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The geodynamics of the Aegean and Anatolia: introduction

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The complexity of the plate interactions and associated crustal deformation in the Eastern Mediterranean region is reflected in many destructive earthquakes that have occurred throughout its recorded history, many of which are well documented and intensively studied. The Eastern Mediterranean region, including the surrounding areas of western Turkey and Greece, is indeed one of the most seismically active and rapidly deforming regions within the continents (Fig. 1). Thus, the region provides a unique opportunity to improve our understanding of the complexities of continental tectonics in an actively collisional orogen. The major scientific observations from this natural laboratory have clearly been helping us to better understand the tectonic processes in active collision zones, the mode and nature of continental growth, and the causes and distribution of seismic, volcanic and geomorphological events (e.g. tsunamis) and their impact on societal life and civilization. The tectonic evolution of the Eastern Mediterranean region is dominated by the effects of subduction along the Hellenic (Aegean) arc and of continental collision in eastern Turkey (Anatolia) and the Caucasus. Northward subduction of the African plate beneath western Turkey and the Aegean region is causing extension of the continental crust and volcanism in the overlying Aegean extensional province. Eastern Turkey has been experiencing crustal shortening and thickening as a result of northward motion of the Arabian plate relative to Eurasia and the attendant post-collisional magmatism (Taymaz *et al.* 1990, 1991*a*, *b*; McClusky *et al.* 2000, 2003; Dilek & Pavlides 2006, and references therein; Fig. 2). The resulting combination of forces (the 'pull' from the subduction zone to the west and 'push' from the convergent zone to the east) is causing the Turkish plate to move southwestward, bounded by strike-slip fault zones: the North Anatolian Fault Zone (NAFZ) to the north and the East Anatolian Fault Zone (EAFZ) to the south. Interplay between dynamic effects of the relative motions of adjoining plates thus controls large-scale crustal deformation and the associated seismicity and volcanism in Anatolia and the Aegean region (Taymaz *et al.* 2004).

Regional synthesis

Given its location in the Alpine–Himalayan orogenic belt, and at the collisional boundary between Gondwana and Laurasia, the geological history of the Aegean region and Anatolia involves the Mesozoic–Cenozoic closure of several Neotethyan oceanic basins, continental collisions and subsequent post-orogenic processes (e.g. Sengör & Yılmaz 1981; Bozkurt & Mittwede 2001; Okay *et al.* 2001; Dilek & Pavlides 2006; Robertson & Mountrakis 2006). The opening of oceanic branches of Neotethys commenced in the Triassic and they closed during the Late Cretaceous to Eocene time interval. The closure of Neotethyan basins is recorded by several suture zones (e.g. Vardar, Izmir–Ankara–Erzincan, Bitlis–Zagros, Intra-Pontide, Antalya sutures), along which Jurassic–Cretaceous ophiolites and mélanges are exposed (e.g. Sengör & Yılmaz 1981; Robertson & Dixon 1984; Dercourt *et al.* 1986; Stampfli 2000; Okay *et al.* 2001; Parlak *et al.* 2002; Elmas & Yılmaz 2003; Parlak & Robertson 2004; Robertson & Ustaömer 2004; Robertson *et al.* 2004*a*, *b*; Stampfli & Borel 2004; Bagcı *et al.* 2005, 2006; Dilek *et al.* 2005; Çelik *et al.* 2006; Dilek & Thy 2006; Parlak 2006, and references therein). The polarity of subduction, the timing of ocean basin opening and closure, and the location of Neotethyan suture zones remain somewhat controversial. The destruction of oceanic basins was also accompanied and followed by: (1) Cretaceous to early Palaeocene arc magmatism (e.g. Pontide arc: Okay & Sahintürk 1997; Yılmaz *et al.* 1997); (2) development of accretionary-type forearc basins (e.g. Haymana–Polatlı Basin; Koçyiğit 1991; Tuz Gölü Basin, Görür *et al.* 1998); (3) late Palaeocene to Miocene and younger post-collisional magmatism (Aldanmaz *et al.* 2000; Keskin 2003; Boztuğ *et al.* 2004, 2006; Karslı *et al.* 2004; Aslan 2005; Innocenti *et al.* 2005; Altunkaynak & Dilek 2006); (4) the development of several blueschist belts (e.g. Late

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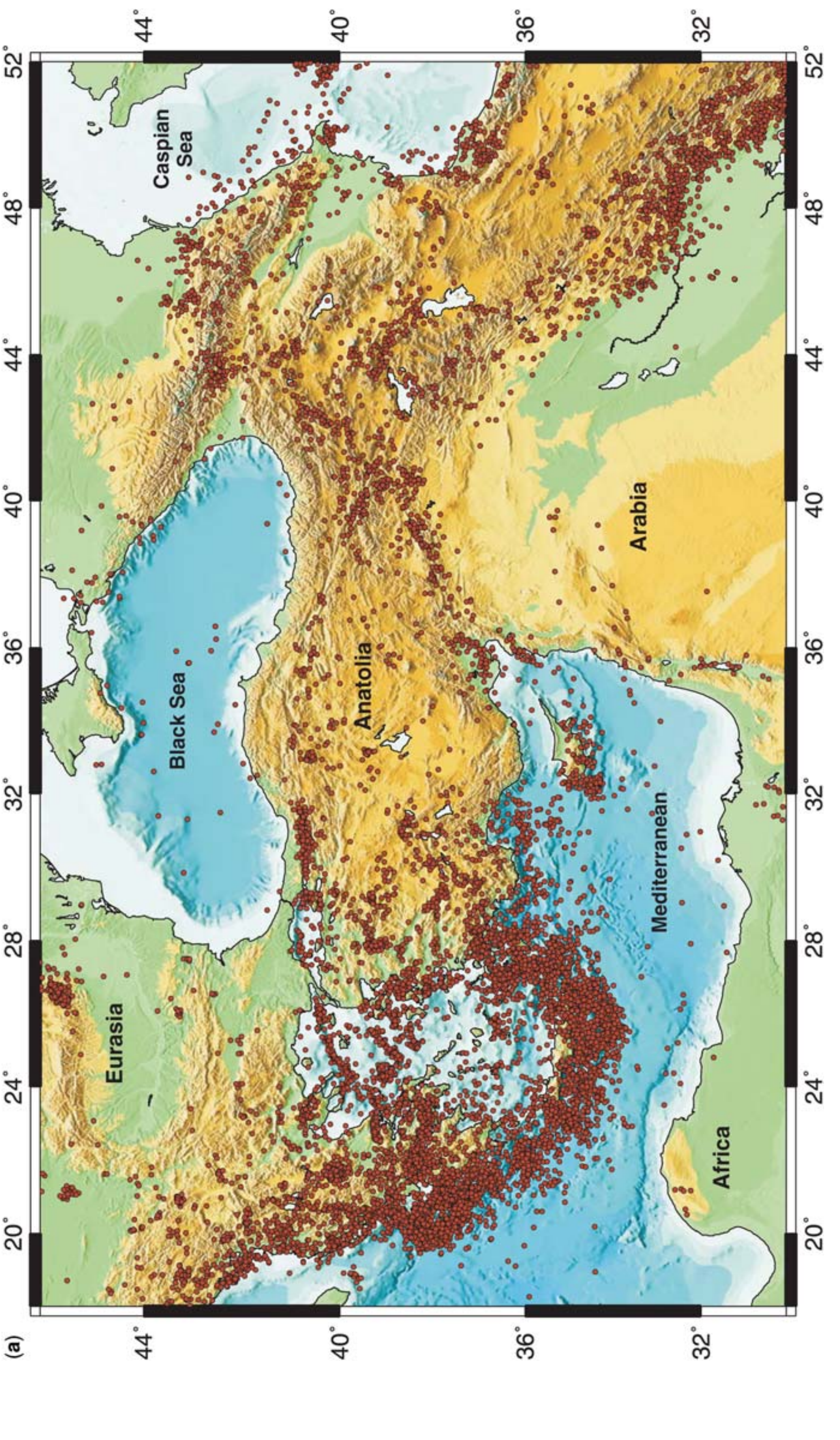
(a)
Caspian Sea
Black Sea
Anatolia
Arabia
Mediterranean
Eurasia
Africa
44°
40°
36°
32°
20°
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28°
32°
36°
40°
44°
48°
52°

