Geoheritage
https://doi.org/10.1007/s12371-019-00406-w

ORIGINAL ARTICLE

New Geosite Candidates at the Western Termination of the Büyük Menderes Graben and their Importance on Science Education

Hülya İnaner[1,2] · Ökmen Sümer[1] · Mehmet Akbulut[1]

Received: 7 December 2018 / Accepted: 6 September 2019

Abstract

The Büyük Menderes Graben (BMG) is one of the best-known and the largest geological structure of the West Anatolian Extensional Province. It includes two nature conservation parks and twelve cultural heritage sites within and in its vicinity. Four geologically distinct features/locations within and in the vicinity of the BMG have been previously enlisted as geosite candidates in the provisional Geological Heritage Inventory of Turkey compiled in 2002 by the Turkish Association for the Conservation of the Geological Heritage (JEMİRKO): (1) the horst-graben structure of the Büyük Menderes region itself, (2) the tafoni from the augen-gneiss from the east of Bafa Lake, (3) the zultanite crystals from the northeast of İlbir Mountain, and (4) the tourmaline (dravite) crystals from the Camızağılı, Çine. In the current study, we are introducing additional three new geosite candidates at the western termination of the BMG with three different main geological subjects. The first one is the Yavansu Fault. Located 2 km south of the Kuşadası village, it has a clearly exposed unique fault surface which is one of the best examples of structural indicators for the WAEP with respect to the normal faulting events. The second one is located in the Hisartepe Volcanics exposed between Kuşadası and Söke, and consists of basaltic lava flows with remarkable prismatic cooling joints and a gorgeous feeder dome reaching up to 150 m height. Final suggestion is the Karina marine fan-delta complex located at the south-eastern border of the Dilek Peninsula National Park. This fan-delta complex is the largest one in the Western Anatolian scale and has remarkable paragon outcrops up to 20 m high between Doğanbey and Karina Lagoon.

Keywords West Anatolian Extensional Province · Büyük Menderes Graben · Volcanic rock suits · Normal fault · Marine fan delta · Geosite candidates

Introduction

The Anatolian Peninsula (a.k.a the Asia Minor) that comprises the Asian part of Turkey is geographically/climatically one of the most preferable settling zones for the human life and thus has been an arena of continuous struggle of civilizations for the past millennia. The extreme convenience of the Anatolian landmass mainly comes as a result of its complex/rich geological and tectonic history, that encompasses a series of N–W trending large suture zones of colliding paleo-continents (namely, the Eurasia and the Gondwanaland) comprising various ancient oceanic/crustal remnants, crystalline massifs, and products of extensive volcanism/magmatism. This leads to a unique opportunity to observe and appreciate the numerous monumental geological heritage assets, which are already very well known around the world and are usually blended with cultural/archeological heritage elements. (e.g., the

The subject of this paper was presented in the IX ProGEO Symposium held in Chęciny, Poland, in 25–28 June 2018 as an oral presentation.

This article is part of the Topical Collection on Geoheritage and Conservation: Modern Approaches and Applications Towards the 2030 Agenda, IX ProGEO Symposium, Poland, 25-28th June, 2018

✉ Hülya İnaner
hulya.inaner@deu.edu.tr

Ökmen Sümer
okmen.sumer@deu.edu.tr

Mehmet Akbulut
makbulut@deu.edu.tr

1 Faculty of Engineering, Department of Geological Engineering, Dokuz Eylül University, Tınaztepe Campus, Buca, 35390 İzmir, Turkey

2 JEMİRKO – The Turkish Association for the Conservation of the Geological Heritage, 06570 Ankara, Turkey

Published online: 04 November 2019

travertines of Pamukkale-Hierapolis or Fairy Chimneys of Cappadocia). One of the target locations for observation of the geological and cultural heritage in Anatolia is located within the West Anatolian Extensional Province (WAEP), one of the most seismically active and rapidly extending regions in the world (Taymaz et al. 1991). This tectonic province presents an impressively rich geological background that includes elements of paleo- and neo-tectonomagmatism.

