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# Lithospheric Velocity Structure of the Anatolain plateau-Caucasus-Caspian Regions

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## Abstract

Anatolian Plateau-Caucasus-Caspian region is an area of complex structure accompanied by large variations in seismic wave velocities. Despite the complexity of the region little is known about the detailed lithospheric structure. Using data from 29 new broadband seismic stations in the region, a unified velocity structure is developed using teleseismic receiver functions and surface waves. Love and Rayleigh surface waves dispersion curves have been derived from event-based analysis and ambient-noise correlation. We jointly inverted the receiver functions with the surface wave dispersion curves to determine absolute shear wave velocity and important discontinuities such as sedimentary layer, Moho, lithospheric-asthenospheric boundary. We combined these new station results with Eastern Turkey Seismic Experiment results (29 stations). Caspian Sea and Kura basin underlained by one of the thickest sediments in the world. Therefore, short-period surface waves are observed to be very slow. The strong crustal multiples in receiver functions and the slow velocities in upper crust indicate the presence of thick sedimentary unit (up to 20 km). Crustal thickness varies from 34 to 52 km in the region. The thickest crust is in Lesser Caucasus and the thinnest is in the Arabian Plate. The lithospheric mantle in the Greater Caucasus and the Kura depression is faster than the Anatolian Plateau and Lesser Caucasus. This possibly indicates the presence of cold lithosphere. The lower crust is slowest in the northeastern part of the Anatolian Plateau where Holocene volcanoes are located.

## Introduction

Caucasus-Caspian shows considerable spatial variability in travel times and phase propagation throughout the area. Myers and Schultz (2000) noted errors of 42 km when locating events in the Caucasus Mountains with sparse regional stations and a standard model (prior to application of an empirical correction). Arrivals at regional distances are strongly affected by crustal and upper-mantle discontinuities. Regional phase variations have been documented on a regional basis by a number of studies (e.g. Kadinsky-Cade et al., 1981; Rodgers et al., 1997; Gök et al, 2003). Lg is known to be blocked by both the Black Sea and South Caspian basins and Sn does propagate through the cold and stable lithosphere of the South Caspian and Black Sea basins (Rodgers et al., 1997b; Sandvol et al., 2001; Gök et al, 2003).

The South Caspian and the Black Sea basins are thought to be underlain by oceanic crust (Mangino and Priestly, 1998; Baumgardt, 2001). The great thickness (up to 20 km) of sediments in the South Caspian strongly affects surface waves as well. Improved coverage and the use of ambient noise tomography for resolving this question is quite critical. So far, a large amount of active source data have been collected, which constrain the shallow velocity structure and depth of the sedimentary cover (Neprochnov et al., 1970; Belousov et al., 1992, Davies and Stewart, 2005; Knapp et al, 2004).

The South Caspian blends into the southern Caucaus in the Kura depression; a sedimentary basin with uncertain structure (i.e. is it an onshore extension of the South Caspian or is it underlain by continental crust?). Poor Sn propagation is evident throughout the Anatolian Plateau. The southern Caucasus (or Lesser Caucasus) differs from the Greater Caucasus to the north due to extensive Quaternary volcanism. Near the South Caspian, the southern Caucasus merges into the Alborz Mountain belt.

Sandvol et al. (2001) observe relatively efficient Lg propagation in the Caucasus and Central Caspian. The discrepancies among studies may reflect the poor station coverage with resulting poor resolution of ray paths. The boundary between the South Caspian and the Central Caspian is called the Absheron-Balkhan sill, an area of high seismicity and may be an area of incipient subduction (Jackson et al., 2002; Brunet et al., 2003).

In this study, we combined surface waves (SW) with receiver functions (RF) to obtain a constrained shear wave velocity model in the region. We used all available broad-band stations (63) in the region distributed in a 13° E-W and 5° N-S block.

**Data and Method**

Relevant global stations exist in the southern Caucasus (GNI), Eurasian platform (KIV), east of the Caspian (ABKT). A limited amount of broadband data was collected in the past from a temporary deployment Caspian Seismic Deployment (Mangino and Priestley, 1998). Recently, permanent broadband stations have been deployed across the region as part of various national networks. That provided an excellent opportunity to study the lithospheric structure. We used data from 29 newly available broad-band stations that are in operation since 2004. We collected almost 18 overlapping months of data and analyzed for receiver functions (RF), surface wave (SW) group and phase velocities. We inverted for shear wave velocity model of lithosphere down to about 120 km depth.

