CALIBRATION OF REGIONAL SEISMIC STATIONS IN THE MIDDLE EAST WITH SHOTS IN TURKEY

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ABSTRACT

The objective of this project is to calibrate regional travel times and propagation characteristics of seismic waves in Turkey and surrounding areas in order to enhance detection and location capabilities in the region. Important data for the project are obtained by large calibration shots in central and southeastern Turkey. The first, a two-ton shot, was fired in boreholes near Keskin in central Anatolia on 23 November 2002. The explosives were placed in 14 holes, each 80 m deep, arranged in concentric circular arrays. Ninety temporary seismic stations were deployed within a 300 km radius around the shot. These and the permanent stations of the Turkish National Seismic Network provided good azimuthal coverage as well as three radial traverses. Most stations within a radius of 200 km recorded the shot. A second shot on 17 July 2003 (1.4 ton ANFO) located 55 km southeast of the first and directly on one of the profiles provided a reversal of the southeast profile. This explosion provides reciprocal calibration data for the first shot near the Keskin short-period array.

A third shot on 12 April 2004 (one ton dynamite in seven holes) was detonated near Gaziantep, at the northeast edge of the Arabian Plate, and recorded along a northwest profile crossing the Arabian-Anatolian Plate boundary.

All obtained travel-time and waveform data are analyzed to obtain a three-dimensional (3-D) crust and upper mantle velocity model. The crustal thickness under Keskin is 38 km and the P_n velocity is 7.9 km/s. In the crust, P velocity increases from 6.1 km/s below the first layer to 6.8 km/s at the lower crust. In central Anatolia, crustal thickness varies between 36 and 38 km.

OBJECTIVES

The primary objectives of the project are to: (1) calibrate the regional travel-times and propagation characteristics of seismic waves across the Middle East and eastern Mediterranean region; (2) calibrate local and regional models for specific International Monitoring System (IMS) stations in Turkey; (3) conduct a reciprocity experiment to provide dense local and near regional calibration of the Keskin-Belbasi IMS array in Turkey; and (4) provide data to enhance IMS detection, location, and discrimination capabilities.

Several shots have been fired in boreholes near, or at regional distances to, the Keskin array in central Anatolia. Data are interpreted to obtain a crust/uppermost mantle in Central Anatolia. Combined with data from other explosions in eastern and western Turkey, a comprehensive database is generated for a 3-D crust/upper mantle velocity model for the region.

RESEARCH ACCOMPLISHED

The first calibration shot was fired in central Turkey near Keskin in November 2002. The detailed technical information and preliminary earth structure was given in a previous SRR paper (Toksöz et al., 2003). Two more explosions were recorded in 2003 and 2004. In addition, available seismic data from various other seismic explosions in Turkey are collected (Bekler, 2001). Locations of the shots and seismic profiles are shown in Figure 1. Information about the shots is listed in Table 1.

