Geological evolution of a tectonic and climatic transition zone: the Beyşehir-Suğla basin, lakes district of Turkey

Alper Gürbüz[1,]*, Nizamettin Kazancı[2], H. Yavuz Hakyemez[3,6], Suzanne A.G. Leroy[4,10], Neil Roberts[5,11], Gerçek Saraç[6], Zeynep Ergun[2], Klaus Arpe[4,7], Sonay Boyraz-Arslan[8,12], Esra Gürbüz[8,13], Koray Koç[9], Özgür Yedek[2], Tahsin Onur Yücel[2]

[1] Niğde Ömer Halisdemir Üniversitesi, Mühendislik Fakültesi, Jeoloji Mühendisliği Bölümü, 51240, Niğde, Turkey

[2] Ankara Üniversitesi, Mühendislik Fakültesi, Jeoloji Mühendisliği Bölümü, 06100, Tandoğan, Ankara, Turkey

[3] Maden Tetkik ve Arama Genel Müdürlüğü, Deniz Araştırmaları Daire Başkanlığı, 06520, Ankara, Turkey

[4] Institute for the Environment, Brunel University, Uxbridge UB8 3PH (West London), UK

[5] School of Geography, Earth and Environmental Sciences, Plymouth University, Plymouth Devon PL4 8AA, UK

[6] Jeolojik Mirası Koruma Derneği (JEMİRKO), P.K. 10, 06100, Maltepe, Ankara, Turkey

[7] Max-Planck-Institute für Meteorologie, 20146 Hamburg, Germany

[8] Aksaray Üniversitesi, Mühendislik Fakültesi, Jeoloji Mühendisliği Bölümü, 68100, Aksaray, Turkey

[9] Akdeniz Üniversitesi, Mühendislik Fakültesi, Jeoloji Mühendisliği Bölümü, 07100, Antalya, Turkey

[10] Laboratoire méditerranéen de préhistoire Europe Afrique, Ecosystèmes Quaternaires LAMPEA (UMR 7269) MMSH, , 13094 Aix-en-Provence Cedex 2, France

[11] School of Archeology, University of Oxford, 1 South Parks Road, Oxford OX1 3TG, UK

[12] Maden Tetkik ve Arama Genel Müdürlüğü, Maden Analizleri ve Teknolojisi Daire Başkanlığı, 06520, Ankara, Turkey

[13] Aksaray Üniversitesi, Mühendislik Fakültesi, Harita Mühendisliği Bölümü, 68100, Aksaray, Turkey

***Corresponding author:** agurbuz@nigde.edu.tr*

ABSTRACT

Central-west Turkey is a transition zone both tectonically and climatologically between the central and western regions of Anatolia. Central Anatolia represents the seismically quiet part of the highly active country. On the other hand, the region has some of the lowest precipitation and highest evaporation ratios of Turkey. Conversely, western Anatolia is one of the most rapidly extending regions of the world and seismically very active. The climate is very different from the central part of Turkey and more humid. The zone between these two regions is also known geologically as the Isparta Angle. This reverse-V-shaped fold and thrust belt has several lake basins today, which have archived the geological and geomorphological history of this tectonic and climatic transition zone. The Beyşehir-Suğla basin is located on the eastern part of this zone. The NW-SE trending basin includes the largest natural freshwater lake of the Mediterranean region: Lake Beyşehir. The Lakes Beyşehir and Suğla are located in this tectonic depression that reaches an incised valley that opens to the Konya closed basin. In order to shed light on the development of the lake basin, our study was mainly conducted within the Neogene and Quaternary units of the region. Our results indicate that the depression region was formed by a transtensional regime in the Middle Miocene, which is controlled by extensional tectonics since the early Quaternary. Also, the current depression has mainly embodied the structures which are the products of these tectonic phases. The Beyşehir-Suğla basin was developed early under a humid and warm climate in the Middle Miocene, then controlled with a relatively more arid and, at times, cold climate more like the central Anatolian basins since the Late Miocene-Pliocene. However, as evidenced by the lack of evaporites in the studied basin and surrounding basins located interior part of the Isparta Angle, these basins were hydrologically protected from the arid climatic conditions probably by the support of karstic features and sources on the carbonate rocks of the Taurus Mountains. The karstic features that particularly prevail in the western half are very important for geologic and geomorphic evolution, and the hydro(geo)logical budget of the drainage basin. Because of bounding by the normal faulted steep slopes in most sectors, the NW-SE-trending Lake Beyşehir could reach its maximum surface area in Quaternary by coastal progressions in the north and south which are determined by the water amount that reached the lake.

Keywords**:** *Neogene, Quaternary, central-west Anatolia, Isparta Angle, fluvio-lacustrine environment, transtension, graben, karst.*

INTRODUCTION

Central-west Turkey represents a transition zone in regard to both tectonic and climatic features of the country (Figs. 1a and b). According to its tectonic position, the region corresponds to the zone between the central Anatolian 'ova' regime (Şengör, 1979) and the western Anatolian extensional regime. This region is also known as the Isparta Angle ("*la courbure d'Isparta*" - Blumenthal, 1963) which is characterized due to its reverse-V-shaped geometry (Fig. 2). To the east of this region, the morphology has a very wide subdued topography. In the west of the Isparta Angle, the geomorphology is shaped by grabens and horsts with a high relief mainly trending in E-W and N-S directions (e.g. Şengör, 1987; Seyitoğlu, 1997; Temiz et al., 1997; Yılmaz et al., 2000; Bozkurt, 2003; Gürbüz et al., 2012; Gürer et al., 2013; Ersoy et al., 2014). All these mentioned tectonics and related morphology influenced the climate, and due to this specific position the region stands for a climatic transition zone between the relatively arid continental climate of central Anatolia and western and southern Turkey's humid Mediterranean climate.

The Neogene and Quaternary units of the Isparta Angle include the clues about the cause, style and timing of changes in the tectonic and climatic history of Turkey. In this framework, there is an increase in the amounts of studies discussing the Neogene evolution of sedimentary basins and volcanism in the region, particularly in the last few decades (e.g. Keller et al., 1977; Koçyiğit, 1983; Boray et al., 1985; Akay and Uysal, 1988; Yağmurlu, 1991a,b; Yağmurlu et al., 1997; Flecker et al., 1998, 2005; Glover and Robertson, 1998; Karakaş and Kadir, 1998; Temel et al., 1998; Fracalanci et al., 2000; Karabıyıkoğlu et al., 2000, 2005; Koçyiğit et al., 2000, 2012; Koçyiğit and Özacar, 2003; Poisson et al., 2003, 2011; Deynoux et al., 2005; Monod et al., 2006; Çiner et al., 2008; Topak et al., 2009; Karaman, 2010; Koç et al., 2012, 2015; Schildgen et al., 2012; Kaya et al., 2014). In this extendable literature list, the main controversies are related to the driving forces for the basin developments, and whether evolution of the sedimentary basins was episodic or continous. On the other hand, researches focused on the Quaternary features of the region are relatively limited (e.g. Farand, 1965; Cohen and Erol, 1969; Bering, 1971; van Zeist et al., 1975; Erol, 1978, 1984, 1997; Roberts, 1980; Doğan, 1997; Nemec et al., 1998; Nemec and Kazancı, 1999; Roberts and Wright, 2003; Zahno et al., 2009). However, the Quaternary period of this region includes an impressive environmental history consists of a wealth of changes in tectonism and climate, and interactions between these natural phenomenons and human (e.g. Aytuğ, 1967; van Zeist and Buitenhuis, 1983; Roberts, 1991). Due to tectonic and climatic features, there are several lakes in the Isparta Angle in different scales and hydrochemistry (Fig. 2). Thus, this region is also known as the 'lakes district of Turkey'. The lake basins hosted numerous archaeological mounds and historical settlements since the late Pleistocene (e.g., Solecki, 1964).

The Lake Beyşehir and Lake Suğla subbasins are located in an elongated NNW-SSE-directed tectonic depression (the Beyşehir-Suğla basin) on the eastern flank of the reverse-V-shaped Isparta Angle (Fig. 2). Although there are important studies describing the glacial, karstic and geomorphic features of some parts of these lake basins (e.g. Nazik, 1985; Değirmenci and Günay, 1992; Ekmekçi, 1993; Doğan, 1997; Zahno et al., 2009; Çılğın, 2015), there is no detailed study focused on Neogene-Quaternary geology and geomorphology of whole of this depression and included lakes with surface and subsurface data. In addition, although its thick and distinctive coal formations, the Beyşehir-Suğla basin has no published generalized stratigraphic section.

In this paper, the Neogene-Quaternary geology of the Beyşehir-Suğla basin has been studied in order to contribute towards the understanding of a basin evolution in a tectonic and climatic transition zone. We present the stratigraphic, sedimentary, structural and geomorphic features of the studied basin mainly based on field studies, borehole data and geomorphic analyses. The depression formed as a transtensional basin probably in a more WNW-ESE orientation during the Middle Miocene. The basin turned into its current more northward (NNW-SSE) geometry during the Mio-Pliocene, while the Central Taurus Mountains rapidly was uplifting and volcanism erupting high amounts of geomaterials, then evolved into a normal fault controlled extensional character in the Plio-Quaternary. The climate seems to have changed consistent with the geomorphic response to large scale tectonics (i.e. orographic barrier development).

GEOGRAPHICAL AND GEOLOGICAL SETTINGS

Lake Beyşehir is the largest freshwater resource not only for Turkey, but also for the Mediterranean region. On the other hand, this lake is the third largest lake of Turkey (*c.* 656 km^2), after the soda and salt lakes of Van and Tuz, respectively. The lake is situated at an elevation of 1123 m and has a maximum depth of 9 m. There are 32 islands in the lake and the largest two of them have been inhabited, as other are rocky and small as big as 1 km^2. The only surface outlet of Lake Beyşehir is the Beyşehir stream/channel. It connects this subbasin to the Lake Suğla subbasin in the south (Fig. 3a), which is located at an altitude of 1094 m, and then to Apa Dam of the Konya basin. The natural water connection between Lakes Beyşehir and Suğla was available until the 20th century. The current Beyşehir stream is not flowing into Lake Suğla. The stream has channelized directly to the Konya plain (*via* the Apa Dam) as a part of the Konya irrigation project. Modern Lake Suğla is also not in its natural form and has been used as an anthropogenic reservoir since 2003. Lakes Beyşehir and Suğla are located in a NW-SE-trending depression bounded by steep slopes: the Beyşehir-Suğla basin (Fig. 3b). The Beyşehir-Suğla basin has a transient climate between the Mediterrenean and continental climates with mean precipitation of ~500 mm/a and ~750 mm/a in Beyşehir and Seydişehir, respectively (e.g., Sarı and İnan, 2011). While the precipitation reaches an amount of >1400 mm/a at its southern neighbour lands, its eastern neighbour, the Konya basin, represents the lowest precipitation (<300 mm/a) of Turkey (e.g., Doğan and Berktay, 2013; Fig. 1b).

The Lake Beyşehir subbasin is approximately 82 km wide and 94 km long drainage basin with a surface area of ~4275 km^2. The subbasin is separated from the Lake Suğla subbasin to the south by a height difference of ~10 m and from the Lake Eğirdir basin to the north by a ~100 m height thresholds. On the other hand, the Lake Suğla subbasin has a drainage area of ~3040 km^2. Drainage of the Lake Suğla subbasin reaches to an incised river valley in the south (i.e. the Mavi Gorge; Fig. 3a), which opens to the Konya closed basin to the east. The eastern margin of the Beyşehir-Suğla basin is bounded by the Sultan Mountains and Erenler-Alaca volcanic mountains, while the western portion is delimited by the Anamas, Dedegöl and Gidengelmez mountains (Figs. 1 and 3b). These mountains are represented by Paleozoic and Neogene units in the east, and mainly Mesozoic rocks in the west (Figs. 2 and 3c). This region is considered geographically as the western Taurus Mountains, and geologically as the Isparta Angle.

The Isparta Angle (Blumenthal, 1963) is one of the geologically most complex regions of Turkey, and includes many sedimentary basins and ridges between those depressions (Fig. 2). The reverse-V-shaped geometry of this large-scale structure seems to be a reflection of junction geometry of the Aegean and Cyprian Arcs beneath it (e.g. Barka and Reilinger, 1997; Biryol et al., 2011), but it is not as simple as it seems. The region consists of very different lithological units belonging to a wide age range (Precambrian to Quaternary) juxtaposed due to collisional and post-collisional tectonics that followed the closing process of the Tethys Ocean (Figs. 3c and d; e.g. Özgül, 1976, 1997; Şengör and Yılmaz, 1981; Koçyiğit, 1983, 1984; Glover and Robertson, 1998; Altıner et al., 1999; Robertson, 2000; Çelik and Delaloye, 2006; Seyitoğlu et al., 2017). Paleozoic-Cenozoic sedimentary units and ophiolites are thrusted over each other in different vergences (e.g., Uysal et al., 1980; Frizon de Lamotte et al., 1995; Poisson et al., 2003). Thus, the basement geology of the region is represented mainly by autochtonous and allochtonous units (e.g. Şenel et al., 1996). In the study area (i.e. the Beyşehir-Suğla basin), the Beyşehir-Hoyran-Hadim nappes (Monod, 1977; Özgül, 1984) are overlie a basement of the Tauride platform units (e.g. Blumenthal 1947; Koçyiğit, 1981, 1983; Robertson, 2000).

The last major contraction event and the related structure (i.e. Aksu thrust fault zone; Fig. 4) are located in the southern part of Isparta Angle (e.g. Koçyiğit et al., 2012). The Kırkkavak fault is described by Dumont and Kerey (1975) as a right-lateral strike-slip, or a reverse fault by Akay and Uysal (1988) that developed during the mentioned contraction process. However, Schildgen et al. (2012) represented the Kırkkavak fault as a normal fault according to kinematic data. Koçyiğit et al. (2012) also suggested the current fault as a reactivated old structure like the current Aksu fault, and it is a normal fault during the Quaternary due to regional extension caused by the slab retreat process. In addition, to the northern part of the Isparta Angle, the Akşehir fault delinates the zone from the outside. Boray et al. (1985) proposed that the Akşehir fault (Sultandağları fault in their paper) is a reverse fault as the component of a still continuing contraction in the region. But, as evidenced by the focal mechanism solutions of the 2000 and 2002 earthquakes (Mw= 6.0 and 6.5 respectively) the region is still controlled by extensional regime and the mentioned structure is a normal fault as suggested by many researchers (Fig. 4; e.g., Atalay, 1975; Koçyiğit, 1984; Koçyiğit and Özacar, 2003; Kaya et al., 2014). The Beyşehir-Suğla basin is positioned between the aforementioned fault structures, which are interpreted as the elements developed previously by contractional forces. Because of a change in the geodynamic processes control the tectonics of central-west Turkey, the region is currently under the effects of extensional tectonics (e.g., Koçyiğit et al., 2000, 2012; Schildgen et al., 2012, 2014). Therefore, the studied region may also include a tectonic regime with a transition history in the Neogene-Quaternary.

METHODS

Field studies during the summer months between 2012 and 2014 were based on stratigraphical, sedimentological, structural and morphological observations to understand the Neogene-Quaternary geological and geomorphic history of the Beyşehir-Suğla basin. In order to support our stratigraphic and sedimentological investigations, we also used core log data of 128 boreholes drilled in the study area by DSİ (State Water Works of Turkey), 124 boreholes by MTA (General Directorate of Mineral Resources and Research) and 7 boreholes in our project (Fig. 3c). After an elimination of boreholes due to their in spitting distances (particularly boreholes of MTA), descriptions of the Quaternary deposits from 47 boreholes determined according to their lithofacies and comparison with surface sequences observed at outcrops (Fig. 3c). Core log data depths vary from 50 to 265 m, and our three boreholes in the Lake Suğla subbasin reached a maximum depth of 75 m.

In addition to field observations, we used topographic maps (1:25,000 and 1:100,000 scales), airphotos (1:15,000 scale), Shuttle Radar Topography Mission (SRTM) data, and satellite images (Landsat 7 and 8, Quickbird-Google Earth and Worldview-Turksat Globe) to understand the effects of tectonic, lithologic and climatic features on geomorphology. We extracted slope and drainage data, and topographic profiles from the Digital Elevation Models (DEMs) created from 1:25,000 scale topographic maps.