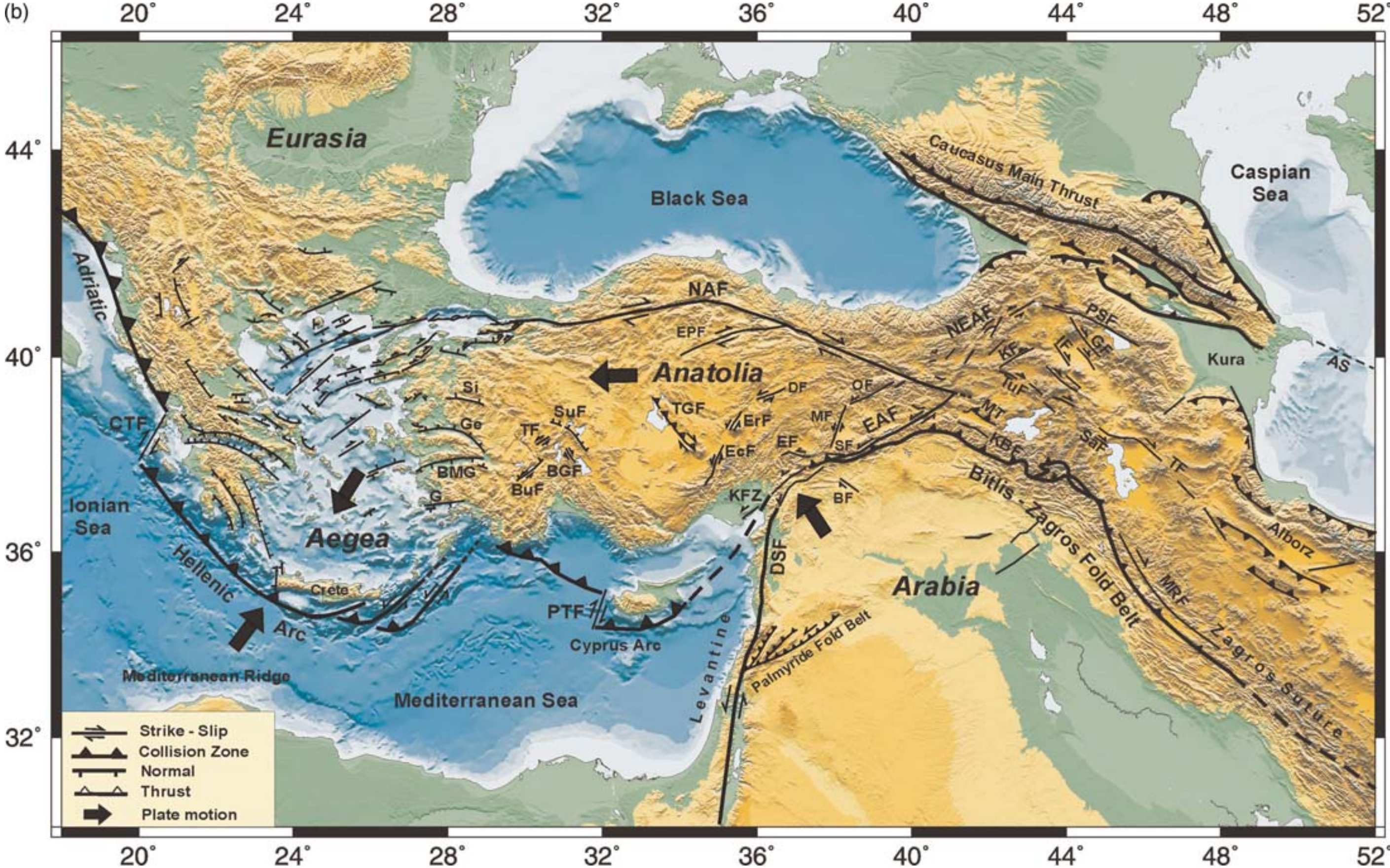
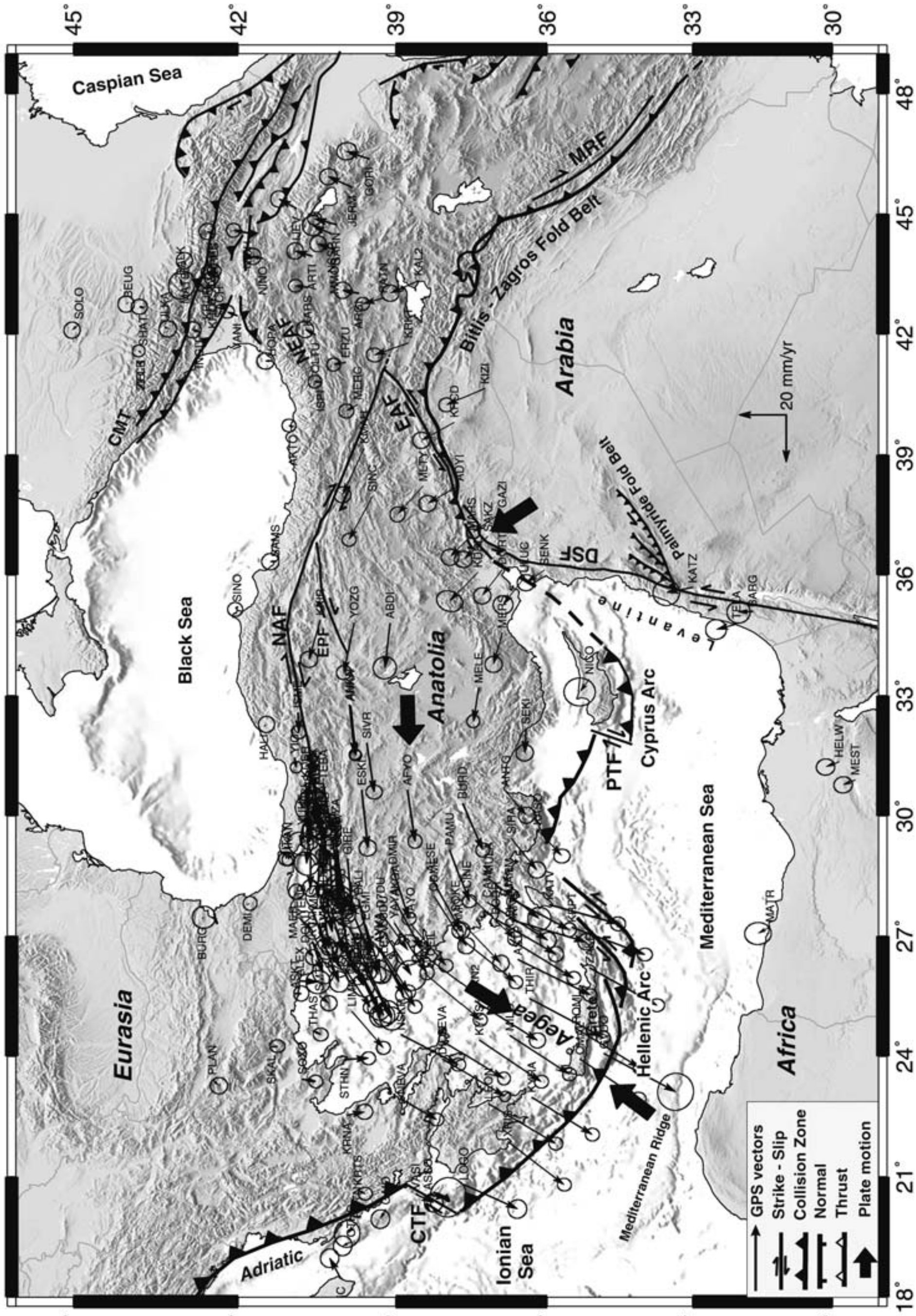


Fig. 1. (**a**) Seismicity of the Eastern Mediterranean region and surroundings reported by USGS–NEIC during 1973–2007 with magnitudes for M > 3 superimposed on a shaded relief map derived from the GTOPO-30 Global Topography Data taken after USGS. Bathymetry data are derived from GEBCO/97–BODC, provided by GEBCO (1997) and Smith & Sandwell (1997*a*, *b*). (**b**) Summary sketch map of the faulting and bathymetry in the Eastern Mediterranean region, compiled from our observations and those of Le Pichon & Angelier (1981), Taymaz (1990), Taymaz *et al.* (1990, 1991*a*, *b*); Şaroğlu *et al.* (1992), Papazachos *et al.* (1998), McClusky *et al.* (2000) and Tan & Taymaz (2006). Large black arrows show relative motions of plates with respect to Eurasia (McClusky *et al.* 2003). Bathymetry data are derived from GEBCO/97–BODC, provided by GEBCO (1997) and Smith & Sandwell (1997*a*, *b*). Shaded relief map derived from the GTOPO-30 Global Topography Data taken after USGS. NAF, North Anatolian Fault; EAF, East Anatolian Fault; DSF, Dead Sea Fault; NEAF, North East Anatolian Fault; EPF, Ezinepazarı Fault; PTF, Paphos Transform Fault; CTF, Cephalonia Transform Fault; PSF, Pampak–Sevan Fault; AS, Apsheron Sill; GF, Garni Fault; OF, Ovacık Fault; MT, Muş Thrust Zone; TuF, Tutak Fault; TF, Tebriz Fault; KBF, Kavakbaşı Fault; MRF, Main Recent Fault; KF, Kağızman Fault; IF, Iğdır Fault; BF, Bozova Fault; EF, Elbistan Fault; SaF, Salmas Fault; SuF, Sürgü Fault; G, Gökova; BMG, Büyük Menderes Graben; Ge, Gediz Graben; Si, Simav Graben; BuF, Burdur Fault; BGF, Beyşehir Gölü Fault; TF, Tatarlı Fault; SuF, Sultandağ Fault; TGF, Tuz Gölü Fault; EcF, Ecemiş Fau; ErF, Erciyes Fault; DF, Deliler Fault; MF, Malatya Fault; KFZ, Karataş–Osmaniye Fault Zone.


Caspian Sea
Black Sea
Eurasia
Anatolia
Arabia
Africa
Aegean
Mediterranean Sea
Ionian Sea
Adriatic
Hellenic Arc
Cyprus Arc
Levantine
Mediterranean Ridge
Bitlis - Zagros Fold Belt
Palmyride Fold Belt
NAF
EAF
NEAF
EPF
DSF
PTF
CTF
CMT
MRF
20 mm/yr
GPS vectors
Strike - Slip
Collision Zone
Normal
Thrust
Plate motion
18°
21°
24°
27°
30°
33°
36°
39°
42°
45°
48°

(a)

