THE CAUCASUS SEISMIC INFORMATION NETWORK STUDY AND ITS EXTENSION INTO CENTRAL ASIA

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ABSTRACT

The Caucasus Seismic Information Network (CauSIN) and the Central Asian Seismic Research Initiative (CASRI) are collaborative projects to build a database of geological, geophysical, and seismic information and to use crustal modeling techniques to create a model to aid in seismic monitoring from the Caucasus to China.

Over the past year we have expanded our database in several ways. We obtained and evaluated regional scale geological maps that cover the Central Asian and Caucasus region. We conducted fieldwork to check the accuracy of the maps. This fieldwork will continue along portions of the Georgian Borjomi-Kazbegi fault during the summer of 2005, with the addition of geophysical surveys including gravity and magnetics.

Our extended collection of seismic data now includes data from Turkey and phase arrival times from local networks in the Caucasus which we have combined with data from the International Seismic Center (ISC) and ground truth events (both earthquakes and explosions) from the U. S. Army Space and Missile Defense Command (SMDC) Research Program. This combined database has been checked for station and event overlaps. Most events are being relocated with the aid of data from local networks. Finally, waveform data from both historical and current events are continually being gathered at Lawrence Livermore National Laboratory (LLNL).

The travel time database has been used for 1D crustal inversions in the Caucasus region. New 1D models will be input to 3D crustal tomography. Due to the political situation in many of the Central Asian countries, communication with scientists in these countries has been limited. Meetings with our Central Asian colleagues during the CauSIN meeting in Vermont in June 2004, and at the CauSIN/CASRI joint meeting in Istanbul in January 2005, have been very important for establishing a good working relationship for data collection in Central Asia.

OBJECTIVES

The primary goal of these projects is to develop a database of geology, tectonics, and seismicity in the Caucasus and Central Asian regions (shown in Figure 1).

With this new database, we will be able to improve earthquake locations and identify potential "ground truth" (GT) events. The dense network, calibration events (mining and quarry blasts), improved models, and better location algorithms (including multiple-event grid search, and double difference) will improve the event locations. Scientists at collaborating countries are assisting with this task, since improved locations will aid in the identification of active faults.

With the ground truth events to serve as validation, we will obtain a detailed crust/upper mantle structure in the Caucasus, eastern Turkey, northwestern Iran, and Central Asia, using data from local seismic stations as well as GSN and other stations operated as part of the national networks. The model will incorporate the extensive geological and geophysical data (e.g., surface seismic reflection profiles, gravity maps) as well as the seismic data.