RESULTS

Neogene deposits

The Beyşehir-Suğla basin has some similarities with the surrounding other sedimentary basins in terms of Neogene stratigraphy (Fig. 5). Except for the Köprüçay, Antalya and Manavgat basins that are located in the inner part of the Isparta Angle, which have Neogene clastics and carbonates deposited in marine environments, all of them have terrestrial Neogene sequences including mainly fluvial and lacustrine deposits. However, there are many detailed tectonostratigraphic and sedimentary studies for the surrounding basins (e.g. Yağmurlu, 1991a,b; Hakyemez et al., 1992; Flecker et al., 1998, 2005; Koçyiğit et al., 2000, 2012; Koçyiğit and Özacar, 2003; Deynoux et al., 2005; Karabıyıkoğlu et al., 2005; Çiner et al., 2008; Topak et al., 2009; Poisson et al., 2011; Koç et al., 2012, 2014), whereas the Beyşehir-Suğla basin has no published generalized stratigraphic section despite its thick and distinctive lignite formations. Here, we present the stratigraphy of the Beyşehir-Suğla basin to understand the characteristics of its long-lasting lacustrine environment (Fig. 5). The Neogene sequence of the basin consists of three lithostratigraphic packages; the Middle Miocene fluvio-lacustrine deposits, the late Middle Miocene-Pliocene volcanics and volcanoclastics, and the Mio-Pliocene fluvio-lacustrine units.

The Middle Miocene deposits unconformably overlay the Paleozoic-Tertiary basement rocks and represent the basin initiatial phase. The package includes alluvial fan, fan delta, braided river and lacustrine deposits. Lower parts mainly consist of gray coloured, coarse-very coarse grained, subrounded pebbly, thick parallel bedded conglomerates (Fig. 6a) interfingered upwards with lacustrine sandstone, siltstone, marl and limestones. The upper parts gradually pass into yellowish gray coloured, medium-thick cross- and parallel-bedded, medium grained, rounded and subrounded conglomerates. According to included vertebrate fossils this sequence has dated as Middle Miocene (MN7; Saraç, 2003; Fig. 5).

The volcanic and volcanoclastic rocks in the study area represent the subsequent dynamic process that shaped the Beyşehir-Suğla basin after its early development.

Particularly in the southern half of the basin, around the Lake Suğla subbasin, the volcanism of Erenler-Alaca Mountains was very effective in terms of sedimentary environments of the basin. The high-K calc-alkaline volcanism started in the latest Middle Miocene and continued to the Late Pliocene (11.45-11.90 Ma to 3.35 Ma; Becker-Platen et al., 1977; Keller et al., 1977). The volcanic products are lava and ignimbrites, predominantly andesitic to dasitic in composition, with rare basalt, basaltic andesite, basaltic trachyandesite and trachyandesite (Temel et al., 1998; Kurt et al., 2003). Pinkish and yellowish coloured pyroclastics (i.e. ignimbrites, tuff and tuffites and agglomerates) are intercalated with fluvial and lacustrine deposits of the Mio-Pliocene in some levels (Fig. 6h, i).

The Mio-Pliocene fluvio-lacustrine deposits, which unconformably overlay the Middle Miocene rocks, are interfingering with volcanic and volcanoclastic units of the Erenler-Alaca Mountains volcanism, and consist of brown-red coloured fluvial conglomerate-sandstone-siltsones alternation in the lower parts (Fig. 6b, d). Conglomerates are polygenic, rounded and medium-fine grained, cross- and parallel-bedded and poorly cemented. Sandstones are mainly interbedded with conglomerates and siltsones, and partly as lensoidal geometries. Grain sizes change coarse to fine, cross-bedding and laminations are usual. Siltstones are thin bedded, but due to weathering process it is not likely to recognize this feature. Red coloured alluvial mudstones interbedded with sandstones and conglomerates represent an alluvial fan environment deposited under semi arid conditions and laterally interfinger with the fluvial deposits (Fig. 6b, d). The medium-thick and parallel bedded mudstones are very coarse grained, and even include blocks. Sandstones are coarse grained and located in the conglomerates and mudstones as thin and discontinues layers. This part of the sequence has a mammalian fauna that indicates Late Miocene (MN11; Umut et al., 1987; Fig. 5). The red coloured deposits of the Mio-Pliocene deposits gradually pass into white coloured, usually thin-medium and rarely thick bedded, parallel laminated clayey limestone and limestone, and gray coloured siltstone and claystone (Fig. 6e, f). These layers also include the economically important amounts of coal formations. Towards the top of the sequence carbonate rate increases and the sequence has been covered by limestone. According to pollen samples collected from the lignite levels, this unit indicates a Late Miocene-Pliocene age; however, the vertebrate and invertebrate faunas represent an age of Pliocene-early Quaternary (e.g. Bering, 1971; Fig. 6).

Quaternary deposits

Despite their importance for active tectonics, climate change and archaeological studies, the less known units of the region are the Quaternary deposits. These deposits have recorded varied depositional environments and events. Understanding their sedimentary features provides signatures of past geological environments. In this section, we present the Quaternary sedimentary features of the Lake Beyşehir and Lake Suğla subbasins based on field observations and subsurface data derived from boreholes (Figs. 3c, 5 and 7).

The Lake Beyşehir subbasin

To the north of the Lake Beyşehir subbasin there is a large Quaternary alluvial plain (Şarkikaraağaç plain) divided by ophiolitic basement rocks as compartments (Figs. 3c and d). There are seven DSİ boreholes located in this part of the depression (Fig. 3c). This area represents the northern watershed of the Lake Beyşehir drainage basin that seperates it from the Lake Eğirdir drainage basin (i.e. geologically the Yalvaç-Yarıkkaya basin). According to the drilling data, the brown/red coloured Quaternary deposits consist of intercalated gravel and clay deposits disconformably overlie the gray/green coloured Mio-Pliocene fluvio-lacustrine sediments. The detrital facies of Neogene and Quaternary deposits represents the mineralogical components of serpentinite, schists and limestones. Lithofacies features of this thick Quaternary sequence indicate a long-lasting alluvial environment in the Şarkikaraağaç plain that was supplied by the eroded materials of synsedimentary uplifted highlands. This can be understood from the thickness of continuous gravel sequences that reach to 100 m. Other than the subsurface Quaternary sequence, there are alluvial fan and talus deposits observed in front of the current mountainous topography. Some of them are operated as gravel/sand-pits. According to the sections in trenches at these areas, these deposits consist of debris flow sediments. The Şarkikaraağaç alluvial plain and surrounding area is drained by the Şarkikaraağaç Stream that flows into Lake Beyşehir (Fig. 3b). The discharge, also the sediment load of the stream is lower today. The northern margins of the lake are embayed coasts. Thus, the northern part of the lake is represented by mud and marsh deposits of a storm-driven estuary.

In the eastern section of Lake Beyşehir subbasin, the sedimentary units of Quaternary period unconformably overlie the volcanic and sedimentary rocks of the Neogene (Figs. 5 and 6h). There are eleven boreholes drilled on Quaternary units in this section. The key level to differentiate Quaternary deposits from the Neogene is accepted as the limestone layers that represent the top of Mio-Pliocene deposits (e.g. Hakyemez et al., 1992; Koçyiğit et al., 2012).

As explained in the previous part, this limestone level represents the late Pliocene or even early Quaternary. According to mollusc content of marl levels of a Mio-Pliocene mapped outcrop (e.g., MTA, 2002) to the east of the lake, Girod (2013) and Glöer and Girod (2013) reported Middle Pleistocene age (eight-pointed star in Fig. 5). The drilled Quaternary sequences mainly indicate intercalations of gravel, sand and clay lithofacies in various colour, grain size and components according to their spatial positions. Nearest boreholes to the lake (i.e. 1143, 1151, 1162, 1165 and 8157; Fig. 3c) show relatively thick sequences overlaying the Neogene limestones. These sequences include gray clays with dark gray and black coloured levels as peat deposits. These levels are the most characteristic sediments of the drilled sequences close to the lake. According to log data all these organic matter rich levels are positioned between the depths of 8-75 m. On the other hand, the gray and dark gray levels of clays and gravels are overlain by yellow and light/dark brown coloured detrital material. Lithological components of gravel levels represent an origin from Neogene limestones with evidence of some macro fossils and older basement rocks. The eastern coast of Lake Beyşehir is generally represented by mud/marsh deposits, but in stream mouths and along the beaches sand and pebble are usual.

To the western section of the basin, the lake leans against the escarpment of the Anamas Mountains. The Quaternary units along this margin are mainly represented by alluvial and colluvial fan deposits located at valley mouths, beach and terrace deposits along the shore, and moraines on the Dedegöl Mountains. The fan deposits are mainly represented by brown-red coloured debris flow sediments. Relatively older (i.e. Pleistocene) coarse grained material (maximum grain size 80 cm) are cemented with carbonaceous matrix as hard conglomerates in some locations, but the Holocene fans are generally represented by uncemented gravel, sand and clay deposits. The largest alluvial fan located on the western margin of the lake is the Yenişarbademli alluvial fan. There is only data from two boreholes along the western section and both of them are drilled on this fan (Fig. 3c). The Quaternary sequence logged in these locations includes brown coloured gravel, sand and clay intercalations deposited as bedload and floodplain sediments. The drilled maximum thickness of these fluvial deposits is 47 m, but the locations of the boreholes are situated to the mid-to-upper parts of the alluvial fan system, and towards the lake they may be a hundred meters thick and present a delta fan character. Beach deposits are extended in front of the cliffs with a very limited area and consist of pebbles and sand within a mineralogical component of basement rocks. As mentioned before, almost all of the islands in the lake are located on the western half of Lake Beyşehir. Similarly to the western lands, there are some alluvial and beach deposits on and around the islands. Some islands are also hosting some ephemeral wetlands. Terrace deposits representing any high amplitudes of lake level change history or tectonic uplift in the basin area are very limited (e.g., Biricik, 1982). Another type of Quaternary deposits in the western section of the drainage basin is represented by moraine deposits with a maximum block size of 35 m. According to the dating studies of Zahno et al. (2009), they are the products of the Last Glacial period.

In the southern section, the coastal areas are mainly represented by marsh deposits. However, differently from the northern coasts, a lagoonal wetland has developed behind the largest beach of Lake Beyşehir, which developed due to longshore drift. Today, this pebbly beach is operated as a touristic place. To the south there are only a few short streams with low discharges. Most important of them has formed the Karadiken alluvial fan. Lithological components of gravels indicate an origin mainly from the Cretaceous limestones. To the southern section of the Lake Beyşehir basin, the only deep drilling data is from a geothermal research study (MTA, 2005; Fig. 3c). According to the core log, the Quaternary thickness is 20 m and includes uncemented gravel, sand and clay. In addition, van Zeist et al. (1975) and Bottema and Woldring (1984) have two boreholes on land, to the SW of the lake. Maximum depth reached in their drillings was 10 m, and the drilled sequences consist of almost homogeneous grey to dark blue-grey clay that represented by ^{14}C age of ~15400 yr BP at 8.9-9.0 m depth.

The region between the lakes Beyşehir and Suğla

The connection between the Lakes Beyşehir and former Suğla via the Beyşehir stream is artificially interrupted due to Konya basin irrigation plan (1908-1914 – e.g., Muşmal, 2008). The current stream is flowing inside a constructed channel. A Quaternary floodplain environment covered a region with a width of approximately 3 km in the region between the Lake Beyşehir and Lake Suğla subbasins. There are seven boreholes drilled in this part by DSİ, two of them are on the Neogene and four on Quaternary units (Fig. 3c). According to the core logs, there is a 250 m sequence of Neogene-Quaternary deposits consisting of fluvial, volcanoclastic and lacustrine deposits and volcanic rocks. At Borehole-6743 Cretaceous units are drilled at 127 m. To the south of this site, the Boreholes 6744 and 6745 did not cut the basement rocks during a depth 250 m. Thus, the point of 6743 probably indicates the approximately position of basement threshold between the two subbasins. The most important lithology in these cores is the dark gray coloured clay with peat deposits. Another key lithology is represented by travertine deposits cropped-out in the west of Kavak village (Fig. 3d). This travertine formation originated from a geothermal spring (43-47^{o}C) positioned close to the Suğla fault line described below.

The Lake Suğla subbasin

There are twelve boreholes of DSİ and three boreholes of our project drilled in Quaternary alluvium in the Lake Suğla subbasin (Fig. 3c). The drilled Quaternary deposits overlie the schists and limestones of basement units unconformably in the western half of the subbasin (e.g., Boreholes 6746 and 14752), while they are underlain by the volcanic and volcanoclastics of Neogene in the eastern half. To the northwest of the current Lake Suğla, the Quaternary units are represented mainly by fine and coarse grained sediment intercalations that pass into brown and then greenish colured clay in the middle part of the basin (Fig. 7). The same clay-gravel alternations overlie the Neogene pyroclastics and andesites towards east. Clay levels are also represented by dark gray plastic features and peat deposits. Gravels were mainly derived from Paleozoic-Mesozoic sedimentary rocks and Neogene volcanics. According to the drilled material, the Quaternary deposits are probably thicker than 100 m.

Structural features

The Lake Beyşehir subbasin is bounded on the western margin by the NW-SE-trending Beyşehir fault (Fig. 4; e.g. Şaroğlu et al., 1987; Emre et al., 2013). This fault is the only one located in this subbasin mapped as an active structure in the active fault maps of Turkey (Şaroğlu et al., 1992; Emre et al., 2013). This normal fault has a length of 50 km. In the field, we observed different fault planes parallel to the active normal fault that indicate pure to oblique right-lateral strike-slip movements (Fig. 8a-d). These planes should represent the former kinematic behaviour of the western margin of the basin. They are located within the basement rocks and we did not observe any contact with the Quaternary deposits. Only some artificially dug surfaces due to road constructions represent juxtaposing with the shores of Lake Beyşehir. However, the strike-slip tectonics could have been effective in the initiation of the Beyşehir-Suğla basin in the middle Miocene, or alternatively they could be remnant traces of older contractional periods of the region before the development of the Beyşehir-Suğla basin. We also observed pure normal and oblique normal fault planes with minor left- and right-lateral strike-slip components that could belong to current Beyşehir fault (Fig. 8e and f). Along this margin, measured planes represent dip values range between 70^{o} and 80^{o} for the normal faults, and between 80^{o} and 90^{o} for the older strike-slip faults. There are some other normal faults observed in the field especially in the eastern and southeastern part of the Lake Beyşehir subbasin that developed antithetically. The Karaağaç and Burunsuz faults represent the antithetic faults delineating the western margin of NE-SW trending Sultan Mountains (Fig. 4). These faults are probably the southeastward continuation of the Yarıkkaya fault zone of Koçyiğit et al. 2012. While the Karaağaç fault possibly corresponds to an earthquake with a magnitude of 4.3 (April 1st, 1997), the activity of the Burunsuz fault in the Quaternary is evaluated as suspicious. However, the uplifted morphology on its footwall caused the tilting of some stream towards east. Another probably active structure in the Lake Beyşehir subbasin is the NE-SW trending Kızılören fault (Fig. 4). Although it has a relatively short length (~7 km), this fault is an important structure because of its approximately perpendicular direction to major basin bounding faults in the basin. But, its trend is consistent particularly with the faults in eastern neighbour, the Konya basin (i.e. Konya fault, Altınekin fault; Fig. 4).

The Lake Suğla subbasin is also bounded on its western margin by a morphologically clear vertical fault scarp with approximately 50 km in length (Fig. 4). In this study, this structure called as the Suğla fault, which corresponds to the Taşağıl and Ahırlı faults of the Suğla fault zone of Doğan and Koçyiğit (2018). It is a mountain front fault that delinates the Gidengelmez Mountains in the west of Lake Suğla subbasin. We could not observe any fault plane including any kinematic data along the western margin of the subbasin indicating a Quaternary movement. On the other hand, the escarpment of Suğla fault extends parallel to the Beyşehir fault in a NW-SE direction. Within this geometric point of view and scarp morphology it may be interpreted as the continuation of the Beyşehir fault as in normal fault character. As mentioned before, there is also a geothermal spring caused travertine deposition around the fault line in the Kavak village (Fig. 3d).

