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ORIGINAL RESEARCH PAPER

Seismotectonic database of Turkey

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Abstract Turkey is located in one of the most seismically active regions in the world. Characterizing seismic source zones in this region requires evaluation and integration of geological, geophysical, seismological and geodetical data. This first seismotectonic database for Turkey presented herein was prepared, under the framework of the National Earthquake Strategy and Action Plan—2023. The geographic information system (GIS)-based database includes maps of active faults, catalogues of instrumental and historical earthquakes, moment tensor solutions and data on crustal thickness. On the basis of these

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data, 18 major seismotectonic zones were delineated for Turkey and the surrounding region. The compilation and storage of the seismotectonic data sets in a digital GIS will allow analyses and systematic updates as new data accrete over time.

Keywords Active fault · Earthquake hazard assessment · Earthquake catalogues · Seismotectonic map · Turkey

1 Introduction

The seismotectonic setting of Turkey has long been described by the westward extrusion of Anatolia due to the collision of the Arabian and Eurasian plates. The majority of the deformation associated with the extrusion is accommodated along major transforms, i.e. the North Anatolian fault (NAF) and the East Anatolian fault (EAF). Moreover, the subduction of the African plate along the Aegean arc (AA) and Cyprian arc (CA) produces a complex tectonic process including a backarc extensional regime in Western Anatolia (Bozkurt 2001 and references therein). Alternative models also have been suggested based on geodynamic and magmatic constraints. These alternatives imply a simple model for the genesis of the extension as being related to the differential advancement of the upper lithosphere over a heterogeneous lower African plate (Agostini et al. 2010 and references therein).

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The seismic activity since the end of the nineteenth century has resulted in 72 devastating earthquakes with more than 90,000 casualties and considerable socio-economic loss. In order to mitigate these impacts in future earthquakes, a series of systematic projects have been initiated to update existing approaches and develop new ones under the framework of the National Earthquake Strategy and Action Plan (NESAP-2023). The plan involves several steps from the reassessment of active faults to seismic hazard assessment including the construction of this seismotectonic database.

Seismic hazard assessment is essential for hazard management efforts such as earthquake-resistant design policies, risk analyses and land-use planning studies. Earthquake geoscience is a rapidly evolving field, and seismic hazard maps need to be revised or updated systematically with the progress in methodology and the accretion of new seismotectonic data. Earlier seismic hazard studies for Turkey include those by Yarar et al. (1980), Erdik and Oner (1982), Erdik et al. (1982, 1985, 1999) and Kayabalı (2002). The most recent efforts were carried out as part of the Seismic Hazard Harmonization in Europe (SHARE—Woessner et al. 2015) and Earthquake Model of the Middle East Region (EMME—http://www.emme-gem.org/) projects, where Turkey is the common country in both projects. However, the seismotectonic data used in those projects are different from the data presented here.

This study introduces a Turkish Seismotectonic Map and its database which was prepared by a multidisciplinary team. The seismotectonic database brings together and integrates geological, geophysical, seismological and geodetical data. The project was coordinated by the General Directorate of Mineral Research and Exploration (MTA) in cooperation with the Disaster and Emergency Management Presidency (AFAD), Boğaziçi University Kandilli Observatory, Earthquake Research Institute (KOERI) and General Command of Mapping (GCM). The main purpose of this paper is to develop and aggregate previously scattered data into a comprehensive seismotectonic database of Anatolia and relevant surrounding areas. The seismotectonic database of Turkey is comprised of five data sets. These are: (1) the active faults, (2) instrumental earthquake catalogue, (3) historical earthquake catalogue, (4) moment tensor catalogue and (5) crustal thickness. The compilation and storage of the seismotectonic data sets in a digital geographic information system (GIS) will allow analyses and systematic updates as new data accrete over time.

2 Tectonic setting

Turkey is characterized by complex geology (Ketin 1966) and is divided into three main tectonic units: the Pontides, Anatolide–Tauride and Arabian platform (Fig. 1). The Pontides show Laurasian affinities, while the others have Gondwanan realm (Okay 2008). These tectonic units collided during the Alpide orogeny and formed Anatolia as a single landmass in the late Tertiary, which bounded four major Neotethyan suture zones: İzmir–Ankara–Erzincan, Intra-Pontide, Inner Tauride and Southeast Anatolian (Okay and Tüysüz 1999). However, the age, origin and even existence of the Intra-Pontide suture zone are all controversial and different views have been published (e.g. Bozkurt and Mittwede 2001).

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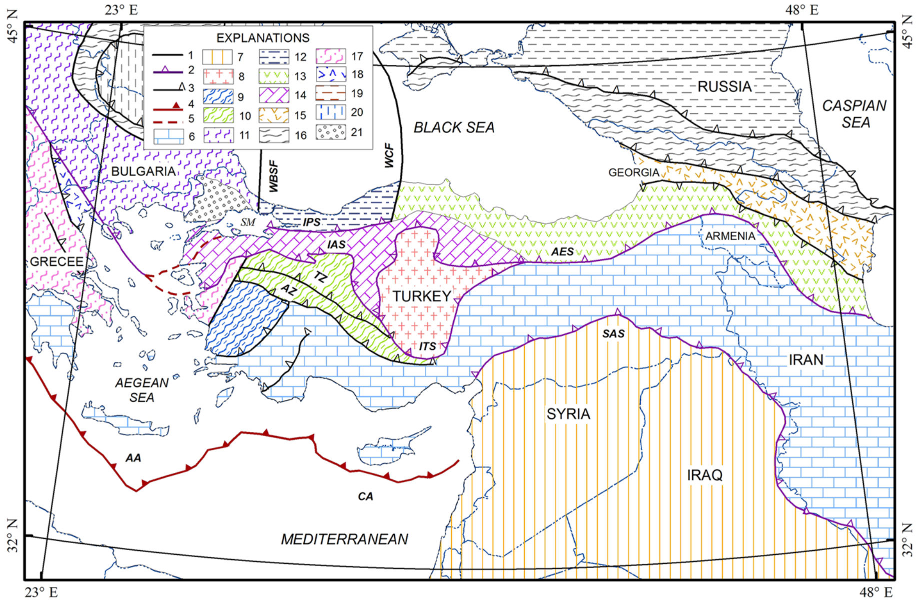

Fig. 1 Simplified tectonic map of Eastern Mediterranean region showing the major sutures and continental blocks (from Okay and Tüysüz 1999). *WBSF* Western Black Sea fault, *WCF* Western Crimea fault, *IPS* Intra-Pontid suture, *IAS* Izmir–Ankara suture, *AES* Ankara–Erzincan suture, *ITS* Inner Tauride suture, *SAS* Southeast Anatolia suture, *AZ* Afyon zone, *TZ* Tavşanlı zone, *AA* Aegean arc, *CA* Cyprian arc. *1* Transform fault; *2* suture zone; *3* thrust zone; *4* active subduction zone; *5* inferred subduction zone; *6* Tauride; *7* Arabian platform; *8* (Kırşehir massif); *9* (Menderes massif); *10* (Afyon–Tavşanlı zone), Anatolide; *11* (Strandja massif); *12* (İstanbul–Zonguldak zone); *13* (Eastern Pontides); *14* (Sakarya continent), Pontides; *15* Lesser Caucasus; *16* Great Caucasus; *17* Pelegonian–Barnova zone; *18* Vardar zone; *19* Scythian platform; *20* Moesian platform; *21* Thrace basin

The Pontides, north of the İzmir–Ankara suture along the Black Sea, comprises the Strandja massif, İstanbul–Zonguldak zone and Sakarya continent fragments (Fig. 1). They were amalgamated into a single terrane by mid-Cretaceous times, folded and thrust-faulted during the Alpide orogeny and have been a land area since the Oligocene (Okay 2008).

The Anatolide–Tauride terrane south of the Pontides (Fig. 1) was separated from Gondwana in the Triassic (Okay 2008). While the Tauride is mostly represented by unmetamorphosed rocks of Precambrian to Triassic age (e.g. Robertson and Dixon 1984; Şengör et al. 1984), the Anatolide is mainly made up from metamorphic rocks of Precambrian to Eocene age (e.g. Ketin 1966; Şengör and Yılmaz 1981). A very large body of ophiolite and ophiolitic melange was emplaced over the Anatolide–Tauride terrane in mid-Cretaceous time (e.g. Bozkurt and Mittwede 2001), and subsequently, the continental collision between the Anatolide–Tauride and the Pontides resulted in a stack of thrust sheets during the late Palaeocene–early Miocene (e.g. Özgül 1984).

The Arabian platform consists of a Pan-African crystalline basement overlain by a Palaeozoic to Tertiary autochthonous sedimentary sequence (e.g.Altıner 1989). Ophiolites, ophiolitic melanges and thrust sheets were emplaced on the platform during Late Cretaceous and Tertiary times (Yılmaz et al. 1993 and references therein). Tertiary–Quaternary volcanic provinces, occupying wide areas, are remarkable in Central Anatolia, notably in the Cappadocia and Galatea regions. East Anatolia is characterized by extensive Neogene collision-related basaltic volcanism that covers a very large area on the plateau (Keskin et al. 1998; Yılmaz et al. 1998; Pearce et al. 1990).

The amalgamated lithospheric fragments across Turkey cause divergence in crustal structure resulting in significant variances in seismogenic depth. Additionally, most of the structures related to the palaeotectonic period form the basis of the active tectonic framework of Turkey and its surroundings.

The present-day tectonics in Anatolia and the surrounding region are intimately associated with the interaction of Eurasian, Arabian and African plates (Reilinger et al. 2006). This interaction of the Earth's major lithospheric plates has resulted in complex tectonics zones, which are subduction, continental collision, crustal extension, extrusion or escape tectonics (Fig. 2).

The African plate subducts along the AA and the CA, dipping to the north, under the Aegean and the Anatolian microplates to the south-west of Turkey (e.g. McKenzie 1978; Le Pichon and Angelier 1979; McClusky et al. 2000). On south-east of Turkey, the Arabian

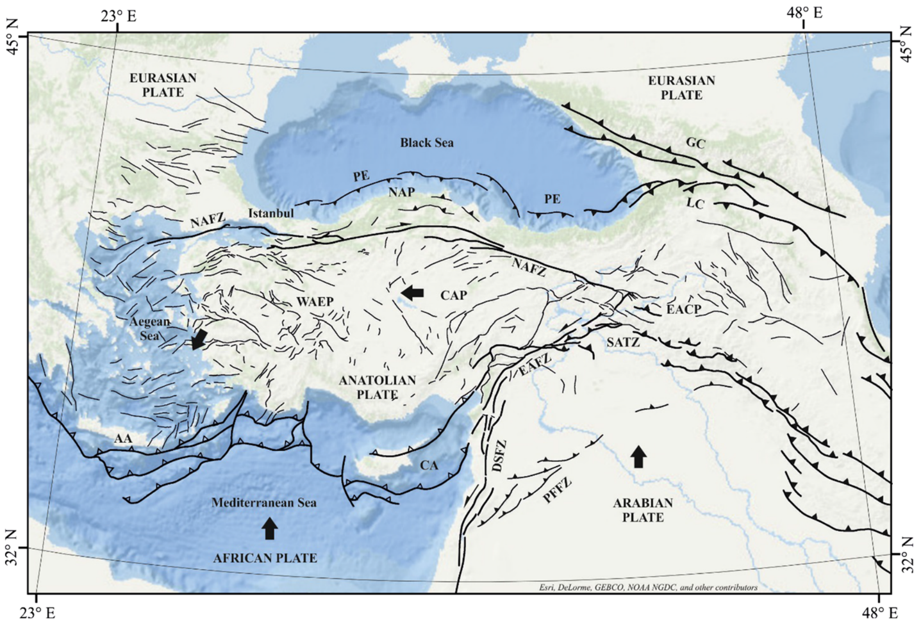

Fig. 2 Active fault map of the Eastern Mediterranean region. Faults in Turkey are simplified from Emre et al. (2013). Faults in the south and east are simplified from Hessami et al. (2003) and Gudjabidze (2003). Faults in Aegean and Balkans are from Burchfiel et al. (2006), Caputo et al. (2012, 2015), Woessner et al. 2015, Garfunkel et al. (2014). Faults in Mediterranean are re-evaluated from Angelier et al. (1982) and, Papazachos and Papaioannou (1999). Faults in Black Sea are re-evaluated from Şengör et al. (1985) and Barka and Reilinger (1997). Neotectonic Provence from Şengör et al. (1985). Subduction zones are shown by *heavy lines with open triangles*: the tips of *triangles* indicate polarity. *Heavy lines with filled triangles* at hanging wall indicate thrust zones. *Heavy lines with half arrows* are transform faults: the half arrows show relative movement along these faults. *Lines* with open triangles represent reverse fault zones. For the other details of the faults in Turkey, see Fig. 3. *AA* Aegean arc, *CA* Cyprian arc, *DSFZ* Dead Sea fault zone, *EAFZ* East Anatolian fault zone, *NAFZ* North Anatolian fault zone, *SATZ* Southeast Anatolian Thrust Zone, *PE* Pontic Escarpment, *LC* Lesser Caucasus, *GC* Great Caucasus, *WEAP* West Anatolian Extensional Provence, *CAP* Central Anatolian Provence, *EACP* East Anatolian Compressional Provence, *NAP* North Anatolian Provence, *PFFZ* Palmyra fault and Fold Zone. *Arrows* indicate direction of plate motion

and Eurasian plates collide along the Bitlis–Zagros suture zone causing crustal thickening and compressional deformation since the Late Miocene (e.g. Dewey et al. 1986).

The African–Eurasian collision began to drive internal deformation in addition to forcing a large part of Turkish territory (Anatolian microplate) to move westward through a process of presumed extrusion (Şengör et al. 1985) or escape tectonics (Şengör and Kid 1979; Burke and Şengör 1986; Dewey et al. 1986; Koçyiğit and Beyhan 1998). The extrusion occurs along conjugate intracontinental transform fault systems: the dextral NAF and sinistral EAF (Fig. 2). The neotectonic period therefore began in the Early Pliocene ($\sim$5 Ma) through Anatolia and adjacent areas (e.g. Şengör 1979, 1980; Şengör et al. 1985; Bozkurt 2001).

There are previous studies on the neotectonic regionalization of Turkey (Şengör et al. 1985; Barka and Reilinger 1997; Koçyiğit and Özacar 2003). Şengör et al. (1985) suggested four distinct neotectonic provinces across Turkey: (1) North Anatolian province; (2) Eastern Anatolian contractional province; (3) Central Anatolian 'Ova' province; and (4) Western Anatolian extensional province (Fig. 2). Each province shows different tectonic characteristics.

Intra-continental transforms represented by the NAF and EAF zones accommodate westward extrusion of the Anatolian microplate (Fig. 2). Continental extension in western Anatolia and over the wider Aegean region is related to the regional extrusion of the Anatolian plate and retreat of the African slab (e.g. Le Pichon and Angelier 1979; Şengör et al. 1984; Reilinger et al. 2010). The discussion of gravitational collapse, subduction rollback, westward escape and lower crustal to mantle processes as the cause of extension in Western Anatolia are described in Bozkurt (2001) and references therein. Bozkurt (2001) also documents the occurrence of extensional tectonics in this region since latest Oligocene–Early Miocene time. Other models interpret the area as an atypical backarc basin, whose opening is not related to progressive slab rollback, steepening and asthenospheric replacement, but related to progressive slab dehydration metasomatizing the mantle wedge, the south-westward migration of the subduction hinge and the subducted slab and matched by asthenosphere upwelling (Agostini et al. 2010; Doglioni et al. 2002, 2007).

The compressional deformation in Eastern Anatolia results in thickening of the crust and includes dominantly reverse faults with associated folds and conjugate strike–slip faulting (Şengör et al. 1985; Dewey et al. 1986; Bozkurt 2001; Koçyiğit et al. 2001). This progressively changes to a subduction-dominated deformation via the Cilicia region towards Cyprus. The Cilicia region is characterized by complex plate interactions, occurring between the African, Anatolian and Arabian plates (Kempler and Garfunkel 1994). All these structures, the collision zone and intra-continental transform faults, meet at the Karasu tectonic trough (Duman and Emre 2013).

Geodetic observations in the Eastern Mediterranean region indicate that Anatolia and its surroundings are presently moving SW with counterclockwise rotation relative to Eurasia (e.g. McClusky et al. 2000; Reilinger et al. 2006; Aktuğ et al. 2013). Reilinger et al. (2006) estimated that the direction of the Anatolian and Aegean plate motions relative to the Eurasian plate is roughly west-north-west at rates of 21 and 33 mm/yr, while the Arabian and African plates motions are north-north-west at rates of 15 and 5 mm/yr. The sinistral motion, between the eastern boundary of the Arabian plate and the Anatolian and African plates, is accommodated by the EAF and DSF zones, respectively. The geodetic data suggest sinistral relative movements of $\sim$4 along the EAF and $\sim$10 mm/yr along the DSF. Along the northern boundary of the Anatolian microplate, the NAF zone accommodates $\sim$24 mm/yr of dextral motion between Anatolian and Eurasian plates in the north. To the south, subduction of the African lithosphere beneath the Anatolian and Aegean microplates occurs along the Aegean ($\sim$35 mm/yr) and Cyprus ($\sim$18 mm/yr) arcs, respectively.

3 Seismotectonic database

The seismotectonic database of Turkey includes five data sets, which are the active faults, instrumental and historical earthquake catalogues, moment tensor catalogue and crustal thickness estimates. All these data sets were individually compiled using several sources; then, each data set was sequentially transferred as a layer into a GIS environment to create a database which is renewable and superimposable.

The historical, instrumental and moment tensor catalogue layers were created as point features with a range of attributes, including date, geographic coordinates, magnitude or intensity and references. The same identity numbers were used in both instrumental and moment tensor catalogues. The active fault database was taken from the renewed active fault map of Turkey prepared by Emre et al. (2013) under the establishment of the Geological Research Department of MTA. Conversely, the active faults in the surrounding regions are mostly from previous data. The faults are input as polyline features with four symbol layers.

The GPS-based annual slip rates of the main fault systems were assigned according to the available literature data. The crustal thicknesses were based on the crustal thickness map of Turkey prepared by Arslan (2012) under the Geophysical Research Department of MTA with a contour interval of 500 m.

A seismotectonic map series of Turkey prepared during the study show all the layers in the database. The map series consists of 18 quadrangles at 1:500,000 scale with accompanying explanatory booklets and appendices, which include the entire catalogues. The seismotectonic data layers and seismotectonic maps are introduced in the following sections.