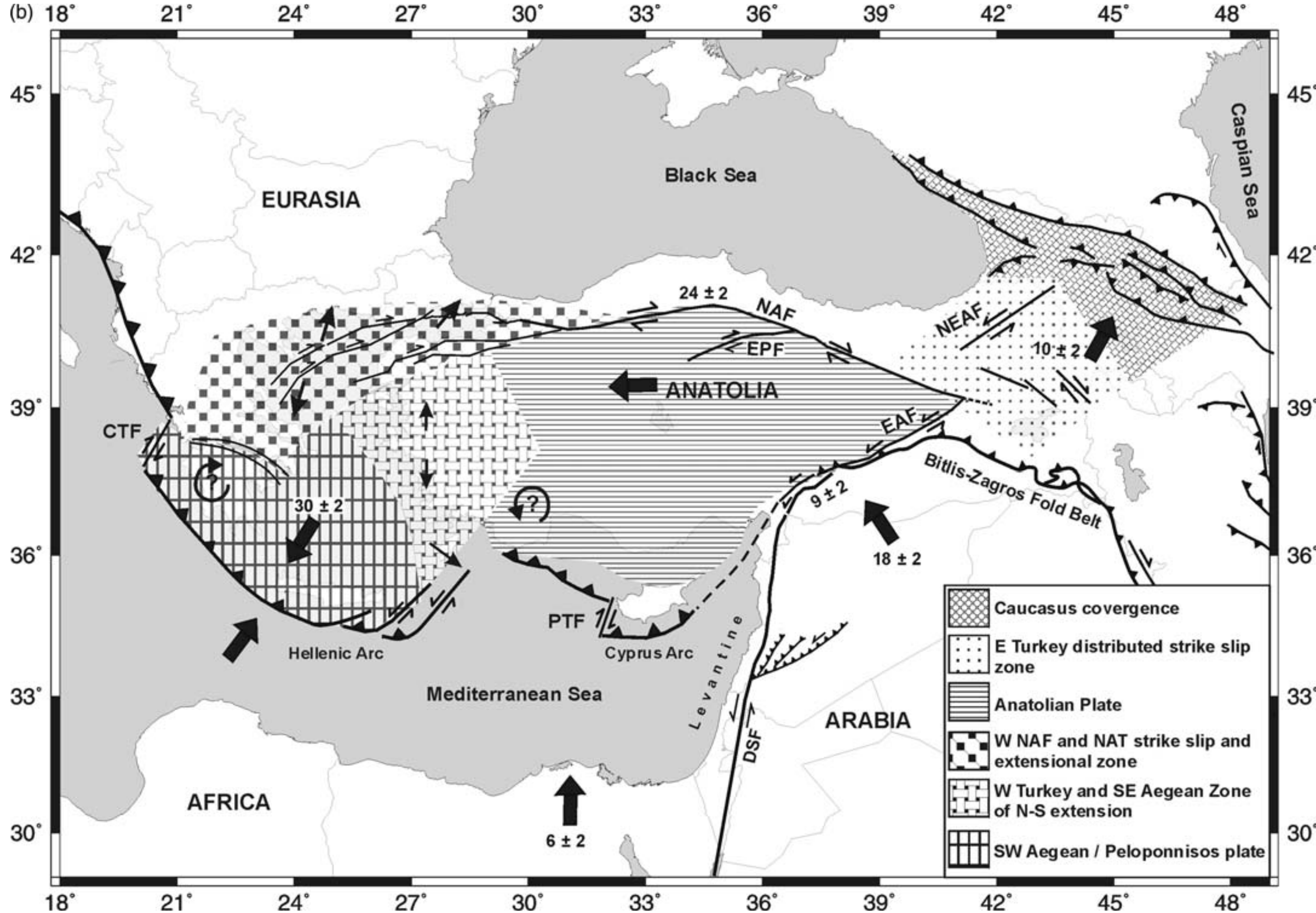


Fig. 2. (**a**) GPS horizontal velocities and their 95% confidence ellipses in a Eurasia-fixed reference frame for the period 1988–1997 superimposed on a shaded relief map derived from the GTOPO-30 Global Topography Data taken after USGS. Bathymetry data are derived from GEBCO/97–BODC, provided by GEBCO (1997) and Smith & Sandwell (1997*a*, *b*). Large arrows designate generalized relative motions of plates with respect to Eurasia (in mm a^{-1}) (recompiled after McClusky *et al.* 2000). NAF, North Anatolian Fault; EAF, East Anatolian Fault; DSF, Dead Sea Fault; NEAF, North East Anatolian Fault; EPF, Ezinepazarı Fault; CTF, Cephalonia Transform Fault; PTF, Paphos Transform Fault; CMT, Caucasus Main Thrust; MRF, Main Recent Fault. (**b**) Schematic map of the principal tectonic settings in the Eastern Mediterranean. Hatching shows areas of coherent motion and zones of distributed deformation. Large arrows designate generalized regional motion (in mm a^{-1}) and errors (recompiled after McClusky *et al.* (2000, 2003). NAF, North Anatolian Fault; EAF, East Anatolian Fault; DSF, Dead Sea Fault; NEAF, North East Anatolian Fault; EPF, Ezinepazarı Fault; CTF, Cephalonia Transform Fault; PTF, Paphos Transform Fault.

Cretaceous Tavşanlı Zone in Turkey: Okay *et al.* 1998; Sherlock 1999; Çamlıca metamorphic belt in NW Turkey: Okay & Satır 2000, and references therein; Eocene–Oligocene Cycladic blueschist belt in the central Aegean: Altherr *et al.* 1979; Avigad & Garfunkel 1989, 1991; Okrusch & Bröcker 1990; Jolivet *et al.* 1994, 2003; Avigad *et al.* 1997; Bröcker *et al.* 2004; Ring *et al.* 2001; Trotet *et al.* 2001; Bröcker & Pidgeon 2007; Lycian Nappes and Menderes Massif: Oberhänsli *et al.* 2001; Okay 2001; Rimmelé *et al.* 2003, and references therein; Bolkar Mountains in the Central Taurides: Dilek & Whitney 1997); (5) high- to low-grade metamorphism affecting larger areas.

The nappe translation and burial of large areas beneath advancing ophiolite nappes has resulted in regional metamorphism and consequent formation of crustal-scale metamorphic massifs, such as the Rhodope Massif, Strandja Massif, Cycladic Massif, Menderes Massif and Central Anatolian Crystalline Complex (Şengör *et al.* 1984; Whitney & Dilek 1997; Bozkurt & Oberhänsli 2001*a*, *b*; Okay *et al.* 2001; Gautier *et al.* 2002; Whitney *et al.* 2003; Şengün *et al.* 2006; Bozkurt 2007, and references therein).

The closure of oceanic basins resulted in crustal thickening and subsequent post-orogenic extension and magmatism in the west (Aegean extensional system) and collisional intracontinental convergence in eastern Turkey and the Caucasus that still prevail in the region. The present-day configuration of the Aegean region is therefore the manifestation of three major structures: (1) the Hellenic–Cyprian subduction zone; (2) the dextral North Anatolian fault system (NAFS); (3) the sinistral East Anatolian fault system (EAFS). Along the Hellenic–Cyprian trenches the African plate is subducting NNE beneath the Anatolian plate at varying rates causing lithospheric tearing and intra-plate deformation (Dilek 2006). The NAFS and EAFS are world-class examples of intracontinental transform fault systems that intersect at a continental triple junction in northeastern Turkey (e.g. Bozkurt 2001; Şengör *et al.* 2005). The continuum of deformation along the NAFS and EAFS has resulted in the WSW extrusion of the intervening Anatolian plate onto the Eastern Mediterranean lithosphere, accompanied by its counter-clockwise rotation, between the converging Eurasian and Arabian plates (Rotstein 1984). The sinistral Dead Sea fault system (DSFS) facilitates the northward motion of Arabia and also plays an important role in the active tectonics of the region.

Subsequent to a series of continental collisions and the demise of the Neotethyan seaways, the Aegean region experienced roughly NNE–SSW-oriented extension since the latest Oligocene to Early Miocene times (Dilek 2006, and references therein). This region, the Aegean extensional system (AES), covers a large area that includes Greece, Macedonia, Bulgaria, Albania and SW Turkey and forms one of the most spectacular and best-studied continental extensional regions. The cause of the onset of extension is controversial and may be (1) slab retreat along the Aegean subduction zone and consequent back-arc extension, (2) collapse of an overthickened crust, (3) westward escape of Anatolia along its plate boundaries, the NAFS and EAFS, or (4) differential rates of convergence between NE-directed subduction of the African plate relative to the hanging-wall Anatolian plate; that is, rapid southwestward movement of Greece relative to Anatolia (e.g. McKenzie 1978; Dewey & Şengör 1979; Le Pichon & Angelier 1981; Rotstein 1984; Şengör *et al.* 1985; Şengör 1979, 1987; Dewey 1988; Jackson & McKenzie 1988; Kissel & Laj 1988; Taymaz *et al.* 1990, 1991*a*; Seyitoğlu & Scott 1991, 1992; Taymaz & Price 1992; Bozkurt & Park 1994; Meulenkamp *et al.* 1994; Taymaz 1996; Saunders *et al.* 1998; Thomson *et al.* 1998; Koçyiğit *et al.* 1999; Bozkurt 2000, 2003; McClusky *et al.* 2000, 2003; Yılmaz *et al.* 2000; Okay 2001; Doglioni *et al.* 2002; Purvis & Robertson 2004; Sato *et al.* 2004; Seyitoğlu *et al.* 2004; Seyitoğlu *et al.* 2004; Bozkurt & Sözbilir 2004, 2006; Purvis *et al.* 2005; and references therein).

The AES is currently under the influence of forces exerted by northward subduction of the African plate beneath the southern margin of the Anatolian plate along the Hellenic–Cyprean trenches and dextral slip on the North Anatolian fault system. The continental extension has expressed itself in two distinct structural styles:

(1) Rapid exhumation of deep-burial metamorphic rocks in the immediate footwall of currently low-angle brittle–ductile normal faults (detachment fault and metamorphic core complexes). The footwall deformation preserves evidence for a progressive transition from ductile to brittle where mylonites are overprinted by breccias and, in turn, by cataclasites. Exhumation was accompanied by synchronous deposition of continental red clastic sediments in the basin(s) located in the detachment hanging walls.

(2) Late stretching of crust and a consequent graben formation along Plio-Quaternary high-angle normal faults (the modern phase of extension or rift mode). Several core complexes (e.g. Rhodope, Cycladic, Kazdağ, Menderes, Niğde core complexes: Lister *et al.* 1984; Dinter & Royden 1993; Gautier *et al.* 1993, 1999; Bozkurt & Park 1994; Gautier & Brunn 1994; Dinter *et al.* 1995; Vandenberg & Lister 1996; Whitney & Dilek 1997; Hetzel *et al.* 1998; Jolivet & Patriat 1999; Jolivet & Faccenna 2000; Lips *et al.* 2001; Bonev & Stampfli 2003; Ring *et al.* 2003; Gessner *et al.* 2004;

Beccaletto & Steiner 2005; Bonev 2006; Bonev *et al.* 2006*a*, *b*; Bozkurt *et al.* 2006; Bozkurt 2007; Régnier *et al.* 2007, and references therein) and overprinting approximately east–west-trending grabens (e.g. Gulf of Corinth, Büyük Menderes and Gediz grabens) therefore form the most prominent elements of the AES.

The Aegean region is therefore considered as a perfect natural laboratory to study mechanisms of core-complex formation, synchronous basin evolution and subsequent graben formation during its post-collisional extensional tectonic evolution. The papers in this book shed some light on various aspects of this extensional tectonics of the Aegean region, but there are still many contentious issues concerning the origin, timing and evolution of Neogene crustal extension in this broad zone of convergence between Africa and Eurasia (see Taymaz & Price 1992; Taymaz 1993; Taymaz *et al.* 2004; Bozkurt & Mittwede 2005; Dilek & Pavlides 2006, and references therein for details).

The Aegean region is also characterized by widespread post-collisional magmatism expressed by extensive volcanic sequences, hypabyssal intrusions and granitoid bodies (Fytikas *et al.* 1976, 1984; Altherr *et al.* 1982; Bingöl *et al.* 1982; Innocenti *et al.* 1984, 2005; Güleç 1991; Seyitoğlu *et al.* 1992, 1997; Hetzel *et al.* 1995*a*, *b*; Richardson-Bunbury 1996; Ercan *et al*. 1997; Yılmaz *et al.* 2001; Işık *et al.* 2003; Erkül *et al.* 2005; Ring & Collins 2005; Tonarini *et al.* 2005; Yücel-Öztürk *et al.* 2005; Aldanmaz 2006; Altunkaynak & Dilek 2006; Bozkurt *et al.* 2006; Pe-Piper & Piper 2006; Dilek & Altunkaynak 2007, and references therein). The extant data suggest that there may have been close temporal and spatial relationships between magmatism and subduction roll-back processes and/or Neogene continental extension in the Aegean region, where the age of volcanic activity becomes younger southwards. There are good examples of synextensional granites emplaced into the footwall rocks of detachment faults (i.e. Simav and Alasehir detachment faults), providing crucial evidence for the age of core-complex formation. Therefore, geochronology and thermochronological studies have recently concentrated on these granitoid bodies in the region (e.g. Ring & Collins 2005; Thompson & Ring 2006).