The most interesting structural features of the Beyşehir-Suğla basin are strike-slip faults, synsedimentary deformations and compressional structures that observed in the Mio-Pliocene deposits (Fig. 9a-h). On the eastern part of the Lake Beyşehir subbasin, we observed some synsedimentary deformation structures and contractional structures (i.e., reverse faults and folds) in outcrops that were excavated during a motorway construction (Fig. 9b-g). Similar structures are also observed in the eastern side of the Lake Suğla subbasin on some fresh outcrops (Fig. 9h). Dipping values of mapped folds in the Middle Miocene deposits generally vary up to 46^{o}, while the Mio-Pliocene units represent relatively lower dip angles (max. 22^{o}). These Neogene layers form anticlines and synclines observable particularly in the east and southeastern part of the Lake Beyşehir subbasin where the Neogene units cover large areas. General orientation of bedding strike data represents a NE-SW trending compression for the Neogene.

Geomorphology

Drainage pattern

The drainage network of the Beyşehir- Suğla basin is shown in Fig. 10. The streams located in the western part of the basin are relatively short. Some of them have less developed relatively small drainage basins and can not reach to the lakes. This is caused by faulted steep scarps and highly effective karstification process. Stepped fault geometry also caused some trellis pattern on the Anamas Mountains of the western flank (Figs. 3b and 10). Because of karstification, dissected and centripetal patterns are also observable along this margin. On a small part of the westernmost part of the drainage basin, deranged pattern has situated on the glaciated lands of the Dedegöl Mountains. In the eastern part of the basin, the fluvial network is more developed. Drainage pattern in this area is mainly dentritic and the lithology is represented mainly by the subhorizantally bedded Neogene clastic rocks. In addition, radial, parallel, and trellis patterns have also developed on this part. While the radial drainage has developed on volcanic and volcanosedimentary rocks in the eastern part of the basin due to domal structures of the Erenler-Alaca volcanic mountains, trellis patterns are located around faults. Parallel-subparallel patterns are observable on limestones around the Mavi Gorge (i.e. Çarşamba stream) in the southeastern part of the Lake Suğla subbasin (Fig. 10). This is the result of presence of Neogene paleosurfaces (e.g. Doğan, 1997) in this region that represent uniformly sloping topography. As deduced from the drainage, topography and stream profiles of the Beyşehir-Suğla basin, some small subbasins have attained recently the fluvial network (i.e. Kızılören; Fig. 10).

Tectonic landforms

The faults that delineate the Beyşehir-Suğla basin represent stepped normal fault pattern that are common features of extensional tectonics and are very important on slope development. The western margin of the basin has the steepest slopes (Figs. 3b, and 11a and b). The faults are parallel and closely-spaced particularly on this margin (Fig. 4). This is a result of reactivation of former fault planes in the Neogene. These structures originated during the contractional paleotectonic regime juxtaposed the allochtonous and autochtonus units of the Isparta Angle before the development of the Beyşehir-Suğla basin (e.g. Akay, 1981; Özgül, 1997; Robertson, 2000; Poisson et al., 2003; Robertson et al., 2003). During the basin initation process by the extensional/transtensional phase, those planes could be reused as normal faults. Six topographic profiles crosscut the mountain fronts orthogonally (TP1-3 for the Lake Beyşehir subbasin and TP6-8 for the Lake Suğla subbasin) and two parallel to the basin long-axes (TP4 and 5) are used to determine the slope knickpoints to interpret possible effects of basin faults on geomorphology. Topographic profiles on the western margin, TP1 and TP2, represent the stepped fault scarps, clearly (Fig. 12). On the opposite side of the Beyşehir-Suğla basin a series of antithetic faults shape the eastern margin. As indicated by a hanging valley on the Sultan Mountains, vertical movements due to faulting on this side has organized fluvial network recently by allowing stream capture processes on the watershed between the Akşehir drainage basin to the east and the Beyşehir-Suğla basin to the west. Lithology should also play an auxiliary role on these processes. The eastern and western flanks of the basin are substantially different from each other in their lithologies, morphologic expressions and uplift origins (Fig. 3). Where the western flank of the Beyşehir-Suğla basin reaches altitudes of about 2500 m that were directly uplifted by tectonics, the eastern flank has a maximum value of about 2000 m related to the volcanic process of the Erenler-Alaca mountains (TP6 in Fig. 12). The gradient of basin floor indicates tilting towards the western margin representing the higher activity of Beyşehir and Suğla faults, and tilting along the long axes towards the lower altitude Lake Suğla subbasin where the basin drains eastward to the Konya basin (TP4 in Fig. 12). In the lowlands of the Beyşehir-Suğla basin there are many hills and ridges developed as a result of erosion and sedimentation processes in the region. On the other hand, some of the ridges in the region related to folding in the Neogene (Fig. 11c), and some of them are remnants of older structures developed during the early Cenozoic (Fig. 11d).

Karstic landforms

The structural control on the formation of karst cavities has been known at least since Martel (1894). Tectonics determine the main orientations of karst systems and controls the mechanical limits to the karst expansion (e.g. Shanov and Kastov, 2015). The study area illustrates a very good relationship between these two features. It is widely known that the karstification process is capable of forming large depressions particularly in Mesozoic carbonate rocks all along the Taurus Mountains (e.g., Atalay, 2003). On the formation of Beyşehir-Suğla basin, the same process has also been an important factor as well as the structural features of the region (e.g. Nazik, 1985, 1992; Doğan, 1997). As mentioned before, the imprints of karstification on the geomorphology is very clear (Fig. 13) and also can be easily read from the fluvial network by the dissected drainage patterns (Fig. 10). To describe the impact of karstification in the Beyşehir-Suğla basin the Gembos (or Kembos) plain is a good example (Fig. 3a; Nazik, 1992; Doğan et al., 2016). This plain is a polje (a form of large, flat floored closed depression formed in karstic regions; Gams, 1978) with a size of 13 km in length and 2.5 km (max.) in width and covered by Quaternary deposits. The Quaternary sequence of the plain mainly consists of fine grained sediments of a weak stream and ephemeral lake development due to flooding that covers an area of about 20 km^2 on the polje's floor during some seasons. Ford and Williams (1989) define three types of poljes according to dominant influence in their origins: border polje, structural polje and baselevel polje (Goudie, 2004). As it seems at Fig. 4 and TP3 in Fig. 12, the Gembos plain is a structural polje consistent with previous suggestions (e.g. Atalay, 2003; Doğan et al., 2017).

The current water budget of the Beyşehir-Suğla basin is largely controlled by karstic agents like cave systems, dolines and headwaters (e.g., Ekmekçi, 1993; Fig. 14). Mesozoic platform carbonates have caused long-acting loss of rock volume by dissolution, and hosted karstification in the study area since late Createceous (e.g. Yılmaz and Altıner, 2006). The bauxite deposits in the carbonate rocks (e.g. Blumenthal and Göksu, 1949; Öztürk et al., 2002) are clear evidence for such a long karstification history in the region. Therefore, we can accept that the effects of karst on the hydrological-hydrogeological budget were also very important during the Neogene-Quaternary evolution of the basin.

As seen from Fig. 15, the outflow of the basin, i.e. the Çarşamba stream, has a narrow incised valley on the bluish coloured Cretaceous limestone which known as the Mavi Gorge (Figs. 3c and d; "mavi" means "blue" in Turkish). The Beyşehir-Suğla basin connects to the Konya closed basin via this gorge. About the origin of this gorge some authors suggest the karstification as the main factor (e.g. Doğan 1997; Öztürk, 2006). The sinkholes around the gorge and cave relics along the walls of the valley support a karstic origin view (Fig. 15). On the other hand, the valley has elbow geometry with an angle of ~90^o. The eastern half of the gorge is perpendicular to the basin bounding mountain front fault of the Konya basin. Thus, the change in the baselevel of the Konya basin due to tectonics may be an important factor on the abrasion of the stream bed and connecting of both basins with surface flow. To conclude, the Mavi Gorge is probably polygenetic, both the karstification of carbonate rocks and tectonics playing important roles as suggested by Doğan and Koçyiğit (2018) and Kuzucuoğlu et al. (2019).

Glacial landforms

Numerous glacial features reported along the Taurus mountains, especially during the last two decades (e.g. Planhol, 1953; Arpat and Özgül, 1972; Doğu, 1993; Çiner et al., 1999; Çiner, 2003; Hughes et al., 2006; Sarıkaya et al., 2008, 2011; Sarıkaya and Çiner, 2015). To the west of the Lake Beyşehir subbasin, the Anamas and Dedegöl mountains reach elevations of about 3000 m (Fig. 1). Particularly, on the Dedegöl Mountains there are many glacial landforms; cirques, glacial valleys and polished surfaces (Fig. 16). The glacial features on the Dedegöl Mountains have been studied in detail by some researchers (e.g. Delannoy and Maire, 1983; Zahno et al., 2009; Çılğın, 2015). Here, we emphasize their existence due to their importance to interpret the climatic history of the region.

The U-shaped Muslu Valley is the most significant landscape on the Dedegöl Mountains. This east-facing glacial valley extends between the elevations of 2000 m and 1450 m. It includes two lateral moraines and ice-abraded bedrock dated cosmogenically by Zahno et al. (2009) (Sarıkaya et al., 2011). Their results show the quantitative evidences of the Pleistocene glaciations and their possible effects in the region until the Holocene. On the other hand, today, the snowline (i.e. ELA) on the western Taurus Mountains is suggested as 3000-3750 m, while it was decreased to values of 2200-2600 m in the Last Glacial Maximum (late Pleistocene) as a result of the cold and humid climatic conditions (Sarıkaya et al., 2008).

DISCUSSION

Tectonic implications

The Beyşehir-Suğla basin is located within the eastern flank of Isparta Angle, a fold-and-thrust belt formed during the Alpine orogeny (Fig. 2). Although there is a consensus on the curved shape of Isparta Angle developed as a result of the bending of an originally E-W-directed orogenic belt (i.e. Taurides/Taurus Mountains), the origin of this shape is still puzzling due to its longlasting complex evolution. Because of this, the Taurus Mountains have nappe emplacements and related clockwise and counterclockwise rotations since the early Cenozoic to early Pliocene (e.g., Akay and Uysal, 1985; Kissel et al., 1993; Şenel et al., 1996; Glover and Robertson, 1998; Robertson, 2000; Andrew and Robertson, 2002; Piper et al., 2002; Poisson et al., 2003, 2011; Robertson et al., 2003; van Hinsbergen et al., 2010; Özsayın and Dirik, 2011; Koçyiğit et al., 2012). According to the results of paleomagnetic analyses in the region, while the eastern part of the Isparta Angle rotated ~40° clockwise direction (Kissel et al. 1993), the western part rotated 30° in counterclockwise (Kissel and Poisson, 1987;

Morris and Robertson, 1993) since the Eocene. However, Piper et al. (2002) suggested a 70° counterclockwise rotation for the eastern flank of the Isparta Angle since the Middle Miocene. Koçyiğit et al. (2012) interpreted the results of Piper et al. (2002) that the eastern flank of this structure was in a more N-S-directed position before the Late Miocene.

As mentioned before, the Isparta Angle represents a transition zone between the seismologically highly active western Turkey and relatively quiet central Turkey. This is a result of complex geodynamics in the region. The Cyprean and Aegean Arcs are connected to each other under this region (e.g., Glover and Robertson, 1998). Furthermore, there is a slab break-off (i.e. tear) process in the eastern portion of the subducted African slab beneath central-east Turkey (e.g., Barka and Reilinger, 1997; Biryol et al., 2011; Schildgen et al., 2012, 2014; Gürbüz and Kazancı, 2015). The position of the Beyşehir-Suğla basin is important to understand a possible tectonic relationship or an interaction between western and central Turkey. The study area is not only located on the transition zone between the central and western Anatolia, at the same time it is located in the middle zone of the eastern flank, between the outer and inner zones of the Isparta Angle. Whereas, there are numerous published works on the neotectonic features of inner and outer zones of the eastern flank (e.g. Koçyiğit, 1983, 1984; Boray, 1985; Şaroğlu et al., 1987; Yağmurlu, 1991a,b; Hançer and Karaman, 1994; Koçyiğit et al., 2000, 2012; Koçyiğit and Özacar, 2003; Poisson et al., 2003, 2011; Robertson et al., 2003; Koç et al., 2012, 2013; Kaya, 2014), there are only limited studies on the middle zone (e.g. Şaroğlu et al., 1987; Schildgen et al., 2012; Doğan and Koçyiğit, 2018).

The outer boundary of the Isparta Angle is delineated by the Akşehir fault (Koçyiğit et al., 2000; i.e. the Sultandağları fault, Boray et al., 1985). While Boray et al. (1985) suggested that this fault is an active structure since the Late Miocene as a right-lateral strike-slip fault with a reverse component, Koçyiğit et al. (2000) proposed this fault as a normal fault with an oblique component and the region is governed by an extensional regime. The authors claimed that the extensional basin developed during Miocene, however, there was a compressional period the broke the extensional regime before the Plio-Quaternary. Koçyiğit et al. (2012) also made a similar suggestion for the Eğirdir basin according to their compressional structure findings in the basin sequence. They observed folds and reverse faults that indicate a Middle Pliocene compression between the extensional early development and Plio-Quaternary periods. For the inner zone of the Isparta Angle, the last contraction phase is represented by the Aksu thrust fault zone (e.g., Poisson et al., 2014), and the movement was from east to west along this structure and dated as Late Miocene (Poisson et al., 1977; Akay and Uysal, 1985; Frizon de Lamotte et al., 1995). According to Poisson et al. (2003), the Pliocene was also affected by this contraction phase, too. Thus, almost all the studies are agree that this part was under a compressional regime and mainly driven by reverse, thrust and strike-slip faults until the Plio-Quaternary (e.g. Glover and Robertson, 1998; Robertson, 2000; Poisson et al., 2003).

In our study, we observed many folds in the Mio-Pliocene sequence that indicate the Beyşehir-Suğla basin has experienced an approximately NE-SW-directed contraction. These contraction-related structures may be developed as synsedimentary in the Pliocene, before the development of later normal faulting. These structures are very important in the extensional framework of the basin development process. Furthermore, as aforementioned, we observed many fault planes with kinematic data represent strike-slip and normal movements on the western margin of the Lake Beyşehir subbasin.

Strike-slip faults in the western margin of the basin are observed mainly behind the normal fault planes and may represent the older movements; on the other hand, the normal faults are close to the current lake area and should represent the younger activity on the basin bounding faults. Today, it is clear from the earthquake focal mechanisms that an extensional regime governs the Beyşehir-Suğla basin and surroundings (Fig. 4).

Several earthquakes with small to medium magnitudes have occurred in the studied basin during the historical and instrumental periods (Fig. 4), but there is not a large scale devastating earthquake in any record. However, there are some small to medium earthquake clusterings around the Beyşehir-Suğla depression particularly after 2000 with casualties [i.e. Afyon-Çay (max. M=6.4), Konya (max. M=5) and Eğirdir (max. M=5.1) clusters; Tan et al., 2008; Koçyiğit et al., 2012]. Seismicity is mainly concentrated along NNW–SSE-oriented normal faults representing an extensional regime in the middle and outer zones of the Isparta Angle, where the earthquake epicentres at depths of 3-40 km. However, the depths of earthquakes in the inner zone reach values of over 130 km with mainly thrust components (Fig. 4).

The Neogene units of the basin may represent a pull-apart basin sequence developed under a transtensional regime. The formation of the fluvio-lacustrine Beyşehir-Suğla basin started in the Middle Miocene with deposition in alluvial fan, braided river system, and then turned into a fan delta sequence interbedded with thin lacustrine siltstones, marl and limestones. This deposition phase is uncomformably overlain by terrestrial deposits starting with coarse grained sediments rapidly fining upwards and then includes a thick lacustrine sequence in addition to thick volcanic and volcanoclastic intercalations. This sequence also represents a rapidly subsiding environment that could be related to a similar transtensional phase, because we did not observed any different basin bounding fault system during the Mio-Pliocene deposition in the Beyşehir-Suğla region. As described above, there is synsedimentary deformation representing a highly active tectonovolcanic phase in the Mio-Pliocene deposits. The mentioned Neogene sequence is also uncomformably covered by a fluvio-lacustrine sequence mainly deposited during the Quaternary period. Fault controlled subsidence due to extensional regime accompanied by recent seismic activity in the region.