Although large-scale events of the distant geological/tectonic past do not have any direct effect on the major episodes of human development, short-lived/sudden earth phenomena such as earthquakes and volcanoes clearly had visible (mainly destructive) impact in human land use and development throughout the history (cf. King et al. 1994; King and Bailey 2010). Slower sedimentary processes such as alluvial/fluvial deposition, delta-formation, and erosion also have a significant (but not necessarily destructive) impact during the life cycles of human generations, leading usually to dramatic changes in the landscape and land use. Abandonment of wealthy seaside cities/ports and their relocation towards the newly formed shorelines, followed by agricultural usage of the new fertile deltaic deposits, are usual consequences of these phenomena. Exemplarily, the development and lifespan of the ancient civilizations/cities that rose and fall within the perimeters of the WAEP had been largely driven by such geological processes, and today, we see their records as significant geological features.

Two prominent distinctive geological trends within the WAEP are the E–W trending Horst-Graben structures (namely, the Western Anatolian Grabens (WAG)) and a mainly NE–SW trending weakness zone (a.k.a the İzmir-Balıkesir Transfer Zone (İBTZ)) (Sümer 2015). The E–W trending structures, from north to south, include Gediz (Alaşehir), Küçük Menderes, and Büyük Menderes grabens (Sümer 2015). Several researchers had studied the geological significance of these structures (e.g., Hamilton and Strickland 1841; Philippson 1911; Zeschke 1954; Arpat and Bingöl 1969, Dumont et al. 1980; Sözbilir and Emre 1990; Cohen et al. 1995; Seyitoğlu and Scott 1992; Koçyiğit et al. 1999; Yılmaz et al. 2000; Sözbilir 2002; Bozkurt and Sözbilir 2004; Purvis and Robertson 2005; Rojay et al. 2005; Gürer et al. 2009; Çiftçi and Bozkurt 2010).

Being impressed (and also usually overwhelmed) by the nature that shape their environment, ancient human civilizations have attributed this irrepressible and unfamiliar force to several metaphysical elements and depictured them as gods in the ancient mythology (cf. Tül et al. 2009). The Meander river located in the antique Caria (the Büyük Menderes River within the Büyük Menderes Graben) is similarly deified and named after the Meander or Maiandros who is depictured as a river god in ancient Greek mythology (one of the sons of Titan gods Oceanus and Tethys, cf. Tül et al. 2009). The Büyük Menderes Graben (BMG; Fig. 1)—the southernmost and largest one of the graben structures in the WAG and its vicinity—had been home to ancient populations for a long time, and in combination to its vast amount of cultural/archeological assets, hosts important geological formations of significant heritage value (two nature conservation parks and twelve ancient cultural heritage sites).

Among these, the Dilek Peninsula-Büyük Menderes Delta National Park and ancient cities of Priene, Magnesia, Tralleis, and Nysa are aligned along the northern borders of the BMG. The well-known city of Ephesus and nearby Larissa and Lebedos are located to the north, within the Küçük Menderes Graben (KMG). The ancient cities of Miletos, Didyma, Myus, and Heraklia are located towards the southern border of the BMG along with the Bafa Lake Nature Park. The ancient city of Samos, although being outside the borders of the Republic of Turkey, should also be added in this list due its proximity to the Dilek Peninsula National Park and the BMG. These heritage elements are considered important assets for the geoconservation for science, education, and tourism. Some of the geological features within the BMG and surroundings has already been enlisted as possible geoheritage/geosite candidates in the Geological Heritage Inventory of Turkey (cf. JEMİRKO 2002; Figs. 1 and 2). In this paper, we aim to present additional three potential geosites at the western termination of the BMG with three different main geological subjects: (1) the Yavansu Fault plane, (2) the gorgeous feeder dome of the columnar basaltic lava flows of the Hisartepe Volcanics, and (3) the Karina marine fan-delta complex located at the south-eastern border of the Dilek Peninsula National Park (Figs. 1 and 2).

Geological Aspects

Research History and Geological Setting

Büyük Menderes Graben (BMG), one of the best areas for observation of graben and horst structures characterizing the regions of intra-continental rifting, is located within the West Anatolian Extensional Province (WAEP).