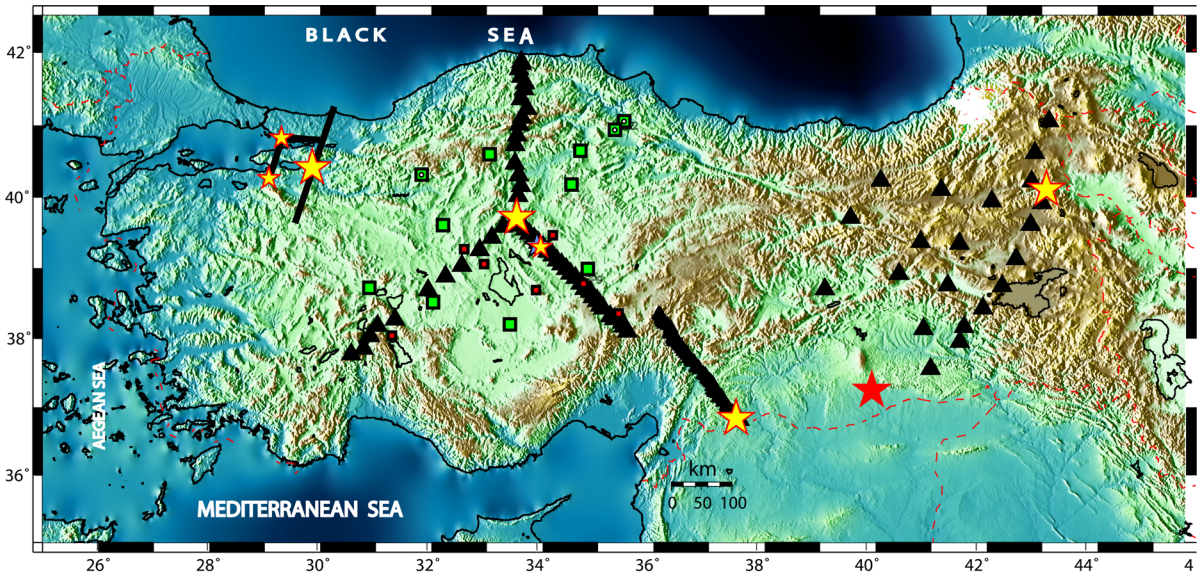


Figure 1. Location of several seismic calibration experiments carried out with active sources in Turkey. Yellow stars show the shot (or explosion) points. Black triangles are seismic recording profiles or stations. Red star is the proposed shot location on the northern edge of the Arabian Plate.

Table 1.

	DATE	LOCATION	O.T.	EXPLOSIVE (T)
Keskin 1	23 November 2002	39.7242 N 33.6355 E	22:47:33:40 UT	Dynamite, 0.280 T
Keskin 2	23 November 2002	39.7242 N 33.6355 E	21:10:04:80 UT	Dynamite, 1.220 T
Agri	5 June 2001	39.803 N 43.167 E	14:10:58:80 UT	Ammonium Nitrate, 12 T
Kaman	17 July 2003	39.326 N 34.001 E	13:48:35:376 UT	Quarry
Gaziantep	12 April 2004	36.800 N 37.730 E		Dynamite, 1 T
Sakarya 1	19 November 2000	40.768 N 29.4587 E	23:30:30:43 UT	Dynamite, 0.3 T
Sakarya 2	23 July 1998	40.1723 N 29.2313 E	12:48:29.5 UT	Dynamite, 6 T

Keskin Calibration Shot

Two calibration shots were fired near Keskin in Central Anatolia on 23 and 24 November 2002. The first shot was 280 kg dynamite in two boreholes. The main shot was 1,720 kg dynamite in twelve 100 m deep holes in granite. This shot was recorded along three profiles of temporary seismic stations, as well as the stations of the Turkish National Seismic network. Locations of the shot and the profiles are shown in Figure 1. Details of the experiment and initial crustal models were given in earlier papers (Toksöz et al., 2002, 2003). Here, we present more detailed crustal velocity models.

Seismic records of the Keskin shot along the three profiles (north, west, and south) are shown in Figure 2. Two-dimensional (2-D) velocity models are obtained for the north and south profiles using travel-time inversions and ray-based synthetic seismograms (Cerveny and Psencik, 1984; Zelt and Smith, 1992). The observed seismic section, matching synthetic seismograms and travel-times for direct, reflected, and refracted phases are shown in Figures 3a and 3b. The 2-D crustal velocity models are also shown. The models incorporate discrete layers and velocity gradients in each layer. The crustal thickness under those shot point is 38 km, and the P_n velocity is 7.9 km. The crustal thickness decreases to the north, and thickness changes are observed where the profile crosses the major fault zones. Along the southern profile, crustal thickness increases to 40 km and P_n velocity to 8.0 km/s.