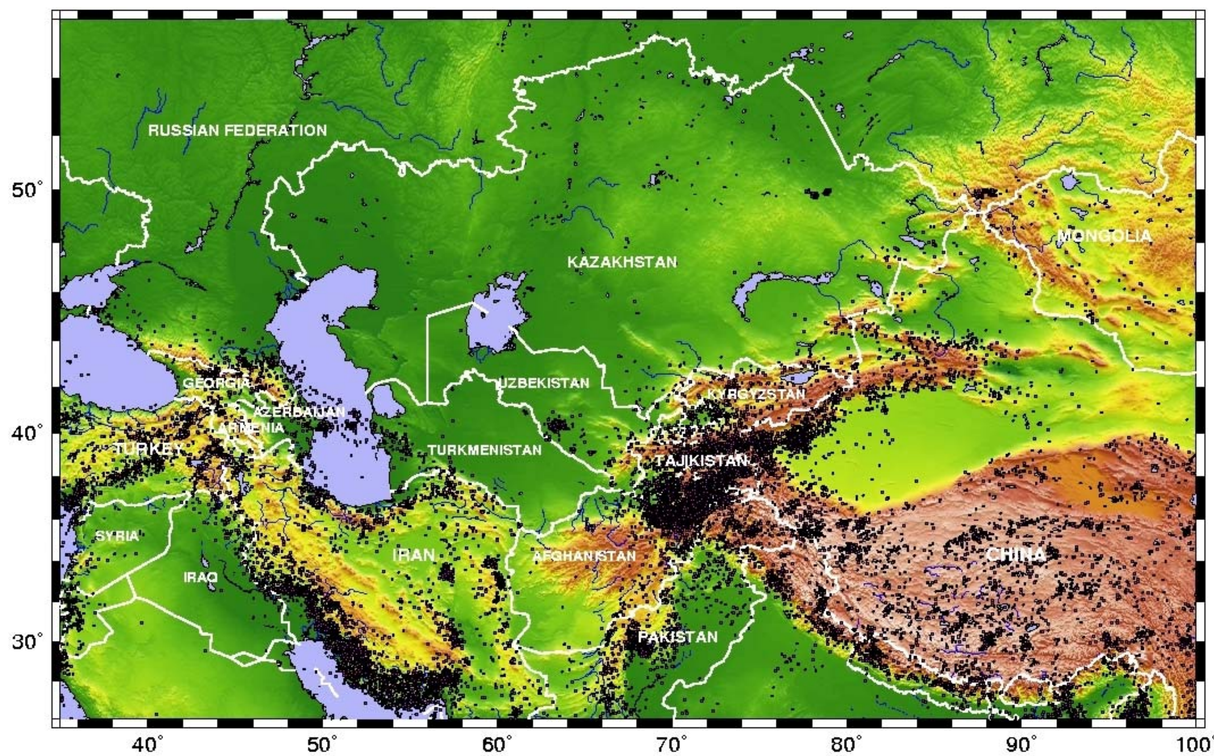

Figure 1. CauSIN and CASRI project area political boundaries and seismicity (USGS).

RESEARCH ACCOMPLISHED

Geology and Tectonics

The goal of the CauSIN and CASRI projects is to produce a seamless tectonic, geological and geophysical model of the Caucasus and Central Asia.

The active tectonics of Central Asia is a consequence of the continental collision and the continuing continental convergence between the Indian and the Eurasian plates. Our approach to reveal the large-scale active tectonics of Asia is to utilize satellite imagery and a few ground truth studies, augmented by the synthesis of the existing Russian and Chinese geological and geophysical data in the mid-seventies (Molnar and Tapponnier, 1975; Tapponnier and Molnar, 1976, 1979). The active tectonic pattern of Asia obtained in these studies (Figure 1) was interpreted as deformation in a rigidly indented rigid-plastic solid, where India is analogous to the indenter and the delineated great strike-slip faults, such as Altyn, Tagh, Kunlun, Sagaing, Red River, Herat, and Quetta-Chaman that correspond to slip lines. Along these slip lines, major continental blocks such as Tibet escape laterally away from the continental collision front.

Within this general tectonic setting, the CASRI project countries, namely Kazakhstan, Uzbekistan, Kyrgyzstan, and Tajikistan, are situated in one of the world's most rapidly deforming continental regions, because the leading tip of the indenting Indian Plate has penetrated furthest into the Eurasian plate in the Hindu Kush-Pamir region (Figures 1 and 2).