3.1 Active faults

The active faults, line sources for seismic hazard analyses, can be divided into two groups: (1) active faults in Turkey (inland) and (2) active faults in the surrounding area. The active fault map of Turkey and its database provide the most recent characteristics of seismic sources on a national basis (Emre et al. 2013). The map outputs are at three different scales: (1) base active fault maps at 1:25,000 scale, (2) active fault map series of Turkey at 1:250,000 scale and (3) active fault map of Turkey at 1:1,250,000 scale. The active fault maps contain 533 single-fault segments, which are substantial potential earthquake sources (Fig. 3). Active faults are classified into four distinct types based on geochronological criteria and character. These are: (1) faults with evidence of earthquake surface rupture, (2) Holocene-active faults, (3) Quaternary-active faults and (4) Probable Quaternary-active faults or lineaments. Fault parameters such as class, activity, type, length, trend and fault plane-attitude are presented for all fault segments on the map including slip rate, seismogenic depth and expected maximum magnitude based on the available data. A complete description of the inland fault parameters is given in Emre et al. (2016). The NAF, EAF and Southeast Anatolian Thrust (SAT) zone are the major structures in Turkey, whereas the Dead Sea fault zone (DSF), Aegean arc, Cyprus Arc, Pontic Escarpment, Great and Lesser Caucasus are the main megastructures responsible for the seismicity around Turkey (Figs. 2, 3). The surrounding active faults, in an ~200-km-wide buffer zone, included in the database were delimited from available data in the literature. The common fault geometries extending from the inland to the surrounding region were classified in a similar manner as the Turkish active faults, but the precision of location was not always available

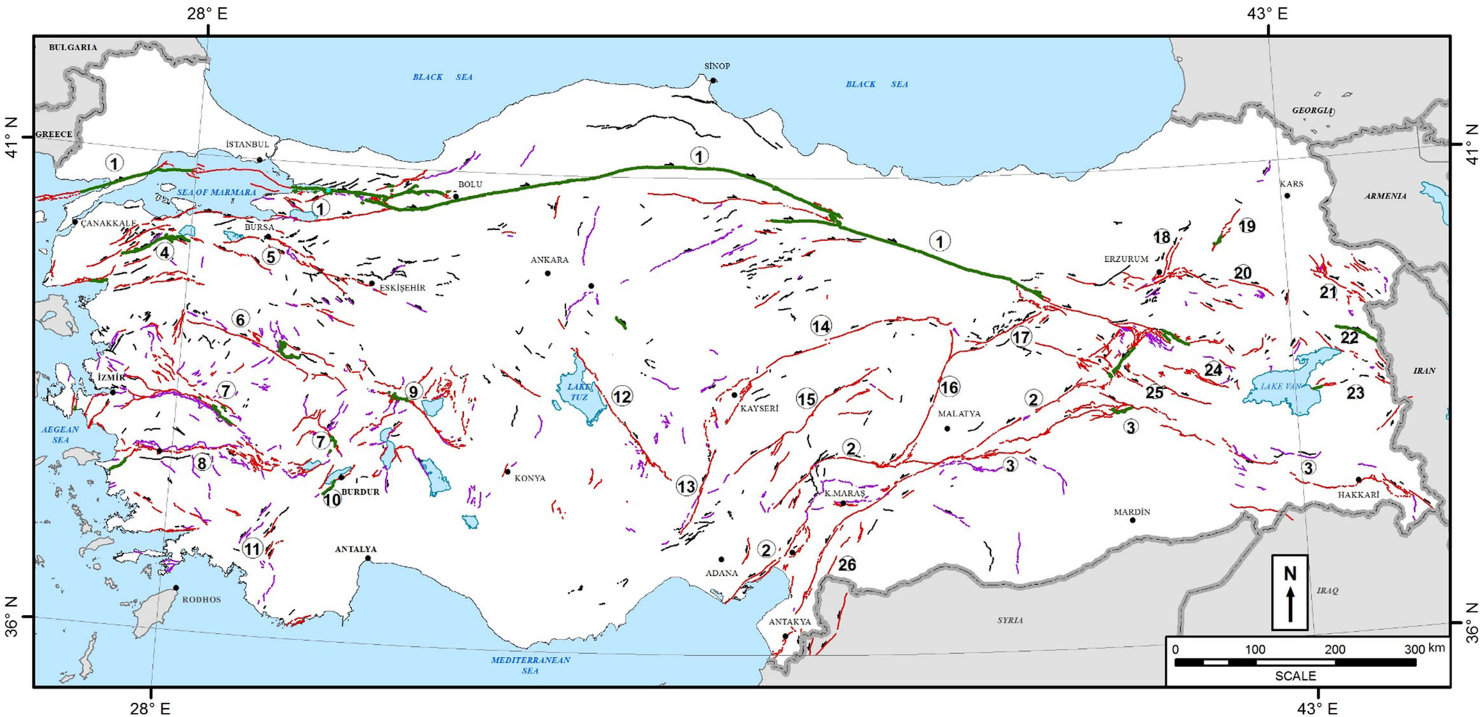

Fig. 3 Active fault map of Turkey simplified from Emre et al. 2013. *Green colour* surface ruptures; *red colour* Holocene-active faults; *purple colour* quaternary faults; and *black colour*, pre-quaternary or lineaments. *FZ* Fault Zone, *GS* Graben System, *1* NAFZ, *2* EAFZ, *3* SATZ, *4* Southern strand of the NAF, *5* Bursa F, *6* Simav FZ, *7* Gediz GS, *8* Büyük Menderes GS, *9* Afyon–Akşehir GS, *10* Burdur GS, *11* Dinar FZ, *12* Tuzgölü FZ, *13* Ecemiş FZ, *14* Deliler FZ, *15* Sarız FZ, *16* Maltya FZ, *17* Ovacık FZ, *18* Erzurum FZ, *19* Horasa-Şenkaya FZ, *20* Tutak F, *21* Balıkgölü FZ, *22* Çaldıran FZ, *23* Van FZ, *24* Muş FZ, *25* Kırkkavak F, *26* DSFZ

as required. The active fault map of Iran (Hessami et al. 2003), Neotectonic map of Iraq and Tectonic map of Georgia (Gudjabidze 2003) were relatively coherent for the continuation of the inland Turkey active faults. Fault information in the Black Sea, Balkans and Aegean regions was taken with minor revisions (Burchfiel et al. 2006; Caputo et al. 2012, 2015; Woessner et al. 2015). The active faults in Mediterranean were reinterpreted from available data prepared by Nur and Ben-Avraham (1978), Angelier et al. (1982) and Papazachos and Papaioannou (1999).

3.2 Earthquake catalogues

One of the major steps in seismic hazard studies is to compile a complete list of earthquakes and their characteristics. However, the available catalogues for Turkey and the surrounding areas have some deficiencies which can impact seismic hazard and risk assessments. These include magnitude heterogeneity, some uncertainties and errors on epicentral location, date and time errors. Therefore, alternative improved and updated instrumental and historical catalogues were prepared to comply with this project's objectives by the broad participation of expert researchers. Both instrumental and historical earthquake catalogues cover Anatolia and the surrounding region for longitudes between 32° and 45°N and latitudes between 23° and 48°E. The earthquakes included in the instrumental and historical catalogues were attributed to the same identity number both on the seismotectonic maps and in the tables of the related catalogues, which are included as explanatory booklets and appendices.

3.2.1 Instrumental earthquake catalogue

During the compilation of the instrumental earthquake catalogue (Kadirioğlu et al. 2016), neither relocation nor fault plane solution was performed. However, a handful of reliable catalogues were assessed to compile 41 available sources, which are earthquake catalogues, agency reports and research articles published after the 1950s for the region. All parametric data derived from the sources were compiled to create an integrated database, which comprises about 37,000 earthquakes between 1900 and 2012. Subsequently, all parameters were analysed to acquire more reliable and relatively uniform inputs for each event and were extracted from the integrated database to form an improved catalogue. The instrumental catalogue includes parametric information for 12,674 earthquakes of magnitudes bigger than magnitude of 4.0 for the time period 1900–2012. For the improved catalogue, parametric data were selected preferentially as follows:

- Turkish catalogues (Kalafat et al. 2011; AFAD catalogue) are considered as primary sources of information for magnitude, location, etc., for earthquakes occurred within Turkish territory after 2005 due to denser local seismic networks after that period.
- Local networks are the prime preference for earthquakes outside Turkish territory. If there is missing information from local networks, ISS–ISC, ISC–EHB and EMSC–CSEM catalogues were chosen.
- Ambraseys and Finkel (1987), Gutenberg and Richter (1954), Ayhan et al. (1981), Alsan et al. (1975) and Ambraseys and Jackson (1998) catalogues were used for events that are not covered by catalogues above.
- In particular, for moment magnitude (M_w) $\geq$ 7.0 events Ambraseys and Jackson (1998), catalogue is utilized.
- Magnitude, depth and location information are mostly from the same catalogue.

- Harvard CMT Catalogue is the prime reference for moment magnitude information.
- If data are taken from the ISC, the ISC–EHB catalogue is preferred for location, depth and time.
- The instrumental catalogue includes the magnitudes (of various types) reported by the source agency.

Figure 4 maps the distribution of the 12,674 instrumental period earthquakes in Anatolia and the surrounding region. Of the 12,674 earthquakes, 203 events have a magnitude (M_w) of 6.0 or greater and 1468 events have $5.0 \leq M < 6.0$. The remaining 11,003 events have $4.0 \leq M < 5.0$. During the last century, 70 large earthquakes were accompanied with observed surface ruptures, 28 of which have been mapped in detail (Emre et al. 2013). While 10 surface rupture events were on the NAF and 2 on the EAF zones, the others have mostly occurred in west and east Anatolia (see Fig. 3).

The moderate-to-large earthquakes are mostly abundant at and near the plate boundaries, which are the NAF, EAF, AA and CA that bound the Anatolian plate. In contrast, the earthquakes are less abundant along the DSF boundary, between Arabian and African plates. Also, there are a considerable number of moderate-to-large earthquakes in eastern and western Anatolian and the Caucasus regions. The greatest concentration of small to mid-scale earthquakes is in western Anatolia. The distribution of the earthquakes becomes sparse, in the central Arabian plate, Aegean and Anatolian region and across the Pontides. The spatial distribution of the small to moderate size earthquakes clearly shows clusters in some areas corresponding to jog structures, terminations of the propagation of surface ruptures, fault junctions or bifurcating zones.

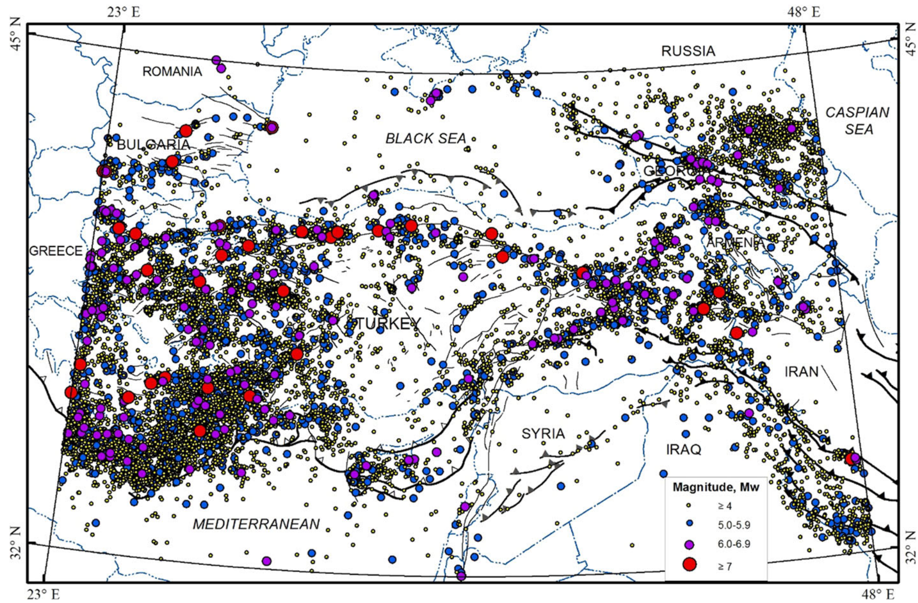

Fig. 4 Seismicity of Anatolia region, 1900–2012, M_w, ≥ 4.0. Faults are as in Fig. 2

3.2.2 Historical earthquake catalogue

Several catalogues (Pınar and Lahn 1952; Ergin et al. 1967, 1971; Soysal et al. 1981; Güçlü et al. 1986; Ambraseys and Finkel 1995; Ambraseys and Jackson 1998; Tan et al. 2008; Ambraseys 2009) have been published about historical earthquakes in Turkey and the surrounding area. Among these, Soysal et al. (1981), Ambraseys and Finkel (1995) and Ambraseys (2009) become prominent. The basic reference for many historical earthquakes associated with Turkey is the catalogue executed by Soysal et al. (1981), which includes parametric earthquake information, from 2100 BC to 1900 AD. The study carried out by Ambraseys and Finkel (1995) is a critical review of the catalogues of earthquakes in Turkey and surrounding areas during the period 1500–1800 AD. Despite the long historical record of the Anatolia region, a historical earthquake catalogue for Turkey, compiled with modern methodology, is not yet available (Albini et al. 2013).

Therefore, a historical earthquake catalogue was also compiled and reorganized during this study. The catalogue was compiled from 20 available sources, following the same method used for the instrumental catalogue. The final improved catalogue created from an integrated database, which comprises about 4500 earthquakes, extracting more reliable and relatively uniform information from the integrated database. During the compilation stage of the historical earthquake catalogue, coordinate and intensity were assigned to the 1554 and 450 events, respectively. The historical earthquake catalogue consists of 2247 events for the time period from 2000 BC to 1900 AD. Of these, 1236 events have intensity (*Io*) *V* and over. As documented in the catalogue, 212 earthquakes with *Io* of *IX* or greater occurred in Anatolia and the immediate surrounding area during the last 4000 years.

Figure 5 maps the distribution of the 2.247 historical period earthquakes in Anatolia and the surrounding region. The historical time events display comparable spatial distributions across the major source faults as the instrumental time records. The most significant differences in between the distributions of the events in the catalogues are the large events related to the CA, DSF and SAT zones. During this study, we have precisely compiled all the available sources to evaluate in full the distributions of the historical earthquakes across Turkey. Nevertheless, as can be recognized from Fig. 5, the catalogue is not complete throughout Turkey, even though it is located in one of the most seismically active regions in the world. However, in the absence of available records, it is not possible to improve the database, further.

3.2.3 Focal mechanism

Very few focal mechanism solution catalogues are available for Turkey and the surrounding region (e.g. Tan et al. 2008; Kalafat et al. 2011). Most of these are reports, not easily accessible or limited to specific periods. However, there are online databases such as those prepared by the United States Geological Survey (USGS) and the global moment tensor solutions by Harvard University (HRVD), which are accessible from their *websites* and *ftp* servers. The moment tensor solutions suggested by different institutions around Turkey and its near vicinity were compiled and reassessed in this study (Fig. 6). As part of the compilation, more than 40 catalogues, agency reports and research articles were assessed, but nine of them are considered as primary sources. These are: AFAD, KOERI, HRVD, USGS, the database of Earthquake Mechanisms of European Area (EMMA), European–Mediterranean Seismological Centre (EMSC–CSEM), International Seismological Centre-Global Earthquake Model Project (ISM-GEM), European and

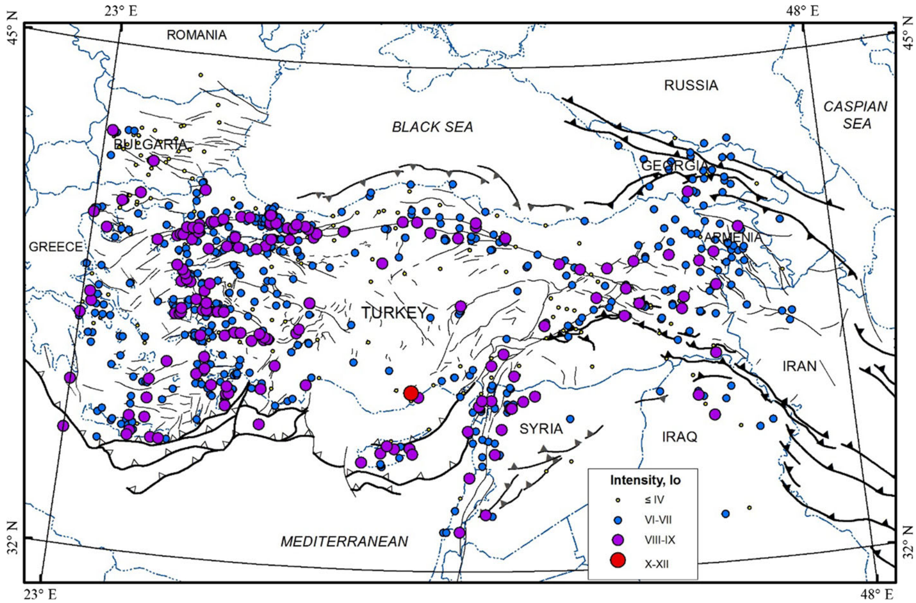

Fig. 5 Historical earthquake distribution across Turkey and surrounding region, BC 2000–AD 1900. Faults are as in Fig. 2

Mediterranean Regional Centroid Moment Tensor (MED-RCMT/RCMT), Institute of Geodynamics and the National Observatory of Athens (NOAH).

The new catalogue contains fault plane solution parameters for the 1517 earthquakes with $M_w \geq 4.0$ in Turkey and its near vicinity from 1906 to 2012. The parametric information includes epicentre, seismic moment, nodal planes and principal axes. The catalogue is accompanied by a reference list for all the events. A significant feature of the catalogue is that it includes all moment tensor solutions from different sources. Thus, the new catalogue provides comparison solutions with each others. As a result, the catalogue includes 3065 individual solutions and their parametric information for 1517 different events. Some of these solutions were developed during this study. Based on magnitude, the distributions of the selected solutions included in the catalogue are: 13 of $M_w > 7.0$, 118 of $6.0 < M_w < 7.0$, 501 of $5.0 < M_w < 6.0$, 784 of $4.0 < M_w < 5.0$ and 101 of $M_w < 4.0$ (Fig. 6). In the catalogue, the oldest event occurred in 1906 offshore İzmir, while the largest event is the 1939 Erzincan earthquake along the NAF zone.

The moment tensor solutions of lower hemisphere equal area projection were plotted on the seismotectonic map of Turkey, and the entire catalogue is provided as an appendix. The instrumental earthquakes and the moment tensor catalogues were attributed by the same identity number both on the seismotectonic maps and in the tables of the related catalogues. While central and western Anatolia display normal faulting as a major mechanism with minor conjugate strike and reverse slips, eastern Anatolia is characterized by both reverse and conjugate strike–slip faulting, which are consistent with prolongation of the NAF and EAF zones and parallel or semi-parallel to the SAT zone. The major faulting mechanism of the AA, CA, Great and Lesser Caucuses is thrust type (Fig. 7).