The first geological research considering the ascension and depression zones within the WAEP starts with approximately N–S trending sections (Hamilton and Strickland 1841) and geological mapping studies (Philippson 1911). Weismantel (1891) uses the earthquake data and the morphology of the region. Extending the southern margin of Gediz and northern margins of Küçük and Büyük Menderes Basins by fault lines on the topographic map, he indicates that these faults are the main reasons for the earthquakes in the region. Philippson (1911), for the first time, suggests that the Gediz and Büyük Menderes Basins are tectonic depression zones and are probably formed under extensional regime. After a quite long time gap, the studies on the geology and metamorphism of

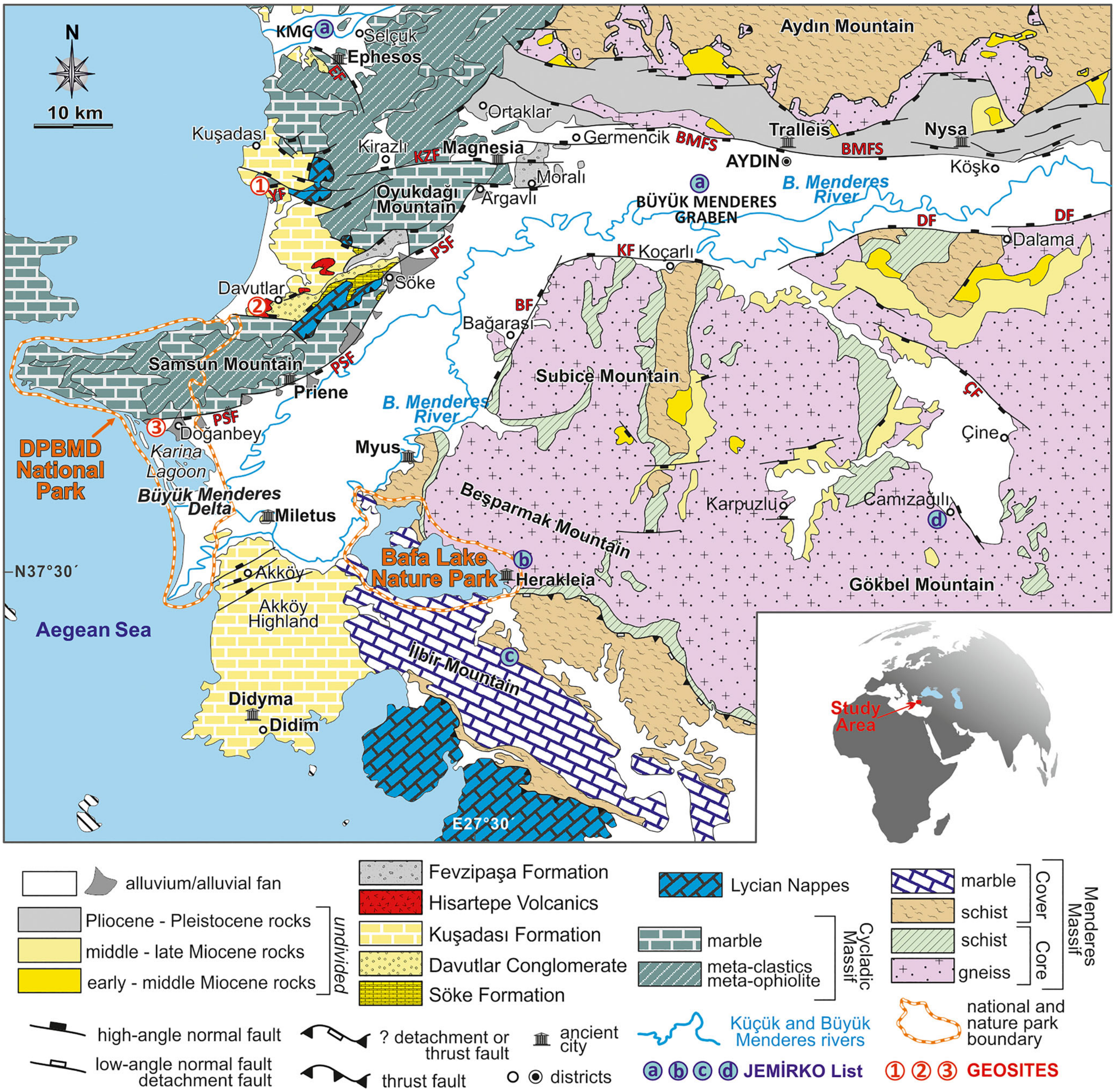

Fig. 1 Geological map of the Büyük Menderes Graben and surroundings (modified and simplified after 1:500,000 scale geological map of Denizli sheet by Mineral Research and Exploration Directorate of Turkey (MTA), Konak and Şenel 2002 and compiled from Okay 2001 and Candan et al. 2011a). DPBMD (Dilek Peninsula Büyük Menderes Delta) National Park, PSF: Priene–Sazlı Fault, BMFS: Büyük Menderes Fault System, BF: Bağarası Fault, KF: Koçarlı Fault, DF: Dalama Fault, KF: Kirazlı Fault, EF: Ephesos Fault, YF: Yavansu Fault. Please see Fig. 2 for detailed explanations of the symbols used for Geoheritage and Geosites

Menderes Massif gathers pace during 1970s and 1980s (e.g., İzdar 1971; Dora 1976; Evirgen 1979; Şengör et al. 1984). With the introduction of the Metamorphic Core Complex theory in the beginning of the 1980s (Coney 1980; Davis 1980)—which resulted in extensive changes in the literature on the continental rift zones—further studies focusing on the metamorphic core complex in the WAEP has started to be implemented (Üşümezsoy 1988; Bozkurt et al. 1993; Emre and Sözbilir 1997). In 2000s, some studies started to focus on the geological evolution of the metamorphic rocks surrounding the BMG with the support of increasing applications of radiometric dating methods (Bozkurt and Satır 2000; Lips et al. 2001; Gessner et al. 2004; Oberhänsli et al. 2010; Koralay et al. 2012). Miocene to modern evolution of the Büyük Menderes Graben and surroundings has also been intensively studied (Sözbilir and Emre 1990; Cohen et al. 1995;