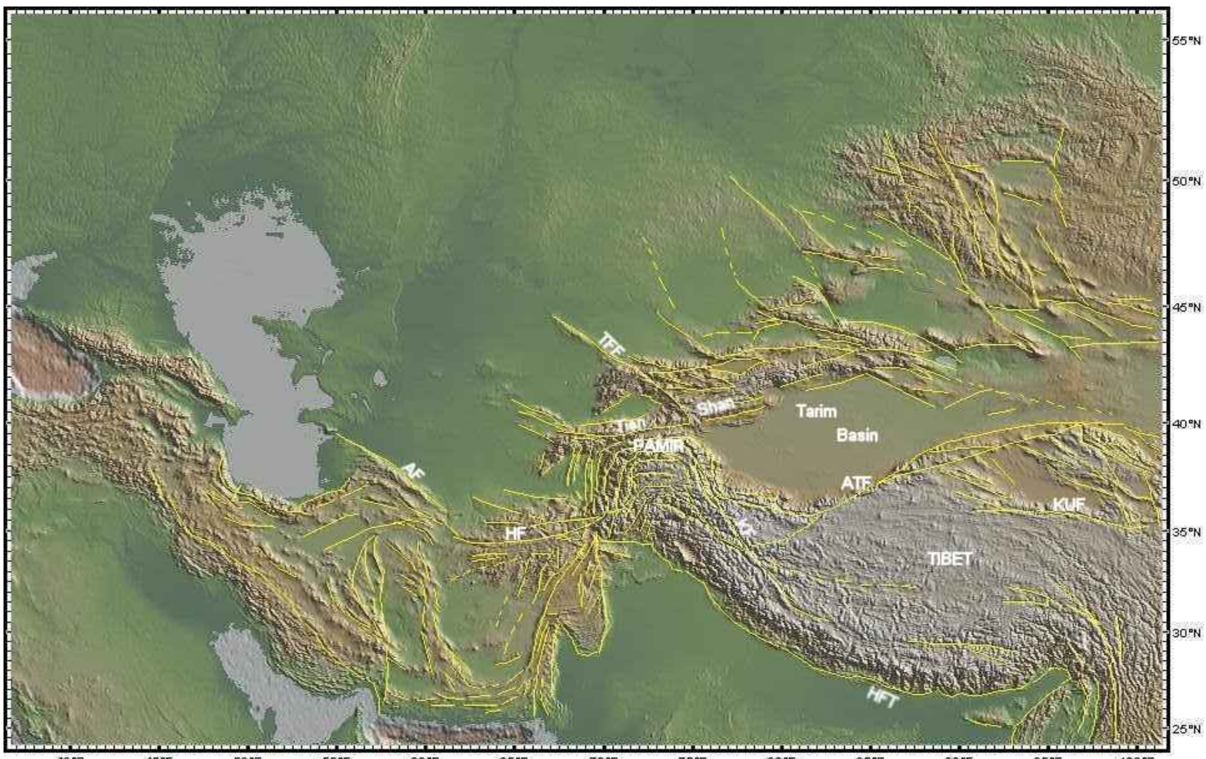

Figure 2. Preliminary tectonic lineament map of Central Asia. Only the major fault zones have been delineated in this figure in order to avoid clutter.

Some prominent faults in this region have been delineated within the scope of the CASRI project using the newly acquired Shuttle Radar Topographic Mission (SRTM) data (Figure 2). The SRTM data is much superior compared to satellite imagery, because it is not affected with cloud cover, and the 3-arc second resolution provides excellent morphological detail of the earth's surface. Furthermore, the capability of artificially illuminating the SRTM data with varying illumination angles and azimuths provides unprecedented advantage to do structural analysis.

Comparison of the previous tectonic maps of the region (e.g. Tapponnier and Molnar, 1979) and Figure 2 indicates that much more tectonic information can be obtained using the high resolution SRTM data compared with the satellite imagery. In fact, some of the delineated faults either have not been mapped previously, or if mapped, the existing data have not been published in the English literature. One of the tasks to be accomplished in the next phase of the CASRI project is to unearth the existing data through active collaboration with our colleagues from the CASRI countries, and to initiate new field excursions to collect structural data in the field and verify those newly delineated fault zones.

Recently acquired GPS data provide important constraints on the nature of the continental deformation in Central Asia (Abdrakhmatov et al., 1996; Reigber et al., 2001; Wang et al., 2001), indicating that the ongoing N-S convergence between the Indian and the Eurasian plates is taken up within a zone of more than 2000 km all the way from the Himalayan Frontal Trust to the mountain ranges of Mongolia. GPS data suggest that 18 mm/yr of convergence is taken up with shortening within the Himalayas, while in the Central Tien Shan the active shortening reaches values up to 13 ± 2 mm/yr. It is also suggested that the rigid Tarim Block rotates clockwise 0.8º/Myr with respect to stable Siberia about a pole located at 96ºE and 43.5ºN (Reigber et al., 2001).

