcely represented in this data set. Users of these data are cautioned to note the varying usage of the word 'volcano' and the variable accuracy and certainty of techniques to determine their age. Users are also strongly recommended to consider the many uncertainties discussed under Frequently Asked Questions and Data Criteria pages of the Global Volcanism Program web site: http://www.volcano.si.edu/gvp/world/index.cfm.

4.2. Geochemical data

Existing geochemical relational database management systems (PetDB, GEOROC, NAVDAT, GERM) are not integrated with GIS or multidisciplinary systems although there is broad recognition of the need for 'seamless' cross-database searching. Building on agreed metadata needs and compatible schema (e.g. EarthChem www.earthchem.org; Sarbas et al., 1999; Nohl and Sarbas, 1999; Lehnert et al., 2000; Staudigel et al., 2003), we have developed a comprehensive, flexible format comprising 34 interrelated tables of analytical values for sample materials (volcanic glass, whole-rock samples, minerals, inclusions, etc.) and metadata that include sample geographical coordinates, data types and quality, lithologic and petrographic character, and sampling and analytical methods used. The data are sample-specific and linked to Endnote bibliographic sources. Collecting and compiling published data proved more time-consuming than we had expected although the process was facilitated by using optical character recognition (OCR) software to acquire editable data and metadata downloads as Excel files. We also benefited from the error-checking 'wizards' in Excel sheets and written algorithms for transforming to the current GIS data-metadata format.

The data sets were compiled using unique sample identifiers, given that in some cases multiple data categories exist for the same sample acquired in different laboratories, and publication in separate journals using different sample identification numbers. Thus all information for locality-specific samples is incorporated in the database as a single entry. Geochemical metadata include: (1) sample latitude and longitude coordinates, including GPS data where available, (2) information on sample age (stratigraphic, paleontological, radiometric), (3) emplacement modes and lithologic character, (4) normalization options (e.g. to volatile-free, 'dry weight' bases for specified oxidation states) to produce derivative data sets as input for plotting and visualization, (5) information on data quality (e.g. analytical techniques and laboratories used, precisions and accuracies, international reference data), and (6) bibliographic sources.

Map-view display of sample localities, measured and estimated ages, and diverse geochemical parameters are basic requirements such that developing tools for manipulating the raw data will be given priority on completion of data compilation. Several tools are already available for visualizing data and producing derivative data sets, including (e.g.) parameter-delimited compilations based, for example, on compositional or spatial-temporal criteria. These apply to: (1) whole-rock geochemical, isotopic, and geochronologic data, (2) normative or other derivative parameters defining 'primitive', 'tholeiitic', 'alkali basaltic', 'ultrapotassic', 'boninite' or other compositions, (3) specified element groups (majors, traces, LILE, HFSE, REE, PGE) and isotopes (Sr, Nd, Pb, Hf, Os, O, H, etc.).

PetroPlot, a petrographic plotting routine developed for the PetDB database (which can be used for query visualization in other geochemical databases) and MatLab, for general statistical evaluation of data were applied. Additional tools being developed will allow for: calculation of parental magma compositions and fractionation paths based on the MELTS algorithm, primitive magma segregation pressures, temperatures, and P_{H2O}, and f_{O2} conditions (interpolated from the worldwide experimental database), and derived functions such as mantle potential temperature (T_p), magma viscosity and density. These and other tools will yield output data in VRGL format which can be used as input for visualizing mantle and magmatic parameters derived from petrologic information with geophysical and other data. Specific sample parameters (e.g. age, element concentrations, isotopic ratios, etc.) will be coded in terms of point colors, shapes, and sizes.

4.3. Remote sensing data

A single seamless mosaic of Landsat TM, bands 742 (RGB) was generated from the NASA's orthorectified global tile coverage collection. The scenes were acquired in or around the 1990s (±3 years). However, individual scenes may range from 1985 to 1996. The selected scenes are of high-quality, relatively cloud-free TM and ETM+ imagery from Landsats 4–5 and 7.

A single seamless mosaic covering the entire Tethys region was generated for the study area from the Moderate Resolution Imaging Spectroradiometer (MODIS) 500 m data, from bands 1 to 7. The Landsat and the MODIS products extend across the entire Tethys belt and allow users to examine structural and lithologic characteristics of the surface.

