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Active Tectonics of Turkey and Surroundings and Seismic Risk in the Marmara Sea Region

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ABSTRACT

We use body-waveform inversion methods of [1] and [2] to resolve source mechanisms and rupture histories of the recent eastern Mediterranean region earthquakes. We compared the shapes and amplitudes of teleseismic long-period P-, SH-, and broadband P-waveforms recorded by GDSN stations in the distance range of 30 – 90º, for which signal amplitudes were large enough with synthetic waveforms. The solutions were also constrained by P-wave first motion polarities of near-field stations. We found strike, dip, rake, centroid depth, seismic moment, and source time functions and rupture history of each event. Hence, we observed rupture process as a spatio-temporal slip distributions on the fault plane determined. The fault plane then were divided into MxN sub-faults and rupture history (source time function) of every sub-fault is described by L, triangles. Strike, dip, rake and centroid depth already obtained were used for initial model for slip distribution inversion. Total fault area, rupture propagation in time, slip directions of each sub-fault and overall source time function were found from the minimum misfit solution of inversion. Other individual earthquake source parameters such as stress drop, rupture velocity were also calculated using the results of both inversion methods. The seismic risk and intensive scientific efforts devoted to the Marmara Sea region are further summarized.

KEYWORDS: Aegean, active faulting and monitoring, current plate interactions, Dead-Sea fault, earthquake source mechanisms; earthquake potential and risk; eastern Mediterranean region, InSAR, Sea of Marmara, North and East Anatolian Fault Zones, sea-bottom, seismology, seismotectonics, seismic hazard, stress interaction.

INTRODUCTION

Turkey, alas, experienced two destructive earthquakes in 1999: the Gölcük-İzmit event on 17 August (M_w=7.4), and the Düzce event on 12 November (M_w=7.1); the most devastating earthquakes that this nation has suffered in recent decades. They occurred on segments of the well-known North Anatolian Fault Zone (NAFZ), the most important active fault zone in Turkey, which passes close to İstanbul and other major urban centers, and cuts across northern Turkey for about more than 1500 km, accommodating ~25 mm/yr of right-lateral motion between Anatolia and the Eurasian plate.

The tectonic evolution of the Eastern Mediterranean region is dominated by effects of subduction along the Hellenic (Aegean) arc and of continental collision in eastern Turkey (Anatolia) and the Caucasus [e.g. [3]; [4]; [5]). Northward subduction of the African plate beneath western Turkey and the Aegean region is causing extension of the continental crust in the overlying Aegean extensional province. Eastern Turkey is instead experiencing crustal shortening and thickening due to northward motion of the Arabian plate relative to Eurasia. The resulting combination of forces: the “pull” from the subduction zone to the west and “push” from the convergent zone to the east, is causing the Turkish plate to move westward, bounded by strike-slip fault zones: the NAFZ to the north and the East Anatolian Fault Zone (EAFZ) to the south. Interplay between dynamic effects of the relative motions of adjoining plates thus controls large-scale crustal deformation and the associated earthquake activity in Turkey (see Figures 1 and 2).

The complexity of the plate interactions and associated crustal deformation in the eastern Mediterranean region is reflected in the many destructive earthquakes that have occurred throughout recorded history. The Aegean region, including surrounding areas of western Turkey and Greece, is indeed one of the most seismically active and rapidly deforming regions within the continents. The wide range of deformation processes occurring in this relatively confined region means that the eastern Mediterranean provides a unique opportunity to improve our understanding of the complexities of continental collision, including strike-slip faulting and crustal extension, as well as the associated seismicity and volcanism: major topics in the Earth Sciences.

In the following sections, we present summary of main features of major faults of Turkey and surrounding regions and relate them for convenience to eight themes of regional synthesis: Marmara Sea Region (NW Turkey); North Aegean Trough and Saros Bay; Lake Districts Regions (SW Turkey); Orta–Çankırı Region (Central Turkey); East Anatolian Fault Zone (E Turkey); Caucasus and Surrounding Regions; Cyprus Arc and Dead Sea Fault Zone, and Seismic Risk in the Marmara Sea Region. They all exhibit the characteristics and structural complexities associated with strike-slip, thrust and normal faulting as a result of crustal deformation.