Kaman Quarry Blast

The Kaman quarry is located along the southern profile 55 km from the Keskin shot point (Figure 4). During the Keskin experiment, one station (n973) was placed at the quarry site. In July 2003, we recorded the quarry blast with an array of 14 stations to the north (including the Keskin shot point) and 11 stations to the south. Seismograms, shown in Figure 4, have good signal-to-noise ratio. Data from the northerly profile of the quarry blast and the southerly profile of the Keskin shot provide an opportunity for a reciprocity test. The Keskin to quarry and quarry to Keskin travel-times agree within 0.04 second. The sampling interval of the seismic data is 0.01 second, and potential errors of picking first arrivals are ± 0.01 second. Since the shots were timed with seismometers near the shot point, the observed 0.04-second difference is within the potential reading errors. Currently, we are looking at waveforms, corrected for instrument response, to determine differences between source functions.

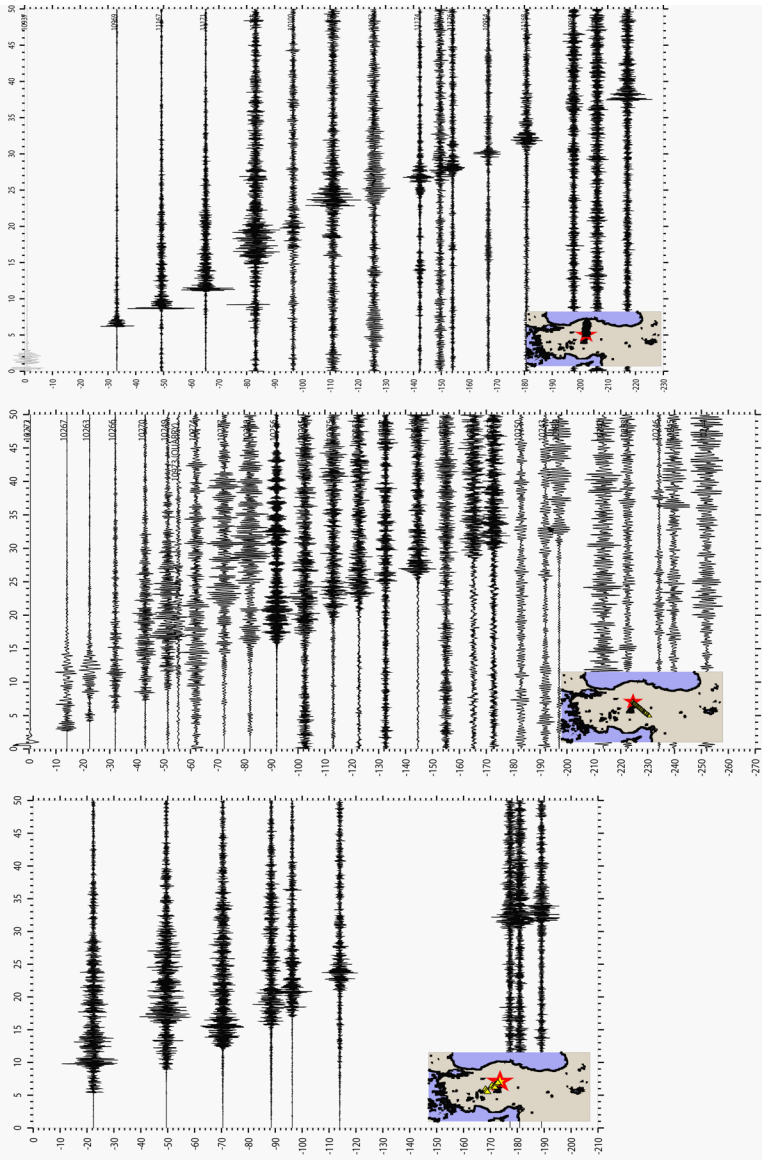
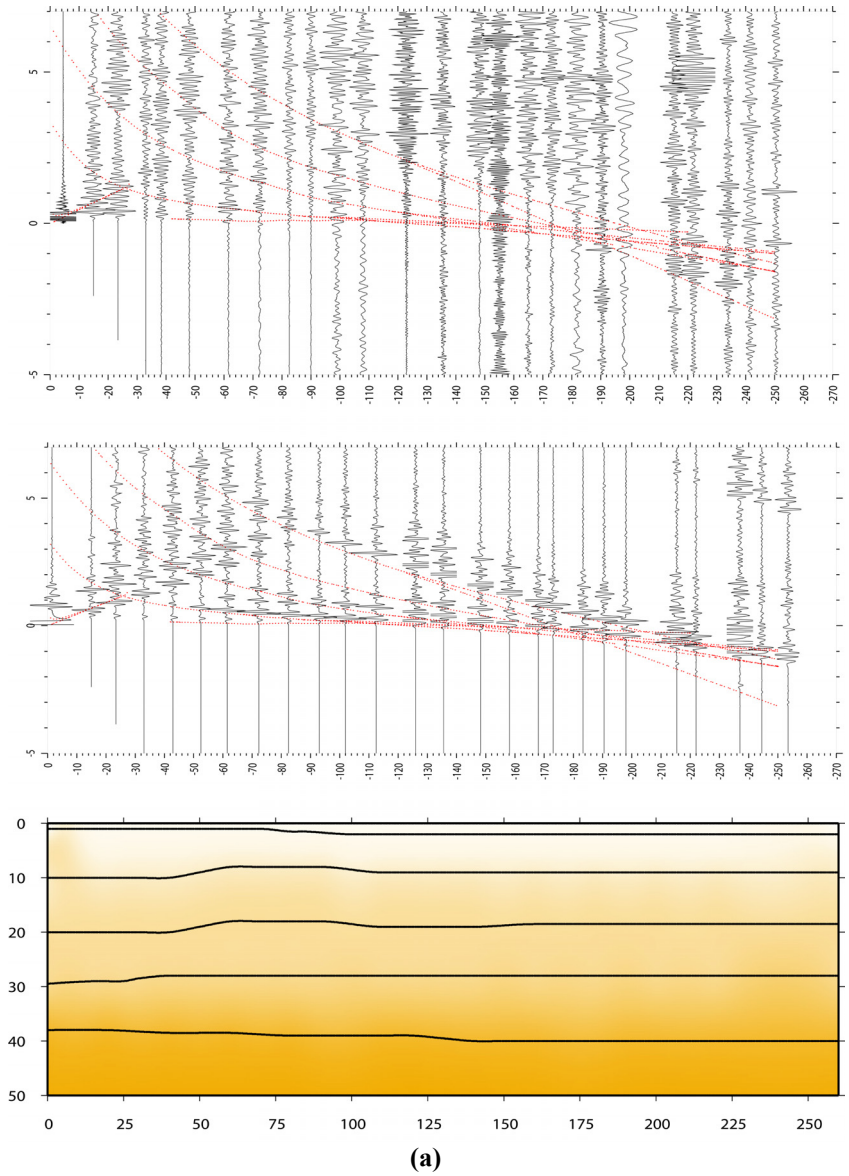
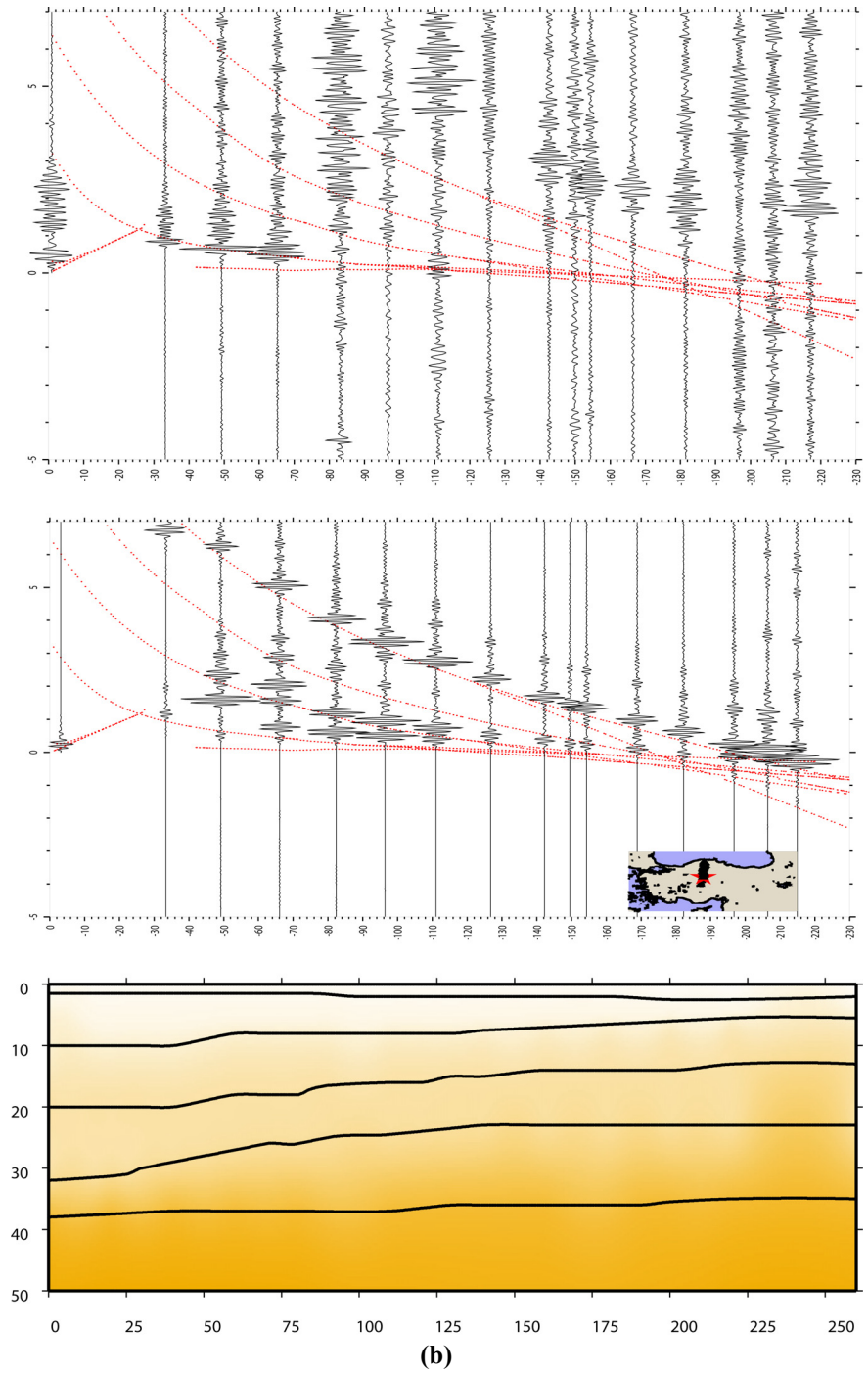