Fig. 2 3D relief map of the Büyük Menderes Graben and surroundings illustrating the conservation assets (compiled from Sümer 2013). DPBMD: Dilek Peninsula Büyük Menderes Delta National Park, KL: Karina Lagoon

Emre and Sözbilir 1997; Bozkurt 2000; Gürer et al. 2009; Şen and Seyitoğlu 2009; Bozcu 2010; Çifçi et al. 2011; Sümer et al. 2013; Koçyiğit 2015).

Rock Units

Menderes Massif

Regional studies on the Menderes Massif, which outcrops in the central part of the Western Anatolia, is quite abundant in the literature. Starting from 1840s, the massif is considered and mapped as metamorphic series (e.g., Hamilton and Strıckland 1841; Philippson 1911; Paréjas 1940). These metamorphic rocks has the largest land coverage in the center of Western Anatolia and has been previously addressed under different names such as the Cyclades-Carie Mass (Tchihatcheff 1867), Lydisch-Karische Masse (Philippson 1911), Massif central (Arabu 1923) and Saruhan Menteşe Core Akyol and Pamir 1929). The current Menderes Massif denomination was first described as Saruhan-Menteşe (or Menderes) by Paréjas (1939). Schuiling (1962) has completed the first systematic geological and petrological research and described the lithostratigraphic pile of the Massif in two main units: the Core and the Cover series (Fig. 3). Dora (1976), also referring to the generalized geological map of Turkey, has grouped the Menderes Massif lithologies from north to south as Eğrigöz, Gördes, Ödemiş, and Çine submassifs. Şengör et al. (1984) have interpreted the geological relation of the core and cover series as a Pan-African unconformity. Candan et al. (1992), for the first time, have described the existence of the internal tectonostratigraphic and napped structure other than the classical pile. Gessner et al. (1998), Hetzel et al. (1998), Ring et al. (1999), and Gessner et al. (2001a) have continued to emphasize this internal napped structure of the Massif. The type of the contact (structural and/or stratigraphic) between the core and cover series has been also a subject to many studies (e.g., Bozkurt et al. 1993; Hetzel et al. 1995; Bozkurt and Park 1997; Gessner et al. 2001b; Bozkurt and Satır 2000; Candan et al. 2011a).