Figure 3 shows a recent geological map compilation covering the CauSIN and CASRI regions. This geological map was originally compiled by Tingdong et al. (1997), and it was published by the Geological Publishing House, Beijing, China, in a scale of 1:5,000,000 as the Geological Map of Asia and Europe. In the original map an equal-area oblique zenithal projection was used with density of graticule: $\Delta\lambda=\Delta\Phi=5°$, Central Meridian: 85ºE, Projection Center: 85ºE - 40ºN. To make it compatible with other datasets, we converted the map into a Lambert Equal area projection (Figure 3). Availability of this geological map is invaluable for the CAUSIN and CASRI projects, because it saves significant amount of time and money.

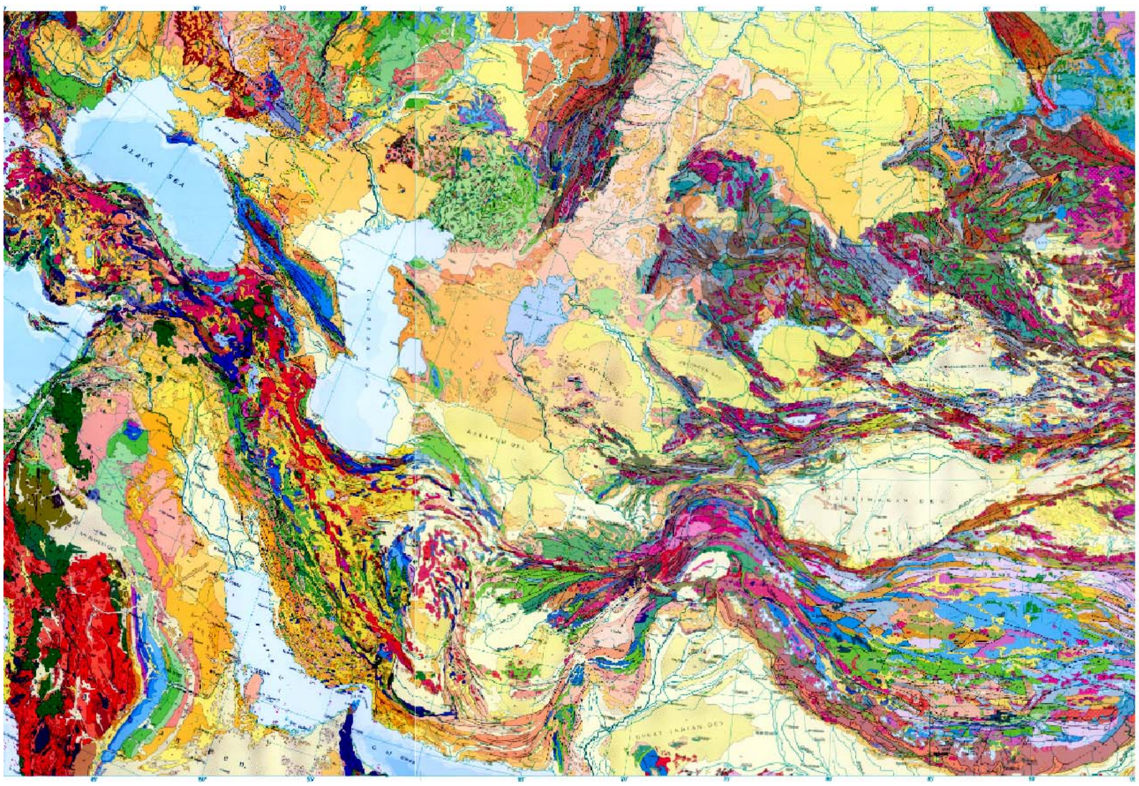

Figure 3. Geological map compilation of the CauSIN and the CASRI regions.

The seismicity data (M > 5) over the last 30 years (Figure 1) show that the Hindu Kush-Pamir and Tien Shan regions are seismically very active. Numerous seismological studies have established that faults in this region are predominantly trust faults that indicate the overall N-S shortening of the Asian continental crust. Some notable exceptions are the strike-slip Talas-Fergano, Altyn-Tagh, Karakoram, Kunlun, Herat, and Quetta-Chaman faults. The sideways escape of continental blocks is accommodated along these major strike-slip fault zones. Also, the faults that form the western and eastern flanks of the Pamir and Hindu Kush region are oblique-slip faults with significant strike-slip components.