MARMARA SEA REGION (NW TURKEY)

The Sea of Marmara is a marine basin in northwest Turkey that connects the Aegean Sea with the Black Sea, and includes a series of tectonically active basins at the western end of the right-lateral North Anatolian Fault (NAF). Across most of Turkey the NAF is a relatively simple, narrow, right-lateral strike-slip fault zone; however it splits into several fault strands in the vicinity of the Sea of Marmara so that the deformation (surface faulting of the NAF) becomes distributed over a 120 km broad zone. The region of the Marmara Sea is a transition zone between the strike slip regime of the NAF and the extension regime of the Aegean Sea, and recently conducted high resolution bathymetric, sparker and deep-towed seismic reflection survey (Ifremer N/O Le Suroit) showed detailed fault systems in the Marmara Sea, and the Main Marmara Fault (MMF) exhibits all the characteristics of a major, active, through-going strike-slip fault though there are disagreements with these interpretations.

Little was known on micro-earthquake activity and their source mechanisms in the Marmara Sea. We have conducted seismological observations within the Sea of Marmara (NW Turkey) in order to investigate the seismicity induced after Gölcük-İzmit (Kocaeli) earthquake (Mw=7.4) of August 17, 1999 by using Ocean Bottom Seismometers (OBSs). This study presents the results of the first marine seismological observations using Ocean Bottom Seismometers (OBSs) in the Marmara Sea to investigate the present status of the detailed micro-seismicity [3]. High-resolution hypocenters and focal mechanisms of micro-earthquakes have been investigated during the Marmara Sea OBS project involving deployment of 10 OBSs each leg within the Çınarcık (eastern Marmara Sea) and Central-Tekirdağ (western Marmara Sea) basins during April-July 2000. We have detected numerous earthquakes within the main basins along the imaged strands of the North Anatolian Fault. We obtained more than 350 well-constrained hypocenters and 9 focal mechanisms during 70 days of observation.

Micro-earthquake seismic activity mainly occurred along the Main Marmara Fault (MMF) in the Marmara Sea. There are a few events along the Southern Shelf. Seismic activity along the Main Marmara Fault (MMF) is quite high, and focal depth distribution along the fault was shallower than 20 km at the western part, and shallower than 15 km at the eastern part. From high-resolution relative relocation studies of some of earthquake clusters, we suggest that the western Main Marmara Fault is almost vertical and the eastern Main Marmara Fault dips to south about 45°. Composite focal mechanisms show a strike-slip regime at the western Main Marmara Fault and complex (strike-slip and normal type) at the eastern Main Marmara Fault (MMF).

We observed many micro-earthquakes and estimated normal type composite mechanisms at the northern part of Armutlu Peninsula. These results are consistent with the seismicity and focal mechanisms of aftershocks of the 1999 Gölcük–İzmit (Kocaeli) earthquake. However, the quality of these results is relatively low because the events were located out of the OBS network. The faulting in strike-slip and normal character is present in the eastern part of the Çınarcık basin. These E–NE trending thrusts are further associated with sea floor topography, and presumably absorb the strike-slip motion transmitted by the NAF. On the other hand, the source mechanism of Çınarcık earthquake (Ms=6.4) of September 18, 1963 confirms the characteristic of normal faulting with a shallow focal depth (e.g. [4]; [5]). Furthermore, the recent fault plane mechanisms of well-located aftershocks of the 1999 earthquake sequence at the foot of the slope have almost pure strike-slip solutions suggesting that there is partitioning of the motion within the Çınarcık basin. The westernmost continuation of NAF into the Sea of Marmara still requires further investigations to better understand the complexity of faulting associated with earthquakes at depth reaching to seismogenic zones.