Core series of the Menderes Massif generally dominantly comprises metamorphic rocks such as orthogneiss, paragneiss, and schists (Candan et al. 2011a). Numerous radiometric dating studies from the geological units from this series—largely described as the Pan-African basement—have presented an age range between 461 and 579 Ma (Satir and Friedrichsen 1986; Loos and Reischmann 1999; Gessner et al. 2004; Koralay et al. 2012). Candan et al. (2011a) have compiled/interpreted all these data indicating that the metamorphic and magmatic evolution of the core series, which represents the Pan-African basement, might be related with the Late

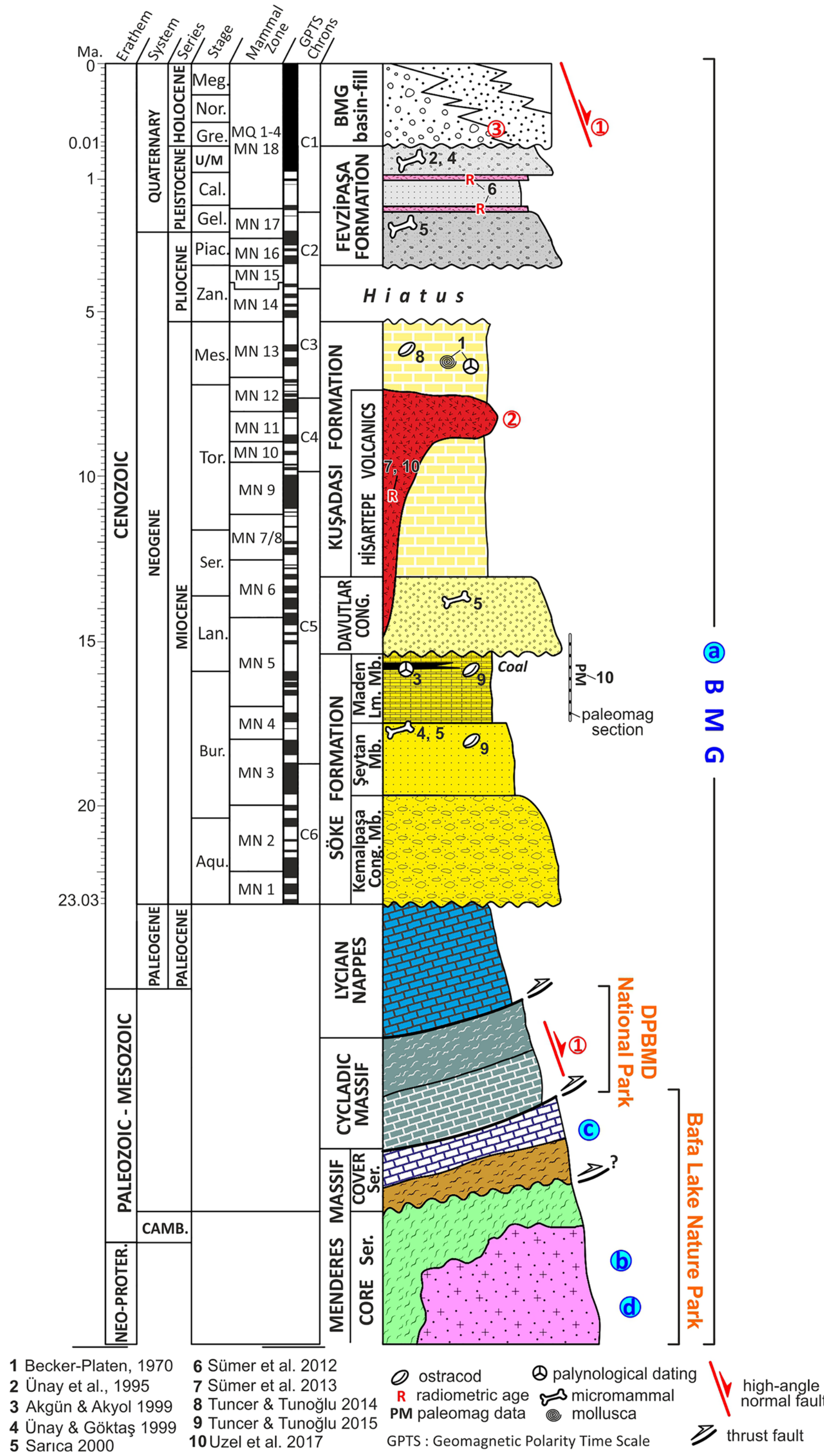

Fig. 3 Generalized stratigraphic columnar section of the Büyük Menderes Graben (modified and combined from Candan et al. 2011b and Sümer et al. 2013). Nature Conservation, Geoheritage and Geosites are shown with the same symbols as in Fig. 2

Neoproterozoic-Cambrian closure of the Mozambique Ocean and final coalescence of the Gondwana continent. The cover series, on the contrary, dominantly consists of metadetritic-metacarbonate–type geological units such as schist, phyllites, and marbles. The units within the cover series are represented by ages between Permian and Paleocene (Çağlayan et al. 1980; Okay 2001; Erdoğan and Güngör 2004; Özer et al. 2017).

Cycladic Massif

The metamorphic rocks especially located and outcropping between Dilek Peninsula and Kuşadası-Selçuk had been considered within the Menderes Massif till the mid-1990s. Although these rock assemblages are primarily considered a part of the Massif, late studies has shown that they present differences in the type of metamorphism and belong to the Cyclades that are spread along the Aegean Sea (Candan et al. 1997; Oberhänsli et al. 1998; Ring et al. 1999; Okay 2001; Çetinkaplan 2002; Ring et al. 2007). The rocks that belong to the Cycladic Massif generally consist of Mesozoic marbles and chlorite-kyanite schists, and blue