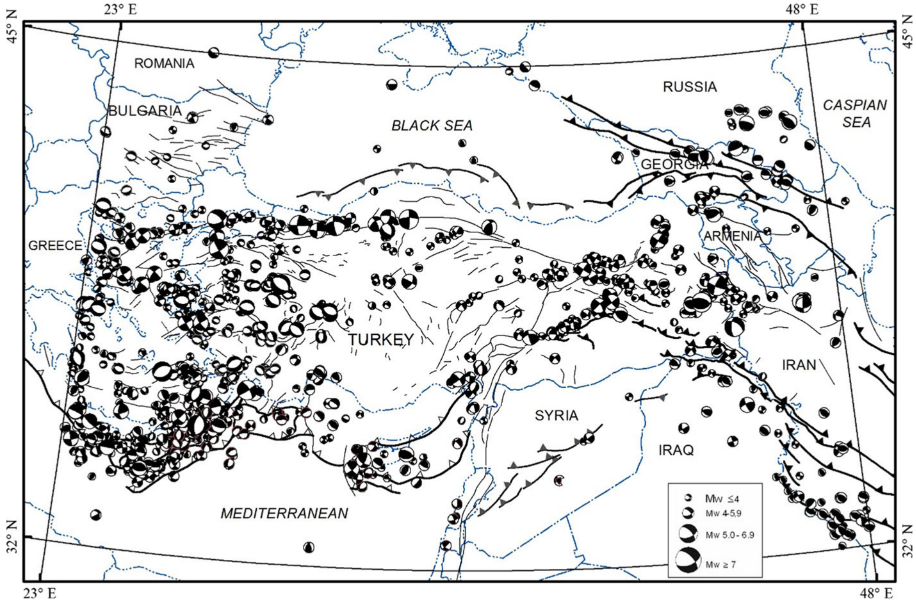

Fig. 6 Map showing distributions of the lower hemisphere equal area projection plots of the focal mechanism solutions of earthquakes and active faults in and surrounding Turkey. The size of each 'beach-ball' is related to the earthquake magnitude. Faults are as in Fig. 2

3.2.4 Crustal thickness and seismogenic depth

Based on Bouguer anomalies derived from the regional gravity data, the thickness of the crust across Anatolia ranges from 31 to 50 km (Arslan 2012; Arslan et al. 2010) (Figs. 7, 8). The thinnest crust of the Pontides, Anatolide and Tauride is 32, 36 and 37 km, respectively (Figs. 7, 8). From west to east, the crustal thickness of the Anatolide–Tauride varies from 32 to 44 km (Fig. 8a, b). On the east of the Karlıova triple junction and north of the Arabian plate, the crust increases from ~40 to ~50 km (Fig. 8c).

The cover sequences overlying high-grade metamorphic or crystalline basement of the upper crust vary across the Pontides, Anatolide–Tauride and Arabian platforms. While Palaeozoic rocks of the İstanbul–Zonguldak zone make up an ~7.5-km-thick sediment sequence (Özgül 2012), Mesozoic volcanic and volcaniclastic rocks in the central and eastern Pontides are of ~10 and 4.5 km thick, respectively (Okay and Şahintürk 1997). The thicknesses both across the Tauride and between different autochthonous and allochthonous units vary considerably from ~3.5 to 10 km (e.g. Özgül 1976; Mackintosh and Robertson 2013; Demirel 2004). The thickness of sedimentary units on the basement in the northern Arabian platform reaches up to 6 km in the Aleppo plateau region (Barazangi et al. 1993). The Neogene sedimentary and volcanic units that cover both the Anatolide and Tauride vary from ~4.5–7 to 10 km thick (e.g. Önal and Kaya 2007; Aydemir 2008; Karadenizli 2011). Additionally, the Thrace Basin overlying the Strandja massif in the Pontides reaches ~9 km in thickness (e.g. Turgut et al. 1983). In Eastern Anatolian, extensive Neogene collision-related basaltic volcanism (Keskin et al. 1998; Yılmaz et al. 1998; Pearce et al. 1990) has accumulated around ~5-km-thick volcanic units (Koçyiğit et al. 2001).

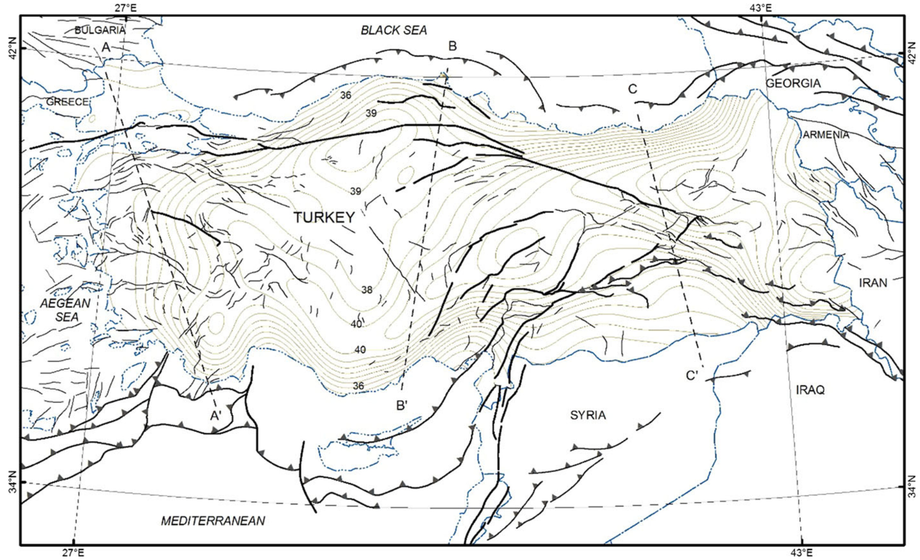

Fig. 7 The map shows crustal thickness across Turkey and locations of crustal depth sections. Contour represents depth of the crust with 500 m intervals (from Arslan 2012). Faults are the same as in earlier map views. The *lines* with labelled *A–A′*, *B–B′* and *C–C′* are locations of the cross sections given in Fig. 8

Of the 12,674 events in the instrumental catalogue, the 93.5 % are shallow-focus earthquakes, with focal depths of less than 70 km, while 6.4 % are mid-focus or intermediate-deep earthquakes with focal depths between 70 and 300 km (Fig. 9). Based on the reported hypocentral depths of these instrumental events, it can be concluded that seismogenic depth ranges from ~15 to ~190 km all over Anatolia and the surrounding region (Fig. 9). Although intermediate-depth earthquakes (70–190 km) are generated by the AA and CA, Anatolia is largely characterized by shallow crustal earthquakes (15–35 km).

The spatial distributions of seismicity in different depth ranges and focal distributions are shown on a series of four sections in Figs. 9 and 10, respectively. Sections A–A′, B–B′ and C–C′ are N–S roughly perpendicular to the major tectonic structures (Fig. 9).

Sections A–A′ and B–B′ shown in Fig. 10 and are ~1600 km long and almost perpendicular to the NAF zone, intraplate structures of Anatolia, the AA and CA. In both sections, the shallow-deep seismicity beneath Anatolia region occurs in a ~600 km wide almost tabular zone, with most of the activity confined to the upper ~20 km upper crust zone. However, lower crust activities are non-negligible in the same zone. The seismic zone along the subduction arcs extends to depths of 140–160 km with ~50-km-wide zone in the section dipping (30°–35°) towards the north beneath the Aegean and Anatolian plates.

Section C–C′ is 950 km wide, N–S and NW–SE oriented, generally perpendicular to the NAF zone, intraplate structures of Anatolia, the CA and the DSF zone (Fig. 10). The most notable features of the section are the two clusters of events in the 40–80 km depth range. The first cluster related to the NAF and inner Anatolian structures appears quite broad (250 km) and occurs around 40 km depth. Only two events are seen at around 80 km depth in this cluster. The second cluster, which is generated by the EAF zone in the Cecilia

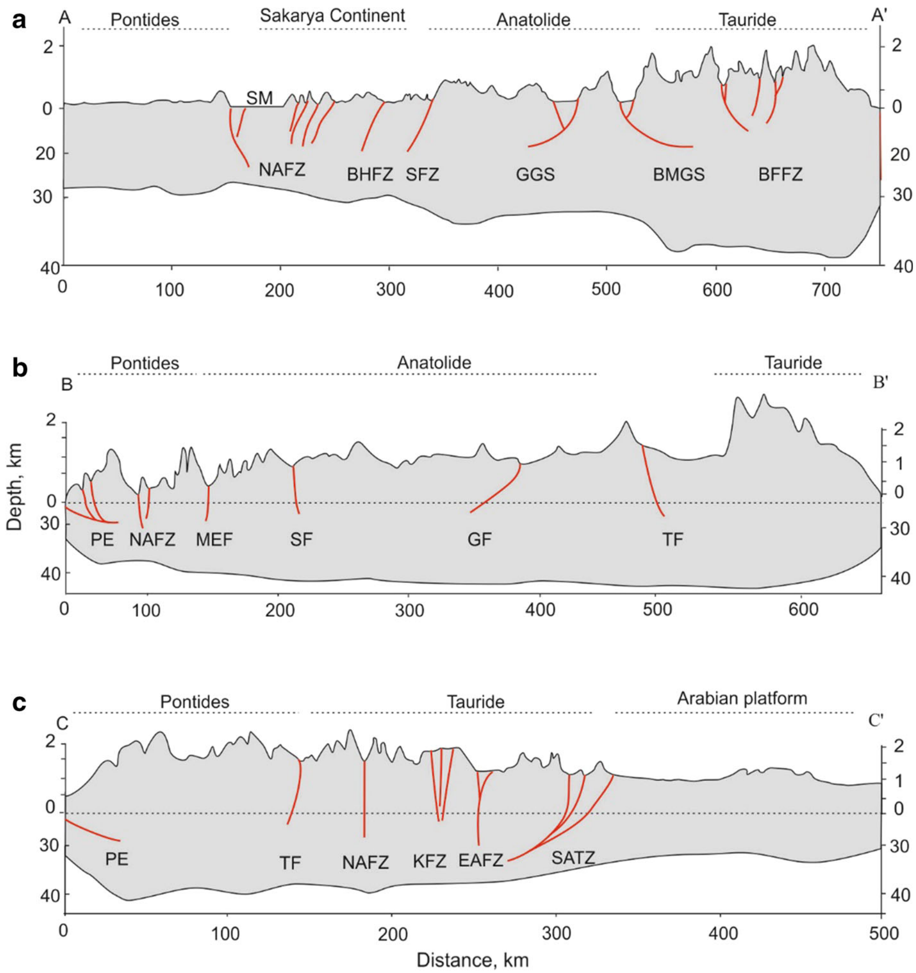

Fig. 8 Crustal thickness cross sections across Turkey. *A–A′* (**a**), *B–B′* (**b**) and *C–C′* (**c**) are from Pontides to Tauride and Anatolide to Arabian platform, respectively. The location of the cross sections is given in Fig. 7. *NAFZ* North Anatolian fault zone, *EAFZ* East Anatolian fault zone, *PE* Pontic Escarpment, *MEF* Merzifon-Esençay fault, *SF* Sungurlu fault, *GF* Gümüşkent fault, *TF* Tuzgölü fault, *BHFZ* Balıkesir-Havran fault zone, *SFZ* Simav fault zone; *GGS* Gediz Graben system, *BMGS* Büyük Menderes Graben system, *BFFZ* Burdur Fethiye fault zone, *TF* Tercan fault; *SATZ* Southeast Anatolian Thrust zone

region, extends up to 80 km depth. Another scattered cluster of events at the southern end of this section occurs at 15–18 km depth in the Arabian plate reaching Palmyra.

Section D–D′ is 1050 km wide and N–S oriented from the Caucasus to the Arabian plate. Eastern Anatolia and the SAF zone (the Bitlis suture) display similar seismic depth extending to ∼70 km (Fig. 10). There is little subcrustal activity in the section related to under-thrusting or subduction of the Arabian lithosphere beneath Eurasia.

As is recognized from the seismicity sections, there is a non-negligible deeper seismicity across Turkey, which may be related to lower crust seismicity. However, there is little knowledge on this subject and it is not evaluated in this study.

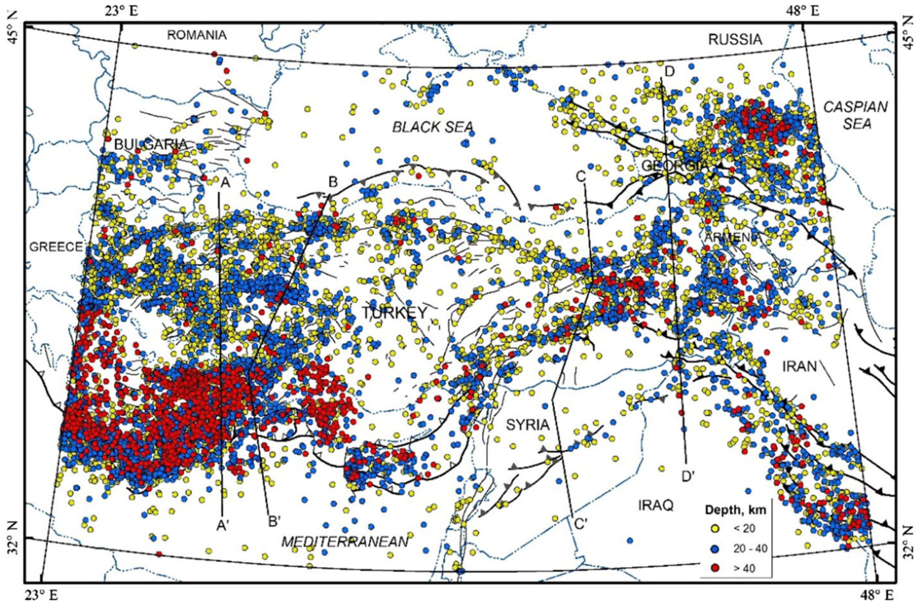

Fig. 9 Based on focal depth, distribution of the seismicity across Turkey and surrounding region, 1900–2012, M_w. Faults are as in Fig. 2. The *lines* with labelled *A–A′*, *B–B′*, *C–C′* and *D–D′* are locations of the cross sections given in Fig. 10

3.2.5 Seismotectonic maps

After compilation of the above seismotectonic data required for seismic hazard assessment in a GIS environment, seismotectonic map layouts were produced at two different scales: (1) seismotectonic map series of Turkey at 1:500,000 scale and (2) seismotectonic map of Turkey at 1:1,250,000 scale.

The seismotectonic map series of Turkey corresponds to 18 maps at 1:500,000 scale with accompanying explanatory booklets and appendices. These books represent the primary source for the data on the maps. As described previously, the instrumental, historical and moment tensor solutions of earthquakes were attributed by the same identity number both on the maps and in the tables of the related catalogues. The crustal thickness contours and GPS-based slip rates of the main fault systems assigned according to the available literature data are also shown on the maps. Figure 11 shows a part of the seismotectonic maps of Turkey in the Karlıova region as an example.

The seismotectonic map of Turkey is a guidance map that shows the spatial distribution and general seismotectonic characteristics of the Turkish territory. The seismotectonic information is intended to facilitate hazard mitigation strategies for national policy and strategy planning. The seismotectonic map series of Turkey (18 sheets at 1:500,000) and the active fault map of Turkey at 1:1.250,000 scale are available at *maps.mta.gov.tr* in pdf format with appendices, which are instrumental and historical earthquake catalogues and fault plane solutions catalogue.

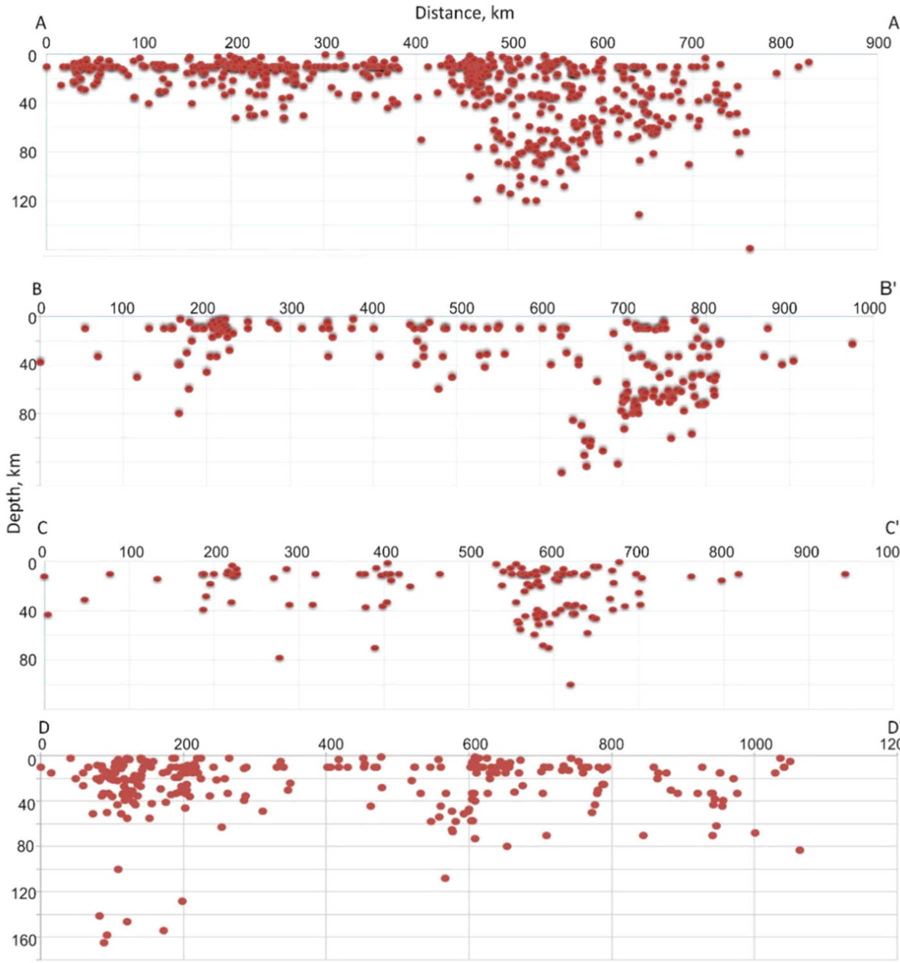

Fig. 10 Seismicity sections. The location of the cross sections is given in Fig. 9. *A–A′* and *B–B′* sections pass through the NAF zone, the western Anatolia extensional region and the Aegean arc, C–C′ section is from Pontic escarpment to the Palmyra traversing the Karlıova triple junction area and the Southeast Anatolian Thrust zone and *D–D′* section crosses Caucasus, eastern Anatolia compressional region, the Southeast Anatolian Thrust zone and Arabian platform

4 Seismotectonic domains

The seismotectonic database and related maps allow us to evaluate the study area in terms of seismotectonic regionalization. Within the general neotectonic framework of Turkey, the seismotectonic database and related maps helped delineate 18 seismotectonic domains in Turkey and the surrounding area (Fig. 12). The tectonic domains define seismotectonic zones or areas, which are characterized by similar seismic sources and seismicity.