Receiver functions (RFs) isolate the response of near vertically propagating plane waves to seismic velocity discontinuities under a seismic station. Crustal RFs are primarily sensitive to the depth of velocity contrasts and have poor sensitivity to absolute velocities. Surface wave dispersion is primarily sensitive to depth averages of the S-wave velocity structure with poor sensitivity to velocity discontinuities or fine structure. Julia et al. (2000) developed a method for estimating structure from the joint inversion of RFs and surface wave group velocity dispersion curves. This method exploits the independent sensitivity of each data type to result in more reliable velocity models. Combining SW dispersion with RF can reduce the non-uniqueness of each dataset. We calculated the Love and Rayleigh wave group velocity dispersion curves of over 1500 waveforms (7-100 sec). We also applied the ambient noise correlation to over 400 station pairs to obtain Rayleigh wave group velocities. The shortest period of overlap was 90 days. We treated those ambient-noise estimates as station-event path and included in the global/regional surface wave tomography estimate of Pasyanos (2005). We then extracted the dispersion curves from the tomography maps of surface waves and combined them with RFs. The phase velocities were obtained with the method of Forsythe et al., (1998) at 20-145s. After generating optimal 1-D fit the phase velocities were inverted in 50km spacing at 13 different frequencies.

**Results and Conclusion**

Results are shown in Figures 2,3,4. We combined current stations with Eastern Turkey Seismic Experiment (ETSE) results of Gök et al., (2006). The Moho map is shown in Figure 2. The crustal thickness results are consistent with the previous studies in the Anatolian plateau with the average thickness of 42 km. The Lesser Caucasus has the thickest crust in the region (~52 km). Arabian plate is around 35 km and the Greater Caucasus is similar to the Anatolian plateau (~42 km).

Horizontal depth slices of 11, 35 and 87 km are shown in Figures 3 and 4. The thick sediments of Kura Basin is still observed with low velocities with the average Vs=2.8 km/s. Eastern part of the Greater Caucasus shows similar low velocities in the upper crust. It should be noted that none of the stations in the region are located on the high mountains of Caucasus. They are all either at Kura or Caspian basin. The northern part of mountains are also overlaid by relatively young Oligocene to Quaternary sediments. The slowest lower crustal velocities are observed in the northeastern Anatolaina plateau and Lesser Caucasus region where the intensified Neogene/Quaternary, Holocene volcanoes were observed (Figure 3, 35 km depth). Gök et al, (2000) noted severe attenuation within the crust where the shear velocities were eliminated at 90-100km epicentral distances.

There were cases where we observed the discrepancy of Love and Rayleigh wave simultaneous inversion. Love waves are sensitive to the velocity of horizontally propagating SH waves while the RFs and Rayleigh waves are sensitive to the vertically propagating SV waves. The inability to fit data in the long period portion of the dispersion curves may indicate the existence of the transverse anisotropy in the upper mantle. To test the existence of anisotropy we performed two separate inversions with individual Love and Rayleigh wave inversions. The results are shown in Figure 4. At 87 km depth, where the lithospheric mantle is present the vertically polarized S wave travels faster than the horizontally polarized S wave (SV > SH). This feature is observed in the Greater Caucasus and Kura but not observed under the Anatolian plateau (Figure 4). We observe slower S-wave velocities throughout the plateau, northern Arabian plate, Lesser Caucasus as well as SH being higher (2–4 per cent) than SV. SH > SV in the asthenosphere might be related to the shear flow with a significant horizontal component. If it is the case we might consider this as the boundary of lithosphere. The lithosphere is possibly slightly deeper (see the boundary in Figure 5)

The slowest crust and upper mantle velocities are observed in Lesser Caucasus progressing from south to north (from Lake Van to Georgian depression) (Figures 3,4). Another feature apparent in the improved Caucasus model is relatively fast shear velocities within Kura Basin and Greater Caucasus. There is little change in the magnitude of velocity estimates across much of the Lesser Caucasus along transects perpendicular to the Caucasus. Figure 6 shows Sn propagation efficiency map of the region (Gök et al., 2003). The boundary of the lithospheric mantle coincides with the zone of efficient Sn propagation.