Climatic implications

At the present time, the studied region is representing a climatologically transition zone positioned between the central Anatolian continental semi-arid climate and relatively more humid Mediterranean climate of west and southwest Anatolia (Fig. 1b). The central Anatolia is a continental plateau with an altitude of *c.* 1000 m, separated from the Mediterranean Sea in the south and Black Sea to the north by two main mountain belts of the country; the Taurus and Pontic Mountains, respectively. The largest intracontinental basin of Turkey is located in this region and evolved into the largest closed basin of the eastern Mediterranean region by a series of tectonic and climatic events related to geodynamics (Gürbüz and Kazancı, 2015). According to current isotopic values of Schemmel et al. (2013), as an orographic barrier with an altitude of over 3000 m the Taurus Mountains controlled the semi-arid climate in central Turkey with rainfall as low as 350 mm/a provide clear evidence for an evaporative regime that directly effects surface water compositions. In the same way, Lüdecke et al. (2013) used isotopic data to understand the climates of older periods. Isotope geochemistry of Oligo-Miocene lacustrine carbonate deposits indicated the least evaporite regime and suggested the absence of any significant orographic barrier (Lüdecke et al., 2013). The palynological and mammal fossils data from central Anatolia also support a similar paleoclimatic trend (e.g. Saraç, 2003, 2012; Akgün et al., 2007; Akkiraz et al., 2009, 2011; Yavuz-Işık et al., 2011; Akgün and Kayseri-Özer, 2012). Towards the late Quaternary, the region was covered with large saline lakes as a result of high evaporative conditions (e.g. Erol, 1969; Kashima, 2002; Gürbüz and Kazancı, 2014; Kuzucuoğlu, 2019; Özsayın et al., 2019). In summary, since the early Neogene the climate of central Turkey has changed from more humid into today's semi-arid conditions.

In western Turkey, the paleoclimatic implications are largely based on paleontological data. Alçiçek (2010) summarized the available data for western Turkey within a stratigraphic framework and represented a densely forested wetland environment in a warm and humid subtropical climate for the early-mid Miocene that turned into a grass dominated steppe ecosystem during an arid climatic condition in middle to late Miocene. Then, a savannah-type ecosystem in a warm and humid climate covered the western Turkey during the Pliocene (Alçiçek, 2010 and references there in). Quaternary environments in western Turkey hosted many freshwater lake occurrances in the main grabens as a result of humid conditions (e.g. Kazancı et al., 2009, 2011; Hakyemez et al., 2013; Kazancı and Roberts, 2019).

As seen from the abovementioned climatic history, while a similar trend has been observed during the early Neogene period for both central and western Turkey, towards the end of Neogene and particularly Quaternary periods the climate has turned into more arid but also more variable over time, with variations between cold and warm, wetter and drier, climatic conditions in the central part of country. In this framework, the Beyşehir-Suğla basin has a critical position to understand climatologically what happened in the zone between these two different regions.

Two of the three packages representing Neogene paleoenvironments in the Beyşehir-Suğla basin suggest some paleoclimatic implications according to their colours, fossil contents (pollen and mammal) and sedimentological features. The Middle Miocene units include gray coloured, rounded and subrounded sediments deposited in an energetic fluvio-lacustrine environment indicate humid conditions. In the Bozkır location to the south of the Suğla subbasin (Figs. 3c and 5), described small mammal *Shizogalerix aff. anatolica* (Hakyemez et al., 1992; Saraç, 2003) which represents forest biotope proximity to water environment (e.g., Ziegler, 1999) supports such climatic conditions. In the surrounding area, the closest basin that could be directly interconnected with the Beyşehir-Suğla depression is the Yalvaç basin which is located to the north of the study area (Figs. 2 and 5). Akgün and Akyol (1992) studied the pollen and spore assemblages of the coal-bearing levels in the Yalvaç basin and described a sub-tropical environment with humid and warm climatic conditions during the Middle Miocene. In the Late Miocene-Pliocene sequence, the lower part consists of brown-red coloured and rounded-subrounded materials that deposited in a semi-arid but highly energetic environment, whereas the upper part turns into gray/white coloured fine-grained clastic rocks and limestones and marls with lignite formations. This sequence includes various large mammal fossils described to the east of the Beyşehir-Suğla basin, in the

Kızılören location (Figs. 3c and 5), represented by Hipparion, *Dicerorhinus orientalis*, Ancylotherium, *Oioceros wegneri*, Gazella, *Palaeoreas lindermayeri*, Plesiaddax, Protoryx and Pliocervus indicating both high vegetation and savanna environment (e.g., Bernor et al., 1996; Bernor and Armour-Chelu, 1999; Gentry et al., 1999; Heissig, 1999). It is known that the Late Miocene is a time of a change from sub-tropical vegetation to a savanna largely in Eurasia (e.g., Saraç et al., 2002). On the other hand, the aferomentioned Late Miocene-Pliocene faunal assemblage in the Beyşehir-Suğla basin consists of grazers and mixed feeders indicating an open environment dominated by habitat mosaics. According to these features, the Mio-Pliocene sequence of the studied basin has a different climatic history rather than aforementioned western and central Anatolian paleoclimates.

Specifically, the Quaternary period of the region has interesting features about the paleoclimatic history of central-west Turkey. Remarkable glacial deposits and landforms are the most important that point out the cold climatic conditions during this period (i.e. glaciations on the Dedegöl Mountains). On the other hand, according to palynological data derived from the boreholes drilled by independent researchers in the Lake Beyşehir subbasin and excavated research pits in the Lake Suğla subbasin, some different paleoclimatic and paleoenvironmental interpretations were suggested by Aytuğ (1967), van Zeist et al. (1975), Roberts (1980) and Bottema and Woldring (1984). Their findings indicate relatively more vegetated late Quaternary environment under more humid and warm interglacial climatic conditions. In the neighboring Lake Eğirdir basin, Nemec and Kazancı (1999) proposed a Quaternary history with a warm-humid climate for the early Pleistocene, a colder climate for the late Pleistocene, coldest climate for the Last Glacial and a warm semi-arid climate for the Holocene according to their sedimentological and palynological analyses on colluvial deposits in the region. According to the borehole and field data represented in our study, the Quaternary of the Lake Beyşehir and Lake Suğla subbasins are mainly represented by fluvial and alluvial fan deposits. The intercalated clay/mud and gravel sequences are widely covered the plain areas. On the other hand, clays include some important peat levels. All the sedimentological features of the Beyşehir-Suğla basin (except the Gembos plain) indicate energetic environments deposited under alternating climatic conditions that could be controlled by pluvial and interpluvial periods (e.g. Erinç, 1952; Erol, 1969, 1978, 1980, 1984, 1997).

Koç (2013) argued that the climate in the Yalvaç basin was not arid during its evolution as evidenced by the lack of evaporites. This is a key point to compare the climatic differences among the basins in the region. To the east of the Beyşehir-Suğla basin, the Konya and Lake Tuz basins include evaporites deposited in the Neogene and Quaternary periods (e.g. Erol, 1969, 1980, 1984, 1997; Gürer and Gürer, 1999; Gürer and Aldanmaz, 2002; Tekin et al., 2008; Gürbüz and Kazancı, 2014). As described above, except these two basins (i.e. Konya and Lake Tuz) none of the neighbouring basins of the Beyşehir-Suğla depression include any evaporitic deposits. This could be as a result of karstic features of the region. The stratigraphic record has caused us to think on the effects of karstification that controlled hydro(geo)logical budget of the basin for the Neogene and Quaternary. The basin should have similar conditions during these periods as today's fluvio-lacustrine environments which are controlled mainly by karstic sources (e.g. Acatay, 1966; Öziş and Keloğlu, 1976; Roberts, 1980; Ekmekçi, 1986, 1993). Thus, in contrast with some previous authors (e.g. Lahn, 1948; Erol, 1978) the Beyşehir-Suğla basin must have been an open type sedimentary basin since its early development and the arid periods did not affect the basin as in the Konya and Lake Tuz basins. All these features indicate that the basin developed under humid conditions in the Middle Miocene, then controlled with relatively arid climate and again in a humid environment more like the central Anatolian basins. But as evidenced by the lack of evaporites in the Beyşehir-Suğla basin and surrounding other basins, which are located in the Isparta Angle on the carbonate rocks of the Taurus Mountains, these basins hydrologically were protected from the arid climatic conditions by the presence of karstic features, and maintained their freshwater states despite the shift to a more arid environment, unlike the central Anatolian basins.

Comparison with surrounding basins

The Beyşehir-Suğla basin and surrounding basins (Fig. 5) are developed mainly within terrestrial settings, except the southernmost Köprüçay, Aksu and Manavgat basins which include marine deposits (e.g. Monod et al., 2006). The Neogene stratigraphy of the studied basin particularly resembles to the Konya and Akşehir basins (Hakyemez et al., 1992; Koçyiğit et al., 2000). Except for small differences it is also similar to the synchronously developed Yalvaç Basin. The Beyşehir-Suğla, Konya and Altınapa basins include relatively voluminous volcanic material due to their close position to the Erenler-Alaca volcanic center, while the Ilgın basin also includes tuff and pumice levels (e.g, Koç, 2013). Yağmurlu et al. (1997) reported that the volcanic levels in the Eğirdir-Kovada basin were the products of another volcanic center located in its west. Only the Yalvaç basin has no reported volcanic material in contrast to surrounding basins (e.g., Koçyiğit et al., 2012; Koç, 2013). This basin is also different from its southern continuation, the Beyşehir-Suğla basin, within the age of coal formation. Whereas the coals of the Yalvaç basin are in Middle Miocene age and deposited in a fluvial environment (Yağmurlu et al., 1991a; Koç, 2013), they are in Late Miocene-Pliocene in the Beyşehir-Suğla basin and deposited in a lacustrine setting. According to unconformity correlation among the surrounding Neogene basins in the close region (Fig. 5) it is clear that there are at least two unconformities in the sequences of terrestrial basins on the Middle Miocene and Pliocene deposits. Early Miocene and Late Miocene unconformities are also reported for the Ilgın and Altınapa basins (e.g., Koç, 2013). The mentioned unconformities before and after the deposition of the Late Miocene-Pliocene sequences could be related to regional geodynamic processes. It is widely accepted in the current literature that the Central Taurus Mountains rapidly uplifted in the Late Miocene as a result of asthenospheric uplift following the slab-tear process under Central Anatolia (e.g., Schildgen et al., 2012, 2014; Lüdecke et al., 2013; Gürbüz and Kazancı, 2015; Meijers et al., 2016; Radeff et al., 2017). By this event, an extensional tectonic phase has controlled the region (e.g., Schildgen et al., 2012; Özsayın et al., 2013, 2019; Gürbüz and Kazancı, 2015). This could be drived an oroclinal bending process caused the current reverse-V-shaped geometry of the Isparta Angle (e.g., Özsayın and Dirik, 2011). Earlier studies suggested a clockwise rotation process (40° - Kissel et al. 1993) for the eastern flank of the Isparta Angle, occurred during the Late Miocene- Pliocene (Frizon de Lamotte et al., 1995; Piper et al., 2002; Poisson et al., 2003; Özsayın and Dirik, 2011).

CONCLUSIONS

The Beyşehir-Suğla basin is located between the Western and Central Anatolian regions of Turkey, in a transition zone controlled by tectonically and climatologically different regimes. The basin has formed on a sequeezed contact of autochtonous and allochtonous units of Paleozoic to Tertiary. The Neogene-Quaternary geology and geomorphology of the depression includes many significant records of basin evolution in such a transition zone. This study describes three sequences for the Neogene-Quaternary periods in the Beyşehir-Suğla region. In the Middle Miocene, a transtensional tectonic regime probably initated the basin development as suggested by the NNW-SSE trending right-lateral stike-slip fault planes. This regime was also active during the Mio-Pliocene as suggested by the sedimentary sequences which represent a pull-apart basin fill. During the Neogene, the climate evolved partly due to a series of tectonic and geodynamic-caused geomorphic changes. According to the stratigraphic comparison among the basins in the Isparta Angle and surrounding basins in central Turkey, the Beyşehir-Suğla basin was developed early and very close to the southern basins including marine deposits. However, the basin has a Neogene sequence consists of mainly terrestrial deposits and is generally similar to the central Anatolian basins, except the lack of evaporitic deposits. However, since the latest Miocene while the central Anatolian basins majorly indicate deposition under a relatively arid climate, the Beyşehir-Suğla basin seems to be protected from hydrological closure due to karstic features of the surrounding basement rocks. The karstic features that particularly prevail in the western half of the basin protect itself from the unstable climatic changes for over millions of years and are very important on the hydro(geo)logical budget of the drainage basin and landscape evolution. Because of bounding by the normal faulted steep slopes in most sectors, the NW-SE-trending Lake Beyşehir could reach its maximum surface area in Quaternary by coastal progressions in the north and south which are determined by the water amount that reached to lake.

ACKNOWLEDGEMENTS

This study was funded by AÜBAP (Ankara University Scientific Research Projects, Grant No: 12B4343002). E.G. acknowledges support from the Scientific and Technological Research Council of Turkey (TÜBİTAK, BİDEB2211-A). The authors would like to thank F. Şaroğlu (JEMİRKO) for fruitful discussions in office, and Y. Suludere (JEMİRKO), S. Öncel (GTÜ), Ö. İleri (MTA) and M. Kibar (AÜ) for discussions in the field, and S. Karadağ, L. Ata and S. Ünal (BÖE) for their hospitality during our field studies.

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Figure captions

Figure 1. **(a)** Seismic zones of Turkey (modified from BİB, 1996). (**b)** Annual precipitation rates in Turkey (modified from Atalay, 1983). **(c)** Location map of the Beyşehir-Suğla basin and the Konya closed drainage basin.

Figure 2. Geological position of the Beyşehir-Suğla basin in the Isparta Angle (modified from MTA, 2002). AşB – Akşehir basin, IB – Ilgın basin, AaB – Altınapa basin, KB – Konya basin, YB – Yalvaç basin, HB – Hoyran basin, EB – Eğirdir basin, KoB – Kovada basin, BDB – Baklan-Dinar basin, AB – Acıgöl basin, BB – Burdur basin, AkB – Aksu basin, KçB – Köprüçay basin, MB – Manavgat basin.

Figure 3. **(a)** Physiographic image of the Beyşehir-Suğla basin and fluvial network. **(b)** Slope map of the study area with settlement names. **(c)** Geological age map of the Beyşehir-Suğla basin. **(d)** Lithological map of the study area. Maps c and d are derived from MTA (2002).

Figure 4. Fault and seismicity map of the Beyşehir-Suğla basin and surrounding region (faults after Koçyiğit et al., 2000; Poisson et al., 2003; Özsayın and Dirik, 2011; Schildgen et al., 2012; and this study). Epicenters of instrumental seismicity are from the Boğaziçi University Kandilli Observatory and Earthquake Research Institute (KOERI), historical earthquake data is from Ambraseys (2009), focal mechanism solutions are from Schildgen et al. (2012).

Figure 5. Generalized stratigraphic column sections of the Beyşehir-Suğla basin (please see text for details) and surrounding basins for comparision of the Neogene-Quaternary units. AşB – Akşehir basin, after Koçyiğit et al. (2000); IB – Ilgın basin, after Koç (2013); AaB – Altınapa basin, after Koç et al. (2012); KB – Konya basin, after Hakyemez et al. (1992); YB – Yalvaç basin, integrated from Yağmurlu (1991), Koçyiğit et al. (2012) and Koç (2013); EKB – Eğirdir-Kovada basin, after Koçyiğit et al. (2012); KçB – Köprüçay basin, after

Karabıyıkoğlu et al. (2005) and Çiner et al. (2008). Stratigraphy of the Köprüçay basin is given in detail, because this basin has a relatively different evolution, including important marine deposits. Stratigraphies of the Aksu and Manavgat basins are not represented as columns, please see Çiner et al. (2008) for their details. Stars on the map represent mammal fossil localities that used to date Neogene-Quaternary deposits in the Beyşehir-Suğla basin. The eight-pointed star indicates mollusc ages from Girod (2013) and Glöer and Girod (2013). Colours of stars for different ages; grey – Pleistocene, light yellow – late Miocene-Pliocene, dark yellow – early-middle Miocene. Please see Figure 2 for geological legend of the location map.

Figure 6. Field photos of various facies from the Neogene deposits in the Beyşehir-Suğla basin. Please check the text for explanations.

Figure 7. Different facies of the Quaternary deposits in the Beyşehir-Suğla basin. Please see the text for explanations.