The basic criteria for the delineation of the domains are lithospheric structures and the active tectonic framework that impact seismicity. The diverse amalgamated lithospheric fragments resulted in variance in the crustal structure across Turkey. Active tectonic

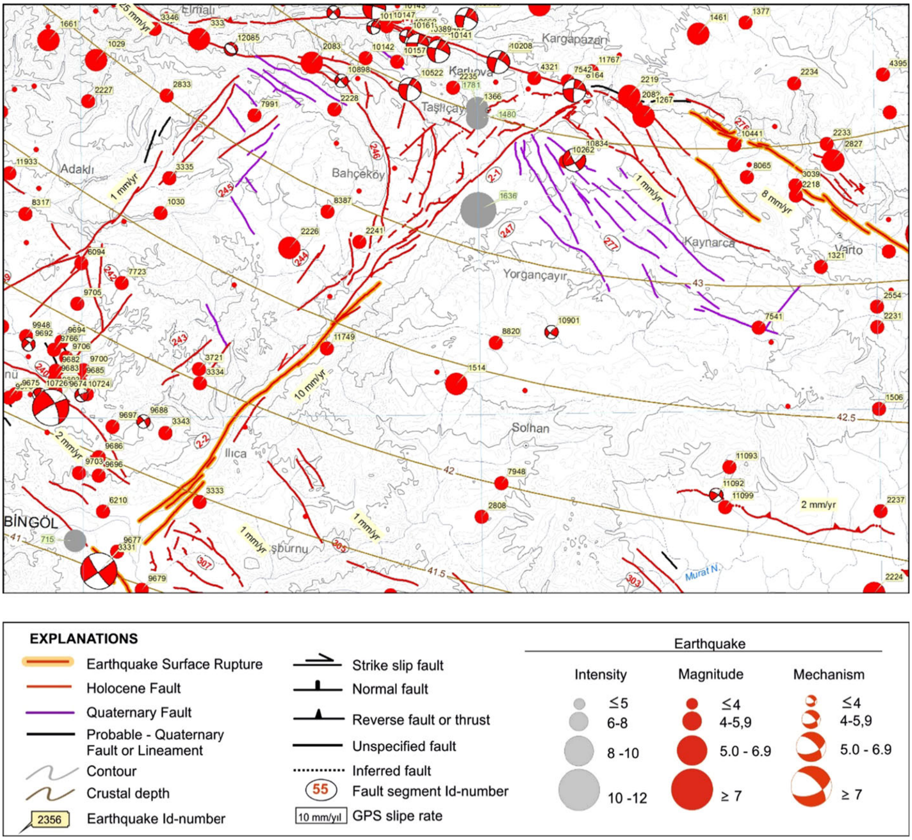

Fig. 11 Map showing an example for seismotectonic maps of Turkey from Karlıova region (*upper*) and explanations of the map (*below*). The map includes seismic sources classified in four types, historical and instrumental earthquakes attributed by the ID no-related catalogues, crustal thickness information, fault mechanism solutions and available GPS-derived slip rates assigned the main fault zone. *Solid colour lines* show faults according to the age of the faults, for example, *red line* with hachure is surface rupture occurred last century, *red line* Holocene, *purple line* Quaternary and *black line* probable Quaternary. *Heavy black lines* indicate types of the fault mechanism such as *lines* with burbs on the *uplift side* and ticks on the *down side* indicate reverse and normal fault types, respectively, while *heavy lines with half arrows* are strike–slip faults indicating motion direction

processes, which are subduction, continental collision, crustal extension, extrusion or escape tectonics, are responsible for the seismicity in the region. The seismotectonic characteristics change from one region to another based on the type of tectonic structure with different mechanisms and crustal composition. The thickness of the seismogenic zone generally increases from west to east, whereas from south to the north, there are fluctuations.

Well-recognized slip rates on the plate boundaries, major structures (e.g. McClusky et al. 2000; Reilinger et al. 2006) and recent GPS studies within plate interiors (e.g. Aktug et al. 2009, 2013) provide important data about tectonic deformation and slip rates in the Anatolian plate. Most of the block boundaries determined by the GPS studies are compatible to the fault zones on the active fault map of Turkey. In fact, the fault zone deformations are more complex than indicated by the models, and the deformations are likely partitioned between different structures in the zone. Based on the available studies, we partitioned GPS-derived slip rates for the substantial fault segments identified in Turkey. The general characteristics of the seismotectonic domains are summarized below.

4.1 Domain 1: North Anatolian fault zone

The domain corresponds to the NAF zone. The NAF is one of the major active faults in the Eastern Mediterranean region (Ketin 1948; Şengör 1979; Sengör et al. 1985; Şaroğlu et al. 1992a, b; Barka 1992; Barka and Reilinger 1997; Emre et al. 2013). In the east–west trending between the Karlıova triple junction and the Aegean Sea basin, the 1400-km-long NAF is a dextral intra-continental transform structure (Figs. 2, 3). The 900-km-long eastern portion, west of Bolu, represents a narrow deformation zone of individual fault segments except for jog structures. In the middle part, near Niksar, the NAF zone bifurcates into the Anatolian plate forming inner strand structures. To the west, in the Marmara region, the fault splays into the strands and forms a 20- to 110-km-broad deformation zone in a complex horsetail-shaped geometry. The northern strand extends westwards into the Gulf of İzmit and traverses 225 km along the Marmara Sea basin floor. It then crosses to the Gulf of Saros reaching as far as the northern Aegean Sea basin. The southern strand splays into fault segments along the Biga Peninsula and forms multi-segment structures.

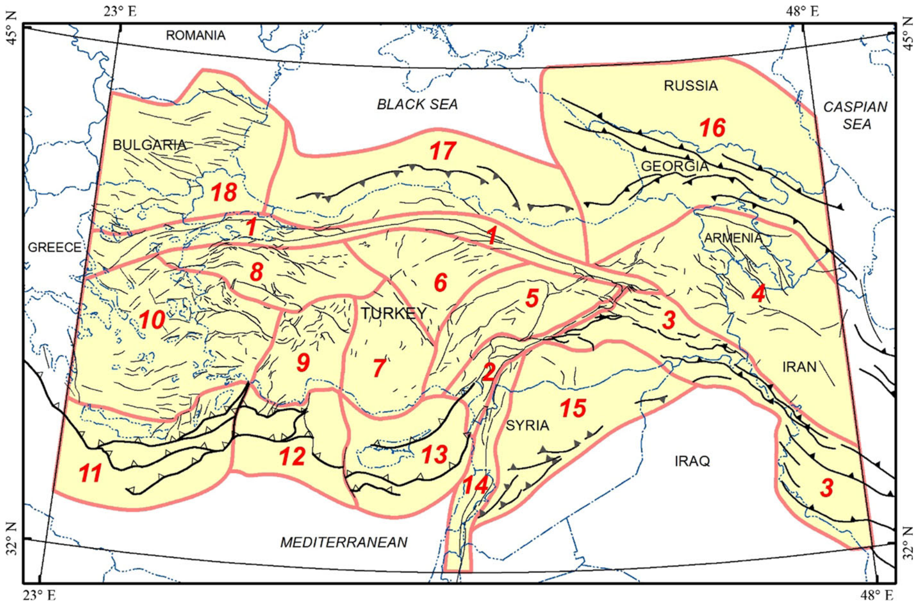

Fig. 12 Major Turkey seismotectonics domains, defined primarily by seismicity and fault zones with similar characteristics. Faults are as in Fig. 2. *Heavy lines with open triangles* show sutures: the tips of *triangles* indicate polarity. *Heavy lines with filled triangles* with on the *uplift side* indicate thrust belts. *Heavy lines* are major intra-plate undifferentiated major faults. Numbers show the domains: *1* North Anatolian fault zone; *2* East Anatolian fault zone; *3* Southeast Anatolian fault zone; *4* Eastern Anatolian; *5* Munzur; *6* Splays of North Anatolian fault zone; *7* Tuzgölü fault zone; *8* NW Anatolia transition fault zone; *9* Faults of İsparta Angle; *10* Western Anatolia graben systems; *11* Aegean arc; *12* Anaximander; *13* Cyprian arc; *14* Dead Sea fault zone; *15* Harran; *16* Caucasus thrust zone; *17* Faults of Pontide; *18* Thrace

The NAF zone was divided into 38 segments by Emre et al. (2013) considering geometry and seismic behaviour (Fig. 3).

The NAF zone expresses pure dextral strike–slip mechanism as the principal type of motion. Along the eastern part, some normal mechanisms are possibly related to large releasing stepover structures and bends, which are formed due to geometry along strike–slip zone and determine segment boundaries. This characteristic feature becomes more prominent to the west, in the Marmara region.

Geological data suggest that the long-term rate of motion on the NAFZ is 5–10 or 17 ± 2 mm/yr (Bozkurt 2001 and references therein). Based on radiometric dating, the Late Quaternary slip rate on the NAF zone varies from 18 ± 5 to 20.5 ± 5.5 mm/yr (Le Pichon et al. 2001, 2003; Hubert-Ferrari et al. 2002; Kozacı et al. 2007), whereas recent GPS data reveal slip rates of 15–25 mm/yr (Reilinger et al. 1997; McClusky et al. 2000, 2003; Meade et al. 2002). Recent GPS studies (Reilinger et al. 2006; Tatar et al. 2012; Ergintav et al. 2014) show that the slip rate increases towards the west from ~17 to 25 mm/yr.

In contrast, seismogenic depth along the NAF zone slightly increases towards the east from ~17 to 20 km (e.g. Kaypak and Eyidoğan 2005; Özalaybey et al. 2002; Çakır et al. 2003; Karabulut et al. 2002).

Seismicity of the NAF zone is one of the best known in the world. In the western part of the fault zone, around the Marmara region, 46 large historical earthquakes were identified (Ambraseys and Finkel 1995; Ambraseys 2002). During the instrumental period, 10 large earthquakes were generated by the NAF. After the 1912 earthquake of M_s 7.4 that occurred on the westernmost section of the NAF zone, an earthquake cycle has been started by the surface wave magnitude (M_s) 7.9, 1939 Erzincan earthquake on the easternmost section of the NAF zone. The earthquake sequence from east to west included 9 large earthquakes that ruptured a total of ~1000 km of the NAF with each earthquake typically triggering a subsequent event to the west (Ambraseys and Zatopek 1969; Ambraseys 1970; Toksöz et al. 1979; Barka and Kadinsky-Cade 1988; Barka 1992, 1996, 1997). Chronologically, these events are the December 27, 1939, Erzincan earthquake (M_s 7.9), the December 20, 1942, Erbaa-Niksar earthquake (M_s 7.1), the November 26, 1943, Tosya earthquake (M_s 7.4), the February 1, 1944, Bolu–Gerede earthquake (M_s 7.3), the May 26, 1957, Abant earthquake (M_s 7.1), the July 22, 1967, Mudurnu earthquake (M_s 7. 2), the March 13, 1992, Erzincan earthquake (M_w 6.3), the August 17, 1999, İzmit earthquake (M_w 7.4) and the November 12, 1999, Düzce earthquake (M_w 7.2). The 1999 İzmit (Barka et al. 2002) and Düzce (Duman et al. 2005) earthquakes developed as the last in the earthquake migration series on the NAF. Additionally, two large events, the December 8, 1905 (M_s 7.4) and September 26, 1932 (M_s 7.1), occurred in the North Aegean Trough and appear related to the westernmost part of the NAF zone.

Based on the earthquake cycles, recent studies suggest a 50 % probability of a major event $M \leq 7.6$ is in the Sea of Marmara within the next half century (Parsons et al. 2000; Şengör et al. 2005).

4.2 Domain 2: East Anatolian fault zone

The EAF zone represents the domain. The EAF zone (Arpat 1971; Arpat and Şaroğlu 1972, 1975; McKenzie 1972, 1978; Jackson and McKenzie 1984; Dewey et al. 1986; Westaway and Arger 1996; Westaway 2003, 2004: Duman and Emre 2013) is 580 km long and forms a complex sinistral strike–slip fault zone boundary between the Anatolian and Arabian plates (Figs. 2, 3). While the EAF exhibits a narrow deformation zone in the north-east, it is separated into northern and southern fault strands to the west and becomes a wide deformation zone. The southern strand of the EAF zone is between Karlıova and Çelikhan and is composed of seven fault segments (Duman and Emre 2013). The northern strand of the EAF zone, termed as Sürgü-Misis fault (SMF) system, is ~380 km from Çelikhan to the Gulf of İskenderun and consists of 8 fault segments (Figs. 2, 3), which exhibits distinctive active left-lateral fault features (Duman and Emre 2013).

Although the primary deformations along the EAF zone are sinistral strike–slip motion, there are several reverse mechanisms consistent with local restraining jog structures in the eastern part of the zone. Consistent with the broad deformation zone of the EAF to the west, both normal and reverse faulting deformations are also observed in the western part of the zone.

The GPS-derived sinistral slip motion of ~10 mm/yr (McClusky et al. 2000; Reilinger et al. 2006) on the EAF zone decreases towards the south partitioning about 1/3 of the slip to the Sürgü-Misis within a broad zone of deformation (Duman and Emre 2013). The GPS-derived slip rate of 9 ± 2 mm/yr (Reilinger et al. 2006) is consistent with a geologic slip rate of 8.3 mm/yr on the eastern part represented by a single strand of the EAF. Based on the geologic data, the slip rate on the main strand of the EAF decreases from 8.3 to 4.0 mm/yr (Şaroglu et al. 1987, 1992a, b; Westaway and Arger 1996; Westaway 2003, 2004; Herece 2008) at the Karasu trough where the EAF and the DSF zones overlap each other. The GPS-based studies indicate a higher 6.8 mm/yr slip rate along the Karasu trough.

There are no geodetic data along the SMF system. According to Holocene, geomorphological offsets of the SMF system Duman and Emre (2013), however, suggest a slip rate of ~3 mm/yr for the eastern half of the SMF system. Farther west, this slip is partitioned into the Toprakkale–Yumurtalık/Karataş and the Yakapınar–Savrun faults, at rates of ~2 and 1 mm/yr, respectively.

The EAF zone has generated a number of destructive earthquakes during the historical and instrumental periods (e.g. Pınar and Lahn 1952; Ergin et al. 1971; McKenzie 1972, 1978; Ayhan et al. 1981; Soysal et al. 1981; Eyidoğan et al. 1991; Jackson and McKenzie 1984; Dewey et al. 1986; Ambraseys and Finkel 1987; Ambraseys 1988; Taymaz et al. 1991; Tan et al. 2008; Kalafat et al. 2011). The EAF experienced a sequence of large earthquakes during the last two centuries, accompanied by surface ruptures (Seymen and Aydın 1972; Arpat and Şaroğlu 1975; Ambraseys and Jackson 1998). These include the 1866 earthquake (M_s 7.2), 1874 earthquake (M_s 7.1), 1893 earthquake (M_s 7.1) and 1971 earthquake (M_s 6.8) and are generated on the Karlıova, Palu, Erkenek and Ilıca segments of the EAF, respectively (Figs. 1, 2). Additionally, the 1905 (M_s 6.8) (Ambraseys and Jackson 1998) and the 2010 (M_w 6.1 and 6.0) earthquakes (Tan et al. 2011) occurred on the Yarpuzlu and the Gökdere restraining bends (Fig. 2), respectively. Although the EAF zone produces moderate earthquakes during the instrumental period, they are not characteristic large earthquakes for the EAF.

Although some of the events in the Karlıova have hypocentres deeper than 20 km, the overall seismicity of the EAF zone is less than 20 km (Türkelli et al. 2003; Bulut et al. 2012). However, seismological data show that the earthquakes on the western half of the SMF system are deep-seated events that reach down to 30 km in the Cilicia region (Aktar et al. 2000; Ergin et al. 2004). In contrast, the earthquakes (Ergin et al. 2004) located within the Düziçi-Osmaniye fault zone are characterized by shallow hypocentres of ~5 km.

At the western part of the EAF in Cilicia region, the earthquake events appear to originate from strike–slip and normal faults representing the plate boundary between the

African, Arabian and Anatolian plates (Aktar et al. 2000; Ergin et al. 2004). While strike–slip events occur in the lower crust, normal events are located in the upper crust relatively shallow. To the east of Amanos Mountains, along the Karasu trough, there is an area of lower seismic activity which displays a significant quiescence of large events for over 200 years.

4.3 Domain 3: Southeast Anatolian fault zone

The domain includes 45 identified fault segments. However, the SAT zone characterizes and almost encompasses the domain. Within the domain, the fault segment lengths range from ~7 to 70 km with an average length of 32 km. The majority of the fault segments are characterized as reverse (25; faults, 55.5 %) and dextral strike–slip motions (14 faults; 31.1 %) structures. The rest of the segments have sinistral strike–slip or normal slip motions.

The Bitlis suture zone is a complex fold-and-thrust belt formed by the collision between the Arabian and Anatolian plates, running from south-east Turkey to the Zagros Mountains in Iran (e.g. Şengör 1979; Şengör and Yılmaz 1981; Yılmaz 1993; Bozkurt 2001). The suture zone was formed as a result of tectonic processes from the Late Cretaceous to Recent, but the geometry and role of the suture zone changed after the Late Pliocene (~3 Ma) when the EAF zone initiated. Consequently, the SAT zone is now represented by active faults within the Bitlis suture.

The ~500-km-long east–west trending SAT zone is almost exclusively characterized by north-verging reverse faults formed due to the prevailing compressional tectonic regime (Figs. 2, 3). It exhibits a broad concave southward geometry becoming progressively younger along the southern front. While it represents a narrow deformation zone to the east, it is cut by the EAF, splays into fault strands and becomes a wide deformation zone to the west (Fig. 3). The SAT zone is divided into 12 main fault segments (Emre et al. 2013).

Additionally, in the north there are some east–west trending faults parallel to the SAT zone and north-verging reverse faults, which are the Van (>95 km long) and Muş (82 km long) fault zones (Fig. 3). The majority of the fault segments trend east to west, but there is an additional set of north–south striking faults within some of the domain, forming an orthogonal fault pattern to the N–S compressional tectonic structure and causing Quaternary volcanic activity. These are extension cracks, namely Ağrı, Tendürek, Diyadin and Nemrut (Emre et al. 2013) (Fig. 2).

GPS-derived slip rates (Reilinger et al. 1997, 2006; Djamour et al. 2011) for the fault segments across this domain vary from 0.2 to 3 mm/yr. Along the SAT zone in the area of interaction between the Iran and Arabian plates, the shortening and sinistral rates are 3.2 ± 0.4 and 1.2 ± 0.4 mm/yr, respectively.

In total, 241 earthquakes (M_w 4.0–6.5) were recorded in this domain between 1900 and 2012. The largest event was the September 6, 1975, Lice event (M_s 6.6) that occurred on the Lice segment of the SAT zone which resulted in surface rupture.