NORTH AEGEAN TROUGH AND SAROS BAY

The most dramatic bathymetric feature of the north Aegean Sea is the North Aegean Trough (NAT), which consists of a series of deep fault-bounded basins. Those in the west have a NE trend, while those in the eastern part of the system trend ENE. The easternmost basin, the Saros trough, is also the narrowest: in its western part, south of Samothraki, the bathymetry and gravity suggest it is a half-graben bounded by a large normal fault system along its northern margin. Such faulting was probably responsible for the earthquake of 27.3.1975, whose mechanism is consistent with right-lateral and normal slip on a fault dipping south ([4]; [5]; [6]). Similar mechanisms are seen for two other, much smaller, earthquakes in the Saros trough. The fault that crosses the Gallipoli peninsula, and which was responsible for the 1912 earthquake, is a continuation of the ENE trend of the Saros trough. Surface ruptures in 1912 also showed a combination of right-lateral and normal slip, which is reflected in the topography. Thus the faulting associated with the Saros trough is a semi-continuous feature from about 25°E to the western basin of the Sea of Marmara at about 27.5ºE, though the asymmetry, and presumably the polarity of the normal faulting, change along strike: with the faults dipping SE in the western part of the trough, NW along the north shore of the Gallipoli peninsula, and SE along Ganosdağ (Gaziköy) bounding the NW side of the deep offshore basin in the western Sea of Marmara. Such a change in the polarity of tilting and faulting along the strike of a basin occurs also in the North Gulf of Evvia in central Greece, and is a common feature of extensional graben.

Fault plane soultions in the western part of the North Aegean Trough show mainly strike-slip faulting, consistent with right-lateral slip on NE-SW striking faults. The lack of normal faulting solutions is perhaps surprising, and may simply reflect the short time period over which high quality data are available. The focal mechanisms obtained by [5] give the impression that the north and central Aegean Sea is dominated by distributed strike-slip faulting: most of it right-lateral with a NE to ENE strike. Normal faulting must, however, be present: strike-slip faulting alone cannot produce the deep basins, and normal faults are obvious in the bathymetry and limited seismic reflection data. Several of the islands appear to be the uplifted footwall crests of such normal faults, and are adjacent to deep basins offshore. There is further evidence from paleomagnetism that this western region rotates clockwise relative to stable Europe. In the central and eastern Aegean, and in NW Turkey, distributed right-lateral strike-slip is more prevalent, on faults trending NE to ENE, and with slip vectors directed NE. Paleomagnetic data in this eastern region is more ambiguous, but consistent with very small or no rotations in the northern part and possibly anticlockwise rotations, relative to Europe, in the south. The strike-slip faulting that enters the central Aegean from the east appears to end abruptly in the SW against the NW-trending normal faults of Greece. The geometry of the deformation resembles the behaviour of a system of broken slats (see [5]) attached to margins that rotate. In spite of its extreme simplicity, a simple model of such broken slats is able to reproduce quantitatively most of the features of the instantaneous velocity field in the Aegean region, including: the slip vectors and nature of the faulting in the eastern and western parts; the senses and approximate rates of rotation; the overall extensional velocity across the Aegean; and the distribution of strain rates, as seen in the seismicity and topography or bathymetry.

LAKE DISTRICTS REGIONS (SW TURKEY)

The Aegean region has been subject to extension since Miocene time, and this extension has left a pronounced expression in the present-day topography. It is further widely accepted that the rapid extension observed in western Turkey is mainly accommodated by large active normal faults that control the geomorphology. The NE–SW trending Burdur, Acıgöl and Baklan, and NW–SE trending Dinar and Sultandağ–Akşehir basins all bounded by large faults form a system of half-graben whose orientation is evident in both the topography and the tilting of Neogene sediments adjacent to them (e.g. [7]; [8]; [9]). The Sultandağları has a marked morphological expression ~ 1000 m in elevation relative to the surrounding plains, and is seismically active as there are well-defined moderate size earthquakes reported in the past and recorded instrumentally. However, December 15, 2000 (M_w=6.0) Çay–Sultandağı earthquake is the first reliable seismological evidence and well recorded event during the instrumental seismology period showing almost pure normal faulting mechanism [9].

The source characteristics of the February 3, 2002 Çay-Sultandağı earthquake sequence also have been investigated by combining teleseismic body-waveforms, near-field strong-motion, and a temporary dense seismic network data sets. We have also used the aftershock seismicity image obtained from the dense temporary seismic network in order to resolve and constrain the spatial extent and geometry of the main rupture plane at depth. The aftershock zone developed following the main shock agrees well with the distributions of damage, and surface ruptures observed in the field. This zone further suggests that the main shock rupture has initiated in the eastern part (between Çay and Sultandağı) and propagated unilaterally to the west. The source mechanism of the February 3, 2002 earthquake comprises two sub-events separated in time involving both normal and strike-slip mechanisms.