Figure 8. Kinematic data observed on strike-slip (a-d) and normal fault (e, f) planes compiled from the western margin of the Lake Beyşehir subbasin.

Figure 9. (a) A strike-slip fault in the southwest of the LakeBeyşehir subbasin, and **(b-h)** Syn-sedimentary deformation and compressional structures, observed in the Mio-Pliocene sequence compiled from the eastern part of the Lake Beyşehir and Lake Suğla subbasins. Please see text for explanions.

Figure 10. Fluvial network of the Beyşehir-Suğla drainage basin.

Figure 11. Fault scarp and fold examples that represent the main tectonic landforms in the Beyşehir-Suğla basin.

Figure 12. Longitudinal and transversal topographic profiles of the Beyşehir-Suğla basin.

Figure 13. Karstic surfaces developed on the carbonate rocks particularly on the western part of the Beyşehir-Suğla basin. (a-b) Plan and (c) Close-up views of the lapias in the field.

Figure 14. Karstic features of the Beyşehir-Suğla basin as hydrogeological agents. (a) Widespread cave formations in the study area, (b-c) dolines, and (d) headwaters in the Lake Suğla basin.

Figure 15. Geomorphic features of the Mavi Gorge (i.e. Çarşamba stream valley) that connects the Beyşehir-Suğla basin with the Konya basin.

Figure 16. Glacial landforms situated on the Dedegöl Mountains.

Figure 17. Block model summarizing the Neogene-Quaternary development of the Beyşehir-Suğla basin.

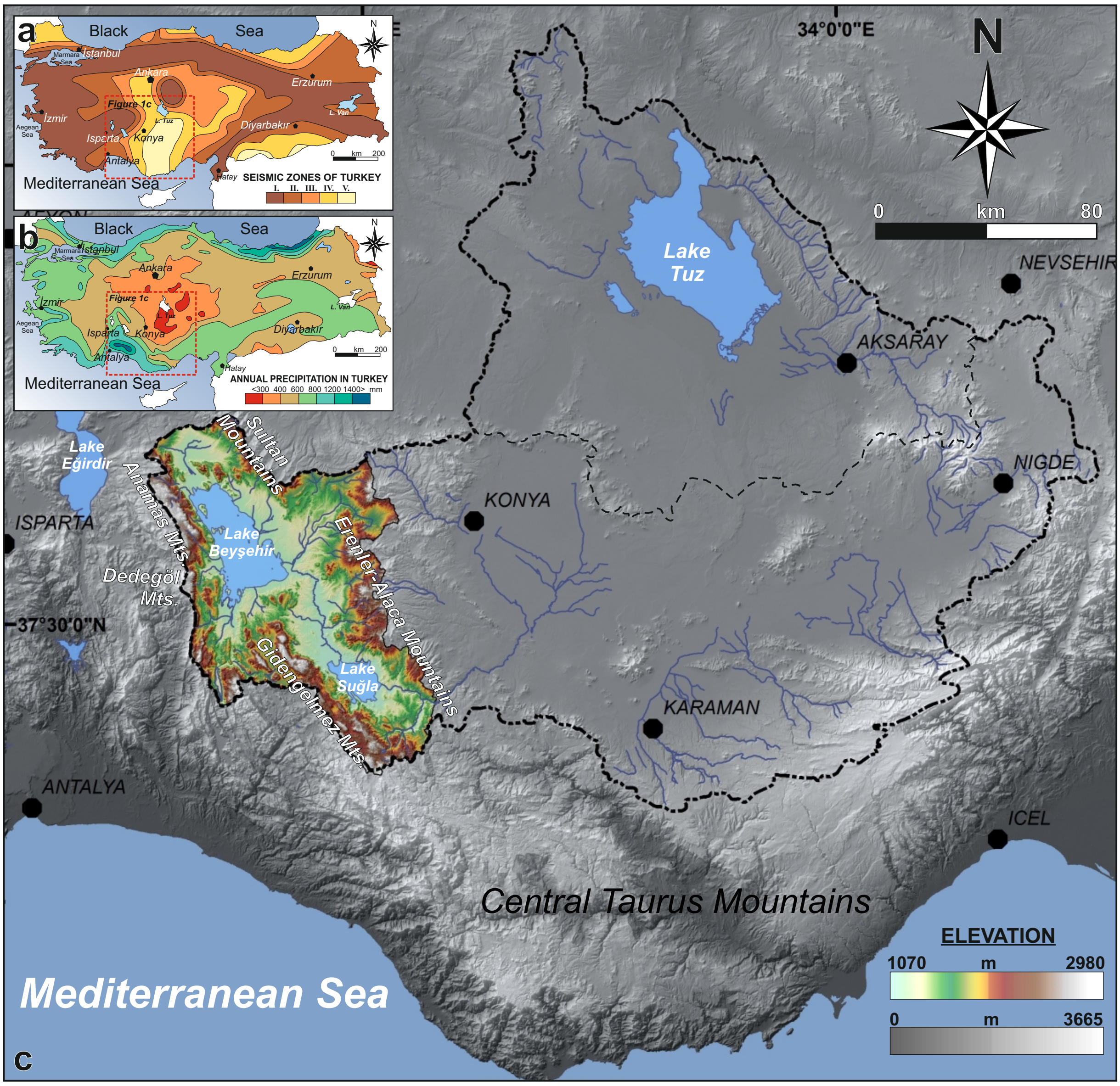
a
Black
Sea
N
Marmara Sea
İstanbul
Ankara
Erzurum
Figure 1c
L. Tuz
L. Van
İzmir
Aegean Sea
Isparta
Konya
Diyarbakır
Antalya
0 km 200
Hatay
Mediterranean Sea
SEISMIC ZONES OF TURKEY
I. II. III. IV. V.
b
Black
Sea
N
Marmara Sea
İstanbul
Ankara
Erzurum
Figure 1c
L. Tuz
L. Van
İzmir
Aegean Sea
Isparta
Konya
Diyarbakır
Antalya
0 km 200
Hatay
Mediterranean Sea
ANNUAL PRECIPITATION IN TURKEY
<300 400 600 800 1200 1400> mm
34°0'0"E
N
0 km 80
NEVSEHIR
Lake Tuz
AKSARAY
NIGDE
KONYA
KARAMAN
Lake Eğirdir
Sultan Mountains
Anamas Mts.
ISPARTA
Lake Beyşehir
Erenler-Alaca Mountains
Dedegöl Mts.
37°30'0"N
Lake Suğla
Gidengelmez Mts.
ANTALYA
ICEL
Central Taurus Mountains
Mediterranean Sea
ELEVATION
1070 m 2980
0 m 3665
c

Figure 1

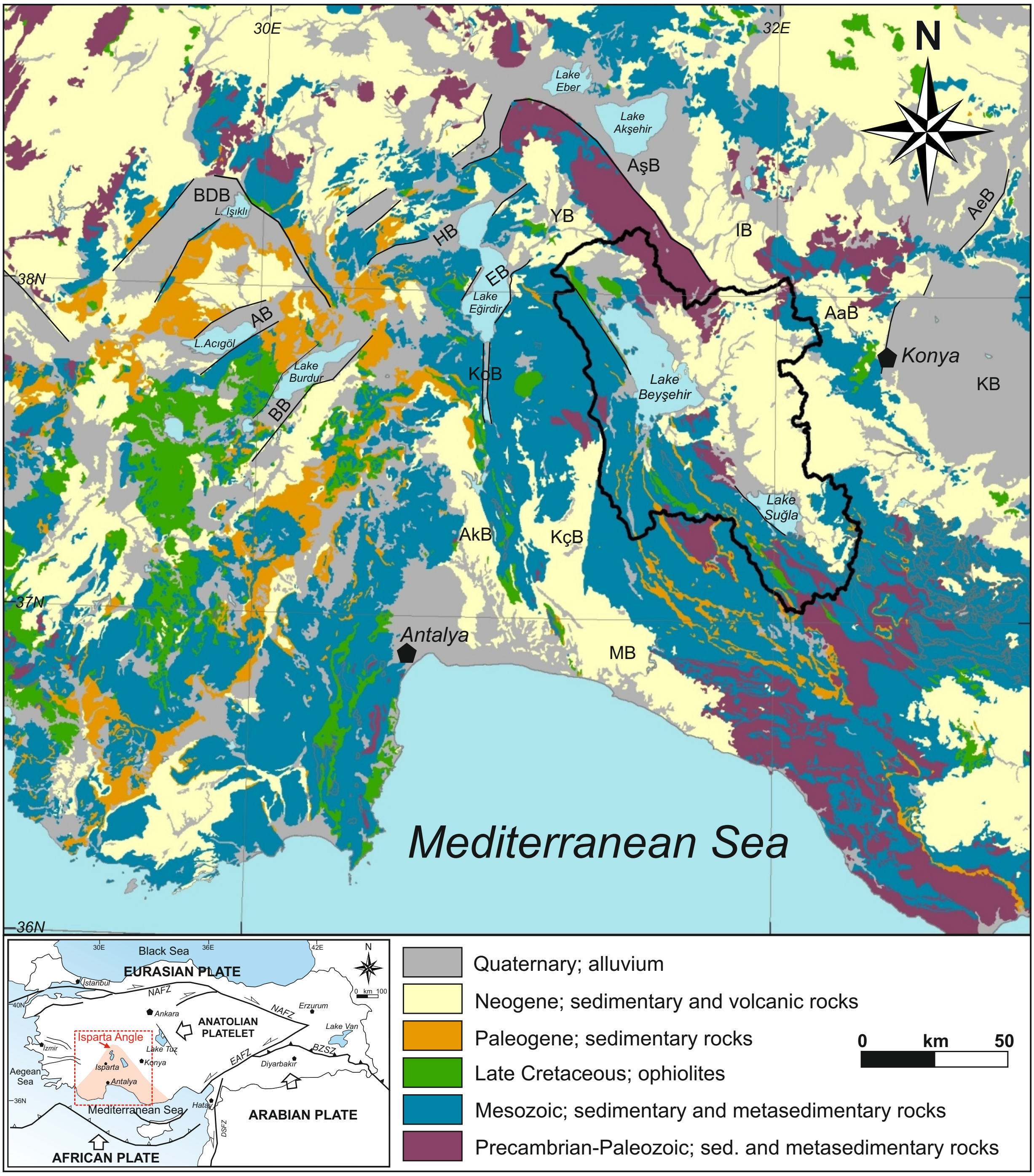
30E
32E
N
Lake Eber
Lake Akşehir
AşB
BDB
L. Işıklı
YB
IB
AeB
HB
EB
38N
Lake Eğirdir
AaB
AB
L.Acıgöl
Konya
Lake Burdur
KoB
Lake Beyşehir
KB
BB
Lake Suğla
AkB
KçB
37N
Antalya
MB
Mediterranean Sea
36N
Black Sea
30E
36E
42E
EURASIAN PLATE
İstanbul
NAFZ
0 km 100
40N
Erzurum
Ankara
NAFZ
ANATOLIAN PLATELET
Lake Van
Isparta Angle
İzmir
Lake Tuz
Konya
Isparta
EAFZ
BZSZ
Diyarbakır
Aegean Sea
Antalya
36N
Hatay
Mediterranean Sea
ARABIAN PLATE
DSFZ
AFRICAN PLATE
Quaternary; alluvium
Neogene; sedimentary and volcanic rocks
Paleogene; sedimentary rocks
Late Cretaceous; ophiolites
Mesozoic; sedimentary and metasedimentary rocks
Precambrian-Paleozoic; sed. and metasedimentary rocks
0 km 50

Figure 2

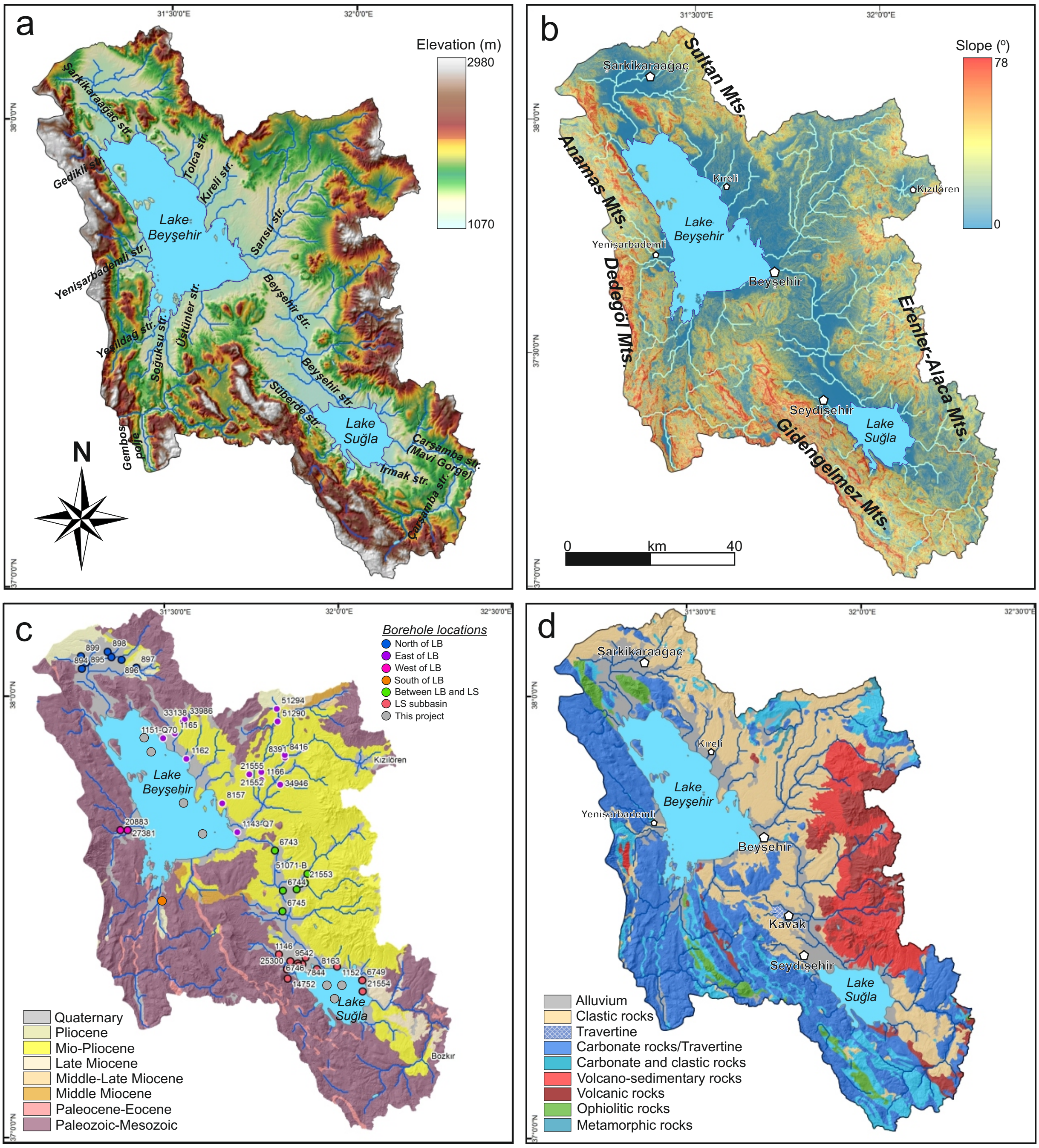
a
Elevation (m)
2980
1070
31°30'0"E
32°0'0"E
38°0'0"N
37°0'0"N
Şarkikaraağaç str.
Gedikli str.
Tolca str.
Kıreli str.
Lake Beyşehir
Sarısu str.
Yenişarbademli str.
Üstünler str.
Beyşehir str.
Yeşildağ str.
Soğuksu str.
Beyşehir str.
Süberde str.
Lake Suğla
Gembos polje
Çarşamba str. (Mavi Gorge)
Irmak str.
Çarşamba str.
N
b
Slope (°)
78
0
Şarkikaraagaç
Sultan Mts.
Anamas Mts.
Kıreli
Kızılören
Lake Beyşehir
Yenişarbademli
Beyşehir
Dedegöl Mts.
Erenler-Alaca Mts.
Seydişehir
Lake Suğla
Gidengelmez Mts.
0
km
40
c
31°30'0"E
32°0'0"E
32°30'0"E
Borehole locations
North of LB
East of LB
West of LB
South of LB
Between LB and LS
LS subbasin
This project
899
898
894
895
897
896
51294
51290
33138
33986
1165
1151-Q70
1162
8391
8416
Kızılören
21555
1166
21552
34946
Lake Beyşehir
8157
20883
27381
1143-Q7
6743
51071-B
21553
6744
6745
1146
9542
25300
8163
6746
7844
1152
6749
14752
21554
Lake Suğla
Bozkır
Quaternary
Pliocene
Mio-Pliocene
Late Miocene
Middle-Late Miocene
Middle Miocene
Paleocene-Eocene
Paleozoic-Mesozoic
d
Şarkikaraagaç
Kıreli
Lake Beyşehir
Yenişarbademli
Beyşehir
Kavak
Seydişehir
Lake Suğla
Alluvium
Clastic rocks
Travertine
Carbonate rocks/Travertine
Carbonate and clastic rocks
Volcano-sedimentary rocks
Volcanic rocks
Ophiolitic rocks
Metamorphic rocks