This introduction is aimed at presenting a synoptic overview of the regional geology and geophysics based on the existing literature, as well as outlining the results of recent literature on existing controversies about the tectonic and geodynamic evolution of the Aegean region. The geology of this region has been reviewed in a series of recent special publications, providing in-depth coverage of the extant data and models, and readers are referred to these publications for additional information (Robinson 1997; Gourgaud 1998; Bozkurt & Rowbotham 1999*a*, *b*; Durand *et al.* 1999; Bozkurt *et al.* 2000; Bozkurt & Mittwede 2001, 2005; Aksu *et al.* 2002, 2005; Akıncı *et al.* 2003; Taymaz *et al.* 2004; Şengör *et al.* 2005; Bozkurt 2006; Dilek & Pavlides 2006; Robertson & Mountrakis 2006).

Research themes

This Special Publication includes a wide range of contributions, illustrating both the diversity of study regions being actively researched and of techniques now available to investigate crustal deformation. It also complements the recent compilations on this region as listed above. Coverage ranges from the Levantine region in the east to SW Bulgaria in the west, with emphasis on the Aegean extensional province and the adjacent western part of the North Anatolian Fault Zone as well as the Hellenic and Cyprean subduction zones. We have grouped papers into the following key themes.

The Aegean Sea and the Cyclades

Katzir *et al.* review the tectonic position and field relations of major ultramafic occurrences in the Cyclades and document in detail the petrography and chemical compositions of ultramafic and associated rocks on the islands of Evvia, Naxos, Tinos and Skyros. They then discuss the origin and mode of emplacement of these rocks and the orogenic evolution of the Cyclades. Widespread serpentinization of most of the ultramafic rocks suggests denudation prior to reburial causing Alpine metamorphism. Relict mantle assemblages and mantle-like oxygen isotope ratios from Naxos meta-peridotites are attributed to the emplacement of these mantle rocks onto a continental margin via collision and subsequent high-pressure (HP) metamorphism (M_1) at 550–650 °C and $\geq$14 kbar. The meta-basites of the Skyros and Evvian mélanges record M_1 temperatures of 450–500 °C and 400–430 °C, respectively. Thus, from Evvia southeastwards progressively deeper (i.e hotter) levels of the subducted plate are exposed. Interestingly, temperatures of the M_2 overprint also increase from Evvia through Skyros to Naxos. The diverse P–T paths of the Cycladic blueschists are predicted by thermal modelling of tectonically thickened crust unroofed either by erosion or by uniform extension.

Mehl *et al.* present detailed structural data from the islands of Tinos and Andros documenting the exhumation of HP metamorphic rocks in the Cyclades. The data are consistent with localization of deformation and its progressive evolution whereby early ductile fabrics are superimposed by low-angle semi-brittle shear planes and, in turn, by steeply dipping late brittle structures. The authors also confirm the role of boudinage formation in localizing ductile–brittle transition and emphasize the continuum of strain from ductile to brittle domains during exhumation. One of the main conclusions of the paper is that the strain localization process depends on both rheological stratification and compositional heterogeneity.

Pe-Piper & Piper document the occurrence of Miocene igneous rocks on the island of Samos as part of a Late Miocene–Quaternary back-arc setting in the Aegean Sea. Three groups of Late Miocene igneous rocks are differentiated: (1) an intrusive complex of monzodiorite and minor granites; (2) potassic trachytes and minor rhyolite; (3) bimodal rhyolites and basalts. New K–Ar ages combined with existing geochronology and biostratigraphy suggest an ages of 10–11 Ma for the first two groups and 8 Ma for the bimodal volcanic rocks. Radiogenic isotope and trace element compositions suggest partial melting of an enriched garnet lherzolite mantle source for the origin of monzodiorite and basalt. The authors show that trachyte and monzodiorite rocks may have evolved by fractional crystallization of a parental magma similar to that of the younger basalt. Emplacement and eruption of the monzodiorite, minor granites, potassic trachytes and rhyolite are attributed to regional extension and listric faulting, whereas the younger basalt extrusion was probably associated with north–south strike-slip faulting that provided pathways for different types of mantle melts.

Piper *et al.* interpret marine seismic reflection profiles from around Santorini to show the distribution of active faults and the occurrence of submarine volcanic rocks interfingering with stratified basinal sediments in the south Aegean arc. Two distinct phases of recent volcanism appear to have taken place in the area: the 1.6 ka and 0.65−0.55 Ma Akrotiri episodes. Accordingly, the ages of subsurface submarine volcanic horizons of Santorini (lower and upper volcanic units) are estimated as latest Pliocene and the younger Akrotiri episode. Because Santorini is located at the intersection of several fault sets of different orientations (east–west, ENE–WSW and NE–SW) and different ages, Late Neogene basin subsidence and volcanism are interpreted to have resulted from changing fault patterns associated with the collision of the African and Aegean–Anatolian plates.

Bonev & Beccaletto document structural evidence on the latest Oligocene to Present extensional tectonics within a back-arc setting in the north Aegean above the Hellenic subduction zone. The data come from two distinct locations: eastern Rhodope–Thrace of Bulgaria–Greece and the Biga Peninsula of NW Turkey. The structural data from the metamorphic rocks are consistent with top-to-the-NNW–SSE- to NE–SW-directed extension in dome-shaped core complexes in the footwalls of low-angle detachment faults. The results of this study combined with the available literature from other parts of the Aegean region suggest that the extensional history in the region comprises syn- and post-orogenic episodes during the Paleocene–Eocene and the latest Oligocene–Early Miocene, respectively. The former event was attributed to gravitationally induced hinterland-directed exhumation of the orogenic stack during the closure of the Vardar Ocean, whereas the latter was the consequence of widespread back-arc extension. The recognition of southward migration of extension and magmatism from the Rhodope complex in the north to the present position of the Hellenic trench in the south supports subduction roll-back processes that have prevailed in the region since Late Cretaceous time.

Georgiev *et al.* report the results of recent global positioning system (GPS) campaigns aimed at monitoring and studying the active deformation in SW Bulgaria. The analyses of GPS data for the 1996–2004 period provide firm evidence for active faulting in the region. The region is divided, based on geology and geodetic data from 38 GPS sites, into five blocks of homogeneous kinematic behaviour with average motions varying between 1.3 and 3.4 mm a^{-1}. The rate of motion for the whole region is *c.* 1.8 $\pm$ 0.7 mm a^{-1} in a N154° direction (to the SSE) with respect to the stable Eurasia; this result correlates well with the geological data on neotectonic motions in SW Bulgaria.

The Hellenic and the Cyprus arcs region

Karagianni & Papazachos present a database of regional earthquakes recorded by a portable broadband three-component digital station and a shear velocity model of the crust and uppermost mantle beneath the Aegean area using simultaneous inversion of Rayleigh and Love waves. The results are consistent with strong lateral variations of the S-wave velocities for the crust and uppermost mantle in the Aegean. The authors confirm the presence of thin crust (<28–30 km) for the whole Aegean Sea region and even thinner (20–22 km) crust in the southern and central Aegean Sea. On the other hand, the crust on land is much thicker, around 40–45 km in western Greece and a mean of 35 km in the rest of the country. A significant sub-Moho upper mantle low-velocity zone (LVL mantle) identified in the southern and central Aegean Sea correlates well with the high heat flow in the mantle wedge above the subducted slab and with the related active volcanism in the region.

Meier *et al.* investigate the structure and dynamics of the plate boundary in the area of Crete by receiver function, surface wave and microseismicity using temporary seismic networks, and summarize the results with special emphasis on their implications for geodynamic models. The authors then propose that the island of Crete represents a horst structure in the central forearc of the retreating Hellenic subduction zone. The reported properties of the lithosphere and the plate interface beneath Crete are attributed to extrusion of material from a subduction channel, driving differential uplift of the island by several kilometres since about 4 Ma.

Yolsal *et al.* inspect historical tsunamis known to have occurred in the Eastern Mediterranean Sea region identified from verified catalogues in three groups and correlate them with the seismogenic zones such as the Hellenic and the Cyprus arcs, the left-lateral strike-slip Dead Sea Fault and the Levantine rift. The authors conduct numerical simulations involving the initiation and propagation of tsunami waves as series of large sea-waves of extremely long wavelength and period generated by an impulsive undersea disturbances or activity near the coasts (i.e. earthquake-induced tsunamis). The authors then compute water surface elevation distributions and theoretical arrival times (i.e. calculated travel times) for the Paphos, Cyprus earthquake of 11 May 1222 and for the Crete earthquake of 8 August 1303, which are known to be the largest and well-documented tsunamigenic events in the region. The authors confirm that the coastal topography, sea bottom irregularities and near-shore bathymetry are crucial components in tsunami wave simulations, and they further suggest that improvement of the resolution of bathymetric maps, particularly for the details of the continental shelf and seamounts, would facilitate a better understanding of tsunami generation and tsunami-prone mechanisms.

Structural complexities associated with strike-slip faulting in Anatolia

Ergin *et al.* report on the influences of the Late Quaternary tectonics and sea-level changes on sedimentation in the Sea of Marmara, as observed in the Sarköy Canyon in the western part of this sea. They present the results of detailed sedimentological work on several sediment cores collected from this submarine canyon. The work is also supported by the interpretation of seismic section profiles and ^{14}C dating of base sections in the sediment cores. The dated sediments (12 ka BP) marked the shift of depositional environment from lacustrine to the present marine conditions. The change of grain size from sand- to gravel-sized particles at the base to siliciclastic mud upwards in the succession is interpreted to mark changes in the Pleistocene–Holocene conditions. The widespread occurrences of faults, synsedimentary structures and submarine slides or slumps interpreted on seismic profiles form the most important records of active tectonics in the canyon and prove once more the major role of faulting and associated deformation on sedimentation in the Sea of Marmara.

Taymaz *et al.* investigate the seismotectonics of the North Anatolian Fault (NAF) in the vicinity of the Orta–Çankırı region (central Turkey) by analysing a moderate-sized ($M_w = 6.0$) earthquake that occurred on 6 June 2000. The authors correlate source rupture characteristics of this event with those obtained from the field mapping (neotectonic) and geodetic (InSAR) studies. The authors then discuss the faulting in this anomalous earthquake in relation to the local geometry of the main strike-slip system (NAF), and speculate that this event may not be a reliable guide to the regional strain field in NW central Turkey. The authors tentatively suggest that one possible explanation for the occurrence of the 6 June 2000 Orta–Çankırı earthquake could be localized clockwise rotations as a result of shearing of the lower crust and lithosphere.