4.4 Domain 4: Eastern Anatolian

The domain is under an N–S compressional tectonic regime (e.g. Şengör 1979; Şengör et al. 1985; Şaroğlu and Yılmaz 1993), and recent deformations are accommodated by conjugate strike–slip faults. The conjugate fault systems appear as prolongations of the NAF and EAF zones with minor reverse component (Fig. 3). The dextral fault zones trending NW–SE are: Balıkgölü (95 km), Hasantimur (33 km), Çaldıran (52 km), Tutak

(57 km), Karayazı (59 km), Kavakbaşı (88 km) fault zones. The sinistral faults with NE–SW direction are Erzurum (63 km) and Horasan–Şenkaya (59 km) fault zones, having a significant reverse component motion. The Balıklıgöl and Çaldıran fault zones mostly run subparallel or link to the Tabriz fault zone farther east (Fig. 2).

The domain is mainly represented by the zone of interactions between the Iran plate and the Caucasus block and its internal deformations. There is no clear geological data on the long-term slip rate of the fault segments, but GPS-derived slip rates are available on the major fault zones of the domain. The shortening along the northern Caucasus block-bounding faults are 10 ± 2 mm/yr (Reilinger et al. 1997, 2006; Kadirov et al. 2008). Aktuğ et al. (2013) suggest a partitioning of this slip between Great and Lesser Caucasus as 6.4 ± 0.2 and 1–2 mm/yr, respectively. There is significant evidence for dextral strike–slip motion (10.8 ± 0.5 mm/yr) with reverse component (3.5 ± 0.5 mm/yr) along the southern boundary of the Caucasus block (Reilinger et al. 2006), which corresponds to the Çaldıran and Tabriz fault zone. The north-east boundary faults of the Caucasus block, Erzurum and Horasan–Narman fault zones, accommodate oblique shortening deformation of 1.4 ± 0.5 mm/yr with sinistral strike–slip of 0.9 ± 0.5 mm/yr.

The domain contains 65 fault segments ranging from 4 to 59 km long. The segments have a general 262°–221° trend, and the average length is ~20 km. The majority of the faults are dextral (39 faults; 60 %) and sinistral (16 faults; 24 %) slip motions, which are considered as part of a conjugate system. Additionally, there are 6 normal and 4 reverse fault segments in the domain. Seismogenic depth varies from 20 to 25 km, while some events extend down to 33 km depth. Slip rates assigned to the segments are between 0.3 and 2.5 mm/yr. In this domain, 581 earthquakes ranging from M_w 4.0 to 7.0 were recorded from 1900 to 2012. Of these, the largest event is the M_w 7.0, November 24, 1976, earthquake generated by the Çaldıran fault.

The Eastern Anatolia region is represented by a more complex structure resulting from differences in the seismogenic thickness ranging from 20 to 25 km (Elliott et al. 2013; Türkelli et al. 2003; Utkucu 2013; Zor et al. 2003). The recent 2011 Van earthquake in the east was a reverse event that shows that seismicity extends below 20 km depth (Elliott et al. 2013; Utkucu 2013).

4.5 Domain 5: Munzur

This domain is characterized by sinistral strike–slip faults that bound distinct terrains and were reactivated during the neotectonic period. The Deliler (204 km), Ecemiş (109 km), Sarız (2015 km), Ovacık (236 km) and Malatya (165 km) are substantial fault zones in the domain representing mainly sinistral strike–slip. All faults extend almost parallel to the EAF and are disposed to link with the Cyprus arc (Figs. 1, 2). The Deliler fault zone consists of 4 left-stepping segments (Fig. 3). It begins with reverse sense in the east and then traverses Anatolian plateau transitioning to strike–slip towards the west. The fault zone connects to the Ecemiş fault zones within the large releasing bend, where the Quaternary Erciyes volcano is located. The Ecemiş fault zone transects the Taurus Mountain from north to south forming a corridor. The Ovacık fault zone bifurcates from the NAF, traverses Munzur Mountain and reaches the triple junction complexity, where it meets with the Malatya and Deliler fault zones (Fig. 3). The N–S oriented Malatya fault represents an obvious active fault morphology. At the south, it joins into the EAF zone forming a fault complexity (Fig. 3). Although the majority of these fault zones are mostly strike–slip, some also have measurable normal and reverse components of slip, most commonly up to the north and south-west. Normal components on the Ecemiş and Deliler faults form a localized releasing subsidence along these faults, while large bend jogs between these faults form a transtensional basin to the west of Erciyes Mountain.

In the domain, strike–slip deformation is accommodated by sliced faults running from NE and NW having normal component towards the SE and SW. Regional study of Reilinger et al. (2006) suggests a 3.3 mm/yr sinistral strike–slip with 1.7 normal component and 4.2 mm/yr pure extension on these structures. Based on the block model of Aktug et al. (2009, 2013), however, the dominant deformations of extension and strike–slip in the region reach up to 5.3 ± 0.1 and 4.8 ± 0.1 mm/yr, respectively.

The domain experiences earthquakes reaching depths of ~17–20 km (Yolsal-Çevikbilen et al. 2012; Bulut et al. 2012). The average depth of hypocentres is between 15 and 20 km while some even reaching down to 39 km depth. The domain includes 54 fault segments trending mostly 173° and 230°. These range from 5 to 92 km long with an average length of ~32 km. The predominant fault type of the domain is sinistral strike–slip (31 faults; 57.4 %). The others are normal (6), oblique (4) and dextral (4) slips motions. GPS-based slip rate varies from 0.1 to 3.6 mm/yr. The domain experienced 232 earthquakes (M_w 4.0–6.3) during the time period between 1900 and 2012.

4.6 Domain 6: Splays of North Anatolian fault zone

The domain is characterized by fault arrays, inferred to splay westward from the NAF zone, around the Niksar releasing stepover. Some of them are the Merzifon-Esençay (229 km), Sungurlu (117 km) and Almus (59 km) faults (Fig. 3). They extend into the Anatolian plate for hundreds of kilometres and display slightly concave southward geometries (Bozkurt and Koçyiğit 1994) and form a typical fishbone structure (Şengör and Barka 1992), which is created by the rotation of en échelon wedges (Kaymakçı 2000; Kaymakçı and White 2000) away from the main NAF zone. The E–W trending faults parallel to the NAF zone mostly display a strike–slip character with reverse and normal components. Some of them, however, are steep reverse structures, which are similar to reactivated thrust faults. The reverse component increases due to the angle with the NAF zone (Fig. 3). Some of them with normal components control formation of negative flower structures such as the Kazova basin (Bozkurt and Koçyigit 1995a, b, 1996).

The domain experiences earthquakes down to ~17–20 km depth (Yolsal-Çevikbilen et al. 2012; Bulut et al. 2012). Yavaşoğlu et al. (2011) suggest that slip along the central part of the NAF is partitioned between splays and ranges from 18.7 ± 1.6 to 21.5 ± 2.1 mm/yr with the main branch accommodating ~90 % of the motion.

Splays of the NAF are P-shears and should have same sense of dextral motion as the major structure. There are, however, additional secondary fault segments having different sense of slip. Fault segments within this domain mostly strike 220° and 250° with varying sense of movements such as sinistral (2), normal (10), reverse (4) and dextral (16). Slip rates on the fault segments are estimated to range from 0.2 to 2 mm/yr, with the highest slip rate of 3.5 mm/yr on the Sungurlu fault segment. Fault segment lengths vary from about 5 to 82 km. There is a significant earthquake activity in the region with mostly moderate size events. The two well-known large events in the domain are the January 24, and March 19, 1938, Akpınar and June 6, 2000, Orta earthquakes.

4.7 Domain 7: Tuzgölü fault zone

The fault zones in the domain are mostly extensional. The Tuzgölü fault zone characterizes and forms the largest active structure of the domain. The Tuzgölü fault zone (e.g. Arpat and Şaroğlu 1975; Şengör et al. 1985) divides the eastern and central Anatolia faulting systems (Fig. 3). There are different opinions regarding the kinematics of this fault zone, for example, Şaroğlu et al. (1897) suggest dextral faulting along the southern part based on offset streams, while Barka and Reilinger (1997) indicate a steep reverse character with dextral component. Some recent researchers (Emre et al. 2013; Kürçer and Gökten 2014) proposed mainly dip slip faults for the zone. This study assigns primarily normal slip motion to the fault which trends NW–SE over about 200 km and is composed of six segments.

There are 16 normal and 2 dextral fault segments identified in this domain varying from 5 to 58 km in length with an average length of ~24 km. To the south of the domain, the fault zones are extensional structures. Many of these faults which trend either NE–SW or SE–NW are relatively short and display rift shape geometry. Some Quaternary volcanic cones appear to be aligned parallel to these extensional fissures. The dominant extensional deformations in the domain reach up to 5.3 ± 0.1 mm/yr (Aktuğ et al. 2013), with the highest slip rate assigned to the Tuzgölü fault zone (Fig. 4). In addition, there is a considerable evidence for compression (~2.5 mm/yr) to the south of Tuzgölü.

In total, 84 earthquakes (M_w 4.1–5.8) were recorded in the domain. The hypocentres typically range from 15 to 18 km depth with the deepest hypocentre reaching 37 km. The Altıneken fault segment (Emre et al. 2013) is inferred to have the largest M5.8 event on January 16, 1921.

4.8 Domain 8: NW Anatolia transition fault zone

This domain represents a transition zone from strike–slip to extensional motion. Tectonic structures observed in this region are generally right-lateral strike–slip faults within a broad restraining bend. The active faults delineated in the domain can be divided into two sets. In the north-west part of the domain, the fault zones are mainly active faults of the southern strands of the NAF zone (Fig. 2). In the north-east, the fault zones are primarily active dextral faults with dip–slip component trending NW–SE. The faults become progressively more oblique with an increasing component of extension towards the west and terminate within the Anatolian plate.

The NAF zone bifurcates into two main strands extending over a 120-km-broad deformation zone in the Marmara region representing complex horsetail geometry. The southern strand traverses tectonic valley, mountainous terrain and depressions and enters the Sea of Marmara in the Gulf of Gemlik. The fault then runs parallel to the southern coast of the Sea of Marmara and splays into multi-fault segments as it reaches the Biga Peninsula. Its termination is accomplished by bending and splaying into subparallel faults, which are the Sarıköy (66 km), Yenice-Gönen (70 km), Pazarköy (42 km), Bekten (19 km) Gündoğan (24 km) and Sinekci (26 km) faults (Fig. 3).

Towards the north-east of the domain, the Orhaneli (30 km), Uluabat (44 km) Manyas (40 km), Bursa (35 km), İnegöl (21 km) Oylat (20 km), Dodurga (56 km) and Eskişehir (42 km) faults are primarily dextral with dip–slip component trending NW–SE (Fig. 3). The faults become progressively more oblique with an increasing component of extension towards the east and terminate within the Anatolian plate.

The Simav fault zone forms the southern boundary of the domain, which separates strike–slip deformations to the north from extensional deformations to the south in western Anatolia. This dextral strike–slip zone is a 205-km-long trending NW–SE and consists of seven segments. To the east, it connects with the graben systems changing from strike–slip to dip–slip motions (Fig. 3).

In the Marmara region, the majority of the westward motion of the Anatolian microplate (24 ± 1 mm/yr) is principally accommodated along the northern branch of the NAFZ. Additionally, GPS studies suggest ~7 mm/yr of dextral slip rate within the region for the southern branch of the NAFZ ranging from 0.9 to 6.8 mm/yr for the dextral component and from 0.8 to 5.5 mm/yr for the vertical motions (Meade et al. 2002; Flerit et al. 2004; Reilinger et al. 2006; Aktug et al. 2009, 2013). For the Simav fault zone, Aktug et al. (2009, 2013) suggest 3.8 mm/yr for the dextral component and 1.3 mm/yr for the extensional component.

The 85 fault segments identified in this domain are largely divided into two sets generally striking 195° and 250°. The fault segments vary in length from 6 to 70 km, with an average of ~26 km. A range of fault types were identified with 45 (52 %) dextral strike–slip, 11 (13 %) reverse, 6 (7 %) normal and 2 (2 %) sinistral strike–slip faults.

The earthquakes recorded between 1900 and 2012 (674 events; M_s between 4.1 and 7.2) in the domain show heavy recent activity, including the large events, which are the 1944 M_s 6.8, the 1953 M_s 7.2, the 1964 M_s 7.0 and the 1970 M_s 7.2 earthquakes. These earthquakes resulted in surface ruptures and were generated by the Edremit, Yenice-Gönen, Manyas and Gediz faults, respectively. Slip rates vary between 0.05 and 7 mm/yr in the domain.

4.9 Domain 9: Faults of İsparta Angle

The domain corresponds to the İsparta Angle (e.g. Blumenthal 1963; McKenzie 1978; Robertson 1998; Koçyiğit and Özacar 2003) region. The region is located above the subduction of the African Plate near the junction between the AA and CA and appears to be rotating counterclockwise with respect to Anatolia (Tiryakioğlu et al. 2013) (Figs. 1, 2).

The İsparta Angle constitutes an important area in the structure of western Anatolia. Many studies refer to the boundary faults of the angle with different sense of movement and names (e.g. Blumenthal 1963; Robertson 1998; Koçyiğit 1983; Glover and Robertson 1998; Dolmaz 2007; Över et al. 2010). This study defines the boundary faults of the angle to the east as the Afyon–Akşehir Graben System and on the west as the fault zones located between Afyon and Fethiye, which are the Burdur (50 km), Acıgöl (72 km) graben systems and the Acıpayam (44 km), Eşen (54 km), Çameli (29 km) Çivril (44 km) and Dinar (55 km) fault zones (Fig. 3). The western boundary faults trend NE–SW beginning at Afyon and extending to the Mediterranean. It consists of parallel fault zones that succeed each other. The faults gain a sinistral strike–slip component and become more complex over a broad zone towards the SW, where they link to the Pliny–Strabo trench. The eastern side of the Isparta Angle is mostly bound by Afyon–Akşehir Graben System and does not extend to the Mediterranean. The graben system (150 km) displays a concave-northward geometry and represents a complex structure bifurcating radial subordinate grabens towards the north. There are faults within the angle area, with trends parallel to the boundary faults and form inner shape geometries similar to the İsparta Angle.

The domain includes 57 fault segments varying from in length from 5 to 45 km, with an average length of 19 km. The majority of the faults are normal (45 faults; 78.9 %), but oblique faults with a sinistral component (7 faults; 12.2 %) and sinistral faults (3 faults; 5.2 %) also have been identified.

The faults that constitute the western boundary of the İsparta Angle gain sinistral sense towards the Pliny–Strabo trench. Slip rates (Reilinger et al. 2006), which can be partitioned on to the fault segments, are between 0.3 and 3.4 mm/yr.

Between 1900 and 2012, 461 earthquakes ranging from M_w 4.0 to 6.8 were recorded in the domain. Most events had focal depth ranging from 20 to 25 km with some events reaching 33 km depth. The largest events among these are the October 3, 1914, Ms7.0 Burdur, May 12, 1971, M_s 6.2 Burdur, October 1, 1995, M_s 6.4 Dinar and February 3, 2003, M_s 6.5 Sultandağı earthquakes.

4.10 Domain 10: Western Anatolia graben systems

This Western Anatolia domain is characterized by the graben systems within an extensional regime. The Gediz and Büyük Menderes graben systems are the most distinct structures in the domain (e g., Şengör et al. 1985; Bozkurt 2001; Koçyiğit et al. 1999). Both have similar length and together represent a V-shaped geometry facing to the west (Fig. 3). The Gediz (150 km) and Büyük Menderes (170 km) graben systems consist of 6 and 17 segments, respectively.

The overall extension rate in the Western Anatolian region is ~20 mm/yr which represents one of the most rapid continental extensions in the world. Block modelling suggests that this extensional motion is partitioned between the major fault system in the region varying from 1.9 to 6.6 mm/yr together with north dextral components up to 4.9 mm/yr (Aktuğ et al. 2009) (Fig. 4).

The seismic activity of the domain is typical with spatially distributed, relatively frequent, moderate magnitude, and shallow crustal earthquakes. This seismicity is derived from the complex extensional tectonic processes which may be related to both westward motion of the Anatolian block and subduction rollback along the Aegean Trench (e.g. McKenzie 1972; Eyidoğan and Jackson 1985; Eyidoğan 1988; Zanchi and Angelier 1993; Zhu et al. 2006).

The domain includes 122 fault segments ranging from 5 to 64 km long. While the majority of the faulting mechanisms of the domain are dip–slip (98 faults; 80.3 %), there are faults characterized by sinistral (5), dextral (18) and reverse (1) slip motions. The hypocentre depths are between 13 and 16 km, while some events are as deep as 38 km deep. During the instrumental period, 971 events with magnitudes between M_w 4.1 and 6.5 were recorded. The three largest events in the domain are the July 16, 1955 (M_s 6.8), the March 23, 1969 (M_s 6.5) and the October 17, 2005 (M_w 5.9) earthquakes which were generated by the Gediz Graben system, Tuzla and Gülbahçe faults, respectively (Emre et al. 2013). Slip rates, which are partitioned by the fault segments in the domain, vary from 0.3 to 6 mm/yr based on the block model of Aktug et al. (2009, 2013).

4.11 Domain 11: Aegean arc

The AA extends in an arcuate shape between the Ionian Islands on the west and the Gulf of Fethiye to the east, where it links to the CA (e.g. McKenzie 1978; Dewey and Şengör 1979; Le Pichon and Angelier 1979). It consists of three main strands: Peloponnesus, Crete and Rhodes (Angelier et al. 1982). The arc, ~1200 km long and 120 km wide, constitutes mega active tectonic structures with distinct seismic activity and plays an important role in the seismic hazard of the Eastern Mediterranean. While the western part of the arc follows the Ionia basin and trench representing pure subduction character in the Aegean plate, the eastern side changes to a transform structure (Le Pichon et al. 1979).

The major faulting mechanism of the AA is thrust with oblique slip vectors due to the arc geometry. The domain also includes a mixture of normal, strike–slip and splay–thrust faulting due to the distributed deformation in the overriding Aegean plate and strike–slip faulting along both the east and west end of the arc, bounded by transform faults (Shaw and Jackson 2010).

The arc accommodates ~35 mm/yr of subduction of the African lithosphere beneath the Anatolian and Aegean micro plates (Reilinger et al. 2006). Shallow crustal seismicity is the highest along the convex side of the AA and widely distributed across the Aegean region. Despite this, the intermediate depth seismicity, which is related to the Benioff zone, is concentrated in the 140-km buffer zone located at the north of the arc, reaching depths of about 180 km (e.g. Papazachos 1990; Meier et al. 2004). Eight major earthquakes with $M_w > 7.0$ were recorded in this domain during the instrumental period. The arc may have the capacity to generate major or great events that exceed the recorded events.

4.12 Domain 12: Anaximander

This domain is a transfer zone between the AA and CA. It is mostly characterized by strike–slip movements along the transform fault, which transfers the convergence from the south to the Antalya Basin (Arvidsson et al. 1998; Papazachos and Papaioannou 1999; Pilidou et al. 2004). While the seismicity is characterized by shallow and intermediate-depth events and the absence of deep events south-west of Cyprus, deeper intermediate events are most abundant beneath the Antalya Basin (Wdowinski et al. 2006).