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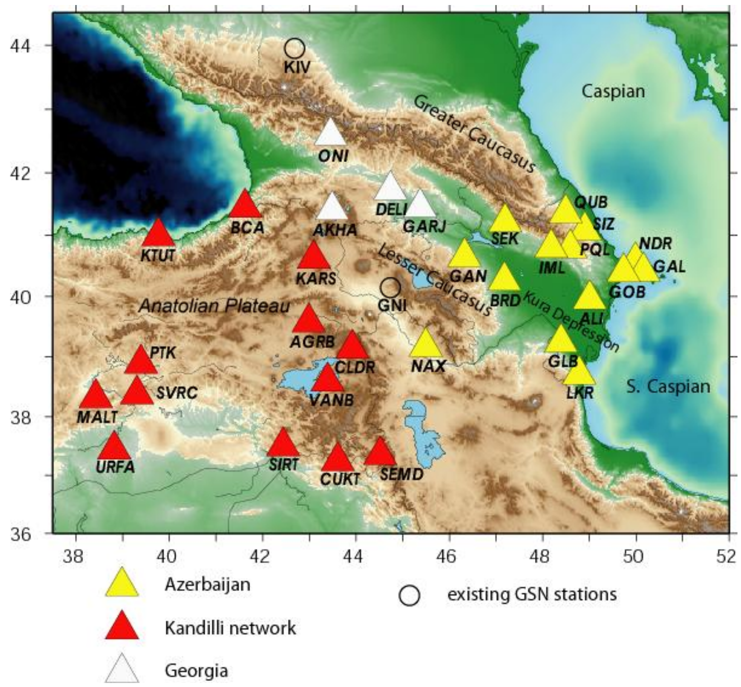


**Figure 1** Stations that contributed this study with the data. Stations are color-coded with their belonging countries. Broad-band stations include STS-2, ESP3T, ESP3ESD and CMG40T type instruments.

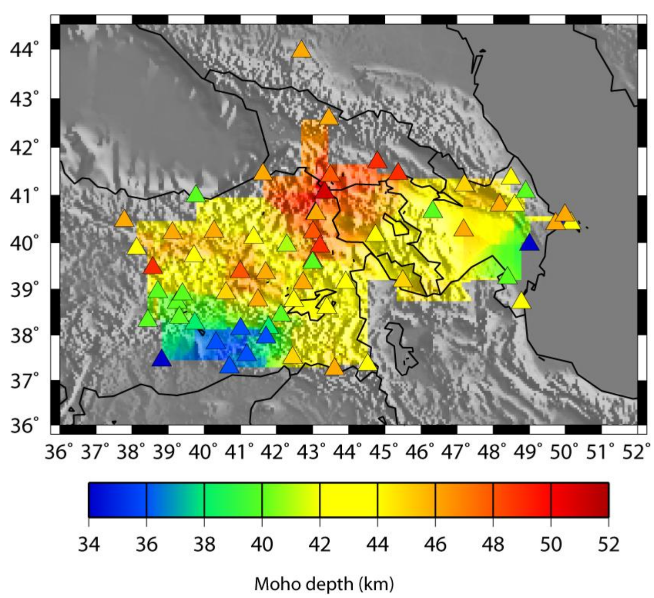


**Figure 2** The figure shows Moho depth in the region including data from ETSE network. The deepest Moho is observed in Lesser Caucasus region and the shallowest is in Arabian Plate.

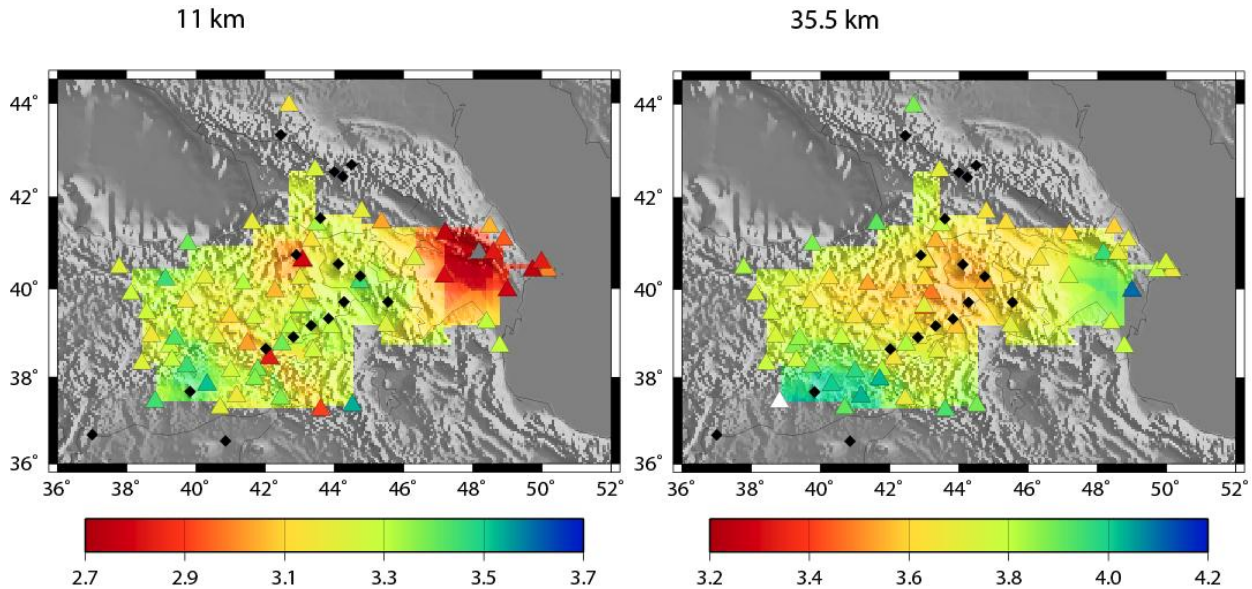


**Figure 3** Horizontal slices of velocities at upper and lower crust. Thick sediments of Kura are still prominent at 11km depth. Slowest velocities are observed in northeastern Arabian Plateau and Lesser Caucasus.