Event Catalog, Phase and Waveform Data

Compiling a comprehensive catalog of seismic events in the Caucasus and Central Asia is a primary objective of these projects. Investigators from LLNL, NER and MIT met with seismologists from the Caucasus and Central Asian countries in the January 2005 in Istanbul to consolidate plans for this effort. We are compiling phase arrival times and waveform data for selected events. The ISC, SMDC, and IRIS data will be used as the backbone of our database which will be supplemented with data from local networks in Georgia, Azerbaijan, Armenia, Kazakhstan, Uzbekistan, Kyrgyzstan, and Tajikistan.

Digital waveform data is important for validating velocity/attenuation models and seismic wave propagation characteristics of the region. We are collecting waveform data of selected events from local/regional network stations, as well as other established databases.

The integration of local data to the general database requires an extensive selection and relocation process. The data from Azerbaijan, shown in Figure 4, is an example. In the general catalog (Figure 4), most epicenters fall on a coarse grid. Recent events, recorded by and located with the aide of expanded national networks, show a better distribution. Relocation of old and recent events will improve epicenters and their association with tectonic features.

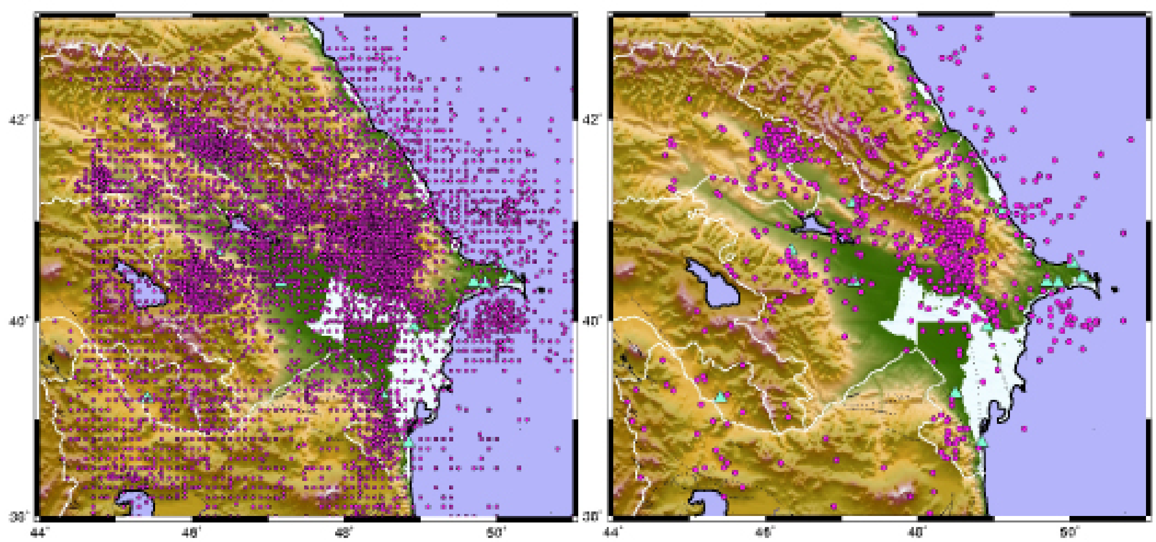

Figure 4. Epicenters in the Azerbaijan catalog. Left: For the period 1900 to 2004. Right: Relocated events in 2002 and 2003.

Near Real Time Data

One important aspect of both projects is to collect data from events in each country in near real-time. It will be useful if they could collect the data and post it in a timely fashion. Over the past several years we have requested data for a number of recent events in Turkey and Iran. Although the participants are cooperative, it takes days or more to get the data from the field and transmit it to us. For the remainder of these projects, we'll be working to improve reporting, publishing, and posting both phase picks and waveforms for regional events recorded on their local networks. An example of data for an earthquake in Iran (2-22-05, Mw = 6.4), recorded in Kazakhstan and Georgia, is shown in Figures 5a and 5b; the epicenter, stations locations, raypaths, and seismograms are presented. Additional data for this and other events in Iran and eastern Turkey are presently being submitted. With continued effort and upgrading of the local networks, it is realistic to expect data within days so that timely analysis can be performed on significant events.