Gürsoy *et al.* stress the importance of travertine occurrences in the study of active faulting, as these deposits are commonly linked to earthquake activity during which geothermal reservoirs are reset and activated by earthquake fracturing. They study the palaeomagnetic record of three travertine fissures in the Sıcak Çermik geothermal field near Sivas in central Anatolia to understand the ambient field at the time of deposition and to identify cycles of secular variation of the geomagnetic field, with the aim of estimating the rate of travertine growth. The travertines are dated by the U–Th method and vary in age between 100 and 360 ka. The authors analyse sequential samples collected from the margins (earliest deposition) to the centres (last deposition) of fissure travertines and conclude, based on the assumption that these cycles record time periods of 1–2 ka, that travertine layers identify resetting of the geothermal system by earthquakes with magnitudes of 4.5–5.5 at every 50–100 years. Travertine precipitation appears to have occurred at rates of 0.1–0.3 mm a^{-1}. The data are also consistent with the occurrence of major earthquakes (M *c.* 7.5) at approximately every 10 ka.

The majority of the papers in this thematic book were presented at the International Symposium on the Geodynamics of Eastern Mediterranean: Active Tectonics of the Aegean, held at the Kadir

Has University, İstanbul, Turkey, during 15–18 June 2005. This meeting was organized in memory of Professor Kâzım Ergin (1915–2002), a source of pride for the İstanbul Technical University. Kâzım Ergin (Mehmet Kâzım Ergin), known to his colleagues and students as Kâzım Hoca, was a Turkish geophysicist whose theoretical and experimental research contributed to many aspects of solid earth geophysics (Taymaz 2002, 2004). He was also an important figure in advancing the teaching of geosciences in Turkey in the decades after World War II, both as an instructor and as an administrator. Ergin served in high-level administrative capacities in various institutions. After the establishment by the government in 1963 of the Scientific and Technical Research Council of Turkey (TÜBİTAK), he was one of the early appointees to its engineering research group. He was eventually elected chairman of the Scientific Board of TÜBİTAK, a capacity in which he served until he retired in 1979. Ergin also served as a director of the Istanbul Technical University; as a member of the NATO Science Committee Executive Council and of its Scientific Board; as a member of the Executive Council of the European Science Foundation (where he was Turkey's first representative); and as an Executive Council rapporteur for the UNESCO Working Group on Seismicity and Seismotectonics. He died on 24 November 2002 on Teachers' Day, an annual holiday in Turkey. He shall always be remembered as one of the pioneering figures in the development of Earth Sciences in Turkey, for his individual contributions as a university teacher and administrator, and for his influence on his colleagues and students.

The symposium was sponsored by Kadir Has University, the Scientific and Technological Research Council of Turkey (TÜBİTAK), the Turkish Academy of Sciences (TT/TÜBA-GEBİP/2001-2-17), the British Council, the Geological Society of London, the Alexander von Humboldt (AvH) Foundation, the Turkish Petroleum Corporation (TPAO), and Gemini-Club Tourism. The editors would like to thank the members of the Organizing Committee and the staff and students at Kadir Has University who ensured the smooth running of the June 2005 symposium. Thanks are due to J. Turner (Series Editor) for his continuous encouragement, help and comments during the preparation of this volume, to the Geological Society Publishing House for editorial work, and to Angharad Hills for her continuous help at every stage of production of this volume. We are grateful to E. Bozkurt, C. Yaltırak and S. Yolsal for their help with editorial work and with the preparation of individual chapters in the book. Critical scholarly evaluation of scientific papers published in this Special Publication was no small task. We are most grateful to the referees for their dedicated and objective work, constructive criticism and suggestions, which collectively improved the quality of this book and helped us maintain high scientific standards. We finally thank the contributors to this book for their time and effort, and active participation in producing this exciting volume on the geodynamics of the Aegean and Anatolia.

References

AKINCI, Ö., ROBERTSON, A. H. F., POISSON, A. & BOZKURT, E. (eds) 2003. The Isparta Angle, SW Turkey—its role in the evolution of Tethys in the Eastern Mediterranean Region. *Geological Journal*, **38**, 191–394.

AKSU, A. E., YALTIRAK, C. & HISCOTT, R. N. (eds) 2002. Quaternary paleoclimatic–paleoceanographic and tectonic evolution of the Marmara Sea and environs. *Marine Geology*, **190**, 1–552.

AKSU, A. E., HALL, J. & YALTIRAK, C. (eds) 2005. Miocene to Recent tectonic evolution of the Eastern Mediterranean: new pieces of the old Mediterranean puzzle. *Marine Geology*, **221**, 1–440.

ALDANMAZ, E. 2006. Mineral–chemical constraints on the Miocene calc-alkaline and shoshonitic volcanic rocks of western Turkey: disequilibrium phenocryst assemblages as indicators of magma storage and mixing conditions. *Turkish Journal of Earth Sciences*, **15**, 47–73.

ALDANMAZ, E., PEARCE, J. A., THIRLWALL, M. F. & MITCHELL, J. 2000. Petrogenetic evolution of late Cenozoic, post-collision volcanism in western Anatolia, Turkey. *Journal of Volcanology and Geothermal Research*, **102**, 67–95.

ALTHERR, R., SCHLIESTEDT, M., OKRUSCH, M. *ET AL.* 1979. Geochronology of high-pressure rocks on Sifnos (Cyclades, Greece). *Contributions to Mineralogy and Petrology*, **70**, 245–255.

ALTHERR, R., KREUZER, H., WENDT, I. *ET AL.* 1982. A late Oligocene/early Miocene high temperature belt in the Attic–Cycladic crystalline Complex (S. E. Pelagonian, Greece). *Geologische Jahrbuch*, **E23**, 97–164.

ALTUNKAYNAK, Ş. & DILEK, Y. 2006. Timing and nature of postcollisional volcanism in western Anatolia and geodynamic implications. *In*: DILEK, Y. & PAVLIDES, S. (eds) *Post-collisional Tectonics and Magmatism in the Mediterranean Region and Asia*. *Geological Society of America*, *Special Papers*, **409**, 321–351.

ASLAN, Z. 2005. Petrography and petrology of the calc-alkaline sarıhan granitoid (NE Turkey): an example of magma mingling and mixing. *Turkish Journal of Earth Sciences*, **14**, 183–207.

AVIGAD, D. & GARFUNKEL, Z. 1989. Low-angle faults above and below a blueschist belt: Tinos Island, Cyclades, Greece. *Terra Nova*, **1**, 182–189.

AVIGAD, D. & GARFUNKEL, Z. 1991. Uplift and exhumation of high-pressure metamorphic terrains—the example of the Cycladic blueschist belt (Aegean Sea). *Tectonophyics*, **188**, 357–372.

AVIGAD, D., GARFUNKEL, Z., JOLIVET, L. & AZANÒN, J. M. 1997. Back-arc extension and denudation of Mediterranean eclogites. *Tectonics*, **16**, 924–941.

BAĞCI, U., PARLAK, O. & HÖCK, V. 2005. Whole-rock and mineral chemistry of cumulates from the Kizildag

(Hatay) ophiolite (Turkey): clues for multiple magma generation during crustal accretion in the southern Neotethyan ocean. *Geological Magazine*, **69**, 53–76.

BAĞCI, U., PARLAK, O. & HÖCK, V. 2006. Geochemical character and tectonic environment of ultramafic to mafic cumulate rocks from the Tekirova (Antalya) ophiolite (southern Turkey). *Geological Journal*, **41**, 193–219.

BECCALETTO, L. & STEINER, C. 2005. Evidence of two-stage extensional tectonics from the northern edge of the Edremit Graben (NW Turkey). *Geodinamica Acta*, **18**, 283–297.

BINGÖL, E., DELALOYE, M. & ATAMAN, G. 1982. Granitic intrusions in western Anatolia: a contribution to the geodynamic evolution of this area. *Eclogae Geologicae Helvetiae*, **75**, 437–446.

BONEV, N. 2006. Cenozoic tectonic evolution of the eastern Rhodope Massif (Bulgaria): basement structure and kinematics of syn- to postcollisional extensional deformation. *In*: DILEK, Y. & PAVLIDES, S. (eds) *Post-collisional Tectonics and Magmatism in the Mediterranean Region and Asia*. Geological Society of America, Special Papers, **409**, 211–235.

BONEV, N. G. & STAMPFLI, G. M. 2003. New structural and petrologic data on Mesozoic schists in the Rhodope (Bulgaria): geodynamic implications. *Comptes Rendus Géosciences*, **335**, 691–699.

BONEV, N., BURG, J.-P. & IVANOV, Z. 2006*a*. Mesozoic–Tertiary structural evolution of an extensional gneiss dome—the Kesebir–Kardamos dome, eastern Rhodope (Bulgaria–Greece). *International Journal of Earth Sciences*, **95**, 318–340.

BONEV, N., MARCHEV, P. & SINGER, B. 2006*b*. $^{40}Ar/^{39}Ar$ geochronology constraints on the Middle Tertiary basement extensional exhumation, and its relation to ore-forming and magmatic processes in the eastern Rhodope (Bulgaria). *Géodinamica Acta*, **19**, 265–280.

BOZKURT, E. 2000. Timing of extension on the Büyük Menderes Graben, western Turkey and its tectonic implications. *In*: BOZKURT, E., WINCHESTER, J. A. & PIPER, J. D. A. (eds) *Tectonics and Magmatism in Turkey and the Surrounding Area*. Geological Society, London, Special Publications, **173**, 385–403.

BOZKURT, E. (ed.) 2001. Neotectonics, seismicity and earthquakes in Turkey. *Geodinamica Acta*, **14**, 1–212.

BOZKURT, E. 2003. Origin of NE-trending basins in western Turkey. *Geodinamica Acta*, **16**, 61–81.

BOZKURT, E. (ed.) 2006. Metamorphic terranes of the Aegean region. *Geodinamica Acta*, **19**, 249–453.

BOZKURT, E. 2007. Extensional vs contractional origin for the Southern Menderes Shear Zone, southwest Turkey: tectonic and metamorphic implications. *Geological Magazine*, **144**, 191–210.

BOZKURT, E. & MITTWEDE, S. K. 2001. Introduction to the geology of Turkey—a synthesis. *International Geology Review*, **43**, 578–594.

BOZKURT, E. & MITTWEDE, S. K. 2005. Introduction: evolution of Neogene extensional tectonics of western Turkey. *Geodinamica Acta*, **18**, 153–165.

BOZKURT, E. & OBERHÄNSLI, R. (eds) 2001*a*. Menderes Massif: structural, metamorphic and magmatic evolution. *International Journal of Earth Sciences*, **89**, 679–882.

BOZKURT, E. & OBERHÄNSLI, R. 2001*b*. Menderes Massif (western Turkey): structural, metamorphic and magmatic evolution—a synthesis. *International Journal of Earth Sciences*, **89**, 679–708.