4.13 Domain 13: Cyprian arc

This domain is represented by the CA, which is another active subduction zone that accommodates convergence between the African and Anatolian plates (e.g. McKenzie 1970; Dewey et al. 1973; Kempler and Ben-Avraham 1987; Vidal et al. 2000). The arc, as the eastern prolongation of the AA, extends eastward towards the Gulf of Iskenderun and links to the other major faults of the region, namely the DSF and EAF zones (Fig. 2).

The southern boundary of the arc is well defined by the collision of the Eratosthenes sea mount (e.g. Robertson et al. 1994; Robertson and Grasso 1995). But there are different views about its eastern continuation, deformation type and the zone width. Some authors argued that there was no certain evidence of arc structure to the east of Cyprus (Robertson and Grasso 1995; McKenzie 1972, 1976; Mart 1994; Morelli 1978; Payne and Robertson 1995), while others suggest a strike–slip mechanism with reverse component (Kempler and Ben-Avraham 1987; Kempler and Garfunkel 1994: Vidal et al. 2000; Bozkurt 2001). The Larnaca–Amanos (~245 km) and Kyrenia–Misis (~295 km) fault zones located behind the CA are considered to be recent tectonic structures related to the evolution of the CA (Aksu et al. 2005a, b; Robertson et al. 2004; Calon et al. 2005a, b; Hall et al. 2005; McCay and Robertson 2013) (Fig. 2).

Focal plane solutions of large events along the CA show thrust slip consistent with expected convergence across the arc (Wdowinski et al. 2006).

The CA accommodates ~18 mm/yr of subduction of the African lithosphere beneath the Anatolian microplate (Reilinger et al. 2006). The seismicity along the CA includes shallow and intermediate depth earthquakes as would be expected from the prolongation of the AA activity (Ambraseys and Adams 1993). There are two obvious gaps in seismicity at the west and east of Cyprus which appears to not have produced significant activity in the last century. When comparing the capability of the structure to the instrumental catalogue, it appears that the arc has not experienced a characteristic earthquake during the instrumental period.

4.14 Domain 14: Dead Sea fault zone

The DSF, an ∼1000-km-long north–south–west trending, is a major sinistral intra-continental transform zone (Girdler 1990 and references therein) (Fig. 2). The DSF zone connects the EAF system and sea floor spreading in the Red Sea and forms a boundary between the African and Arabian plates. Its ∼250-km-long northern part, towards Anatolia into the Karasu through, exhibits a 50-km-wide zone created by right stepover.

The total offset suggested for the southern part of the DSF is ∼105 km, but the offsets decreases northward (Garfunkel et al. 2014 and references therein). For the northern section, the estimated offset varies from 25 to 70 km in the diffuse fault zone (e.g. Westaway 2003; Trifonov et al. 1991). The sinistral movements along the boundary of the Arabian and African plates, formed by the DSF zone, are ∼4 mm/yr (Reilinger et al. 2006).

The domain comprises the northern part of the DSF zone. The DSF zone traverses a tectonic valley, mountainous terrain and depressions and enters Turkey from the Asi tectonic valley. The fault then runs parallel to the eastern side of the Karasu tectonic trough and splays into fault segments. The fault segments locally exhibit a transpressive character because of the right-stepping en échelon faults.

The domain has experienced 29 earthquakes (M_w 4.0–5.6) between 1900 and 2012 with hypocentral depths between 15 and 20 km. A few events reach up to around 39 km deep. The domain includes 8 fault segments, which range from 9 to 85 km long with an average length of 39.5 km; the major fault type of the domain is sinistral strike–slip (5 faults; 57.4 %). The other identified faults are normal (2) and reverse (1) slip.

4.15 Domain 15: Harran

Domain 15 forms the most stable part of a promontory that projects north from the Arabian plate. It appears stable seismically and is bounded by the Palmyra reverse and fold zone. Most of the seismicity, which has 32 events ranging from M_w 4.1 to 5.3 between 1900 and 2012, have an average focal depth of 20 km and were generated by the Palmyra zone in the domain. The domain includes seven fault segments ranging between 9 and 50 km long in Turkey. The slip rates (Reilinger et al. 2006) attributed to these faults are between 0.3 and 2 mm/yr.

4.16 Domain 16: Caucasus thrust zone

The Lesser–Greater Caucasus (LGC) (Fig. 2) is characterized by WNW-trending active thrust to reverse faults, folds zone (Koçyiğit et al. 2001) and encompasses an area ∼1150 km long and ∼350 km wide. During the middle to late Pliocene, the LGC formed synchronously with the collision of the Arabian and Eurasian plates (e.g. Philip et al. 1989). Total shortening in the LGC has been estimated at about 200 km (Dotduyev 1986). Current shortening rates are estimated to be ∼10 mm/yr (Reilinger et al. 1997). The LCG zone has generated moderate earthquakes, but not many large events, and has a seismic history similar to that of the CA and SAT zones (Fig. 5).

4.17 Domain 17: Faults of Pontide

This domain occupies the Pontide orogenic belt running between the Black Sea and the inner Anatolian plateau. The main structure is the Pontic Escarpment (PE) (Erdik et al. 1983), which separates the Pontid belt and abyssal plain of Black Sea (Fig. 2). The nature of the entire PE is not well known, but it appears to be a reverse fault zone that controls morphologically the southern continental slope of the Black Sea. It constitutes a western continuation of the Lesser Caucasus thrust in the Eastern Black Sea basin, having well-known recent seismic activity (Zonenshain and Le Pichon 1986; Robinson et al. 1996; Okay and Şahintürk 1997; Rangin et al. 2002). We assumed that the PE is a compressional tectonic structure bounding Pontide terrain uplifted from Late Eocene to Recent.

Available data indicate that the Pontic escarpment is a mega morphotectonic and structural element of the Pontide frontal thrust; however, there are no high-resolution seismic data to understand the origin and activity of Pontic Escarpment or the faults on the Black Sea shelf along Turkish coast.

Besides the PE, the domain contains relatively few active fault segments. To the east, there are no currently active faults. To the west, there are three active fault zones, having reverse senses of movement. All splay from the NAF zone, and secondary compressional structures formed as a consequence of the large-scale restraining bend (e.g. Yildirim et al. 2011). According to the active fault data base of Emre et al. (2013, 2016) which was utilized for the delineation of seismotectonic domains across Turkey and the surroundings regions, there are several mapped (onshore) probable Quaternary fault or lineaments and Quaternary faults in the central and western Pontides. These are the Erikli, Ekinveren, Karabük, Devrek, Yığılca and Çilimli faults. Additionally, there is a large database of seismic lines from oil and gas exploration along the Pontides, but this database has not been fully exploited for mapping Quaternary-active faults due to the deficiency of geological–geomorphological evidence.

Recent GPS-derived slip rate and seismic activity reveal that the Eastern Black Sea is under a compressional tectonic regime in N–S direction (Barka and Reilinger 1997; Tarı et al. 2000). The M_s 6.8 September 3, 1968, Bartın earthquake (Alptekin et al. 1986) is the most recent large event to have occurred in the PE zone revealing the compressional regime. The reverse faulting mechanism of the 1968 event resulted in an uplift of 40 cm along the on shore coast (Ketin and Abdüsselamoğlu 1969). The 1968 event is interpreted as the reactivation of palaeotectonic reverse or thrust structures within the PE zone by the NAF system (Barka and Reilinger 1997). However, there are no available geological–geomorphological or seismic data showing the precise location of the source fault associated with this event. The slip rate across the domain is smaller than 5 mm/yr (Barka and Reilinger 1997).

4.18 Domain 18: Thrace

Domain 18 covers Thrace, Bulgaria and north-eastern part of Greece. A fault zone trending E–W is located to the south of the Stara Planina Mountains and corresponds to the Carpathian Arc. While the northern part of this zone is shortening of 3 ± 1 mm/yr, southern part is extensional 3–4 mm/yr (Kotzev et al. 2001). However, active faults of the domain are not well known.

There are 41 fault segments in the domain varying from 27 to 178 km long (Burchfiel et al. 2006), and it has distinct seismicity from 1900 to 2012. With 4 events larger than M_s

7.1, there are 316 events recorded between 1900 and 2012. The large events are the April 4, 1904 (M_s 7.1), the April 4, 1904 (M_s 7.8), the June 14, 1913 (M_s 7.0) and the April 19, 1928 (M_s 7.1). Although large events have occurred in the domain, source faults or related surface has not been defined for these events (Meyer et al. 2002).

5 Concluding remarks

A synthesis of the available geological, seismological and geodetic data allows the following implications regarding the seismotectonic of Anatolia and its surroundings.

- The seismicity in Anatolia and the surrounding region is generated from complex tectonics processes, related to the recent interactions of the Eurasian, Arabian and African plates. These processes are subduction, post-continental collision, crustal extension and extrusion or escape tectonics. The NAF and EAF zones, which are intra-continental transform faults, accommodate the westward extrusion of the Anatolian microplate. Subduction occurs along the AA and CA to the south-west. In western Anatolia and for the wider Aegean region, continental extension occurs and is controlled by both the escape and extrusion of the Anatolian plate and the collision and retreat of the African slab. The compressional deformation in Eastern Anatolian is accommodated by folds, reverse and conjugate strike–slip fault systems. The DSF zone is the boundary between the African and Arabian plates and the transform between sea floor spreading in the Red Sea and the EAF and CA zones.
- Consequently, the major structures, the NAF, EAF, DSF, AA and CA zones, are responsible for the seismicity of Anatolia and the surrounding region, which are components of recent plate tectonics in the Eastern Mediterranean.
- In addition to the major active structures, there are 533 single-fault segments, which have been identified as substantial potential earthquake sources across Anatolia. These fault segment lengths range between 4 and 330 km. The majority of the fault segments exhibit primarily strike–slip (261 faults; 48.9 %) and normal slip (227 faults; 42.5 %) mechanisms. The rest of the segments (45 faults; 8.6 %) have reverse slip characteristics.
- The distribution of the seismic activity across Anatolia is mostly consistent with the active fault map of Turkey and is largely generated by plate motions along major transform or subduction related faults, which create recent intraplate crustal deformation zones.
- During the instrumental time period, 12,674 events with magnitude larger than 4.0 occurred in Anatolia and the surrounding region (defined as the area between 32° and 45°N and 23°–48°E). Of these, 203 events are greater than magnitude (M_w) 6.0 and 1468 events are $5.0 \leq M_w < 6.0$. For all events, the total shallow-focus earthquake and mid-focus or intermediate earthquakes are 93.5 and 6.4 %, respectively. Similarly, 1.236 historical events with intensity $>V$ were identified for the time period AD 1900–BC 2000, in the same region. In general, the spatial distribution of the epicentres in historical and instrumental time correlates well with active fault maps of Turkey. Both instrumental and historical large events display comparable spatial distributions across the major source faults.
- The seismicity in Anatolia is characterized by shallow depth crustal earthquakes, but the surrounding region is represented by mid-focus or intermediate depths. At shallow crustal depths, seismicity is concentrated within the Anatolian plate and along

transform plate boundaries. While the greatest concentration of small and mid-scale shallow-deep earthquakes is in the western Anatolia, large shallow-deep earthquakes are generated by strike–slip faults in north and east Anatolia. This seismicity in western Anatolia is controlled by the complex extensional tectonics related to both extrusion and subduction rollback processes. At mid-depths, seismicity is almost exclusively generated by the AA and CA, which are events that occur in between subducting and overriding plates.

- During the last century, 203 destructive earthquakes with a magnitude (M_w) of 6.0 or greater have struck Anatolia and the immediate surrounding. Of these, 70 earthquakes resulted in surface ruptures, 28 of which have been mapped in detail. While the NAF and EAF zones comprise 10 and 2 of these surface ruptures, respectively, the others are distributed in the west and east Anatolia regions.
- Based on the hypocentral depths of 12.674 events included in the new earthquake catalogue, the seismogenic depth ranges from ~15 to ~190 km all over Anatolia and the surrounding region. Although intermediate-deep earthquakes (70–190 km) are generated by the AA and CA, Anatolia is largely characterized by shallow crustal earthquakes (15–35 km). The diverse amalgamated lithospheric fragments, suture zones and the various ongoing, tectonic processes cause significant variances in seismogenic depth from one region to the other across Anatolia. From west to east, the thickness of the seismogenic zone increases, whereas from south to north there are fluctuations in the thickness of the seismogenic zone.
- All the data, including seismic zones, catalogues of instrumental and historical earthquakes, moment tensor solutions, crustal thickness contours and slip rates, required for seismic hazard assessment were documented in a GIS environment. Subsequently, we prepared two seismotectonic maps at two different scales. These are the seismotectonic map series of Turkey (1:500,000 scale) and seismotectonic map of Turkey (1:1,250,000 scale).
- The seismotectonic database and related maps allow us to evaluate the study area with regard to seismotectonics regionalization. On the basis of these data, Turkey and the surrounding region were divided into 18 major seismotectonic zones which are characterized by similar seismic sources and seismicity.

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References

AFAD, Disaster and Emergency Management Authority, earthquake department catalogue, 2007–2012. http://www.deprem.gov.tr/sarbis/Veritabani/DDA.aspx?param=1

Agostini S, Doglioni C, Innocenti F, Manetti P, Tonarini S (2010) On the geodynamics of the Aegean rift. Tectonophysics 488(1):7–21

Aksu AE, Calon TJ, Hall J, Yaşar D (2005a) Origin and evolution of the Neogene Iskenderun Basin, northeastern Mediterranean. Sea Mar Geol 221:161–187. doi:10.1016/j.margeo.2005.03.010

Aksu AE, Hall J, Yaltırak C (2005b) Miocene to recent tectonic evolution of the eastern Mediterranean: new pieces of the old Mediterranean puzzle. Mar Geol 221:1–13. doi:10.1016/j.margeo.2005.03.014

Aktar M, Ergin M, Özalaybey S, Tapırdamaz C, Yörük A, Biçmen F (2000) A lower-crustal event in the northeastern Mediterranean: the 1998 Adana earthquake (Mw = 6.2) and its aftershocks. Geophys Res Lett 27:2361–2364. doi:10.1029/2000GL011412

Aktuğ B, Nocquet JM, Cingöz A, Parsons B, Erkan Y, England P, Lenk O, Gürdal MA, Kilicoglu A, Akdeniz H, Tekgül A (2009) Deformation of western Turkey from a combination of permanent and campaign GPS data: limits to block-like behaviour. J Geophys Res 114. B10404. doi:10.1029/2008jb006000

Aktuğ B, Parmaksız E, Kurt M, Lenk O, Kılıçoğlu A, Gürdal MA, Özdemir S (2013) Deformation of Central Anatolia: GPS implications. J Geodyn 67:78–96. doi:10.1016/j.jog.2012.05.008

Albini P, Musson RMW, Gomez-Capera AA, Locati M, Rovida A, Stucchi M, Viganò D (2013) Global historical earthquake archive and catalogue (1000–1903). GEM technical report, GEM Foundation, 2013-01 V1.0.0. Pavia, Italy. doi:10.13117/GEM.GEGD.TR2013.01

Alptekin Ö, Nabelek J, Toksöz MN (1986) Source mechanism of the Bartın earthquake of September 3, 1968 in northwest Turkey: evidence for active thrust faulting at the southern Back Sea margin. Tecronophysics 122:73–88

Alsan E, Tezuçan L, Bath M (1975) An earthquake catalogue for Turkey for the interval 1913–1970. Kandilli Observatory Seismological Department Çengelköy-İstanbul Turkey and Seismological Institute Box 517, S-751 20 Uppsala, Sweden

Altıner D (1989) An example for the tectonic evolution of the Arabian Platform margin (SE Anatolia) during the Mesozoic and some criticisms of the previously suggested models. In: Sengör AMC (ed) Tectonic evolution of Tethyan regions. Kluwer Academic Publishing, Dordrecht, pp 117–129

Ambraseys NN (1970) Some characteristic features of the North Anatolian fault zone. Tectonophysics 9:143–165

Ambraseys NN (1988) Engineering seismology. J Earthq Eng Struct Dyn 17:1–105

Ambraseys NN (2002) The seismic activity of the Marmara Sea region over the last 2000 years. Bull Seismol Soc Am 92(1):1–18

Ambraseys NN (2009) Earthquakes in the Mediterranean and Middle East: a multidisciplinary study of seismicity up to 1900. Cambridge University Press. ISBN 978 0 521 87292 8. doi:10.1017/S0016756810000452

Ambraseys NN, Adams RD (1993) Seismicity of the Cyprus region. Terra Nova 5:85–94. doi:10.1111/j.1365-3121.1993.tb00229.x

Ambraseys NN, Finkel CF (1987) Seismicity of Turkey and neighbouring regions, 1899–1915. Ann Geophys 5B(6):701–726

Ambraseys NN, Finkel CF (1995) The seismicity of Turkey and adjacent areas—a historical review, 1500–1800. Muhittin Salih Eren, İstanbul

Ambraseys NN, Jackson JA (1998) Faulting associated with historical and recent earthquakes in the Eastern Mediterranean region. Geophys J Int 133:390–406

Ambraseys NN, Zatopek A (1969) The Mudurnu Valley, West Anatolia, Turkey, earthquake of 22 July 1967. Bull Seismol Soc Am 59(2):521–589

Angelier J, Lybéris N, Le Pichon X, Barrier E, Huchon P (1982) The tectonic development of the Aegean arc and the sea of Crete a synthesis. Tectonophysics 86:159–196

Arpat AE (1971) 22 Mayıs, 1971 Bingöl Depremi-Ön Rapor. Institute of Mineral Research and Exploration Report No: 4697

Arpat E, Şaroğlu F (1972) Doğu Anadolu Fayı ile ilgili bazi gözlemler ve düşünceler. MTA Dergisi 78:33–39

Arpat E, Şaroğlu F (1975) Türkiye'deki bazı önemli genç tektonik olaylar. Türkiye Jeoloji Kurumu Bülteni 18:91–101

Arslan S (2012) 1:1.500.000 ölçekli Türkiye Kabuk Kalınlığı Haritası. MTA Genel Müdürlüğü yayını

Arslan S, Akin U, Alaca A (2010) Gravite verileriyle Türkiye'nin kabuk kalınlığı yapısının incelenmesi. MTA Dergisi 140:57–73

Arvidsson R, Ben-Avraham Z, Eckström G, Wdowinski S (1998) Plate tectonic framework for the October 9, 1996 Cyprus earthquake. Geophy Res Lett 25:2241–2244

Aydemir A (2008) Hydrocarbon potential of the Tuzgolu (Salt Lake) Basin, Central Anatolia, Turkey: a comparison of geophysical investigation results with the geochemical data. J Petrol Sci Eng 61:33–47. doi:10.1016/j.petrol.2007.10.004