Near-field strong-motion data recorded at permanent station (Afyon) and temporary strong motion acceleographs (Sultandağı, Çay, Bolvadin and Çobanlar) operated by Earthquake Research Department (ERD–Ankara) have been also used to further verify the source mechanism parameters obtained from the inversion of teleseismic body-waveforms. It is, however, rather difficult to explain the westernmost termination of the main shock rupture extend based on the scattered aftershock activity alone though that may well be related to co-seismic phase of the main shock which has been followed by the largest aftershock (M_w=5.8) having source mechanism orthogonal to existing (mapped) fault trace. Thus, we attempt to determine the westernmost extend of the main rupture zone by forward modeling of strong-motion data acquired at Afyon.

ORTA-ÇANKIRI REGION (CENTRAL TURKEY)

The seismotectonics of the North Anatolian Fault (NAF) in the vicinity of Orta–Çankırı region is examined, and consists of study of a moderate size (M_w=6.0) earthquake that occurred on June 6, 2000. The instrumental epicenter of this earthquake is about 25 km south of the North Anatolian Fault Zone (NAFZ), and rapid focal mechanism solutions of USGS-NEIC, and Harvard-CMT show a combination of normal and strike-slip faulting, demonstrating that this earthquake is not directly related to the right-lateral movement of the North Anatolian Fault. However, it is the first event with magnitude greater than 5 between Ankara and Çankırı to be recorded seismically since 1900, and therefore contains valuable data to improve our understanding of the neotectonic framework of the northwest central Anatolia. Field observations were carried out in the vicinity of Orta town immediately after the earthquake indicating no apparent surface rupture, but reported damage was most intense in the villages southwest of Orta town [10].

The June 6, 2000 Orta-Çankırı earthquake occurred close to a restraining bend in the E–W striking right-lateral strike-slip fault that moved in the much larger earthquake of August 13, 1951 (Ms = 6.7). The faulting in this anomalous earthquake could be related to the local geometry of the main strike-slip system, and may not be a realiable guide to the regional strain field in the northwest central Turkey. We tentatively suggest that one possible explanation for the occurrence of June 6, 2000 Orta-Çankırı earthquake would be localized clockwise rotations due to shear of the lower crust and lithosphere.

The source parameters and uncertainties of the June 6, 2000 Orta-Çankırı earthquake were: Nodal Plane 1: strike 2° ± 5°, dip 46° ± 5°, rake –29° ± 5°; Nodal Plane 2: strike 113°, dip 70°, rake –132°; principle axes: P=338° (48°), T=232° (14°), B=131° (39°); focal depth 8 ± 2 km (though this does not include uncertainty related to velocity structure), and seismic moment Mo = 140–185 x 10^{16} Nm.

Furthermore, analysis of a coseismic interferogram, spanning a 10 month interval, revealed a pear-shaped pattern of deformation with ~5 concentric fringes of range increase (subsidence) in the south and ~2 fringes of range decrease in the north. Inversion of these data suggested that the earthquake occurred on the north-south nodal plane (cf. nodal plane 1 above): strike 357 ± 15°, dip 55 ± 19°, rake -20 ± 15°, length 9 ± 2.4 km, depth range 3.6 +1.0/-2.0 km to 7.4 +7.3/-1.71 km, and 1 m of slip. This solution has a seismic moment of M_o = 14 x 10^{17} Nm.

The InSAR data also suggest that the North-South fault plane (Nodal Plane 1 above) was the one that ruptured during the earthquake. The InSAR mechanism is in good agreement with the solution of teleseismic P- and SH- body waveforms. Although, the magnitude of slip was poorly constrained, trading off with the depth range of faulting such that solutions with a large depth range had small values of slip and vice versa. The misfit was small and the geodetic moment constant for fault slips greater than ~1 m.

The local geological observations reflect that North Anatolian Fault Zone and its splay Kırıkkale–Erbaa Fault creates NW–SE shortening and NE–SW extension between Çankırı and Ankara. The Orta-Çankırı earthquake of June 6, 2000 occurred close to a restraining bend in the E–W striking right-lateral strike-slip fault that moved in the much larger earthquake of August 13, 1951 (M_s=6.7).