We generated a set of four mosaics from Shuttle Imaging Radar C (SIR-C) L-band image surveys. All of the generated mosaics were processed from the HH polarization data at a ground resolution of 100 m. Two of the mosaics were generated from radar images acquired along the Shuttle's ascending orbits, and the remaining two mosaics were produced from images acquired along descending orbits. The radar data were acquired during two shuttle missions

(9–20 April 1994 and 30 September to 11 October 1994). The radar data are particularly useful for delineation of subtle surficial structural elements and for delineation of buried features (e.g. paleo-valleys) in arid and semi-arid terrains.

Digital topography with a spatial resolution of 30 Arc second (~1 km) was generated from Shuttle Radar Topography Mission (SRTM) data set. The tiles were mosaiced into a single seamless dataset covering the Tethys collision belt. These data sets allow users to study geomorphological characteristics over the Tethys collision region and are used in 3-D representations of the other surface data layers.

4.4. Geophysical data

We have complied the following geophysical datasets.

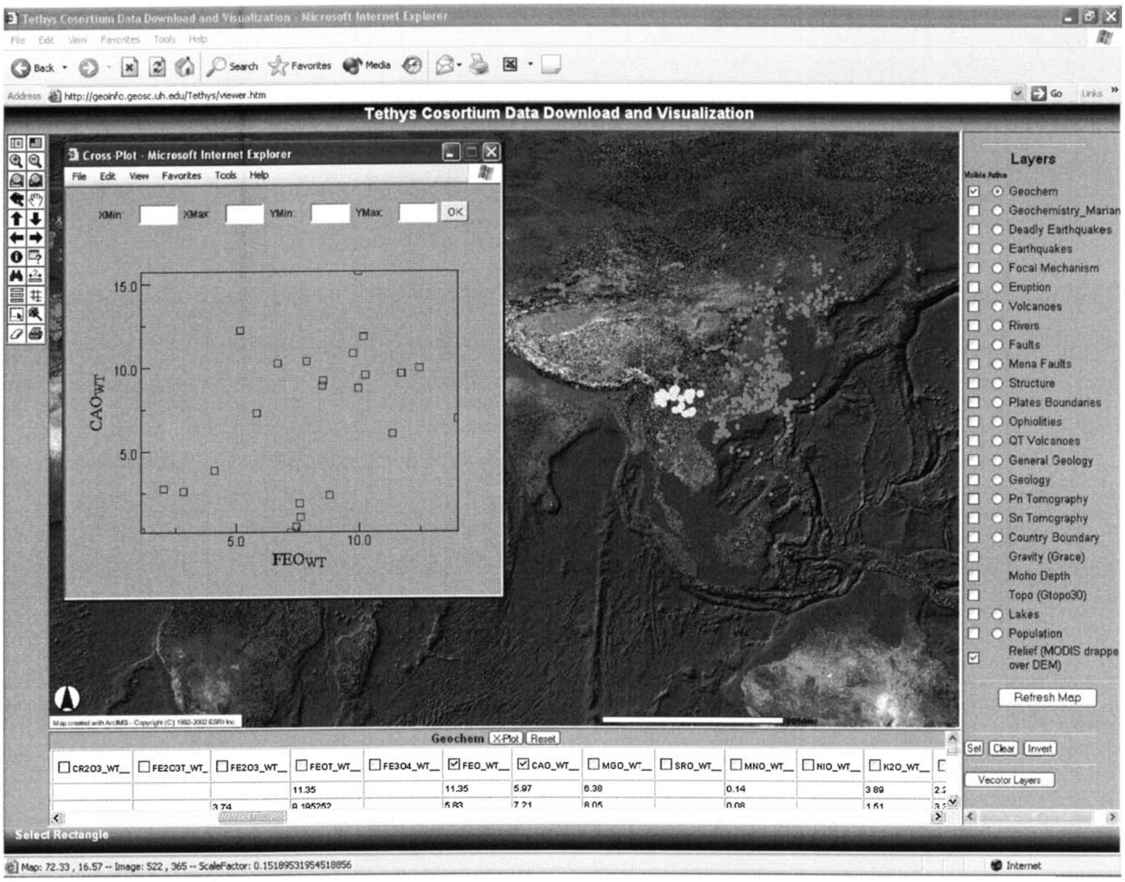
Eastern Mediterranean GPS Crustal Motion (McClusky et al., 2000) is Global Positioning System (GPS) measurements of crustal motions for the period 1988–1997 at 189 sites extending east–west from the Caucasus mountains to the Adriatic Sea and north–south from the southern edge of the Eurasian plate to the northern edge of the African plate. The data may be used to study crustal motion and deformation in the Arabia–Africa–Eurasia plate collision zone.

North Africa and Middle East Focal Mechanisms was obtained from http://www.atlas.geo.cornell.edu. The principal purpose of constructing this database was to be able to represent and view the prevailing focal mechanisms in the Middle East and North Africa region.