Ayhan E, Alsan E, Sancaklı N, Üçer SB (1981) Turkey and surrounding earthquake catalogue 1881–1980. Boğaziçi University Publications, Istanbul

Barazangi M, Seber D, Chaimov T, Best J, Litak R, Al-Saad D, Sawaf T (1993) Tectonic evolution of the northern Arabian plate in western Syria. In: Recent evolution and seismicity of the Mediterranean region. Kluwer Academic Publishers, Amsterdam, pp 117–140

Barka AA (1992) The North Anatolian fault. Ann Tecton 6:174–195

Barka AA (1996) Slip distribution along the North Anatolian fault associated with the large earthquakes of the period 1939 to 1967. Bull Seismol Soc Am 86(5):1238–1254

Barka A (1997) Neotectonics of the Marmara region in active tectonics of northwest Anatolia. In: Schindler C, Pfister M (eds) The Marmara poly-project. Hochshulverlag AG and der ETH, Zurich, pp 55–87

Barka AA, Kadinsky-Cade K (1988) Strike–slip fault geometry in Turkey and its influence on earthquake activity. Tectonics 7:663–684

Barka A, Reilinger R (1997) Active tectonics of the Eastern Mediterranean region: deduced from GPS, neotectonic and seismicity data. Analli di Geofisica 40(3):587–610

Barka AA, Akyüz S, Altunel E, Sunal G, Çakır Z, Dikbaş A, Yerli B, Armijo R, Meyer B, Chabalier JB, Rockwell T, Dolan JR, Hartleb R, Dawson T, Christofferson S, Tucker A, Fumal T, Langridge R, Stenner H, Lettis W, Bachhuber J, Page W (2002) The surface rupture and slip distribution of the 17 August 1999 İzmit earthquake (M 7.4), North Anatolian fault. Bull Seismol Soc Am 92(1):43–60

Blumenthal MM (1963) Le systeme structural du Taurus sud Anatolies. Bull Soc Geol Fr. In: Livre a Memoire de Professor P. Fallot. Mem Soc Geol Fr 1(2):611–662

Bozkurt E (2001) Neotectonics of Turkey—a synthesis. Geodin Acta 14:3–30. doi:10.1016/S0985-3111(01)01066-X

Bozkurt E, Koçyiğit A (1995a) Almus fault zone: its age, total offset and relation to the North Anatolian fault zone. Turk J Earth Sci 4:93–104

Bozkurt E, Koçyiğit A (1995b) Stratigraphy and geologic evolution of the Almus fault zone in Almus–Tokat region. Assoc Turk Pet Geol Bull 7:1–16

Bozkurt E, Koçyiğit A (1996) Kazova basin: an active negative flower structure on the Almus fault zone, a splay fault system of the North Anatolian fault zone, Turkey. Tectonophysics 265:239–254

Bozkurt E, Mittwede SK (2001) Introduction to the geology of Turkey—a synthesis. Int Geol Rev 43(7):578–594. doi:10.1080/00206810109465034

Bulut F, Bohnhoff M, Eken T, Janssen C, Kılıç T, Dresen G (2012) The East Anatolian fault zone: seismotectonic setting and spatiotemporal characteristics of seismicity based on precise earthquake locations. J Geophys Res Solid Earth. doi:10.1029/2011jb008966

Burchfiel BC, King RW, Todosov A, Kotzev V, Durmurdzanov N, Serafimovski T, Nurce B (2006) GPS results for Macedonia and its importance for the tectonics of the Southern Balkan extensional regime. Tectonophysics 413:239–248

Burke K, Şengör AMC (1986) Tectonic escape in the evolution of the continental crust. In: Barazangi M (ed) Reflection seismology, continental crust, geodynamic series, vol 14. American Geophysical Union Special Publication, Washington, pp 41–53. doi:10.1029/GD014p0041

Çakır Z, de Chabalier JB, Armijo R, Meyer B, Barka AA, Peltzer G (2003) Coseismic and early post-seismic slip associated with the 1999 Izmit earthquake (Turkey), from SAR interferometry and tectonic field observations. Geophys J Int 155:93–110

Calon T, Aksu A, Hall J (2005a) The Oligocene-recent evolution of the Mesaoria Basin (Cyprus) and its western marine extension, Eastern Mediterranean. Mar Geol 221:95–120. doi:10.1016/j.margeo.2005.03.012

Calon TJ, Aksu AE, Hall J (2005b) The neogene evolution of the outer Latakia Basin and its extension into the Eastern Mesaoria Basin (Cyprus), Eastern Mediterranean. Mar Geol 221:61–94. doi:10.1016/j.margeo.2005.03.013

Caputo R, Chatzipetros A, Pavlides S, Sboras S (2012) The greek database of seismogenic sources (GreDaSS): state-of-the-art for northern Greece. Ann Geophys 55(5):859–894. doi:10.4401/ag-5168

Caputo R, Sboras S, Pavlides S, Chatzipetros A (2015) Comparison between single-event effects and cumulative effects for the purpose of seismic hazard assessment. A review from Greece. Earth Sci Rev 148:94–120

Demirel IH (2004) Petroleum systems in the eastern and central Taurus region, Turkey. Mar Pet Geol 21:1061–1071. doi:10.1016/j.marpetgeo.2004.06.001

Dewey JF, Şengör AMC (1979) Aegean and surrounding regions: complex multiplate and continuum tectonics in a convergent zone. Geol Soc Am Bull 90:84. doi:10.1130/0016-7606(1979)90<84:aasrcm>2.0.co;2

Dewey JF, Pitman WC, Ryan WB, Bonnin J (1973) Plate tectonics and the evolution of the Alpine system. Geol Soc Am Bull 84:3137–3180. doi:10.1130/0016-7606(1973)84<3137:PTATEO>2.0.CO;2

Dewey JF, Hempton MR, Kidd WSF, Saroglu F, Şengör AMC (1986) Shortening of continental lithosphere: the neotectonics of Eastern Anatolia—a young collision zone. Geol Soc Lond Spec Publ 19:1–36. doi:10.1144/gsl.sp.1986.019.01.01

Djamour Y, Vernant P, Nankali HR, Tavakoli F (2011) Nw Iran-eastern Turkey present-day kinematics: results from the Iranian permanent GPS network. Earth Planet Sci Lett 307:27–34

Doglioni C, Agostini S, Crespi M, Innocenti F, Manetti P, Riguzzi F, Savaşçın MY (2002) On the extension in western Anatolia and the Aegean Sea. J Virtual Explor 8:169–184
Doglioni C, Carminati E, Cuffaro M, Scrocca D (2007) Subduction kinematics and dynamic constraints. Earth Sci Rev 83:125–175
Dolmaz MN (2007) An aspect of the subsurface structure of the Burdur–Isparta area, SW Anatolia, based on gravity and aeromagnetic data, and some tectonic implications. Earth Planets Space 59:5–12
Dotduyev SI (1986) Nappe structure of the greater Caucasus range. Geotectonics 20:420–430
Duman TY, Emre O (2013) The East Anatolian fault: geometry, segmentation and jog characteristics. Geol Soc Lond Spec Publ 372:495–529. doi:10.1144/sp372.14
Duman TY, Emre O, Dogan A, Ozalp S (2005) Step-over and bend structures along the 1999 Duzce earthquake surface rupture, North Anatolian fault, Turkey. Bull Seismol Soc Am 95:1250–1262
Elliott J, Copley A, Holley R, Scharer K, Parsons B (2013) The 2011 Mw 7.1 Van (Eastern Turkey) earthquake. J Geophys Res Solid Earth 118:1619–1637. doi:10.1002/jgrb.50117
Emre Ö, Duman TY, Özalp S, Elmacı H, Olgun Ş, Şaroğlu F (2013) Active fault map of Turkey with an explanatory text 1:1,250,000 scale. General Directorate of Mineral Research and Exploration, Special Publication Series 30
Emre Ö, Duman TY, Özalp S, Çan T, Olgun Ş, Elmacı H, Şaroğlu F (2016) Active fault database of Turkey. Bull Earthq Eng (in review)
EMSC-CSEM, European-Mediterranean Seismological Centre earthquake catalog, 1998–2012. http://www.emsc-csem.org/Earthquake/?filter=yes
Erdik M, Oner S (1982) A rational approach for the probabilistic assessment of the seismic risk associated with the North Anatolian fault. In: Işıkara A (ed) Multi-disciplinary approach to earthquake prediction. Vogel Vieweg, Brauschweig-Wiesbaden, pp 115–127
Erdik M, Doyuran V, Yücemen S, Gulkan P, Akkas N (1982) A probabilistic assessment of the seismic hazard in Turkey for long return periods. In: Proceedings 3rd international earthquake microzonation conference, Seattle, Washington, pp 1261–1272
Erdik M, Doyuran V, Gülkan P, Akçora G (1983) Probabilistic assessment of the seismic intensity in Turkey for the siting of nuclear power plants. In: Proceedings of 2nd CSNI specialist meeting on probabilistic methods in seismic risk assessment for nuclear power plants. Lawrence Livermore National Laboratory, Livermore, CA, USA
Erdik M, Doyuran V, Akkas N, Gulkan PA (1985) Probabilistic assessment of the seismic hazard in Turkey. Tectonophysics 117:295–344
Erdik M, Biro Y, Onur T, Sesetyan K, Birgoren G (1999) Assessment of earthquake hazard in Turkey and neighboring regions. Ann Geofis 42(6):1125–1138
Ergin K, Güçlü U, Uz Z (1967) Türkiye ve civarının deprem kataloğu (M.S. 11-1964). İTÜ, Maden Fakültesi, Arz Fiziği Enstitüsü Yayınları, No: 24, 169 s
Ergin K, Güçlü Ü, Aksoy G (1971) Türkiye ve civarının deprem kataloğu (1965–1970). İTÜ Arz Fiziği Enst. Yay. 28, 74 s
Ergin M, Aktar M, Eyidoğan H (2004) Present-day seismicity and seismotectonics of the Cilician Basin: Eastern Mediterranean Region of Turkey. Bull Seismol Soc Am 94:930–939. doi:10.1785/0120020153
Ergintav S, Reilinger RE, Çakmak R, Floyd M, Çakır Z, Doğan U, King RW, McClusky S, Özener H (2014) Istanbul's earthquake hot spots: geodetic constraints on strain accumulation along faults in the Marmara seismic gap. Geophys Res Lett 41:5783–5788. doi:10.1002/2014GL060985
Eyidoğan H (1988) Rates of crustal deformation in western Turkey as deduced from major earthquakes. Tectonophysics 148:83–92
Eyidoğan H, Jackson J (1985) A seismological study of normal faulting in the Demirci, Alaqehir and Gediz earthquakes of 1969–70 in western Turkey: implications for the nature and geometry of deformation in the continental crust. Geophys J R Astr Soc 81:569–607
Eyidoğan H, Güçlü U, Utku Z, Değirmenci E (1991) Türkiye büyük depremleri makrosismik rehberi (1900-1988). İTÜ. Maden Fak., Jeofizik Müh. Bölümü yayınları, 198 s
Flerit F, Armijo R, King G, Meyer B (2004) The mechanical interaction between the propagating North Anatolian fault and the back-arc extension in the Aegean. Earth Planet Sci Lett 224:347–362. doi:10.1016/j.epsl.2004.05.028
Garfunkel Z, Ben-Avraham Z, Kağan E (2014) Dead sea transform fault system—reviews. Springer, Berlin
Girdler RW (1990) The dead-sea transform-fault system. Tectonophysics 180:1–13. doi:10.1016/0040-1951(90)90367-H
Glover C, Robertson AHF (1998) Neotectonic intersection of the Aegean and Cyprus tectonic arcs: extensional and strike–slip faulting in the Isparta Angle, SW Turkey. Tectonophysics 298:103–132
Güçlü U, Altınbaş G, Eyidoğan H (1986) Türkiye ve çevresi deprem kataloğu (1971–1975). İTÜ Yayını, Maden Fak., No: 30, 191 s., İstanbul

Gudjabidze GE (2003) Geological map of Georgia 1:500 000. In: Gamkrelidze IP (ed.) Georgian State Department of Geology and National Oil Company 'Saknatobi' Tbilisi
Gutenberg B, Richter CF (1954) Seismicity of the earth and associated phenomena, 2nd edn. Princeton University Press, Princeton
Hall J, Aksu A, Calon T, Yaşar D (2005) Varying tectonic control on basin development at an active microplate margin: Latakia Basin, Eastern Mediterranean. Mar Geol 221:15–60. doi:10.1016/j.margeo.2004.05.034
Herece E (2008) Doğu Anadolu Fayı (DAF) Atlası. MTA Özel Yayın Serisi, No: 13, 359 s., Ankara
Hessami K, Jamali F, Tabassi H (2003) Major active faults of Iran. Ministry of Science Research and Technology, International Institute of Earthquake Engineering and Seismology, Tehran
HRVD and GCMT, The Harvard Centroid Moment Tensor Catalogue, The Global Centroid-Moment-Tensor Project, 1976-2012
Hubert-Ferrari A, Armijo R, King GCP, Meyer B, Barka A (2002) Morphology, displacement, and slip rates along the North Anatolian fault, Turkey. J Geophys Res 107:2235. doi:10.1029/2001JB000393
ISC, International Seismological Centre Event Catalog, 1960–2010. http://www.isc.ac.uk/iscbulletin/search/catalogue/
ISN, Iraqi Meteorological and Seismology Organization, Iraq
ISS, Bulletins of International Seismological Summary, 1918–1963
Jackson J, McKenzie D (1984) Active tectonics of the Alpine-Himalayan belt between western Turkey and Pakistan. Geophys J R Astr Soc 77:185–264
Kadirioğlu FT, Kartal RF, Kılıç T, Kalafat D, Duman TY, Eroğlu Azak T, Özalp S, Emre Ö (2016) An improved earthquake catalogue ($M \geq 4.0$) for Turkey and its near vicinity. Bull Earthq Eng (In review)
Kadirov F, Mammadov S, Reilinger R, McClusky S (2008) Some new data on modern tectonic deformation and active faulting in Azerbaijan (according to global positioning system measurements). In: Proceedings of Azerbaijan National Academy of Sciences, The Sciences of Earth vol 1, pp 82–88
Kalafat D, Güneş Y, Kekovalı K, Kara M, Deniz P, Yılmazer M (2011) Bütünleştirilmiş Homojen Türkiye Deprem Kataloğu (1900-2010); $M \geq 4.0$). Boğaziçi Üniversitesi Kandilli Rasathanesi ve Deprem Araştırma Enstitüsü Yayın No: 1049, 640 s., Bebek-İstanbul
Karabulut H, Bouin M, Bouchon M, Dietrich M, Cournou C, Aktar M (2002) The seismicity in the eastern Marmara sea after the August 17, 1999 Izmit earthquake. Bull Seismol Soc Am 92:387–393
Karadenizli L (2011) Oligocene to Pliocene palaeogeographic evolution of the Cankiri-Corum Basin, central Anatolia, Turkey. Sedim Geol 237:1–29. doi:10.1016/j.sedgeo.2011.01.008
Kayabalı K (2002) Modeling of seismic hazard for Turkey using the recent neotectonic data. Eng Geol 63:221–232
Kaymakçı N (2000) Tectonostratigraphic evolution of the Çankırı Basin (Central Anatolia, Turkey). Geologica Ultraiectina, Mededlingen van de Faculteit Aardwetenschappen, Universiteit Utrecth No. 190
Kaymakçı N, White SH (2000) Van Dijk M (2000) Palaeostress inversions in a multiphase deformed area: kinematic and structural evolution of the Çankırı basin (central Turkey), Part 1—northern area. In: Bozkurt E, Winchester JA, Piper JDA (eds) Tectonics and magmatism in Turkey and the surrounding area. Geological Society Special Publication no 173. Geological Society, London, pp 295–323
Kaypak B, Eyidoğan H (2005) One-dimensional crustal structure of the Erzincan basin, Eastern Turkey and relocations of the 1992 Erzincan earthquake ($Ms = 6.8$) aftershock sequence. Phys Earth Planet Inter 151:1–20. doi:10.1016/j.pepi.2004.11.009
Kempler D, Ben-Avraham Z (1987) The tectonic evolution of the Cyprean Arc. Ann Tecton 1:58–71
Kempler D, Garfunkel Z (1994) Structures and kinematics in the northeastern Mediterranean: a study of an irregular plate boundary. Tectonophysics 234:19–32. doi:10.1016/0040-1951(94)90202-X
Keskin M, Pearce JA, Mitchell J (1998) Volcano-stratigraphy and geochemistry of collision-related volcanism on the Erzurum–Kars Plateau, northeastern Turkey. J Volcanol Geotherm Res 85:355–404. doi:10.1016/S0377-0273(98)00063-8
Ketin İ (1948) Über die tektonisch-mechanischen Folgerungen aus den grossen anatolischen Erdbeben des letzten Dezenniums. Geol Rundsch 36:77–83
Ketin İ (1966) Tectonic units of Anatolia (Asia Minor). Miner Resour Explor Inst Bull 66:23–34
Ketin İ, Abdüsselamoğlu Ş (1969) Bartın depreminin etkileri. Türkiye Jeoloj Kurumu Bülteni 12(1–2):66–76
Koçyiğit A (1983) Hoyran Gölü (Isparta Büklümü) Dolayının Tektoniği. TJK Bült 26:1–10
Koçyiğit A, Beyhan A (1998) A new intracontinental transcurrent structure: the Central Anatolian fault zone, Turkey. Tectonophysics 284:317–336
Koçyiğit A, Özacar A (2003) Extensional neotectonic regime through the NE edge of outer Isparta Angle, SW Turkey: new field and seismic data. Turk J Earth Sci 12:67–90