The faulting in this anomalous earthquake could be related to the local geometry of the main strike-slip system (the extension fractures that are oriented parallel to the axis of shortening), and may not be a reliable guide to the regional strain field in the northwest central Anatolia.

EAST ANATOLIAN FAULT ZONE (E TURKEY)

The East Anatolian Fault Zone (EAFZ) is a band of active seismicity and tectonism that joins the eastern end of the North Anatolian Fault Zone (NAFZ) to the Mediterranean Sea in the Gulf of İskenderun. It is much less distinct, both morphologically and structurally, than the North Anatolian Fault Zone that ruptured almost along its entire length in a series of large earthquakes between 1939 and 2000. There has been little seismicity associated with the East Anatolian Fault Zone this century, though many large earthquakes are known to have occurred in or near it within the last 500 years [12]. Although some clear strands of NE-SW left-lateral strike-slip faulting are clear on satellite images the structure of the zone is more complicated than this: with several pull-apart basins, conjugate fractures, and also considerable thrusting and folding. Structures within the zone are rarely continuous for longer than a few tens of km, and discontinuities between fault segments may have controlled the extent of rupture in historical earthquakes (e.g. [12]; [13]).

The knowledge of motions in the East Anatolian Fault Zone is also crucial for an understanding of the present-day kinematics of the eastern Mediterranean. East of the junction between the North and East Anatolian Fault Zones (near Karlıova) is a region of mixed strike-slip and thrust faulting that extends from the Turkey-Iran border north into the Caucasus. This region accommodates the shortening between Arabia and Eurasia, which began about 12 Myr ago and which is proceeding today at a rate of about 27 mm/yr in a direction 335^o based on the NUVEL-1 plate motion model. But, recent estimates of GPS measurments during 1988-1997 give the rate of motion about 18 ± 2 mm/yr in a direction 335^o. On the other hand central Turkey is a relatively flat, elevated plateau, and although it is neither completely aseismic, nor devoid of active faults, its morphology and seismicity suggest that it is relatively inactive compared with the North and East Anatolian Fault Zones.

CAUCASUS REGION

Earthquakes in the greater Caucasus usually exhibit NW-SE thrust faulting mechanism solutions (e.g. [14]; [15]). The western part of the mountain belt has only one moderate size event occurred on July 16, 1963, Mw=6.3, and verifies that northward dipping shallow thrust fault active beneath the southern border of the western greater Caucasus. In contrary, Racha earthquake (29 April 1991, Mw=6.9), and its four moderate size aftershocks, and earthquake of Barisakho (23 October.1992, Mw=6.2) indicate that most of the stress accumulation occurs within the central part of the Caucasus mountain belt. A series of earthquakes (i.e. 14 May 1970, 28 July 1976; 31 January 1999, 21 February 1999) shows that northern boundary thrust faults of the eastern greater Caucasus dips southwards with a very shallow angle (~5-10°). The similar mechanisms were also reported along the Caspian coast of the greater Caucasus where earthquakes have uniform slip distribution in time and space. However, the Lesser Caucasus is not capable of generating destructive earthquakes as the Greater Caucasus. The only earthquake (7 December 1988, Mw=6.8) in Spitak, indicates that right-lateral motion with thrust component active on the Pampak-Sevan Fault (PSF). In contrast to the field observations and preliminary summarized mechanism solutions, slip distribution of the Spitak earthquake exhibits that the rupture is not too complex. Furthermore, the energy release and rupture propagation also agree well with the field observations and aftershock distributions reported. The main active faults strike to the southwest end of the NEAFZ in the direction of ~N45°E (i.e. 30 October 1983, Mw=6.6; 3 December 1999, Mw=5.6). On the other hand, right-lateral strike-slip faulting mechanism has not been observed beyond Georgia-Turkey-Armenia border. This is the northeast end of the right-lateral strike-slip zone (NEAFZ), and the major events (02 January 1978, Mw=5.6; 13 May 1986, Mw=5.8; 16 December 1990, Mw=5.5) strike approximately in the direction of N60°E. The difference in fault strike angles (~15°) and slip vector orientations (~20°) between the both ends of the NEAF indicates that is bounded by block rotations clockwise along the strike: SW to NE. There is no further seismological evidence for a left-lateral strike-slip faulting, except the north dipping thrust faulting of Racha sequences in the region to the north of the Greater Caucasus. Although large events in the Caucasus have uniform slip distribution, there are two asperities on the fault surface of Avaj–NW Iran earthquake (22 June 2002, Mw=6.4).