BOZKURT, E. & PARK, R. G. 1994. Southern Menderes Massif: an incipient metamorphic core complex in western Anatolia, Turkey. *Journal of the Geological Society, London*, **151**, 213–216.

BOZKURT, E. & ROWBOTHAM, G. (eds) 1999*a*. Advances in Turkish Geology, Part I: Tethyan Evolution and Fluvial–Marine Sedimentation. *Geological Journal*, **34**, 3–222.

BOZKURT, E. & ROWBOTHAM, G. (eds) 1999*b*. Advances in Turkish Geology, Part II: Magmatism, Micropalaeontology and Basin Evolution. *Geological Journal*, **34**, 223–319.

BOZKURT, E. & SÖZBILIR, H. 2004. Tectonic evolution of the Gediz Graben: field evidence for an episodic, two-stage extension in western Turkey. *Geological Magazine*, **141**, 63–79.

BOZKURT, E. & SÖZBILIR, H. 2006. Evolution of the large-scale active Manisa fault, southwest Turkey: implications on fault development and regional tectonics. *Geodinamica Acta*, **19**, 427–453.

BOZKURT, E., WINCHESTER, J. A. & PIPER, J. D. A. (eds) 2000. *Tectonics and Magmatism in Turkey and the Surrounding Area*. Geological Society, London, Special Publications, **173**.

BOZKURT, E., WINCHESTER, J. A., MITTWEDE, S. K. & OTTLEY, C. J. 2006. Geochemistry and tectonic implications of leucogranites and tourmalines of the Southern Menderes Massif, southwest Turkey. *Geodinamica Acta*, **19**, 363–390.

BOZTUĞ, D., JONCKHEERE, R., WAGNER, G. A. & YEĞINGIL, Z. 2004. Slow Senonian and fast Palaeocene–early Eocene uplift of granitoids in the central eastern Pontides, Turkey: apatite fission–track results. *Tectonophysics*, **382**, 213–228.

BOZTUĞ, D., ERÇIN, A. İ., KURUÇELIK, M. K., GÖÇ, D., KÖMÜR, İ. & İSKENDEROĞLU, A. 2006. Geochemical characteristics of the composite Kaçkar batholith generated in a Neo-Tethyan convergence system, Eastern Pontides, Turkey. *Journal of Asian Earth Sciences*, **27**, 286–302.

BRÖCKER, M. & PIDGEON, R. T. 2007. Protolith ages of meta–igneous and metatuffaceous rocks from the Cycladic blueschist unit, Greece: results of a reconnaissance U–Pb zircon study. *Journal of Geology*, **115**, 83–98.

BRÖCKER, M., BIELING, D., HACKER, B. & GANS, P. 2004. High-Si phengite records the time of greenschist-facies overprinting: implications for models suggesting mega-detachments in the Aegean Sea. *Journal of Metamorphic Geology*, **22**, 427–442.

ÇELIK, O. F., DELALOYE, M. & FERAUD, G. 2006. Precise Ar-40–Ar-39 ages from the metamorphic sole rocks of the Tauride Belt Ophiolites, southern Turkey: implications for the rapid cooling history. *Geological Magazine*, **143**, 213–227.

DERCOURT, J., ZONENSHAIN, L. P., RICOU, L.-E. *ET AL.* 1986. Geological evolution of the Tethys belt from the Atlantic to the Pamirs since the Lias. *Tectonophysics*, **123**, 241–315.

Dewey, J. D. 1988. Extensional collapse of orogens. *Tectonics*, **7**, 1123–1139.

Dewey, J. F. & Şengör, A. M. C. 1979. Aegean and surrounding region: complex multiplate and continuum tectonics in a convergent zone. *Geological Society of America Bulletin*, **90**, 84–92.

Dilek, Y. 2006. Collision tectonics of the Mediterranean region: causes and consequences. *In*: Dilek, Y. & Pavlides, S. (eds) *Post-collisional Tectonics and Magmatism in the Mediterranean and Asia*. Geological Society of America, Special Papers, **409**, 1–13.

Dilek, Y. & Altunkaynak, S. 2007. Cenozoic crustal evolution and mantle dynamics of post-collisional magmatism in western Anatolia. *International Geology Review*, **49**, 431–453.

Dilek, Y. & Pavlides, S. (eds) 2006. *Post-collisional Tectonics and Magmatism in the Mediterranean and Asia*. Geological Society of America, Special Papers, **409**.

Dilek, Y. & Thy, P. 2006. Age and petrogenesis of plagiogranite intrusions in the Ankara mélange, central Turkey. *Island Arc*, **15**, 44–57.

Dilek, Y. & Whitney, D. L. 1997. Counterclockwise *PTt* trajectory from the metamorphic sole of a Neo-Tethyan ophiolite (Turkey). *Tectonophysics*, **280**, 295–301.

Dilek, Y., Shallo, M. & Furnes, H. 2005. Rift-drift, seafloor spreading, and subduction tectonics of Albanian ophiolites. *International Geology Review*, **47**, 147–176.

Dinter, D. A. & Royden, L. 1993. Late Cenozoic extension in northeastern Greece: Strymon valley detachment system and Rhodope metamorphic core complex. *Geology*, **21**, 45–48.

Dinter, D. A., Macfarlane, A. M., Hames, W., Isachsen, C., Bowring, S. & Royden, L. 1995. U–Pb and $^{40}Ar/^{39}Ar$ geochronology of the Symvolon granodiorite: implications for the thermal and structural evolution of the Rhodope metamorphic core complex, northeastern Greece. *Tectonics*, **14**, 886–908.

Doglioni, C., Agostini, S., Crespi, M., Innocenti, F., Manetti, P., Riguzzi, F. & Savaşçin, Y. 2002. On the extension in western Anatolia and the Aegean Sea. *Journal of Virtual Exploration*, **8**, 169–183.

Durand, B., Jolivet, L., Horváth, F. & Sérrane, M. (eds) 1999. *The Mediterranean Basins: Tertiary Extension Within the Alpine Orogen*. Geological Society, London, Special Publications, **156**.

Elmas, A. & Yilmaz, Y. 2003. Development of an oblique subduction zone—tectonic evolution of the Tethys suture zone in southeast Turkey. *International Geology Review*, **45**, 827–840.

Ercan, T., Satir, M., Sevin, D. & Türkecan, A. 1997. Batı Anadolu'daki Tersiyer ve Kuvarterner yaşlı kayaçlarda yeni yapılan radyometrik yaş ölçümlerinin yorumu. *Bulletin of Mineral Research and Exploration Institute (MTA) of Turkey*, **119**, 103–112 [in Turkish with English abstract].

Erkül, F., Helvaci, C. & Sözbİlİr, H. 2005. Stratigraphy and geochronology of the Early Miocene volcanics in the Bigadiç borate basin, western Turkey. *Turkish Journal of Earth Sciences*, **14**, 227–253.

Fytikas, M., Guiliano, O., Innocenti, F., Marinelli, G. & Mazzuoli, R. 1976. Geochronological data on recent magmatism of the Aegean Sea. *Tectonophysics*, **31**, 29–34.

Fytikas, M., Innocenti, F., Manetti, P., Mazuoli, R., Peccerillo, A. & Villari, L. 1984. Tertiary to Quaternary evolution of volcanism in the Aegean region. *In*: Dixon, J. E. & Robertson, A. H. F. (eds) *The Geological Evolution of the Eastern Mediterranean*. Geological Society, London, Special Publications, **17**, 687–700.

Gautier, P. & Brun, J.-P. 1994. Ductile crust exhumation and extensional detachments in the central Aegean (Cyclades and Evvia Islands). *Geodinamica Acta*, **7**, 57–85.

Gautier, P., Brun, J.-P. & Jolivet, J. 1993. Structure and kinematics of Upper Cenozoic extensional detachment on Naxos and Paros (Cyclades islands, Greece). *Tectonics*, **12**, 1180–1194.

Gautier, P., Brun, J.-P., Moriceau, R., Sokoutis, D., Martinod, J. & Jolivet, L. 1999. Timing, kinematics and cause of Aegean extension: a scenario based on comparison with simple analogue experiments. *Tectonophysics*, **315**, 31–72.

Gautier, P., Bozkurt, E., Hallot, E. & Dirik, K. 2002. Pre-Eocene exhumation of the Niğde Massif, Central Anatolia, Turkey. *Geological Magazine*, **139**, 559–576.

GEBCO 1997. *General Bathymetric Chart of the Oceans, Digital Version.* CD-ROM. British Oceanographic Data Centre, Birkenhead.

Gessner, K., Collins, A. S., Ring, U. & Güngör, T. 2004. Structural and thermal history of poly-orogenic basement: U–Pb gecohronology of granitoid rocks in the southern Menderes Massif, western Turkey. *Journal of the Geological Society, London*, **161**, 93–101.

Görür, N., Tüysüz, O. & Sengör, A. M. C. 1998. Tectonic evolution of the Central Anatolian basins. *International Geology Review*, **40**, 831–850.

Gourgaud, A. (ed.) 1998. Volcanism in Anatolia. *Journal of Volcanology and Geothermal Research*, **85**, 1–537.

Güleç, N. 1991. Crust–mantle interaction in western Turkey: implications from Sr and Nd isotope geochemistry of Tertiary and Quaternary volcanics. *Geological Magazine*, **123**, 417–435.

Hetzel, R., Passchier, C. W., Ring, U. & Dora, O. O. 1995*a*. Bivergent extension in orogenic belts: the Menderes Massif (southwestern Turkey). *Geology*, **23**, 455–458.

Hetzel, R., Ring, U., Akal, C. & Troesch, M. 1995*b*. Miocene NNE-directed extensional unroofing in the Menderes Massif, southwestern Turkey. *Journal of the Geological Society, London*, **152**, 639–654.

Hetzel, R., Romer, R. L., Candan, O. & Passchier, C. W. 1998. Geology of the Bozdağ area, central Menderes Massif, SW Turkey: Pan-African basement and Alpine deformation. *Geologische Rundschau*, **87**, 394–406.

Innocenti, F., Kolios, N., Manetti, P., Mazzuoli, R., Peccerillo, A., Rita, F. & Villari, L. 1984. Evolution and geodynamic significance of Tertiary orogenic volcanism in northeastern Greece. *Bulletin of Volcanology*, **47**, 25–37.

INNOCENTI, F., AGOSTINI, S., DI VINCENZO, G., DOGLIONI, C., MANETTI, P., SAVAŞÇIN, M. Y. & TONARINI, S. 2005. Neogene and Quaternary volcanism in western Anatolia: magma sources and geodynamic evolution. *Marine Geology*, **221**, 397–421.