Koçyiğit A, Yusufoğlu H, Bozkurt E (1999) Evidence from the Gediz Graben for episodic two-stage extension in western Turkey. J Geol Soc Lond 156:605–616
Koçyiğit A, Yılmaz A, Adamia S, Kuloshvili S (2001) Neotectonics of East Anatolian Plateau (Turkey) and Lesser Caucasus: implication for transition from thrusting to strike–slip faulting. Geodin Acta 14:177–195. doi:10.1016/S0985-3111(00)01064-0
Kotzev V, Nakov R, Burchfel BC, King R, Reilinger R (2001) GPS study of active tectonics in Bulgaria: results from 1996 to 1998. J Geodyn 31:189–200
Kozacı Ö, Dolan J, Finkel R, Hartleb R (2007) Late Holocene slip rate for the North Anatolian fault, Turkey, from cosmogenic 36Cl geochronology: implications for the constancy of fault loading and strain release rates. Geology 35(10):867–870. doi:10.1130/G23187A.1
KRDAE, Boğaziçi University, Kandilli Observatory and Earthquake Research Institute. Catalogue 2011–2012. http://udim.koeri.boun.edu.tr
Kürçer A, Gökten YE (2014) Neotectonic-period characteristics, seismicity, geometry and segmentation of the Tuz Gölü fault zone. Bull Miner Res Explor 149:19–68
Le Pichon X, Angelier J (1979) The Aegean arc and trench system: a key to the neotectonic evolution of the eastern Mediterranean area. Tectonophysics 60:1–42
Le Pichon X, Angelier J, Aubouin J, Lyberis N, Monti S, Renard V, Got H, Hsu K, Mart Y, Mascle J, Matthews D, Mitropoulos D, Tsoflias P, Chronis G (1979) From subduction to transform motion a seabeam survey of the Aegean trench system. Earth Planet Sci Lett 44:441–450
Le Pichon X, Şengör AMC, Demirbağ E, Rangin C, İmren C, Armijo R, Görür N, Çağatay N, Mercier de Lepinay B, Meyer B, Saatçılar R, Tok B (2001) The active main Marmara fault. Earth Planet Sci Lett 192:595–616
Le Pichon X, Chamot-Rooke N, Rangin C, Şengör AMC (2003) The North Anatolian fault in the Sea of Marmara. J Geophys Res 108(B4):2179. doi:10.1029/2002JB001862
Mackintosh PW, Robertson AHF (2013) Sedimentary and structural evidence for two-phase Upper Cretaceous and Eocene emplacement of the Tauride thrust sheets in central southern Turkey. Geol Soc Lond Spec Publ 372:299–322. doi:10.1144/SP372.2
Mart Y (1994) Ptolemaïs basin: the tectonic origin of a Senonian marine basin underneath the southeastern Mediterranean Sea. Tectonophysics 234:5–17
McCay GA, Robertson AHF (2013) Upper Miocene-Pleistocene deformation of the Girne (Kyrenia) Range and Dar Dere (Ovgos) lineaments, northern Cyprus: role in collision and tectonic escape in the easternmost Mediterranean region. Geol Soc Lond Spec Publ 372:421–445. doi:10.1144/sp372.6
McClusky S et al (2000) Global positioning system constraints on plate kinematics and dynamics in the eastern Mediterranean and Caucasus. J Geophys Res 105:5695–5719
McClusky S, Reilinger R, Mahmoud S, Ben Sari D, Tealeb A (2003) GPS constraints on Africa (Nubia) and Arabia plate motions. Geophys J Int 155:126–138. doi:10.1046/j.1365-246X.2003.02023.x
McKenzie DP (1970) Plate tectonics of the Mediterranean region. Nature 226:239–243
McKenzie D (1972) Active tectonics of the Mediterranean region. Geophys J R Astr Soc 30:109–186
McKenzie DP (1976) The East Anatolian fault: a major structure in eastern Turkey. Earth Planet Sci Lett 29:189–193
McKenzie D (1978) Active tectonics of the Alpine-Himalayan belt: the Aegean Sea and surrounding region. Geophys J R Astr Soc 55:217–254
Meade BJ et al (2002) Estimates of seismic potential in the Marmara Sea region from block models of secular deformation constrained by global positioning. Bull Seismol Soc Am 92:208–215
Meier T, Rische M, Endrun B, Vafidis A, Harjes HP (2004) Seismicity of the Aegean subduction zone in the area of western and central Crete observed by temporary local seismic networks. Tectonophysics 383:149–169. doi:10.1016/j.tecto.2004.02.004
Meyer B, Armijo R, Dimitrov D (2002) Active faulting in SW Bulgaria: possible surface rupture of the 1904 Struma earthquakes. Geophys J Int 148:246–255
Morelli C (1978) Eastern Mediterranean: geophysical results and implications. Tectonophysics 46:333–346
Nur A, Ben-Avraham Z (1978) The eastern Mediterranean and the Levant: tectonics of continental collision. Tectonophysics 46:297–311
Okay AI (2008) Geology of Turkey: a synopsis. Anschnitt 21:19–42
Okay AI, Şahintürk Ö (1997) Geology of the Eastern Pontides. In: Robinson AG (ed) Regional and petroleum geology of the Black Sea and surrounding region. AAPG Mem 68:291–311
Okay AI, Tüysüz O (1999) Tethyan sutures of northern Turkey. Geol Soc Lond Spec Publ 156:475–515. doi:10.1144/gsl.sp.1999.156.01.22
Önal M, Kaya M (2007) Stratigraphy and tectono-sedimentary evolution of the Upper Cretaceous–Tertiary sequence in the southern part of the Malatya Basin, East Anatolia, Turkey. J Asian Earth Sci 29:878–890. doi:10.1016/j.jseaes.2006.06.004

Over S, Pinar A, Ozden S, Yilmaz H, Can U, Kamaci Z (2010) Late Cenozoic stress field in the Cameli Basin, SW Turkey. Tectonophysics 492(1–4):60–72
Özalaybey S, Ergin M, Aktar M, Tapırdamaz C, Biçmen F, Yörük A (2002) The 1999 İzmit earthquake sequence in Turkey: seismological and tectonic aspects. Bull Seismol Soc Am 92:376–386
Özgül N (1976) Toroslar'm bazı temel jeoloji özellikleri. Bull Geol Soc Turk 19:65–78
Özgül N (2012) Stratigraphy and some structural features of the İstanbul Palaeozoic. Turk J Earth Sci 21:817–866. doi:10.3906/yer-1111-6
Özgül N (1984) Alanya Tektonik Penceresi ve batı kesiminin jeolojisi. Ketin Simpozyumu (eds) Ercan T, Çağlayan AM TJK Ankara 97–120
Papazachos BC (1990) Seismicity of the Aegean and surrounding area. Tecronophysics 178:287–308
Papazachos BC, Papaioannou CA (1999) Lithospheric boundaries and plate motions in the Cyprus area. Tectonophysics 308:193–204
Parsons T, Toda S, Stein RS, Barka A, Dieterich JH (2000) Heightened odds of large earthquakes near Istanbul: an interaction-based probability calculation. Science 288(5466):661–665
Payne AS, Robertson AHF (1995) Neogene supra-subduction zone extension in the Polis graben system, West Cyprus. J Geol Soc Lond 152:613–628
Pearce JA et al (1990) Genesis of collision volcanism in Eastern Anatolia, Turkey. J Volcanol Geotherm Res 44:189–229. doi:10.1016/0377-0273(90)90018-B
Philip H, Cisternas A, Gvishiani A, Gorshkuv A (1989) The Caucasus: an actual example of the initial stages of continental collision. Tectonophysics 161:1–21
Pilidou S, Priestley K, Jackson J, Maggi A (2004) The 1996 Cyprus earthquake: a large, deep event in the Cyprean Arc. Geophys J Int 158:85–97
Pınar N, Lahn E (1952) Türkiye Depremleri İzahlı Kataloğu. T.C. Bayındırlık Bakanlığı, Yapı ve İmar İşleri Reisliği Yayınları, 6(36), Ankara
Rangin C, Bader AG, Pascal G, Ecevitoğlu B, Görür N (2002) Deep structure of the Mid Black Sea High (offshore Turkey) imaged by multi-channel seismic survey (BLACKSIS cruise). Mar Geol 182:265–278. doi:10.1016/S0025-3227(01)00236-5
Reilinger RE, McClusky SC, Souter BJ, Hamburger MW, Prilepin MT, Mishin A, Guseva T, Balassanian S (1997) Preliminary estimates of plate convergence in the Caucasus collision zone from global positioning system measurements. Geophys Res Lett 24:1815–1818. doi:10.1029/97GL01672
Reilinger R, McClusky S, Vernant P, Lawrence S, Ergintav S, Cakmak R, Ozener H, Kadirov F, Guliev I, Stepanyan R, Nadariya M, Hahubia G, Mahmoud S, Sakr K, ArRajehi A, Paradissis D, Al-Aydrus A, Prilepin M, Guseva T, Evren E, Dmitrotsa A, Filikov SV, Gomez F, Al-Ghazzi R, Karam G (2006) GPS constraints on continental deformation in the Africa–Arabia–Eurasia continental collision zone and implications for the dynamics of plate interactions. J Geophys Res. doi:10.1029/2005jb004051
Reilinger R, McClusky S, Paradissis D, Ergintav S, Vernant P (2010) Geodetic constraints on the tectonic evolution of the Aegean region and strain accumulation along the Aegean subduction zone. Tectonophysics 488:22–30. doi:10.1016/j.tecto.2009.05.027
Robertson AHF (1998) Mesozoic–Tertiary tectonic evolution of the easternmost Mediterranean area: integration of marine and land evidence. In: Robertson AHF, Emeis K-C, Richter C (eds) Proceedings of ODP, scientific results 160. College Station, TX, pp 723–782
Robertson AHF, Dixon JE (1984) Introduction: aspects of the geological evolution of the Eastern Mediterranean. In: Dixon JE, Robertson AHF (eds) The Geological evolution of the Eastern Mediterranean, vol 17. Geological Society, London, Special Publications, pp 1–74
Robertson AHF, Grasso M (1995) Overview of the Late Tertiary—recent tectonic and paleo-environmental development of the Mediterranean Region. Terra Res 7:114–117
Robertson AHF et al (1994) Probing continental collision in the Mediterranean Sea. EOS Trans AGU 75:233
Robertson AHF, Ünlügenç UC, İnan N, Taşlı K (2004) The Misis–Andırın complex: a Mid-Tertiary melange related to late-stage subduction of the Southern Neotethys in S Turkey. J Asian Earth Sci 22:413–453. doi:10.1016/S1367-9120(03)00062-2
Robinson AG, Rudat JH, Banks CJ, Wiles RLF (1996) Petroleum geology of the Black Sea. Mar Pet Geol 13:195–223
Şaroğlu F, Yılmaz Y (1993) Doğu Anadolu'da neotektonik dönemdeki jeolojik evrim ve havza modelleri. MTA Dergisi 107:73–94
Şaroğlu F, Emre Ö, Boray A (1987) Türkiye'nin Diri Fayları ve Depremsellikleri. Maden Tetkik ve Arama Genel Müdürlüğü Jeoloji Etütleri Dairesi Başkanlığı, Ankara, MTA Rapor No: 8174, III + 394 s. + 11 harita
Şaroğlu F, Emre Ö, Kuşçu İ (1992a) Türkiye Diri Fay Haritası, ölçek 1:1.000.000, Maden Tetkik ve Arama Genel Müdürlüğü, Ankara
Şaroğlu F, Emre Ö, Kuşcu İ (1992b) The East Anatolian fault zone of Turkey. Ann Tecton 6:99–125

Şengör AMC (1979) The North Anatolian transform fault: its age, offset and tectonic significance. J Geol Soc Lond 136:269–282

Şengör AMC (1980) Türkiye'nin neotektoniğinin esasları. Türkiye Jeololoji Kurumu Yayınları

Şengör AMC, Barka AA (1992) Evolution of escape related strike slip systems: implications for disruption of collisional orogens. In: 29th international geological congress, 21 August–3 September 1992, Kyoto Japan, Abstracts 1, I-2-56, O-1, 1721

Şengör AMC, Kid WSF (1979) Post-collisional tectonics of the Turkish-Iranian plateau and a comparison with Tibet. Tecronophysics 55:361–376

Şengör AMC, Yılmaz Y (1981) Tethyan evolution of Turkey: a plate tectonic approach. Tectonophysics 75:181–241

Şengör AMC, Tüysüz O, İmren C, Sakınç M, Eyidoğan H, Görür G, Le Pichon X, Rangin C (2005) The North Anatolian fault: a new look. Annu Rev Earth Planet Sci 33:37–112

Şengör AMC, Yılmaz Y, Sungurlu O (1984) Tectonics of the Mediterranean Cimmerides: nature and evolution of the western termination of Palaeo-Tethys. In: Dixon JF, Robertson AHF (eds) The geological evolution of the Eastern Mediterranean, vol 17. Geological Society Special Publication, London, pp 117–152

Şengör AMC, Görür N, Şaroglu F (1985) Strike–slip faulting and related basin formation in zones of tectonic escape: Turkey as a case study. In Biddle KT, Christie-Blick N (eds) Strike–slip deformation, basin formation and sedimentation society of economic paleontologist and mineralogists, vol 37. Special Publication, pp 227–264

Seymen İ, Aydın A (1972) Bingöl deprem fayı ve bunun Kuzey Anadolu fay zonu ile ilişkisi. MTA Dergisi 79:1–8

Shaw B, Jackson J (2010) Earthquake mechanisms and active tectonics of the Aegean subduction zone. Geophys J Int 181:966–984

Soysal H, Sipahioğlu S, Kolçak D, Altınok Y (1981) Türkiye ve çevresinin tarihsel deprem kataloğu, M.Ö. 2100—M.S. 1900. TÜBİTAK Proje No: TBAG 341, 87 s, İstanbul

Tan O, Tapırdamaz MC, Yoruk A (2008) The earthquake catalogues for Turkey. Turk J Earth Sci 17:405–418

Tan O, Pabuçcu Z et al (2011) Aftershock study and seismotectonic implications of the 8 March 2010 Kovancılar (Elazığ, Turkey) earthquake (MW = 6.1). Geophys Res Lett 38:L11304. doi:10.1029/2011GL047702

Tarı E, Sahin M, Barka A, Reilinger R, King RW, McClusky S, Prilepin M (2000) Active tectonics of the Black Sea with GPS. Earth Planets Space 52:747–751

Tatar O, Poyraz F, Gursoy H, Cakir Z, Ergintav S, Akpinar Z, Koçbulut F, Sezen F, Türk T, Hastaoğlu KÖ, Polat A, Mesci B, Gürsoy Ö, Ayazli İE, Çakmak R, Belgen A, Yavaşoğlu H (2012) Crustal deformation and kinematics of the eastern part of the North Anatolian fault zone (Turkey) from GPS measurements. Tectonophysics 518:55–62

Taymaz T, Eyidoğan H, Jackson J (1991) Source parameters of large earthquakes in the East Anatolian fault zone (Turkey). Geophys J Int 106:537–550

Tiryakioğlu I, Floyd M, Erdoğan S, Gülal E, Ergintav S (2013) GPS constraints on active deformation in the Isparta Angle region of SW Turkey. Geophys J Int Adv Access. September 17, 2013

Toksöz MN, Shakal AF, Michael AJ (1979) Space–time migration of earthquakes along the North Anatolian fault zone and seismic gaps. Pegeoph 117:1258–1270

Trifonov VG, Trubikhin VM, Adjamian J, Jallad Z, El-Khair Y, Ayad H (1991) The Levant fault zone in northwestern Syria. Geotectonics 2:63–75

Turgut S, Siyako M, Dilki A (1983) The geology and the petroleum prospects of the Thrace Basin. Proc Geol Congr Turk 4:35–46

Türkelli N et al (2003) Seismogenic zones in Eastern Turkey. Geophys Res Lett 30(24):8039. doi:10.1029/2003gl018023

Utkucu M (2013) 23 October 2011 Van, Eastern Anatolia, earthquake (M (W) 7.1) and seismotectonics of Lake Van area. J Seismol 17:783–805. doi:10.1007/s10950-012-9354-z

Vidal N, Alvarez-Marrón J, Klaeschen D (2000) The structure of the Africa–Anatolia plate boundary in the eastern Mediterranean. Tectonics 19:723–739. doi:10.1029/2000tc900011

Wdowinski S, Ben-Avraham Z, Arvidsson R, Ekström G (2006) Seismotectonics of the Cyprian arc. Geophys J Int 164(1):176–181. doi:10.1111/j.1365-246X.2005.02737.x

Westaway R (2003) Kinematics of the Middle East and Eastern Mediterranean updated. Turk J Earth Sci 12:5–46

Westaway R (2004) Kinematic consistency between the Dead Sea fault zone and the Neogene and Quaternary left-lateral faulting in SE Turkey. Tectonophysics 391:203–237. doi:10.1016/j.tecto.2004.07.014

Westaway R, Arger J (1996) The Gölbasi basin, southeastern Turkey: a complex discontinuity in a major strike–slip fault zone. J Geol Soc Lond 153:729–744

Woessner J, Danciu L, Giardini D, Crowley H, Cotton F, Grünthal G, Valensise G, Arvidsson R, Basili R, Demircioglu MN, Hiemer S, Meletti C, Musson RW, Rovida AN, Sesetyan K, Stucchi M, the SHARE consortium (2015) The 2013 European Seismic Hazard Model: key components and results. Bull Earthq Eng. doi:10.1007/s10518-015-9795-1

Yarar R, Ergunay O, Erdik M, Gulkan P (1980) A preliminary probabilistic assessment of the seismic hazard in Turkey. In: Proceedings 7th world conference earthquake engineering Istanbul, pp 309–316

Yavasoğlu H, Tarı E, Tüysüz B, Çakır Z, Ergintav S (2011) Determining and modeling tectonic movements along the central part of the North Anatolian fault (Turkey) using geodetic measurements. J Geodyn 51:339–343

Yildirim C, Schildgen TF, Echtler H, Melnick D, Strecker MR (2011) Late Neogene and active orogenic uplift in the Central Pontides associated with the North Anatolian fault: implications for the northern margin of the Central Anatolian Plateau, Turkey. Tectonics 30:TC5005. doi:10.1029/2010TC002756

Yılmaz Y (1993) New evidence and model on the evolution of the Southeast Anatolian Orogen. Geol Soc Am Bull 105:251–271. doi:10.1130/0016-7606(1993)105<0251:Neamot>2.3.Co;2

Yılmaz Y, Yiğitbaş E, Genç ŞC (1993) Ophiolitic assemblages and metamorphic of southeast Anatolia and their significance in the geological evaluation of the orogenic belt. Tectonics 12:1280–1297

Yılmaz Y, Güner Y, Saroğlu F (1998) Geology of the Quaternary volcanic centres of the east Anatolia. J Volcanol Geotherm Res 85:173–210. doi:10.1016/S0377-0273(98)00055-9

Yolsal-Çevikbilen S, Biryol CB, Beck S, Zandt G, Taymaz T, Adıyaman HE, Özacar AA (2012) 3-D crustal structure along the North Anatolian fault zone in north-central Anatolia revealed by local earthquake tomography. Geophys J Int 188:819–849. doi:10.1111/j.1365-246X.2011.05313.x

Zanchi A, Angelier J (1993) Seismotectonics of Western Anatolia—regional stress orientation from geophysical and geological data. Tectonophysics 222:259–274. doi:10.1016/0040-1951(93)90052-L

Zhu LP, Akyol N, Mitchell BJ, Sozbilir H (2006) Seismotectonics of western Turkey from high resolution earthquake relocations and moment tensor determinations. Geophys Res Lett. doi:10.1029/2006gl025842

Zonenshain LP, Le Pichon X (1986) Deep basin of the Black Sea an Caspaian Sea as remnants of Mesosoic back arc basin. Tecronophysics 123:181–211

Zor E, Sandvol E, Gürbüz C, Türkelli N, Seber D, Barazangi M (2003) The crustal structure of the East Anatolian plateau (Turkey) from receiver functions. Geophys Res Lett 30(24):8044. doi:10.1029/2003GL018192