Figure 3

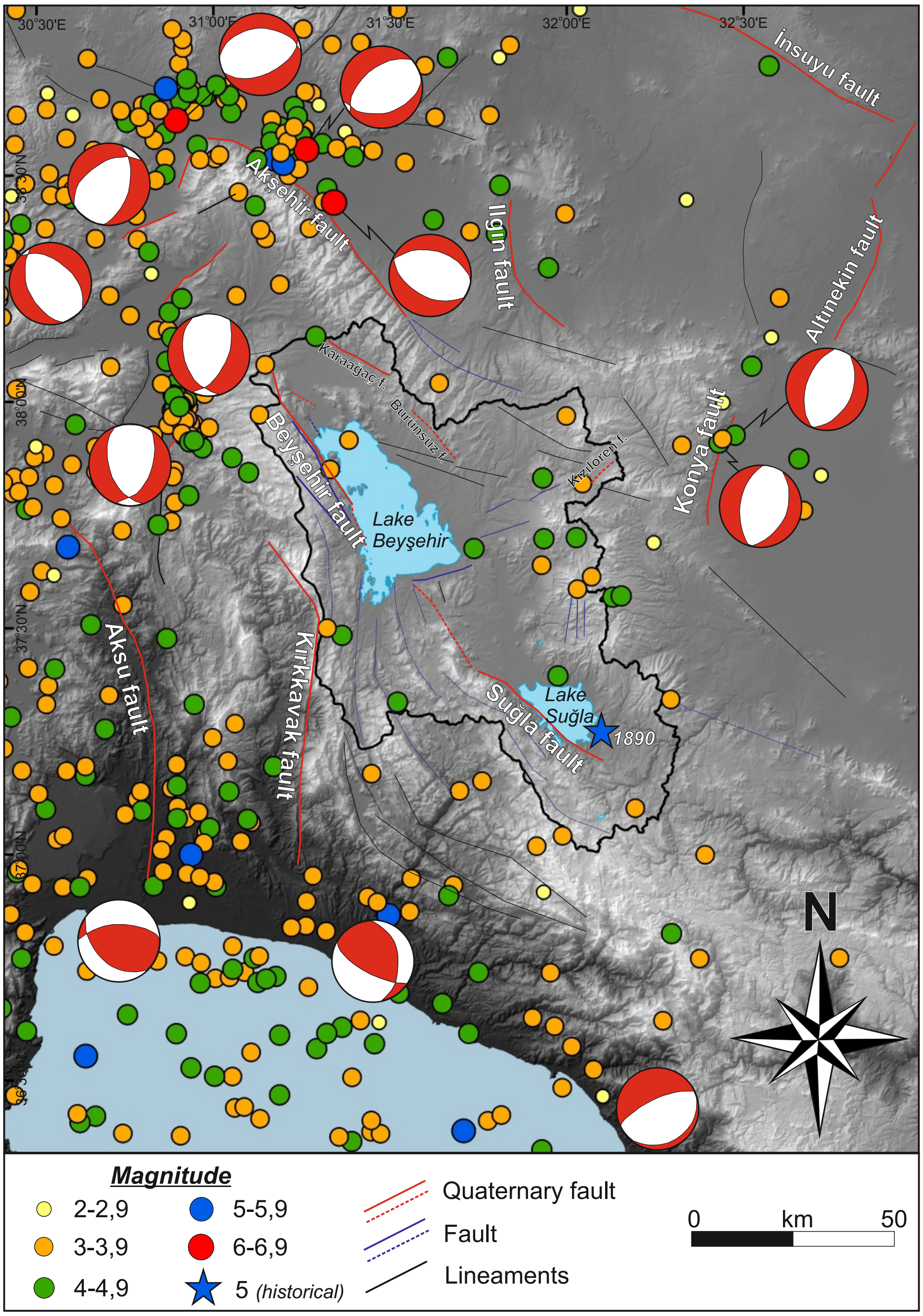
30°30'E
31°00'E
31°30'E
32°00'E
32°30'E
38°30'N
38°00'N
37°30'N
37°00'N
36°30'N
İnsuyu fault
Akşehir fault
Ilgın fault
Altınekin fault
Karaağaç f.
Burunsuz f.
Kızılören f.
Konya fault
Beyşehir fault
Lake Beyşehir
Aksu fault
Kırkkavak fault
Lake Suğla
Suğla fault
1890
N
Magnitude
2-2,9
3-3,9
4-4,9
5-5,9
6-6,9
5 (historical)
Quaternary fault
Fault
Lineaments
0
km
50

Figure 4

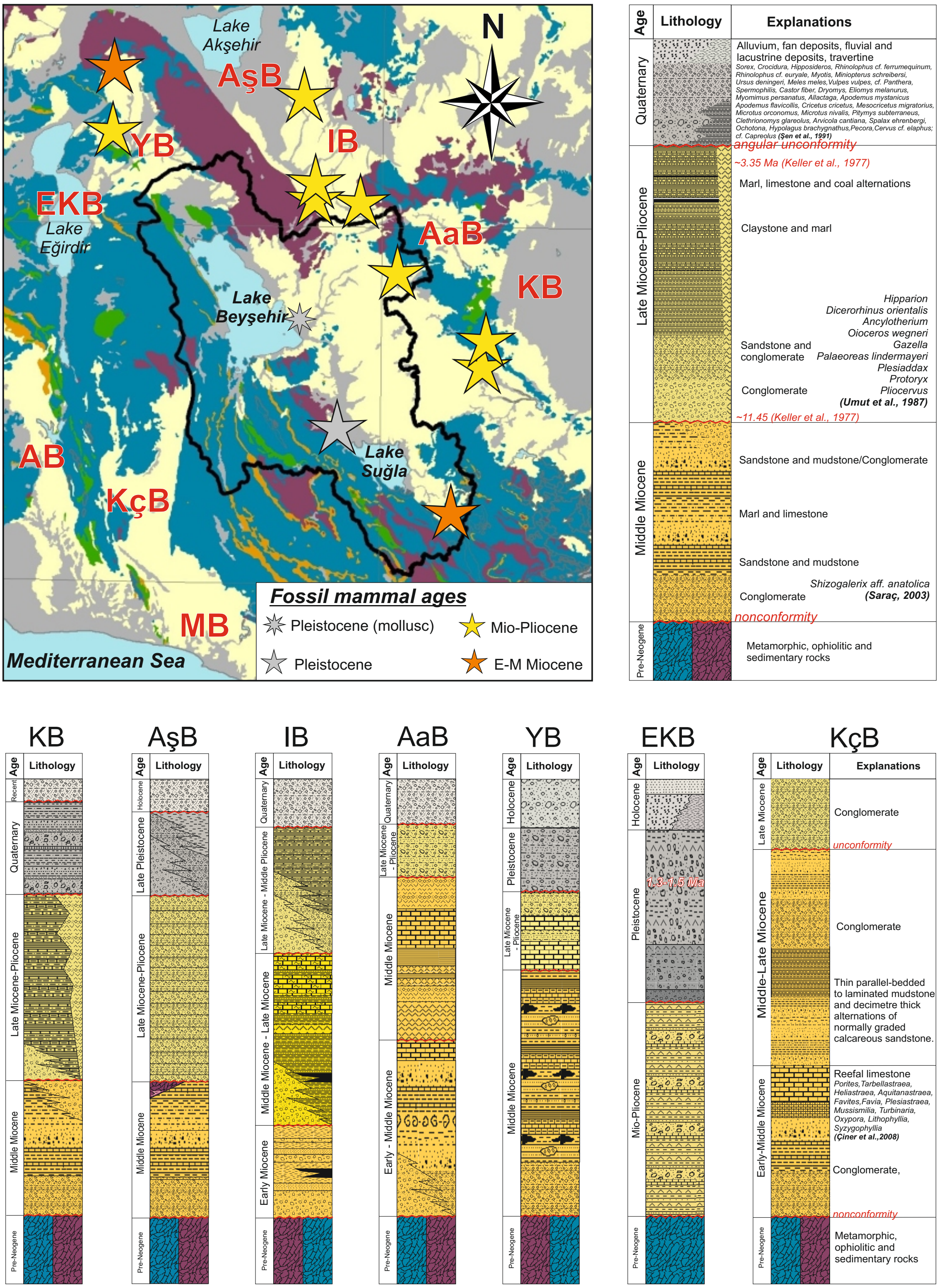
Lake Akşehir
AşB
N
YB
IB
EKB
Lake Eğirdir
AaB
KB
Lake Beyşehir
AB
KçB
Lake Suğla
MB
Mediterranean Sea
Fossil mammal ages
Pleistocene (mollusc)
Mio-Pliocene
Pleistocene
E-M Miocene
Age
Lithology
Explanations
Quaternary
Alluvium, fan deposits, fluvial and lacustrine deposits, travertine
Sorex, Crocidura, Hipposideros, Rhinolophus cf. ferrumequinum, Rhinolophus cf. euryale, Myotis, Miniopterus schreibersi, Ursus deningeri, Meles meles,Vulpes vulpes, cf. Panthera, Spermophilis, Castor fiber, Dryomys, Eliomys melanurus, Myomimus persanatus, Allactaga, Apodemus mystanicus Apodemus flavicollis, Cricetus cricetus, Mesocricetus migratorius, Microtus orconomus, Microtus nivalis, Pitymys subterraneus, Clethrionomys glareolus, Arvicola cantiana, Spalax ehrenbergi, Ochotona, Hypolagus brachygnathus,Pecora,Cervus cf. elaphus; cf. Capreolus (Şen et al., 1991)
angular unconformity
Late Miocene-Pliocene
~3.35 Ma (Keller et al., 1977)
Marl, limestone and coal alternations
Claystone and marl
Hipparion
Dicerorhinus orientalis
Ancylotherium
Oioceros wegneri
Gazella
Palaeoreas lindermayeri
Plesiaddax
Protoryx
Pliocervus
(Umut et al., 1987)
Sandstone and conglomerate
Conglomerate
~11.45 (Keller et al., 1977)
Middle Miocene
Sandstone and mudstone/Conglomerate
Marl and limestone
Sandstone and mudstone
Shizogalerix aff. anatolica
(Saraç, 2003)
Conglomerate
nonconformity
Pre-Neogene
Metamorphic, ophiolitic and sedimentary rocks
KB
Age
Lithology
Recent
Quaternary
Late Miocene-Pliocene
Middle Miocene
Pre-Neogene
AşB
Age
Lithology
Holocene
Late Pleistocene
Late Miocene-Pliocene
Middle Miocene
Pre-Neogene
IB
Age
Lithology
Quaternary
Late Miocene - Middle Pliocene
Middle Miocene - Late Miocene
Early Miocene
Pre-Neogene
AaB
Age
Lithology
Quaternary
Late Miocene - Pliocene
Middle Miocene
Early - Middle Miocene
Pre-Neogene
YB
Age
Lithology
Holocene
Pleistocene
Late Miocene - Pliocene
Middle Miocene
Pre-Neogene
EKB
Age
Lithology
Holocene
Pleistocene
1.3-1.5 Ma
Mio-Pliocene
Pre-Neogene
KçB
Age
Lithology
Explanations
Late Miocene
Conglomerate
unconformity
Middle-Late Miocene
Conglomerate
Thin parallel-bedded to laminated mudstone and decimetre thick alternations of normally graded calcareous sandstone.
Early-Middle Miocene
Reefal limestone
Porites,Tarbellastraea, Heliastraea, Aquitanastraea, Favites,Favia, Plesiastraea, Mussismilia, Turbinaria, Oxypora, Lithophyllia, Syzygophyllia
(Çiner et al.,2008)
Conglomerate,
nonconformity
Pre-Neogene
Metamorphic, ophiolitic and sedimentary rocks