IŞIK, V., TEKELI, T. & SEYITOĞLU, G. 2003. Ductile–brittle transition along the Alaşehir detachment fault and its structural relationship with the Simav detachment fault, Menderes Massif, western Turkey. *Tectonophysics*, **374**, 1–18.

JACKSON, J. & MCKENZIE, D. 1988. The relationship between plate motions and seismic moment tensors and rates of active deformation in the Mediterranean and Middle East. *Geophysical Journal*, **93**, 45–73.

JOLIVET, L. & FACCENNA, C. 2000. Mediterranean extension and the Africa–Eurasia collision. *Tectonics*, **19**, 1095–1106.

JOLIVET, L. & PATRIAT, M. 1999. Ductile extension and the formation of the Aegean Sea. *In*: DURAND, B., JOLIVET, L., HORVÁTH, F. & SÉRRANE, M. (eds) *The Mediterranean Basins: Tertiary Extension within the Alpine Orogen*. Geological Society, London, Special Publications, **156**, 427–456.

JOLIVET, L., BRUN, J.-P., GAUTIER, P., LALLEMANT, S. & PATRIAT, M. 1994. 3-D kinematics of extension in the Aegean from the Early Miocene to the present, insights from the ductile crust. *Bulletin de la Société Géologique de France*, **65**, 195–209.

JOLIVET, L., FACCENNA, C., GOFFÉ, B., BUROV, E. & AGARD, P. 2003. Subduction tectonics and exhumation of high-pressure metamorphic rocks in the Mediterranean orogen. *American Journal of Science*, **303**, 353–409.

KARSLI, O., AYDIN, F. & SADIKLAR, M. B. 2004. Magma interaction recorded in plagioclase zoning in granitoid systems, Zigana Granitoid, eastern Pontides, Turkey. *Turkish Journal of Earth Sciences*, **15**, 287–306.

KESKIN, M. 2003. Magma generation by slab steepening and breakoff beneath a subduction–accretion complex: an alternative model for collision-related volcanism in Eastern Anatolia, Turkey. *Geophysical Research Letters*, **30**, 8046.

KISSEL, C. & LAJ, C. 1988. Tertiary geodynamical evolution of the Aegean arc: a palaeomagnetic reconstruction. *Tectonophysics*, **146**, 183–201.

KOÇYİĞİT, A. 1991. An example of an accretionary fore-arc basin from central Anatolia and its implications for the history of subduction of Neo-Tethys in Turkey. *Geological Society of America Bulletin*, **103**, 22–36.

KOÇYİĞİT, A., YUSUFOĞLU, H. & BOZKURT, E. 1999. Evidence from the Gediz Graben for episodic two-stage extension in western Turkey. *Journal of the Geological Society, London*, **156**, 605–616.

LE PICHON, X. & ANGELIER, J. 1981. The Aegean Sea. *Philosophical Transactions of Royal Society of London, Series A*, **300**, 357–372.

LIPS, A. L. W., CASSARD, D., SÖZBILIR, H. & YILMAZ, H. 2001. Multistage exhumation of the Menderes Massif, western Anatolia (Turkey). *International Journal of Earth Sciences*, **89**, 781–792.

LISTER, G. S., BANGA, G. & FEENSTRA, A. 1984. Metamorphic core complexes of cordilleran-type in the Cyclades, Aegean Sea, Greece. *Geology*, **12**, 221–225.

MCCLUSKY, S., BALASSANIAN, S., BARKA, A. *ET AL.* 2000. Global positioning system constraints on plate kinematics and dynamics in the eastern Mediterranean and Caucasus. *Journal of Geophysical Research*, **105**, 5695–5719.

MCCLUSKY, S., REILINGER, R., MAHMOUD, S., BEN-SARI, D. & TEALEB, A. 2003. GPS constraints on Africa (Nubia) and Arabia plate motions. *Geophysical Journal International*, **155**, 126–138.

MCKENZIE, D. 1978. Active tectonics of the Alpine–Himalayan belt: the Aegean Sea and surrounding regions. *Geophysical Journal of the Royal Astronomical Society*, **55**, 217–254.

MEULENKAMP, J. E., VAN DER ZWAAN, G. J. & VAN WAMEL, W. A. 1994. On Late Miocene to recent vertical motions in the Cretan segment of the Hellenic arc. *Tectonophysics*, **234**, 53–72.

OBERHÄNSLI, R., PARTZSCH, J., CANDAN, O. & ÇETINKAPLAN, M. 2001. First occurrence of Fe–Mg-carpholite documenting a high-pressure metamorphism in metasediments of the Lycian nappes, SW Turkey. *International Journal of Earth Sciences*, **89**, 867–873.

OKAY, A. İ. 2001. Stratigraphic and metamorphic inversions in the central Menderes Massif: a new structural model. *International Journal of Earth Sciences*, **89**, 709–727.

OKAY, A. İ. & ŞAHINTÜRK, Ö. 1997. Geology of the Eastern Pontides. *In*: ROBINSON, A. G. (ed.) *Regional and Petroleum Geology of the Black Sea and Surrounding Region*. Association of American Petroleum Geologists, Memoirs, **68**, 291–311.

OKAY, A. İ. & SATIR, M. 2000. Coeval plutonism and metamorphism in a latest Oligocene metamorphic core complex in northwest Turkey. *Geological Magazine*, **137**, 495–516.

OKAY, A. İ., HARRIS, N. B. W. & KELLEY, S. P. 1998. Exhumation of blueschists along a Tethyan suture in northwest Turkey. *Tectonophysics*, **285**, 272–299.

OKAY, A. İ., TANSEL, İ. & TÜYSÜZ, O. 2001. Obduction, subduction and collision as reflected in the Upper Cretaceous–Lower Eocene sedimentary record of western Turkey. *Geological Magazine*, **138**, 117–142.

OKRUSCH, M. & BRÖCKER, M. 1990. Eclogites associated with high-grade blueschists in the Cycladic archipelago, Greece: a review. *European Journal of Mineralogy*, **2**, 451–478.

PAPAZACHOS, B. C., PAPADIMITRIOU, E. E., KIRATZI, A. A., PAPAZACHOS, C. B. & LOUVARI, E. K. 1998. Fault plane solutions in the Aegean Sea and the surrounding area and their implication. *Bollettino di Geofisica Teorica ed Applicata*, **39**, 199–218.

PARLAK, O. 2006. Geodynamic significance of granitoid magmatism in the southeast Anatolian orogen: geochemical and geochronogical evidence from Goksun–Afsin (Kahramanmaras, Turkey) region. *International Journal of Earth Sciences*, **95**, 609–627.

PARLAK, O. & ROBERTSON, A. 2004. The ophiolite-related Mersin Melange, southern Turkey: its role in the tectonic–sedimentary setting of Tethys in the Eastern Mediterranean region. *Geological Magazine*, **141**, 257–286.

PARLAK, O., HÖCK, V. & DELALOYE, M. 2002. The supra-subduction zone Pozantı–Karsantı ophiolite, southern Turkey: evidence for high-pressure crystal fractionation of ultramafic cumulates. *Lithos*, **65**, 205–224.

PE-PIPER, G. & PIPER, D. J. W. 2006. Unique features of the Cenozoic igneous rocks of Greece. *In*: DILEK, Y. & PAVLIDES, S. (eds) *Post-collisional Tectonics and Magmatism in the Mediterranean Region and Asia.* Geological Society of America, Special Papers, **409**, 259–282.

PURVIS, M. & ROBERTSON, A. H. F. 2004. A pulsed extension model for the Neogene–Recent E–W-trending Alaşehir Graben and the NE–SW-trending Selendi and Gördes basins, western Turkey. *Tectonophysics*, **391**, 171–201.

PURVIS, M., ROBERTSON, A. H. F. & PRINGLE, M. 2005. Ar-40–Ar-39 dating of biotite and sanidine in tuffaceous sediments and related intrusive rocks: implications for the Early Miocene evolution of the Gördes and Selendi basins, W Turkey. *Geodinamica Acta*, **18**, 239–253.

RÉGNIER, J. L., MEZGER, J. E. & PASSCHIER, C. W. 2007. Metamorphism of Precambrian–Palaeozoic schists of the Menderes core series and contact relationships with Proterozoic orthogneisses of the western Çine Massif, Anatolide belt, western Turkey. *Geological Magazine*, **144**, 67–104

RICHARDSON-BUNBURY, J. M. 1996. The Kula volcanic field, western Turkey: the development of a Holocene alkali basalt province and the adjacent normal faulting. *Geological Magazine*, **133**, 275–283.

RIMMELÉ, G., JOLIVET, L., OBERHÄNSLI, R. & GOFFÉ, B. 2003. Deformation history of the high-pressure Lycian nappes and implications for tectonic evolution of SW Turkey. *Tectonics*, **22**, 1007–1029.

RING, U. & COLLINS, A. S. 2005. U–Pb SIMS dating of synkinematic granites: timing of core complex formation in the northern Anatolide belt of western Turkey. *Journal of the Geological Society, London*, **162**, 1–10.

RING, U., WILLNER, A. & LACKMANN, W. 2001. Stacking of nappes with different pressure–temperature paths: an example from the Menderes nappes of western Turkey. *American Journal of Science*, **301**, 912–944.

RING, U., JOHNSON, C., HETZEL, R. & GESSNER, K. 2003. Tectonic denudation of a Late Cretaceous–Tertiary collisional belt: regionally symmetric cooling patterns and their relation to extensional faults in the Anatolide belt of western Turkey. *Geological Magazine*, **140**, 421–441.

ROBERTSON, A. H. F. & DIXON, J. E. 1984. Introduction: aspects of the geological evolution of the Eastern Mediterranean. *In*: DIXON, J. E. & ROBERTSON, A. H. F. (eds), *The Geological Evolution of the Eastern Mediterranean*. Geological Society, London, Special Publications, **17**, 1–74.

ROBERTSON, A. H. F. & MOUNTRAKIS, D. (eds) 2006. *Tectonic Development of the Eastern Mediterranean Region*. Geological Society, London, Special Publications, **260**.

ROBERTSON, A. H. F. & USTAÖMER, T. 2004. Tectonic evolution of the intra-Pontide suture zone in the Armutlu Peninsula, NW Turkey. *Tectonophysics*, **381**, 175–209.

ROBERTSON, A. H. F., ÜNLÜGENÇ, U. C., İNAN, N. & TASLI, K. 2004*a*. The Misis–Andirin complex: a mid-Tertiary mélange related to late-stage subduction of the southern Neotethys in S Turkey. *Journal of Asian Earth Sciences*, **22**, 413–453.

ROBERTSON, A. H. F., USTAÖMER, T., PICKETT, E. A. *ET AL*. 2004*b*. Testing models of Late Palaeozoic–Early Mesozoic orogeny in Western Turkey: support for an evolving open-Tethys model. *Journal of the Geological Society, London*, **161**, 501–511.