We also attempted to obtain relations of seismic moment, fault dimension, stress drop and maximum slip on the fault plane. Most of the stress drop values are approximately 60 bars, but they are in the range of 30 to 100 bars that agree with the observations from continental earthquakes. Fault length and width ratios change between 0.5-1.5 except the Spitak earthquake, whose fault length is ~2.5 times longer than its width. We observed a linear relation between fault area and stress drop for most of the events. However, the largest two earthquakes (Spitak and Racha) have ~70 bars stress drop while the fault area are about ~300 km^2 and ~500 km^2, respectively.

CYPRUS ARC AND DEAD SEA FAULT ZONE

The seismotectonics of Cyprus Arc and Dead Sea Fault Zone (DSFZ) is a distinct component in the plate tectonics of the Eastern Mediterranean region, and this study is based on the tectonic characteristics of a comprehensive seismicity occurred in the region during the 20th century, on newly retrieved and obtained fault plane mechanisms solutions of waveform inversion of teleseismic long-period and broad-band body-waveform data [16].

Active tectonics of the Eastern Mediterranean region is evolved as a result of the interaction between the African, Arabian and Eurasian plates. The observed seismic activity is related to the tectonic interactions of the Dead Sea Transform Fault (DSTF), Hellenic and Cyprus Arcs, the East and North Anatolian Fault Zones, and Bitlis–Zağros suture zone. The overall systems have important role for the evolution of the tectonics of the region. Dead Sea Fault Zone (DSFZ) that forms the boundary between the African and Arabian plates along the eastern margin of the Mediterranean Sea in the Middle East, joins the divergent plate boundaries along the Red Sea rift in the south with the Alpine orogenic belt in the north. Most of the seismicity is concentrated along the southern part of the Dead Sea Fault Zone, especially in the Gulf of Aqaba, and Gulf of Suez. Cyprus arc that extends from the Gulf of Antalya in the west, and the Gulf of İskenderun in the east, meets the Hellenic arc in the westernmost corner of Cyprus and joins the Eastern Anatolian Fault (EAF) in the east. Tectonic structure and seismic activity along the Cyprus Arc is different from that of the Hellenic Arc as the focal depths of earthquakes increase towards the Antalya Bay.

The characteristics of seismotectonics of the region can be summarized as: [1] Along the Dead Sea Fault Zone, source mechanism solutions of earthquakes show left-lateral strike slip faulting with normal component that is in a good agreement with the geology and tectonic structure of the region. They are associated with predominantly normal mechanisms within a rift zone and therefore constitute a unique phenomenon, yet to be deduced. [2] At the southwest part of Cyprus, most of the mechanisms show right lateral strike-slip faulting with thrust component, but some shallow focus earthquakes give the normal faulting with strike-slip component. [3] As expected, thrust mechanisms along the Cyprus Arc mirror its convergent nature and typical curved geometry too. [4] The presence of other unexpected mechanisms near the transform zone however reflects the heterogeneous deformation it induces around. These mechanisms enabled us to examine the seismotectonic characteristics of the region. The strike and rake directions of the retrieved mechanisms usually reflect the geometry and the large-scale type of deformation observed along the boundaries of the neighbouring plates: the Dead Sea Transform, the Cyprus Arc convergent zone and the Suez Rift. Nevertheless, along each of these boundaries we found anomalous solutions that verify the complexity of the deformation processes along plate margins. Transtension and transpressional solutions in the eastern segment of the arc reflect the left-lateral shear motion between Anatolia and Sinai there. However, shear mechanisms found between Cyprus and the Eratosthenes Seamount pose a problem regarding its collision process.

SEISMIC RISK IN THE MARMARA SEA REGION

The intensive scientific efforts are recently devoted to the Marmara Sea region because of the historical record of damage to large cities such as İstanbul, and the close proximity of the North Anatolian fault which is submerged beneath the Marmara Sea (e.g. [17]; [18]; [19]; [20]; [21]; [22]; [23]; [24]; [25]).