Moho (2°×2° grid; Bassin et al., 2000) data set was created as part of the Reference Earth Model initiative, whose goal is to provide the geophysical community with a model that fits a great variety of geophysical constraints. The reference model is available for use by a wide range of possible users, including seismologists, mineral physicists, and geodynamicists.

Pn tomography in the Middle East 1°×1° degree grid was obtained from Hearn and James (1994). The data set may be used to better understand the effects of subduction and continental collision on the uppermost mantle structure beneath the plateau. The regions with the highest errors in velocity (≥200 m/s) are beneath the northern and south-eastern edges of the image, because of the thin ray path coverage.

Sn tomography in the Middle East (1°×1° grid; Sandvol et al., 2001) can be used to understand seismic attenuation in the lithospheric mantle in the Middle East. From this, the general rheological and thermal structure may be inferred.



☐ CR2O3_WT__	☐ FE2O3T_WT_	☐ FE2O3_WT__	☐ FEOT_WT__	☐ FE3O4_WT__	☑ FEO_WT__	☑ CAO_WT__	☐ MGO_WT__	☐ SRO_WT__	☐ MNO_WT__	☐ NIO_WT__	☐ K2O_WT__
			11.35		11.35	5.97	6.38		0.14		3.89
		3.74	9.195252		5.83	7.21	8.05		0.08		1.51

Fig. 5. Java applet tool to plot geochemistry as scatter graph.

Global Shear Wave Splitting Directions (point coverage) data set can be used to map current and/or preserved mantle flow. This data set represents global shear wave splitting parameters collected from single station average results. Parameters used for plotting shear waves splitting include fast direction and a lag time.

5. Visualization tools

A considerable amount of our efforts were dedicated to bring online manipulation and visualization tools that are available on desktops. Examples of such tools include: (1) pixel ID, threshold, 3-D drape, stretching, contouring, filtering and image statistics including minimum, maximum, median, and histogram. This was achieved by bringing online the IDL image processing tools and developing our own software (Java, C++, XML).

In order to plot the geochemistry data of ophiolites and Quaternary Tertiary Volcanics (QTV), we have developed a Java applet to create scatter graph. Codes were written to connect the Java Applet to ArcIMS and attributes of tables. This application is shown in Fig. 5. Samples are selected using ArcIMS selection tool which brings table of attributes for the selected points, field can be selected from this table to make a scatter plot. The scale of the resultant graph could be changed by typing in minimum and maximum X and Y values.

Using ArcObjects and VBA we created a tool to make a thematic map for geochemical data. Using this tool chemical variation for a selected element can be spatially plotted and visualized from the difference in diameter or color of circle. In Fig. 6 different colors of circle shows variation in Sr^{87}/Sr^{86} ages for the Izzo-Bonnin-Mariana (IBM) arc system.

6. Continental collision model development

In order to develop a comprehensive model for the processes involved in continental collision and accretion it is essential to integrate data and models from a wide variety of disciplines. The TETHYS database is an essential tool in this endeavor and we are therefore using to examine the evolution of the Eurasian, Indian, African, and Arabian lithosphere. A model for the evolution of these plates and their interactions will serve to better understand plate tectonics on our planet.

Our databases provide excellent opportunity to combine datasets from a variety of earth sciences. For example,