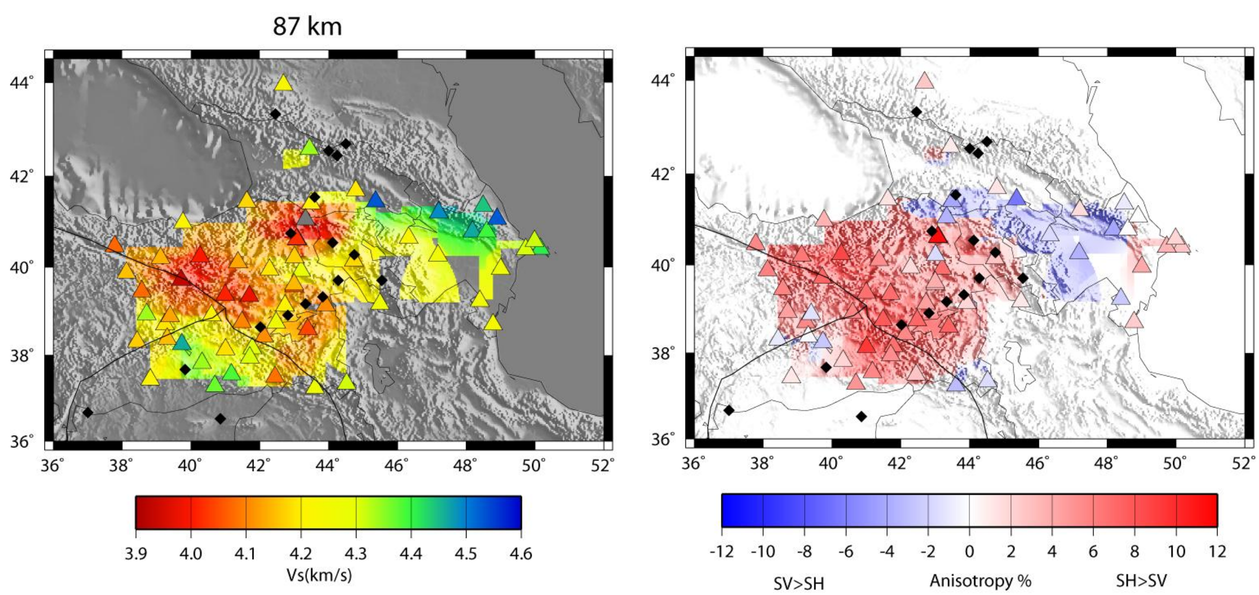


**Figure 4** Absolute velocities at 87 km depth versus anisotropy on the right panel. We performed Rayleigh+RF and Love+RF inversion to obtain anisotropy.

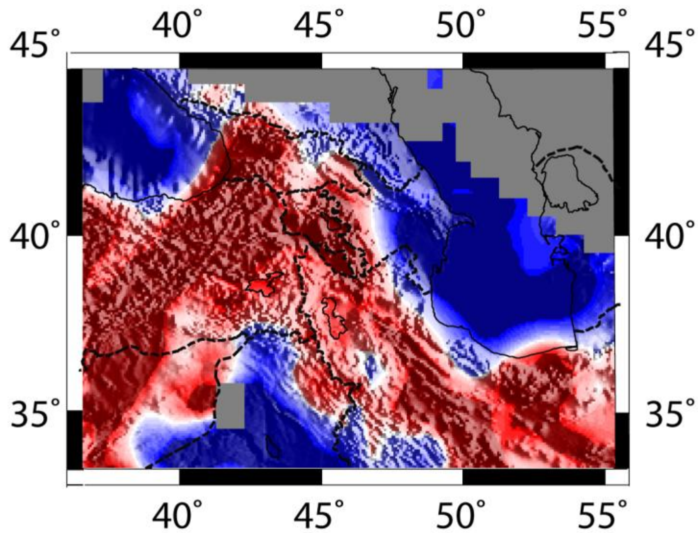


**Figure5** Sn propagation efficiency tomography. Red is blocked Sn and blue is efficiently propagating Sn.