Figure 2. Seismic data recorded along three profiles from the Keskin shot. Insets show the locations of the shot and the profiles.



(a)

Figure 3a. Observed seismograms from the southern profile of the Keskin shot, and synthetic seismograms, travel-time curves based on the crustal structure and velocities. Reduced travel-time scale (t – Δ/6 km/s) is used.



(b)

Figure 3b. Observed seismograms from the northern profile of the Keskin shot, and synthetic seismograms, travel-time curves based on the crustal structure and velocities. Reduced travel-time scale (t – Δ/6 km/s) is used.

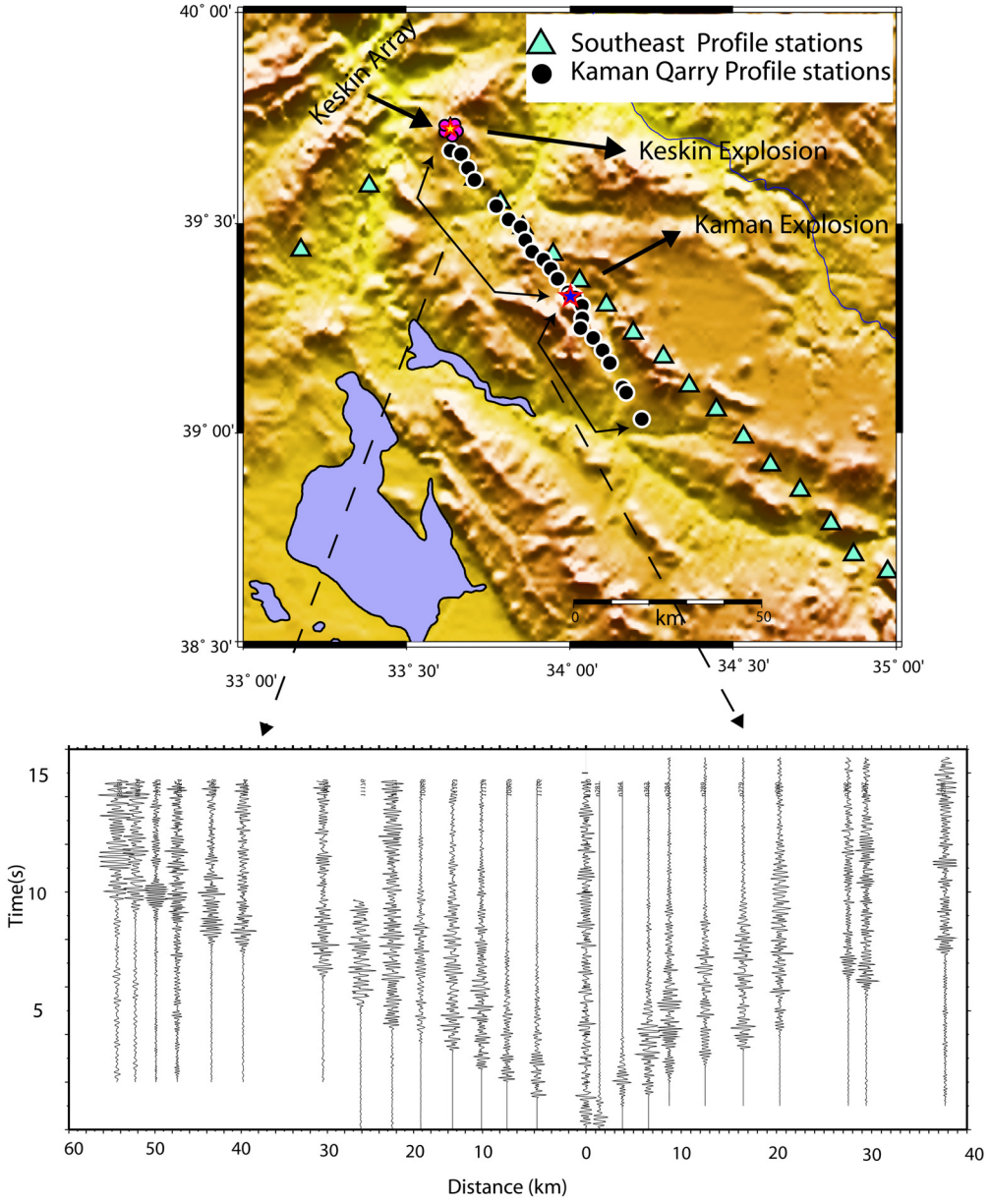


Figure 4. Seismic data from the quarry blast to the south of Keskin array. Locations of the quarry blast, Keskin, and seismic stations are shown at the top of the figure. Triangles are stations that recorded the 2002 Keskin shot, and circles are stations that recorded the quarry blast. Seismograms are shown at the bottom of the figure.

Gaziantep Shot

A one-ton (dynamite) shot was detonated (on 12 April 2004) in southeastern Turkey, at the northern tip of the Arabian Plate. Sixty-one seismic stations were deployed along a linear array oriented northwest toward Keskin. The shot location, recording array, and seismograms are shown in Figure 5. The array crosses the boundary between the Arabian and Anatolian Plates, and the extension of the Dead Sea rift zone near the Maras triple junction. As

seen in the data in Figure 4, the attenuation of the crustal seismic phases across the rift zone is dramatic. Yet the P_n propagation is not affected by the rift structure.