The most recent probability estimate of a $M \geq 7$ earthquake rupturing beneath the Sea of Marmara is ~ 35–70% in the next 30 years if a time-dependent model that included coseismic and postseismic effects of the 1999 Mw=7.4 Gölcük-İzmit earthquake is used (see [25] for further details). This estimate of course incorporate recently obtained bathymetric images of the North Anatolian fault beneath the Sea of Marmara (e.g. [20]; [21]; [22]), and improved earthquake catalog for the period between A.D. 1500 and 2000 using the regional attenuation relation of [23].

CONCLUSIONS

We have briefly summarized the characteristics of the recent earthquakes and active tectonics of Turkey and surroundings with an emphasise on the Marmara Sea region. However, the westernmost continuation of NAF into the Sea of Marmara still requires further investigations to better understand the complexity of faulting associated with earthquakes at depth reaching to seismogenic zones. Hence, the present active crustal deformation and monitoring provides an improved physical basis for mitigation of the effects of future earthquakes in this vulnerable region.

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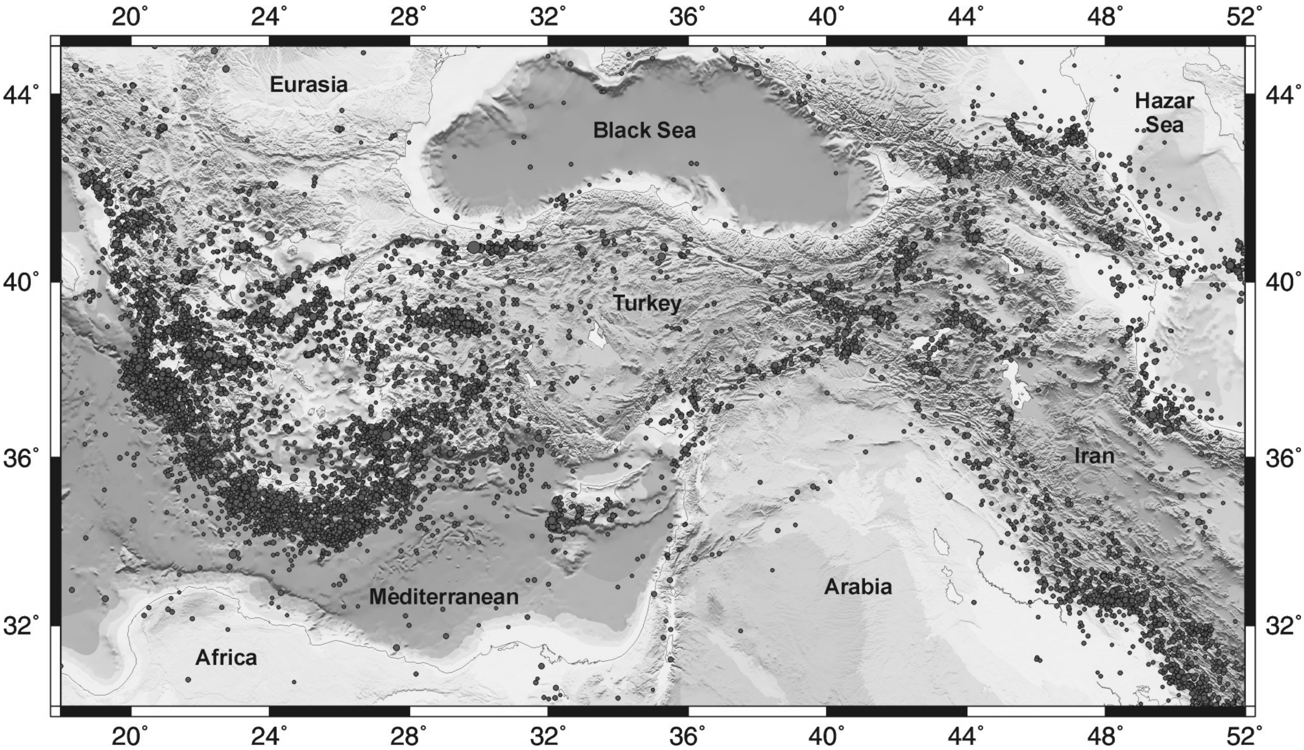

Figure 1. Seismicity of the eastern Mediterranean region for the period of 1964-2001 with magnitudes, M >4.0 after ISC. Topography and bathymetry data are taken after NASA-SRTM30 and BODC-GEBCO [see 28], respectively.