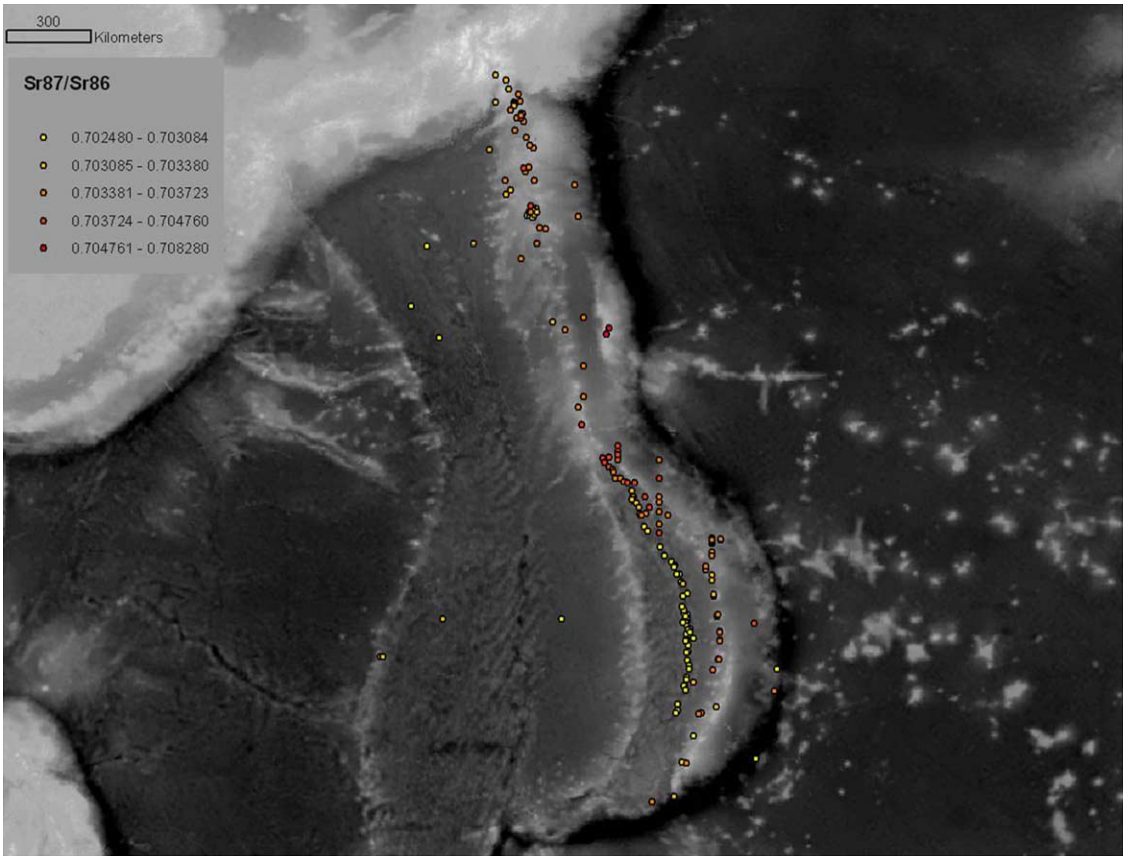


Fig. 6. Thematic Mapper tool is developed using ArcObject and VBA to plot the geochemistry spatially. In this example Sr^{87}/Sr^{86} variation can be seen in different colors (web version only).