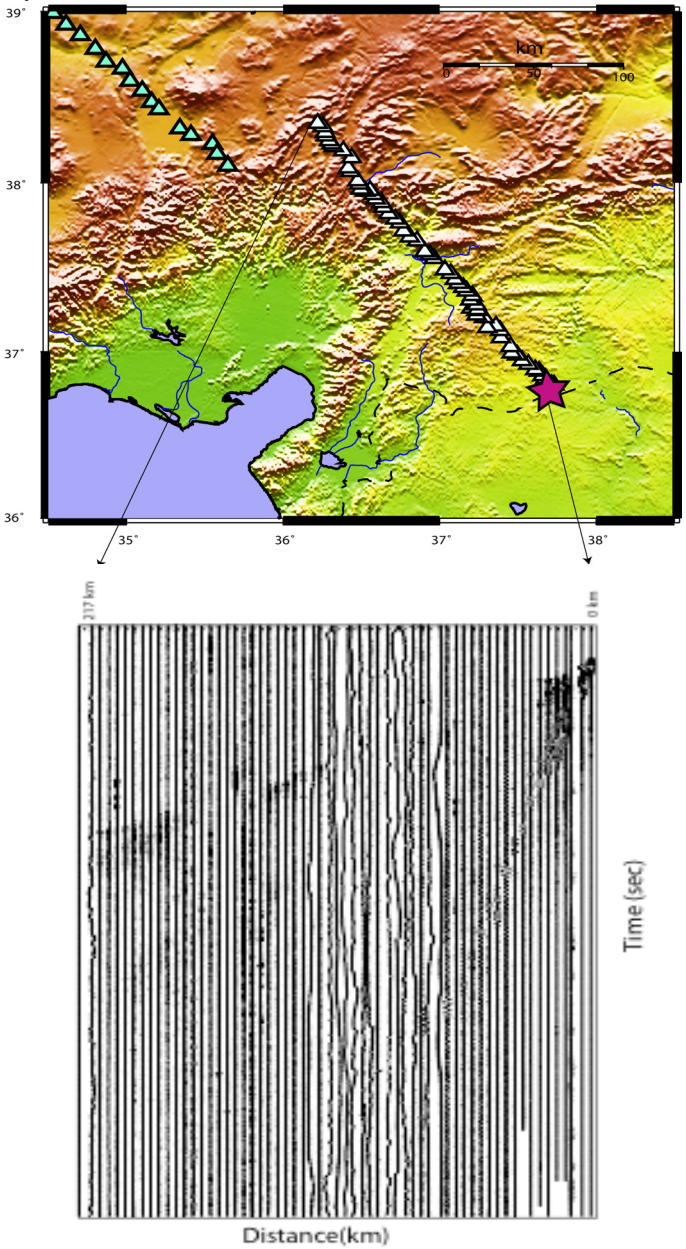


Figure 5. Location of the Gaziantep profile and the seismic data. The shot location is shown by a purple star. The profile crosses the extension of the Dead Sea rift zone, near the Maras triple junction. Note the strong attenuation of seismic crustal phases by the rift. The P_n arrivals are attenuated less.

Other Active Source Seismic Studies

Other refraction experiments in Turkey complemented those carried out as part of this project, the majority of which were carried out by the Kandilli Observatory and Earthquake Research Institute (Bekler, 2001). The two significant ones were in the Sakarya region of western Turkey and the Agri Province of eastern Turkey. Data from these shots are collected and being integrated with the data from Keskin and other shots conducted under this project.

Sakarya Refraction Experiment. A refraction experiment was conducted in November 2000 in the eastern Marmara Sea (Figure 6). A 180 km long profile, oriented in the north-south direction across the North Anatolian

Fault Zone, was used. Three shots were fired along the profile, one at each end and one in the middle. Charge sizes were 350 kg at the end shots and 325 kg in the middle shot point. Explosives were loaded into 50-meter deep holes. Data were collected with instrumentations similar to those used in our explosion studies (Figure 6a).