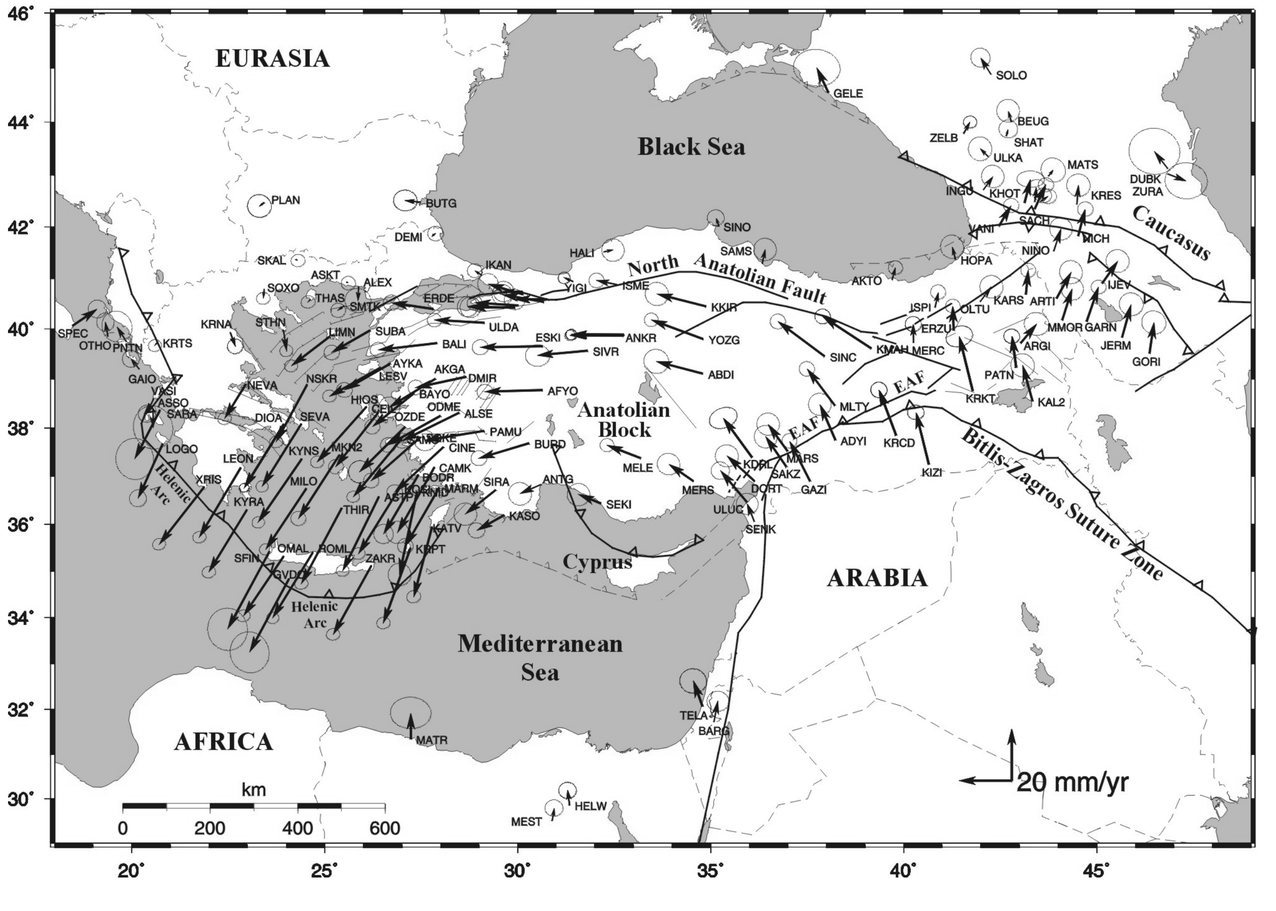

Figure 2. GPS horizontal velocities and their 95% confidence ellipses in a Eurasia-fixed reference frame for the period 1988-1997 at 189 sites extending east-west from the Caucasus mountains to the Adriatic Sea and north-south from the southern edge of Eurasian plate to the northern edge of the African plate (see. [19] for further details).

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