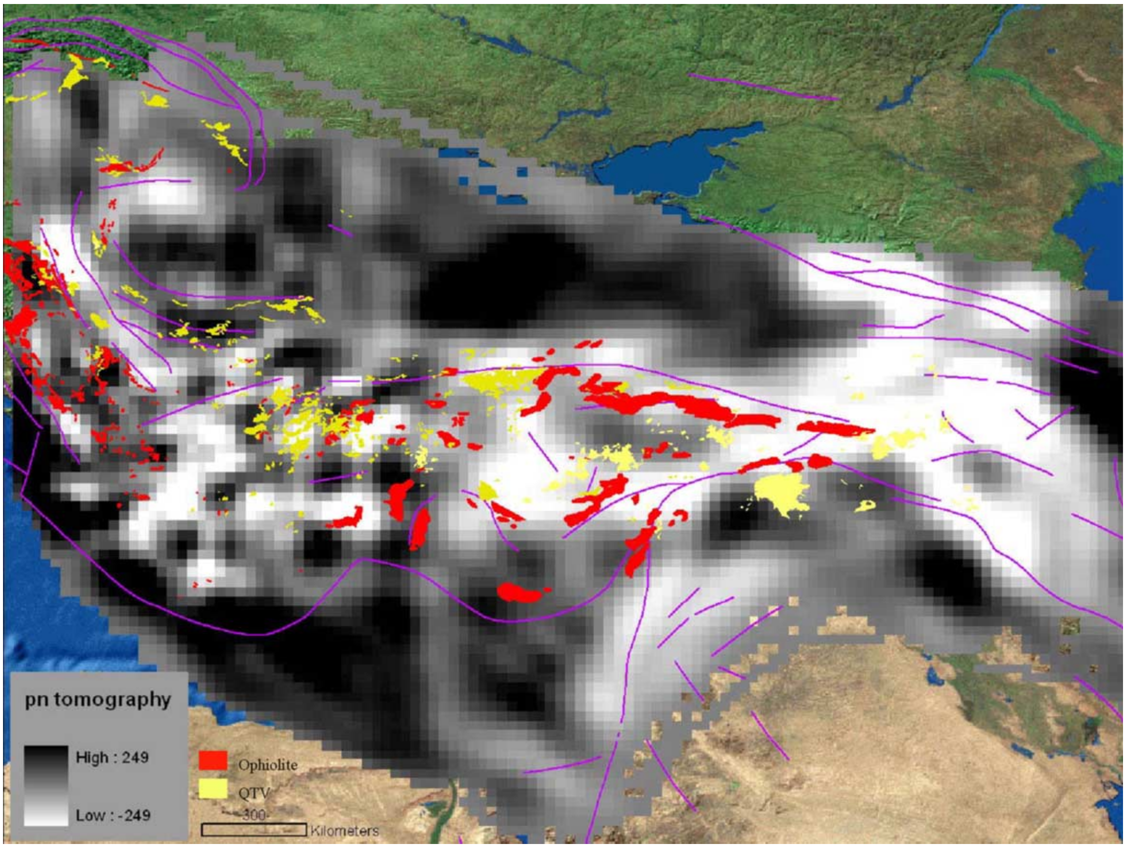


Fig. 7. 'Natural Laboratory' examples of combining datasets bearing on basic questions, i.e. tomography, structural, ophiolite and QTV for NW Turkey.

seismic tomography data can be used to infer the present-day thermal and rheologic structure for the mantle. We have included both travel time and attenuation tomography data sets in our database. Fig. 7 shows an example of the potential for combining different layers of data. In tomography, black data shows high velocity, thus indicating more rigidity and colder material whereas white could be inferred hotter mantle. Adding data from our structural dataset will reveal major faults like the north Anatolian and east Anatolian fault (Fig. 7). Ophiolite exposures could be added from the geology database and Tertiary and Quaternary Volcanics from the volcanics database to further improve visualization. Furthermore measurement of seismic anisotropy can be used to map mantle flow within the upper mantle and possibly the mantle transition zone. The inferred mantle flow patterns will be tested using our comprehensive geochemical database.

The IBM subduction factory appears to be the best example of an active rollback cycle and, as a focus of the international MARGINS initiative, is well-documented by bathymetric, geophysical, petrologic, and geochemical data. With our database we are trying to create a 4-D working model of the IBM region in collaboration with MARGINS researchers as a template to aid in interpreting the Tethyan ophiolite record and understanding pre-collision mantle dynamics.

Orogenic ophiolites represent a long standing paradox—lithologic assemblages reflecting coeval effects of compression and extension—and in this respect resemble modern accreted forearc complexes. Our project will help the research to look at the ophiolite genesis.

Three-dimensional seismic tomography provides increasingly high-resolution 'snapshots' of lithospheric and asthenospheric thermal structure which may be used in developing and testing plate collision models and defining seismic and magmatic boundary conditions. Tomography shows that post-collision slab detachment and the lateral migration of slab tearing during a diachronous collision are common dynamic elements in the western Pacific and Mediterranean regions.

As a typical collision progresses, such effects are matched by along-strike changes in the stress field, vertical motions, and upper mantle thermal state, while magmatic activity progresses from calc-alkaline to high-K calc-alkaline, potassic, ultrapotassic, and OIB-like basalts. It is thus possible to reconcile upper mantle thermal structures with diverse geological information—including lithospheric structure, the timing of tectonic and magmatic events, and mantle enrichment–depletion histories—in 4-D geodynamic models.

Studies of post-collision slab tearing and detachment have mostly involved tomographic imaging and interpreting earthquake distributions. For example, intermediate-depth seismicity in the SE Carpathian 'bend zone' is mostly associated with a high-velocity near-vertical slab at ca. 100–170 km depth while a SE-dipping high-velocity zone beneath the Transylvanian Basin may represent the base of lithosphere belonging to the overriding plate. In contrast, low-velocity regions down to 70–80 km depth beneath the Carpathian forearc may represent underthrust crustal materials (Fan et al., 1998). However, important clues may be gained from associated magma compositions and tectonics.

While the database is not complete, the basic structure is established and a substantial proportion of relevant data set is compiled. Several of these may be accessed on the web although others await verification of metadata (e.g. concerning analytical methods, sampling coordinates, and age relations for geochemical data). Utility of the evolving database system is being tested by project participants in the form software tool development, proposal planning, and interdisciplinary research (including several graduate student projects).

Over the next year, we will be adding several additional datasets, as well as bringing many new tools on line. Some of these additional datasets will include tying in already established datasets from other sites. Tools currently in their final stages of development include integration of IDL (from RSI Inc.) based tools, such as contours, image statistics and filtering and enhancement routines, and data transect profiles. In addition to these tools, we are working to include the 3-D display capabilities if IDL, and RSI's web based ION for better manipulation of the 3-D datasets.

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