Figure 5


a
b
c
d
e
f
g
Q
i
Mpl
h
Ignimbrite
Limestone
Lignite
Limestone
i
Ignimbrite

Figure 6

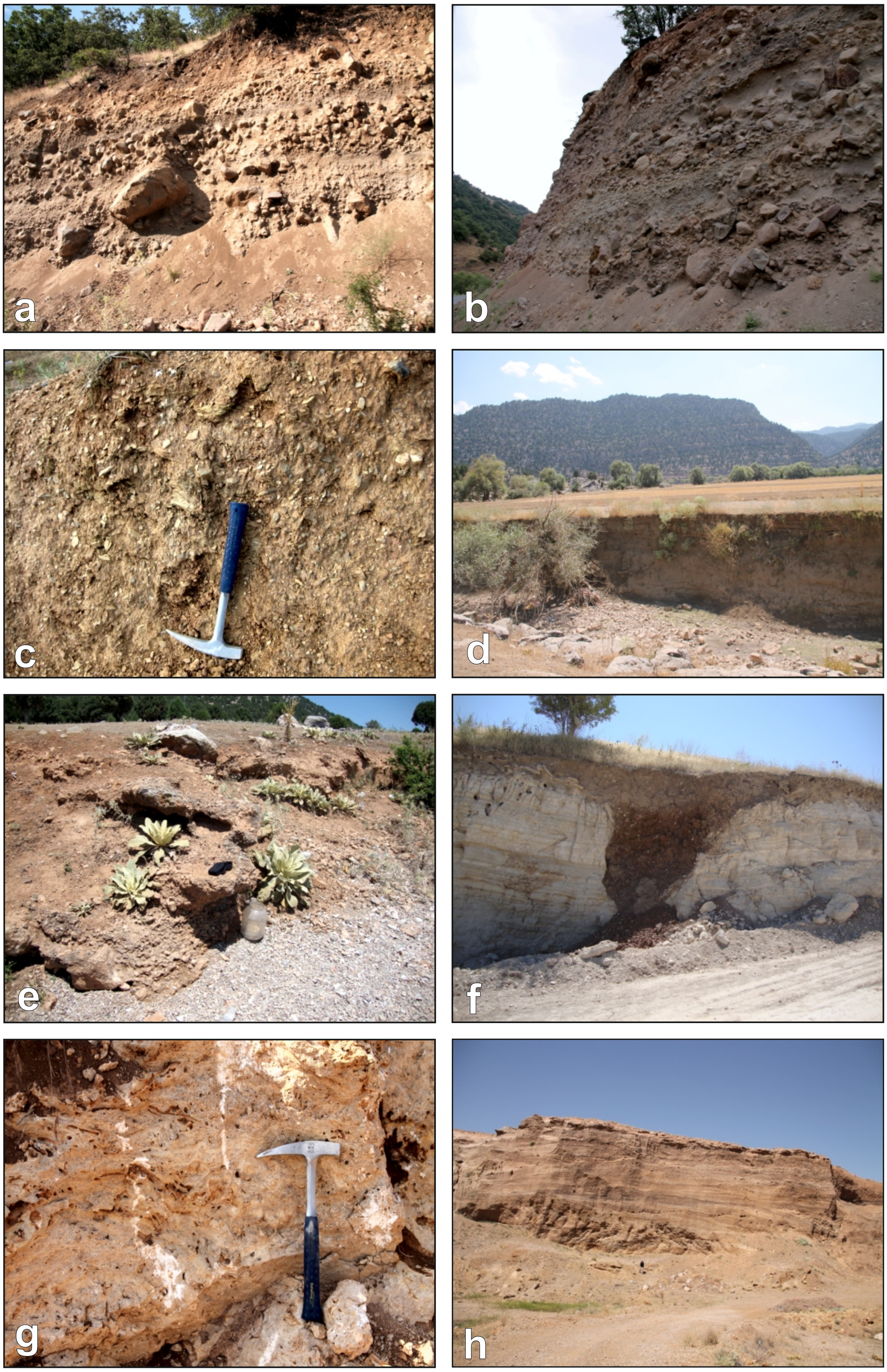

Figure 7

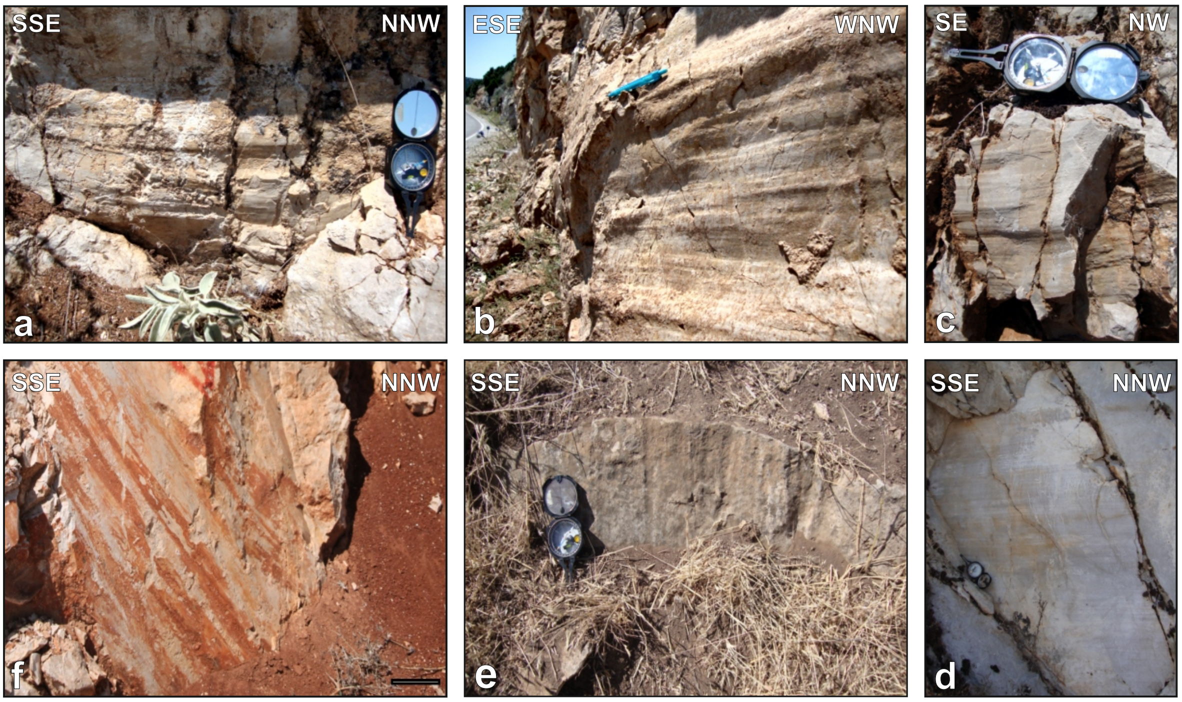

Figure 8

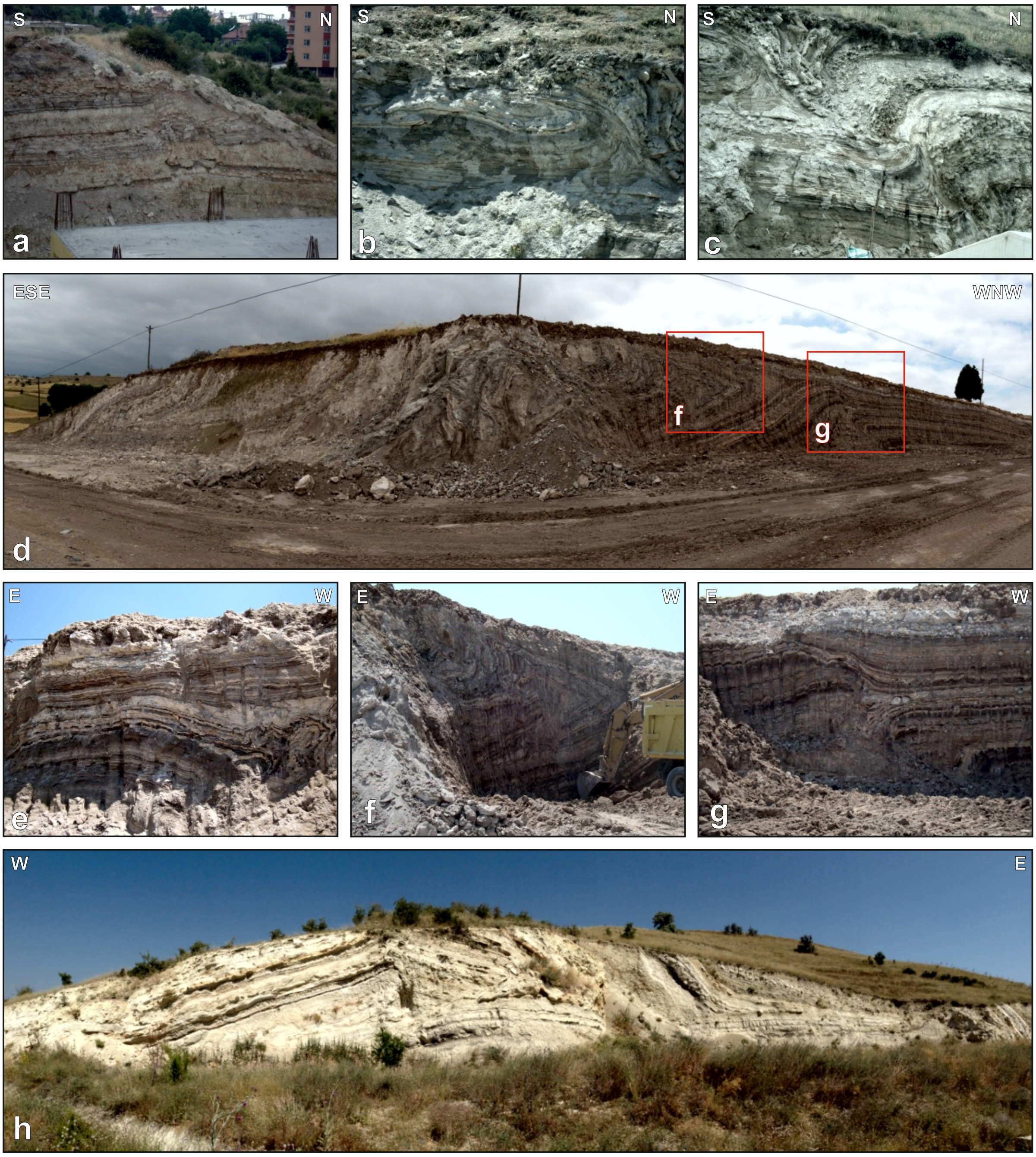

Figure 9

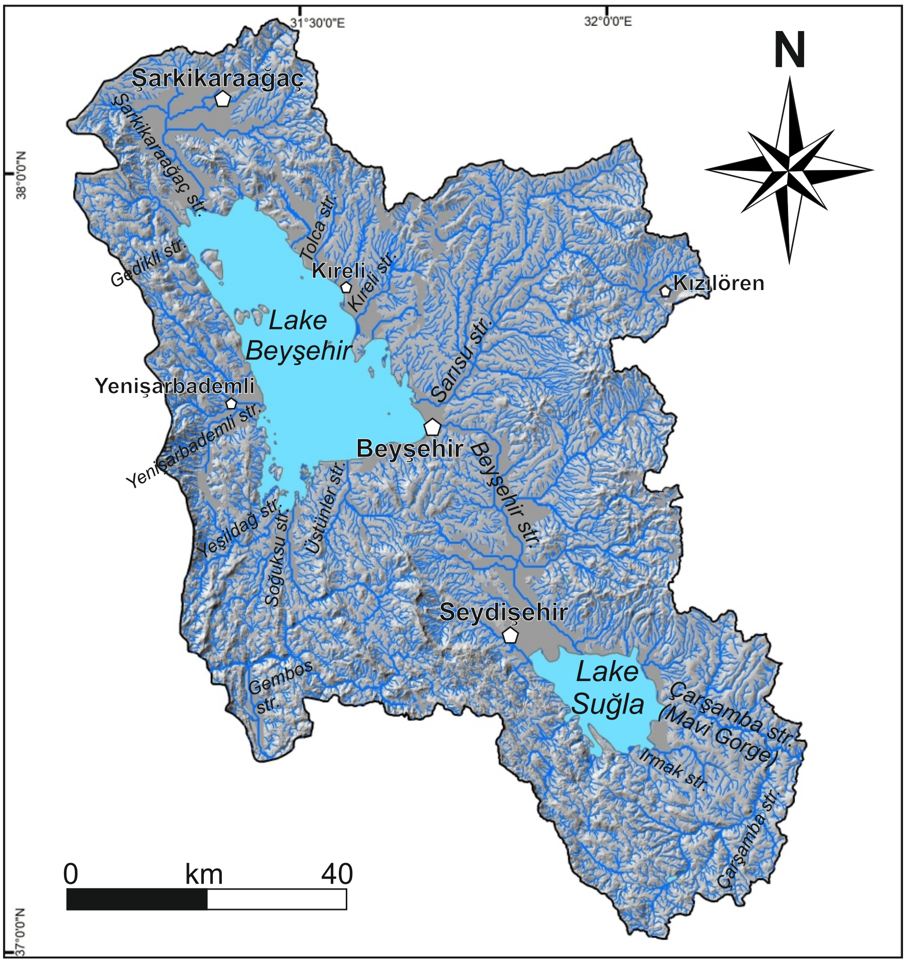
31°30'0"E
32°0'0"E
38°0'0"N
37°0'0"N
N
Şarkikaraağaç
Şarkikaraağaç str.
Gedikli str.
Tolca str.
Kıreli
Kıreli str.
Lake Beyşehir
Kızılören
Sarısu str.
Yenişarbademli
Yenişarbademli str.
Beyşehir
Beyşehir str.
Yeşildağ str.
Soğuksu str.
Üstünler str.
Seydişehir
Gembos str.
Lake Suğla
Çarşamba str. (Mavi Gorge)
Irmak str.
Çarşamba str.
0
km
40

Figure 10

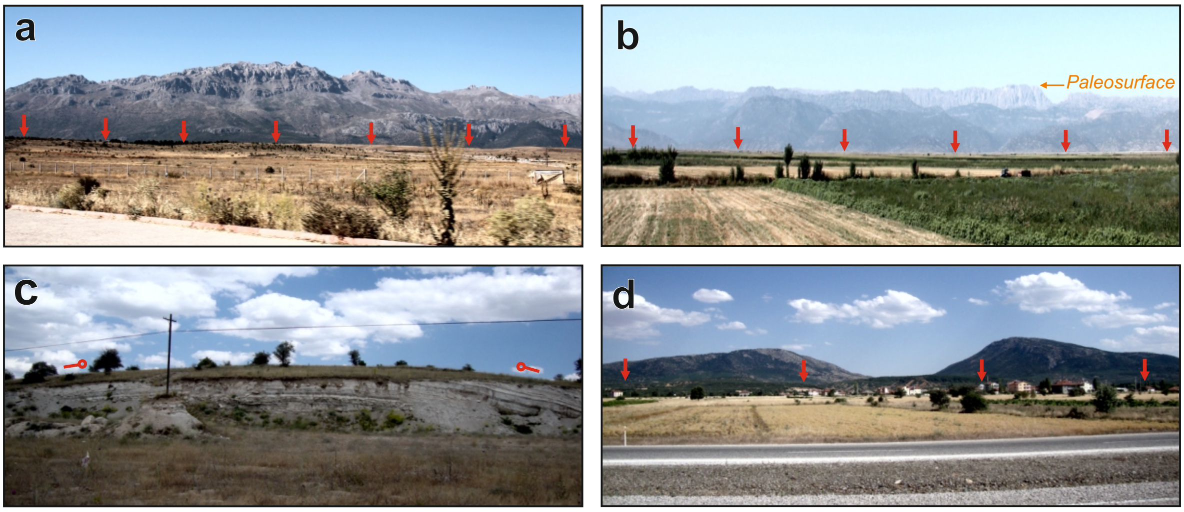

Figure 11

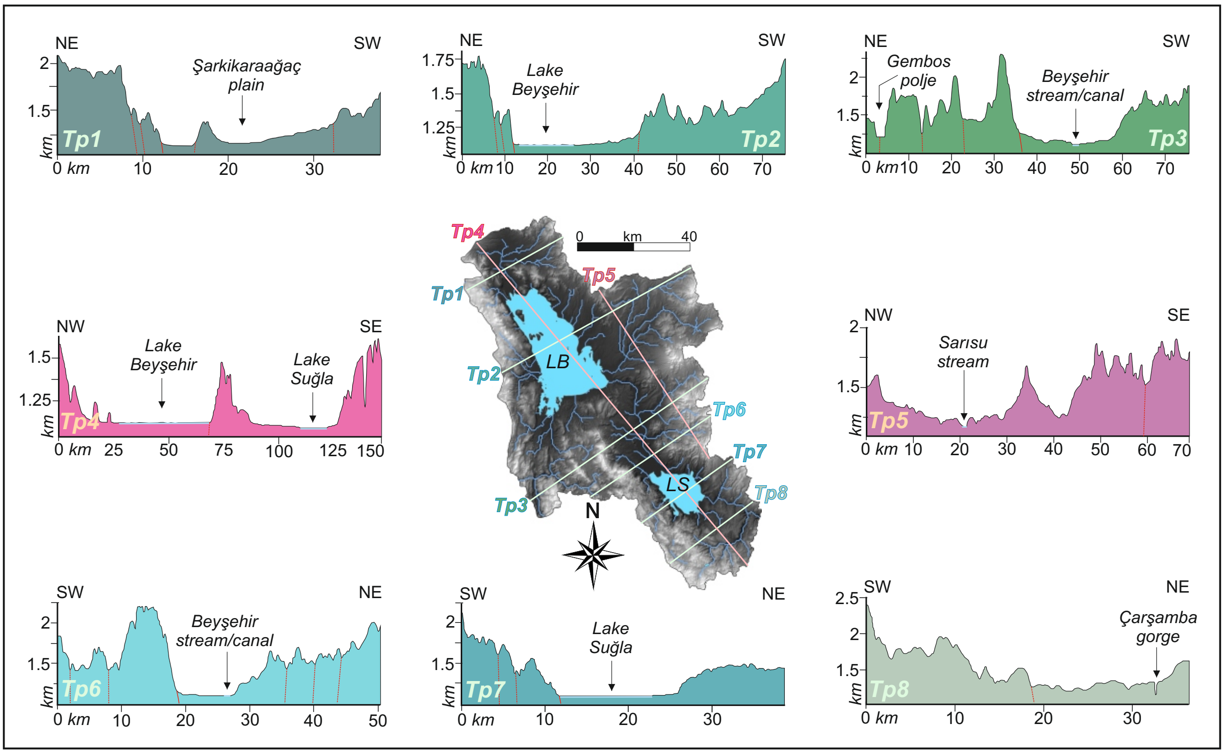
NE
SW
Şarkikaraağaç plain
Tp1
km
2
1.5
0 km
10
20
30
NE
SW
Lake Beyşehir
Tp2
km
1.75
1.5
1.25
0 km
10
20
30
40
50
60
70
NE
SW
Gembos polje
Beyşehir stream/canal
Tp3
km
2
1.5
0 km
10
20
30
40
50
60
70
Tp4
Tp5
Tp1
Tp2
Tp3
Tp6
Tp7
Tp8
LB
LS
0
km
40
N
NW
SE
Lake Beyşehir
Lake Suğla
Tp4
km
1.5
1.25
0 km
25
50
75
100
125
150
NW
SE
Sarısu stream
Tp5
km
2
1.5
0 km
10
20
30
40
50
60
70
SW
NE
Beyşehir stream/canal
Tp6
km
2
1.5
0 km
10
20
30
40
50
SW
NE
Lake Suğla
Tp7
km
2
1.5
0 km
10
20
30
SW
NE
Çarşamba gorge
Tp8
km
2.5
2
1.5
0 km
10
20
30