Seismic Velocity Structure

Analysis of seismic data will be used to produce a 3D structure of the region. To obtain the starting model for the 3D tomography, we use VELEST (Kissling, 1993), a 1D joint inversion program that simultaneously solves for event locations, station delays, and a 1D earth model. The starting models are based on the Crust 2.0 (Bassin et al., 2000) model. Figure 6 shows event locations and the 1D velocity profiles. In Figure 6 (left), both ISC and final VELEST locations are shown. In Figure 6b (right), 1D velocity profiles for each of 15 iterations are shown. The greatest variation in the final models is in the depth range of 0-20 kilometers, which is not unexpected given that we are using a 1D model in a region with much lateral variation, from continental crust in the central Caucasus to oceanic crust in the Caspian and Black Seas.

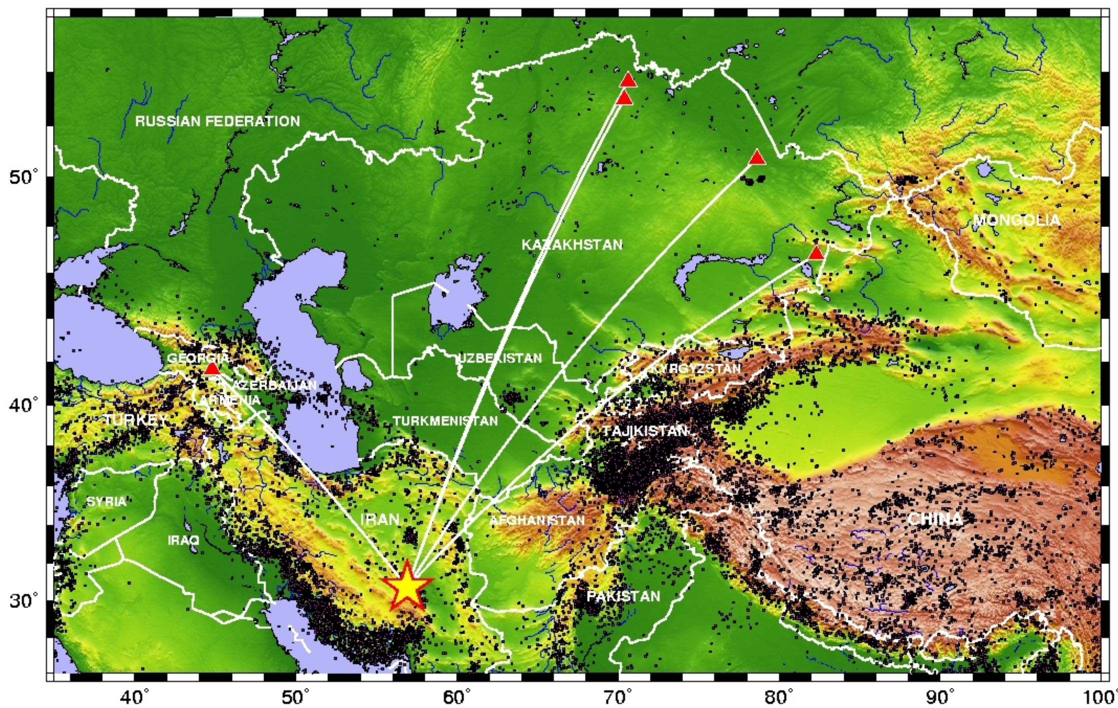

Figure 5a. Iran 2/22/05 earthquake location (yellow/red star). We are continuing our effort to make data from moderate to large events available to all participants in the study soon after the events happen. So far we have collected waveform recordings from one station in Georgia and four stations in Kazakhstan.