ROBINSON, A. G. (ed.) 1997. *Regional and Petroleum Geology of the Black Sea and Surrounding Region*. Association of American Petroleum Geologists, Memoirs, **68**.

ROTSTEIN, Y. 1984. Counterclockwise rotation of Anatolian block. *Tectonophysics*, **108**, 71–91.

ŞAROĞLU, F., EMRE, Ö. & KUŞÇU, İ. 1992. *Active Fault Map of Turkey, 2 sheets*. Maden ve Tetkik Arama Enstitüsü, Ankara.

SATO, T., KASAHARA, J., TAYMAZ, T., ITO, M., KAMIMURA, A., HAYAKAWA, T. & TAN, O. 2004. A study of microearthquake seismicity and focal mechanisms within the Sea of Marmara (NW Turkey) using ocean bottom seismometers (OBSs). *Tectonophysics*, **75**, 181–241.

SAUNDERS, P., PRIESTLEY, K. & TAYMAZ, T. 1998. Variations in the crustal structure beneath western Turkey. *Geophysical Journal International*, **134**, 373–389.

ŞENGÖR, A. M. C. 1979. The North Anatolian Transform Fault: its age, offset and tectonic significance. *Journal of the Geological Society, London*, **136**, 269–282.

ŞENGÖR, A. M. C. 1987. Cross-faults and differential stretching of hanging walls in regions of low-angle normal faulting: examples from eastern Turkey. *In*: COWARD, M. P., DEWEY, J. F. & HANCOCK, P. L. (eds) *Continental Extensional Tectonics*. Geological Society, London, Special Publications, **28**, 575–589.

ŞENGÖR, A. M. C. & YILMAZ, Y. 1981. Tethyan evolution of Turkey: a plate tectonic approach. *Tectonophysics*, **75**, 181–241.

ŞENGÖR, A. M. C., SATIR, M. & AKKÖK, R. 1984. Timing of tectonic events in the Menderes Massif, western Turkey: implications for tectonic evolution and evidence for Pan-African basement in Turkey. *Tectonics*, **3**, 693–707.

ŞENGÖR, A. M. C., GÖRÜR, N. & ŞAROĞLU, F. 1985. Strike-slip deformation, basin formation and sedimentation: strike–slip faulting and related basin formation in zones of tectonic escape. *In*: BIDDLE, K. T. & CHRISTIE-BLICK, N. (eds) *Strike–slip Faulting and Basin Formation*. Society of Economic Paleontologists and Mineralogists, Special Publications, **37**, 227–264.

ŞENGÖR, A. M. C., TÜYSÜZ, O., İMREN, C. *ET AL*. 2005. The North Anatolian Fault: a new look. *Annual Review of Earth and Planetary Sciences*, **33**, 37–112.

ŞENGÜN, F., CANDAN, O., DORA, Ö. O. & KORALAY, E. 2006. Petrography and geochemistry of paragneisses in the Çine submassif of the Menderes Massif, western Anatolia. *Turkish Journal of Earth Sciences*, **15**, 321–342.

SEYITOĞLU, G. & SCOTT, B. C. 1991. Late Cenozoic crustal extension and basin formation in west Turkey. *Geological Magazine*, **128**, 155–166.

SEYITOĞLU, G. & SCOTT, B. C. 1992. The age of the Büyük Menderes Graben (west Turkey) and its tectonic implications. *Geological Magazine*, **129**, 239–242.

SEYITOĞLU, G., SCOTT, B. C. & RUNDLE, C. C. 1992. Timing of Cenozoic extensional tectonics in west Turkey. *Journal of the Geological Society, London*, **149**, 533–538.

SEYITOĞLU, G., ANDERSON, D., NOWELL, G. & SCOTT, B. C. 1997. The evolution from Miocene potassic to Quaternary sodic magmatism in western Turkey: implications for enrichment processes in the lithospheric mantle. *Journal of Volcanology and Geothermal Research*, **76**, 127–147.

SEYITOĞLU, G., IŞIK, V. & ÇEMEN, İ. 2004. Complete Tertiary exhumation history of the Menderes Massif, western Turkey: an alternative working hypothesis. *Terra Nova*, **16**, 358–363.

SHERLOCK, S. 1999. ^{40}Ar–^{39}Ar and Rb–Sr geochronology of high-pressure metamorphism and exhumation history of the Tavşanlı Zone, NW Turkey. *Contributions to Mineralogy and Petrology*, **137**, 46–58.

SMITH, W. H. F. & SANDWELL, D. T. 1997*a*. *Measured and estimated seafloor topography (version 4.2).* World Data Centre-A for Marine Geology and Geophysics Research Publication, **RP-1**.

SMITH, W. H. F. & SANDWELL, D. T. 1997*b*. Global seafloor topography from satellite altimetry and ship depth soundings. *Science*, **277**, 1957–1962.

STAMPFLI, G. M. 2000. Tethyan oceans. *In*: BOZKURT, E., WINCHESTER, J. A. & PIPER, J. D. A. (eds) *Tectonics and Magmatism in Turkey and Surrounding Area.* Geological Society, London, Special Publications, **173**, 1–23.

STAMPFLI, G. M. & BOREL, J. D. 2004. The TRANSMED transects in space and time: constraints on the paleotectonic evolution of the Mediterranean domain. *In*: CAVAZZA, W., ROURE, F. M., SPAKMAN, W., STAMPFLI, G. M. & ZIEGLER, P. A. (eds) *The TRANSMED Atlas – The Mediterranean Region from Crust to Mantle*. Springer, Berlin, 53–80.

TAN, O. & TAYMAZ, T. 2006. Active tectonics of the Caucasus: earthquake source mechanisms and rupture histories obtained from inversion of teleseismic body waveforms. *In*: DILEK, Y. & PAVLIDES, S. (eds) *Post-collisional Tectonics and Magmatism in the Mediterranean and Asia*. Geological Society of America, Special Papers, **409**.

TAYMAZ, T. 1990. *Earthquake source parameters in the Eastern Mediterranean Region*. PhD thesis, University of Cambridge.

TAYMAZ, T. 1993. The source parameters of Çubukdağ (Western Turkey) earthquake of 11 October 1986. *Geophysical Journal International*, **113**, 260–267.

TAYMAZ, T. 1996. S–P-wave traveltime residuals from earthquakes and lateral heterogeneity in the upper mantle beneath the Aegean and the Hellenic Trench near Crete. *Geophysical Journal International*, **127**, 545–558.

TAYMAZ, T. 2002. Obituary: Kâzım Ergin. *Turkish Journal of Earth Sciences*, **11**, 247–250.

TAYMAZ, T. 2004. Geophysicists: Kâzım Ergin. *EOS Transactions, American Geophysical Union*, **85**, 14.

TAYMAZ, T. & PRICE, S. 1992. The 1971 May 12 Burdur earthquake sequence, SW Turkey: a synthesis of seismological and geological observations. *Geophysical Journal International*, **108**, 589–603.

TAYMAZ, T., JACKSON, J. A. & WESTAWAY, R. 1990. Earthquake mechanisms in the Hellenic Trench near Crete. *Geophysical Journal International*, **102**, 695–731.

TAYMAZ, T., JACKSON, J. A. & MCKENZIE, D. P. 1991*a*. Active tectonics of the North and Central Aegean Sea. *Geophysical Journal International*, **106**, 433–490.

TAYMAZ, T., EYIDOĞAN, H. & JACKSON, J. A. 1991*b*. Source parameters of large earthquakes in the East Anatolian Zone (Turkey). *Geophysical Journal International*, **106**, 537–550.

TAYMAZ, T., WESTAWAY, R. & REILINGER, R. (eds) 2004. Active Faulting and Crustal Deformation in the Eastern Mediterranean Region. *Tectonophysics*, **391**, 1–374.

THOMSON, S. N. & RING, U. 2006. Thermochronologic evaluation of postcollision extension in the Anatolide orogen, western Turkey. *Tectonics*, **25**, paper number TC3005.

THOMSON, S. N., STÖCKHERT, B. & BRIX, M. R. 1998. Thermochronology of the high-pressure metamorphic rocks of Crete, Greece: implications for the speed of tectonic processes. *Geology*, **26**, 259–262.

TONARINI, S., AGOSTINI, S., ONNOCENTI, F. & MANETTI, P. 2005. δ^{11}B as tracer of slab dehydration and mantle evolution in western Anatolia Cenozoic magmatism. *Terra Nova*, **17**, 259–264.

TROTET, F., JOLIVET, L. & VIDAL, O. 2001. Tectonometamorphic evolution of Syros and Sifnos islands (Cyclades, Greece). *Tectonophysics*, **338**, 179–206.

VANDENBERG, L. C. & LISTER, G. S. 1996. Structural analysis of basement tectonites from the Aegean metamorphic core complex of Ios, Cyclades, Greece. *Journal of Structural Geology*, **18**, 1437–454.

WHITNEY, D. L. & DILEK, Y. 1997. Core complex development in central Anatolia, Turkey. *Geology*, **25**, 1023–1026.

WHITNEY, D. L., TEYSSIER, C., FAYON, A., HAMILTON, M. A. & HEIZLER, M. 2003. Tectonic controls on metamorphism, partial melting, and intrusion: timing and duration of regional metamorphism and magmatism in the Niğde Massif, Turkey. *Tectonophysics*, **376**, 37–60.

YILMAZ, Y., TÜYSÜZ, O., YIĞITBAŞ, E., GENÇ, Ş. C. & ŞENGÖR, A. M. C. 1997. Geology of tectonic evolution of the Pontides. *In*: ROBINSON, A. G. (ed.)

Regional and Petroleum Geology of the Black Sea and Surrounding Region. Association of American Petroleum Geologists Memoirs, **68**, 183–226.

YILMAZ, Y., GENÇ, Ş. C., GÜRER, Ö. F. *ET AL*. 2000. When did the western Anatolian grabens begin to develop? *In*: BOZKURT, E., WINCHESTER, J. A. & PIPER, J. D. A. (eds) *Tectonics and Magmatism in Turkey and the Surrounding Area*. Geological Society, London, Special Publications, **173**, 353–384.

YILMAZ, Y., GENÇ, Ş. C., KARACIK, Z. & ALTUNKAYNAK, S. 2001. Two contrasting magmatic associations of NW Anatolia and their tectonic significance. *Journal of Geodynamics*, **31**, 243–271.

YÜCEL-ÖZTÜRK, Y., HELVACI, C. & SATIR, M. 2005. Genetic relations between skarn mineralization and petrogenesis of the Evciler Granitoid, Kazdağ, Çanakkale, Turkey and comparison with world skarn granitoids. *Turkish Journal of Earth Sciences*, **14**, 225–280.