Figure 12

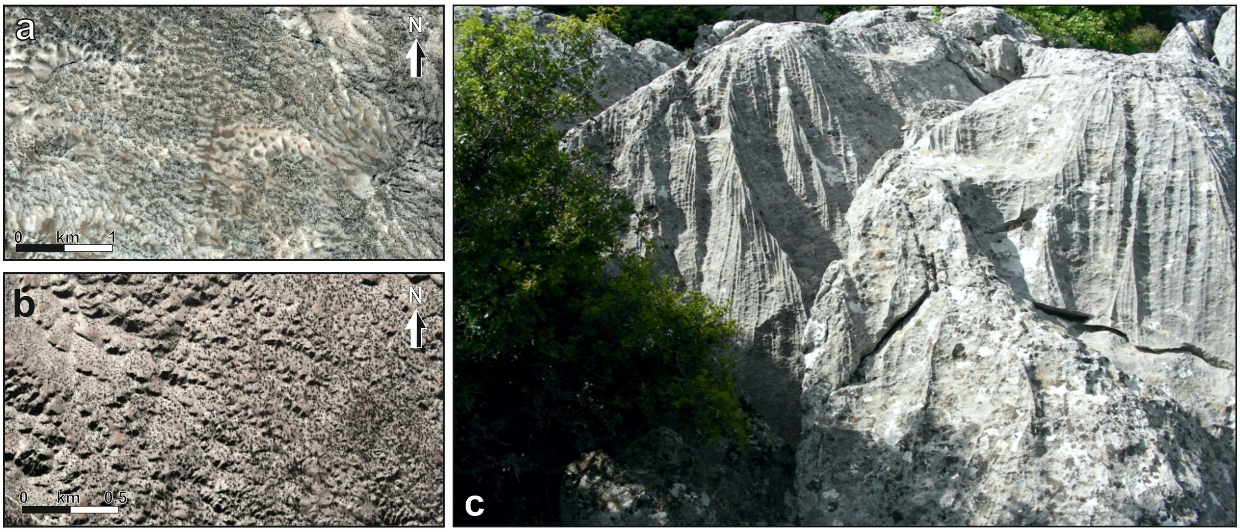

Figure 13

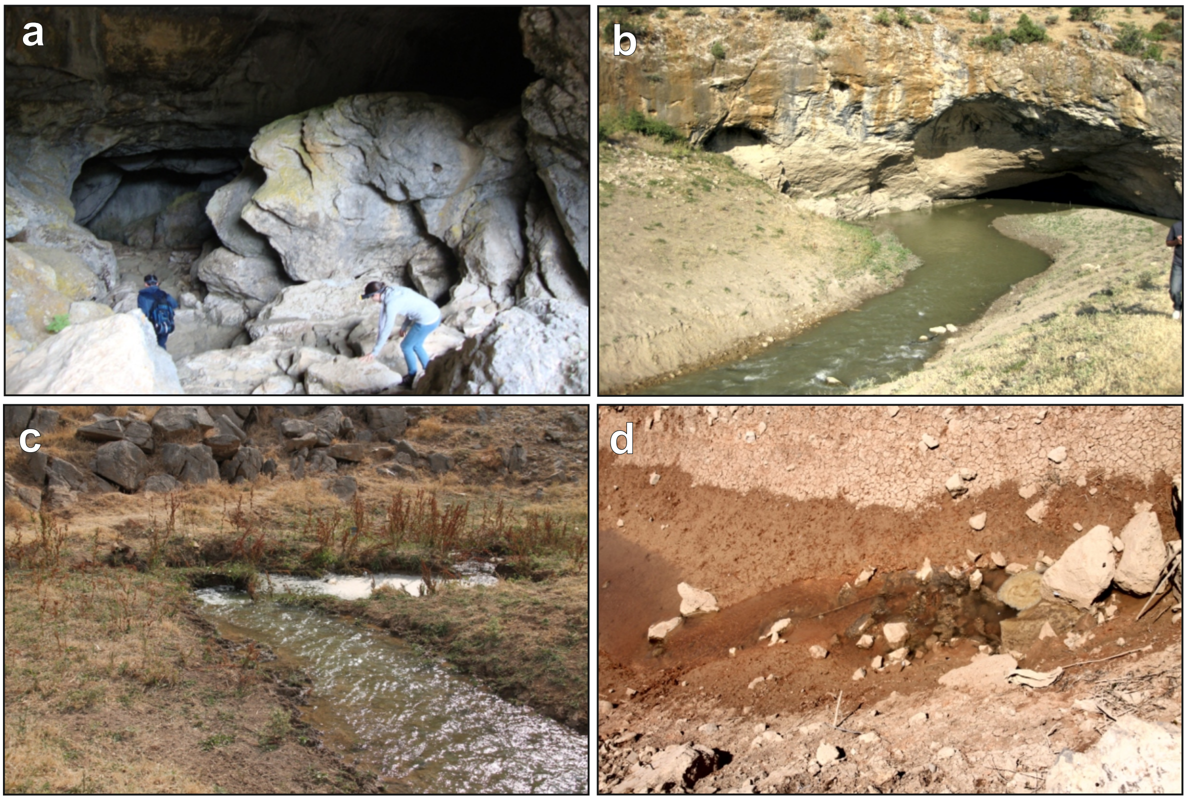

Figure 14

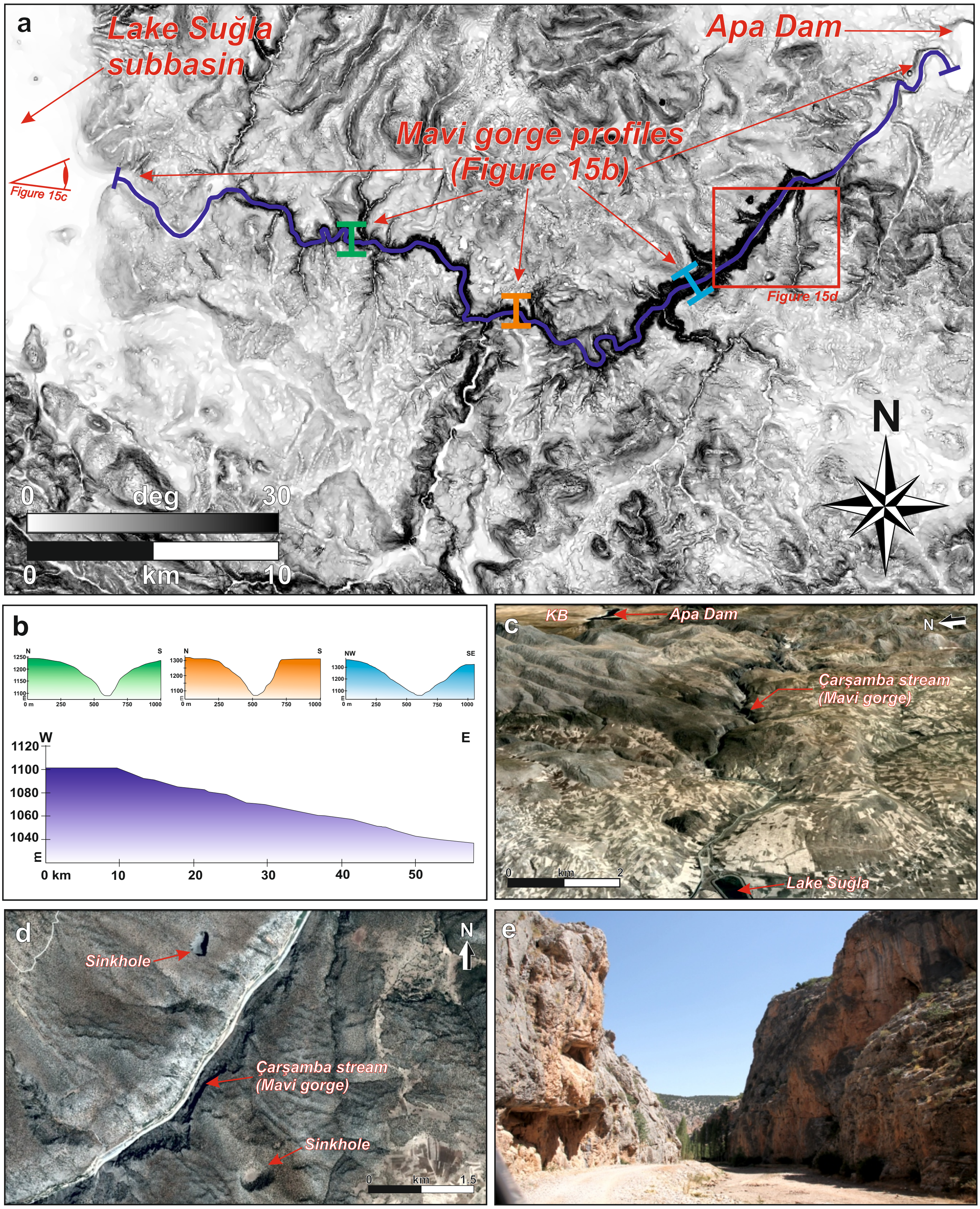
a
Lake Suğla subbasin
Apa Dam
Mavi gorge profiles (Figure 15b)
Figure 15c
Figure 15d
0 deg 30
0 km 10
N
b
N S
1250 1200 1150 1100 m
0 m 250 500 750 1000
N S
1300 1200 1100 m
0 m 250 500 750 1000
NW SE
1300 1200 1100 m
0 m 250 500 750 1000
W E
1120 1100 1080 1060 1040 m
0 km 10 20 30 40 50
c
KB
Apa Dam
N
Çarşamba stream (Mavi gorge)
0 km 2
Lake Suğla
d
Sinkhole
N
Çarşamba stream (Mavi gorge)
Sinkhole
0 km 1.5
e

Figure 15

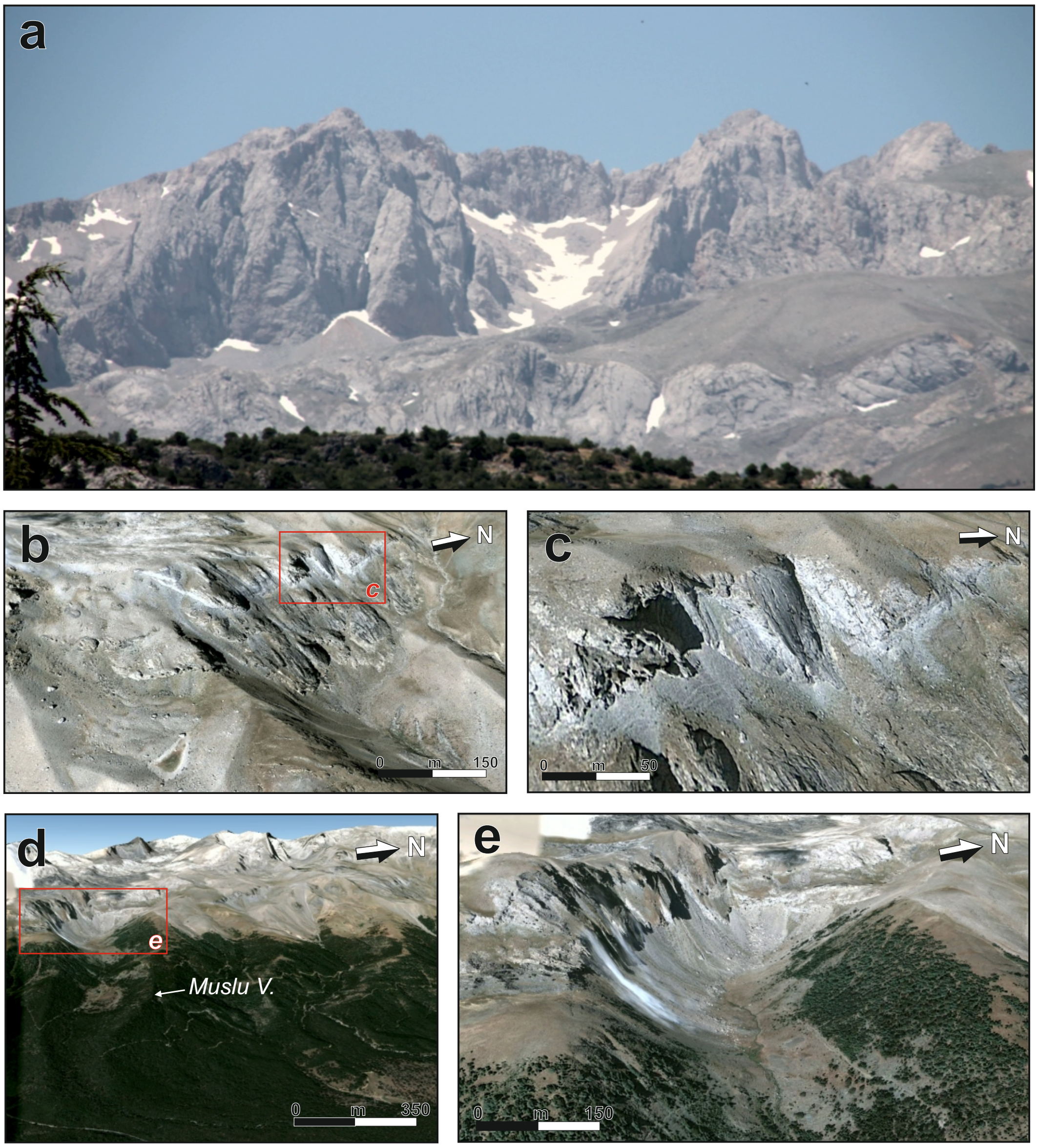

Figure 16

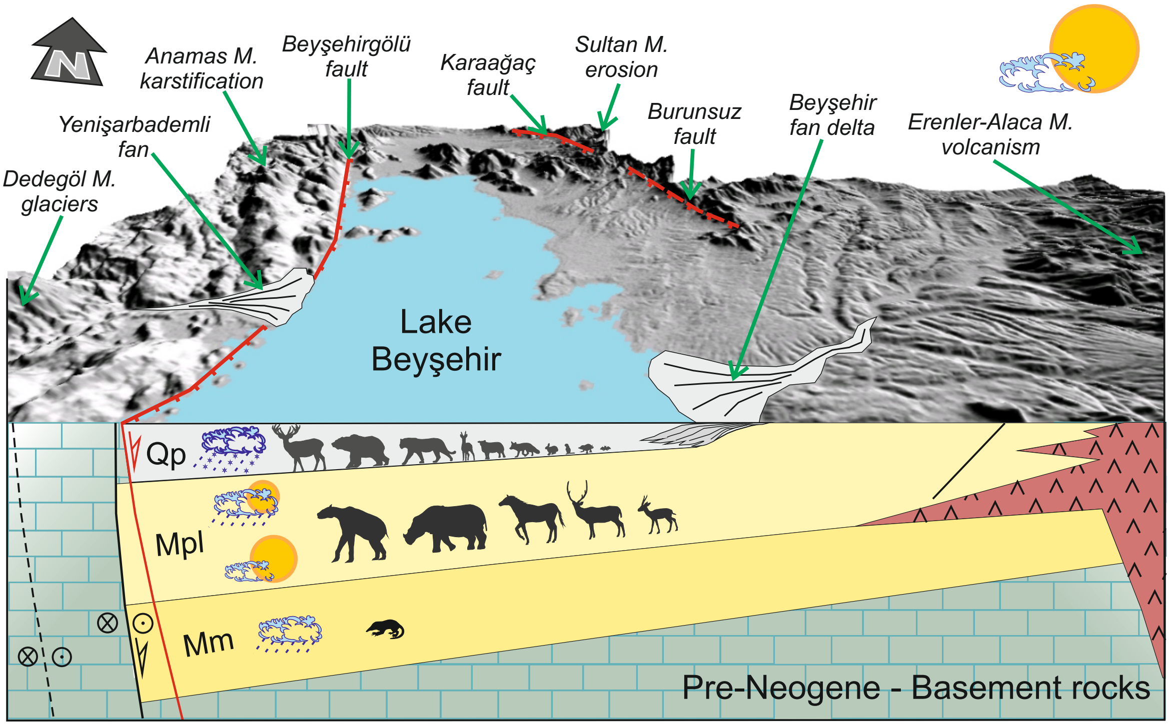
Anamas M. karstification
Beyşehirgölü fault
Karaağaç fault
Sultan M. erosion
Burunsuz fault
Beyşehir fan delta
Erenler-Alaca M. volcanism
Yenişarbademli fan
Dedegöl M. glaciers
Lake Beyşehir
Qp
Mpl
Mm
Pre-Neogene - Basement rocks

Figure 17