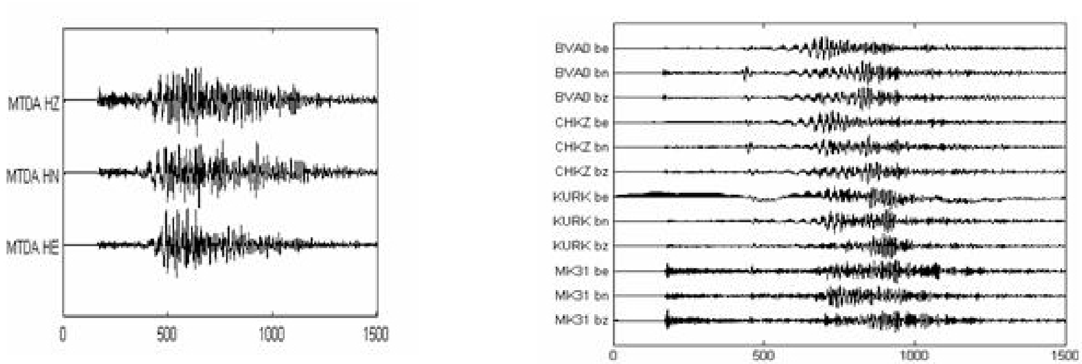

Figure 5b. Traces from stations in Georgia (left) and Kazakhstan (right) for the Iran 02/22/05 earthquake.

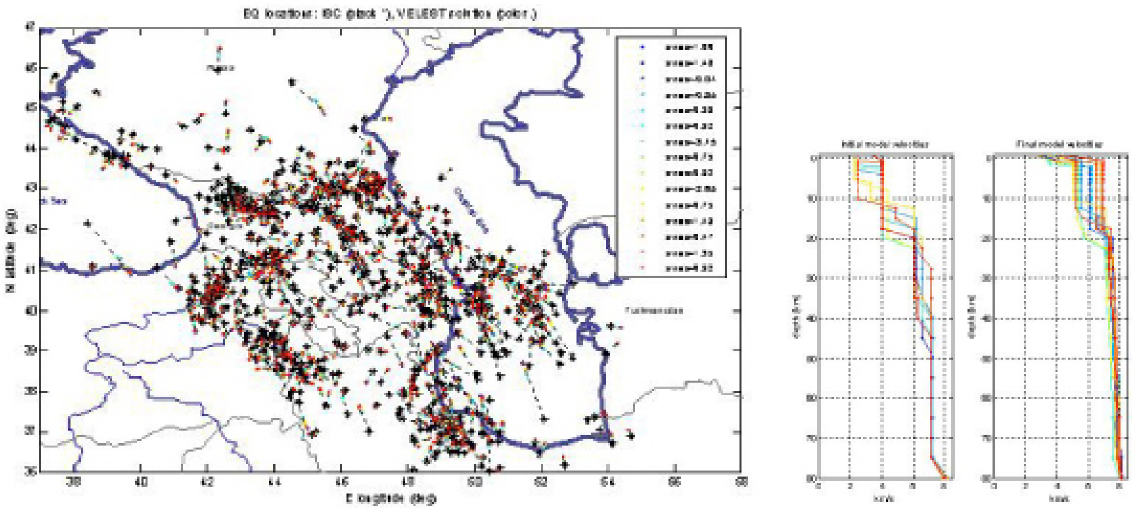

Figure 6. VELEST location/inversions of the Caucasus data. Left: Dashed lines connect the ISC locations (black *) and the VELEST final location. Right: 1D velocity profiles for 15 iterations.

CONCLUSIONS AND RECOMMENDATIONS

Progress is being made in collecting and evaluating data from regional events collected on local networks in the Caucases and Central Asia for the database. We selected 100 earthquakes recorded in the Caucasus for detailed study as part of the CauSIN project. A similar approach was adopted for the CASRI project. Events occurring within the region are particularly important to constrain crustal models. Furthermore, as additional broadband stations are added in the Caucasus and Central Asia and existing stations are upgraded more comprehensive data will be available.

Based on the additional regional data, and a number of ground truth events, we are refining our 1-D crustal models. The 3-D crustal models for the Caucasus and Central Asia will be developed. Using these crustal models, we will relocate critical events to delineate active faults. This is particularly important for identifying hazards and locating events in the regions. Based on refined locations, updated fault and tectonic maps will be completed.

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