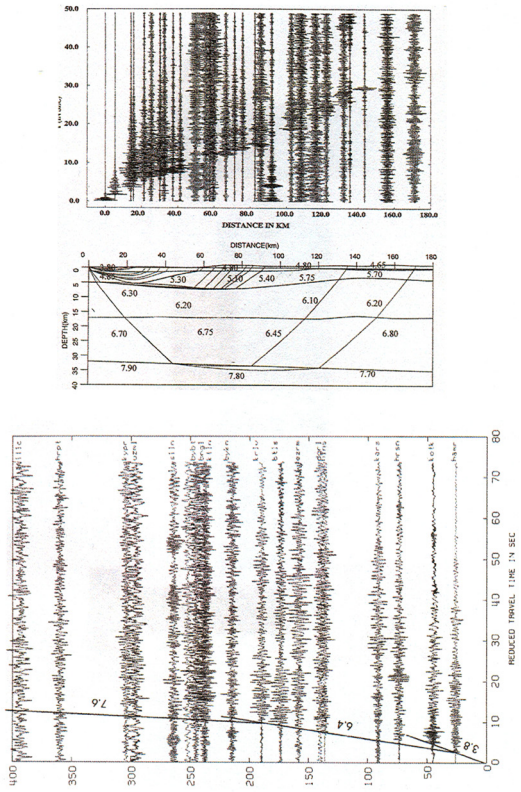


Figure 6. (a) Seismic refraction profiles from Sakarya shot. (b) Seismograms from Agri Dam Gallery explosions. Locations of explosions and stations are shown in Figure 1.

The calculation of P wave velocity structure was obtained using 2-D raytracing (SEIS83 package, Cerveny and Psencik, 1984), and inversion (RAYINVR program of Zelt and Smith, 1992). A 2-D crustal velocity structure beneath the profile was obtained. The P wave velocities at the top layer vary from 3.8 km/s to 4.8 km/s along the profile. The part shallow crust has high velocity gradients. Below the top layer seismic velocities vary between 6.2 km/s and 6.8 km/s with variable velocity gradients between 7 to 17 km depth. Clear P_n arrivals were not observed, and depth could not be determined.

Agri Dam Explosion. Two explosions were conducted as a part of the Agri Dam construction work. One was a ripple fire consisting of 20 holes which were filled with a total of three tons of Ammonium Nitrate. The second explosion was in a T-shaped gallery 100 meters away from the first shot point. This gallery shot (with 12 tons of explosives) was recorded by 18 stations of the Eastern Turkey Seismic Experiment (ETSE) PASSCAL broadband array (Gurbüz et al., 2004; Turkelli et al., 2003). The preliminary results show very high Lg and Sn attenuation in eastern Turkey. The shot was observed out to a maximum distance of about 300 km. (Figures 6b). The crust was characterized by three velocities of 3.8, 6.4, and 7.6 km/s. The thickness of the crust at the shot point was found to be 34 km (Gurbüz et al., 2004), much thinner than anticipated.

CONCLUSIONS AND RECOMMENDATIONS

Seismic recordings from calibration shots, a quarry blast, and Agri Dam construction explosions, obtained under this project increased by tenfold the amount of deep crustal sounding data in Turkey. Analysis of these data gives a

crustal thickness of 38 km under Keskin. Crust thins to the north and northwest, and is about 32 km thick to the east of the Sea of Marmara. South of Keskin, crustal thickness increases to 40 km.

In eastern Turkey, crustal thickness obtains from refraction (Gurbüz et al., 2004) and receiver function studies (Zor et al., 2004) are between 34 and 40 km, much less than 50 to 55 km some previous studies had suggested. The P_n velocities vary between 7.9 and 8.0 km/s.

Attenuation of seismic waves in the Anatolian Plate is variable. Attenuation is higher in Eastern Anatolia than the central plateau. Along one profile crossing the Arabian-Anatolian Plate boundary and the northern extension of the Dead Sea rift, a dramatic extinction of P-wave crustal phases was observed. Yet the P_n propagation along the same profiles was not affected.

For future work, we recommend the study of seismic wave propagation and attenuation across the Anatolian-Arabian continental collision zone and the Bitlis Suture. A broadband seismic network deployment and a calibration shot of about 10 tons in southeastern Turkey at the northern tip of the Arabian Plate would provide much needed data for the study.

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