amphibole-bearing metabasites and metabauxite intercalations (Candan et al. 1997; Oberhänsli et al. 1998). The dominant rock type in the Cycladic Massif is the marble. Marbles mainly outcrop at Samsun Mountains and Oyukdağı, located north of Söke (Fig. 1). Other rock units of the lithology generally presents a metaflysch character. $^{40}Ar/^{39}Ar$ dating of phengite crystals from the schists of the metadetritic sequence yields a Middle Eocene age (40 Ma; Oberhänsli et al. 1998). Age of metamorphism of the counterpart lithologies in Samos and Cyclades ranges between 55 and 30 Ma (Gessner et al. 2011). Ring et al. (2007) suggests an age between 32 and 42 Ma for some packages of the Cycladic Massif. The general consensus is that these rocks are firstly subjected to high-pressure (HP) and low-temperature (LT) metamorphism in the final stages of subduction and further exposed to Barrovian-type burial metamorphism during Late Eocene-early Oligocene (Çetinkaplan 2002).

Lycian Nappes

Lycian Nappes are especially located as overthrusted metasedimentary sequences (de Graciansky 1972). There are many studies in the literature on Lycian Nappes (e.g., Brunn et al. 1970; Gutnic 1979; Collins and Robertson 1997; Rimmelé et al. 2003; Özer et al. 2017). The rock assemblages of the Lycian Nappes located in the BMG and surroundings outcrop to the western–northwesternmost part of the BMG, easternmost part of western Söke and Samsun Mountains, east-southeast of Kuşadası, and west of Oyukdağ (Fig. 1). The existence of rock assemblages of Lycian Nappes in and around BMG is firstly introduced by Güngör and Erdoğan (2001). Çetinkaplan (2002), Rimmelé et al. (2006), and Çakmakoğlu (2007) later re-evaluated the outcrops of these rock assemblages around the BMG. These rock units are represented dominantly by dolomitic and recrystallized limestones that show marble-like textural characteristics and small amounts of red-green–colored metadetritic rocks. Fossil ages from some packages from these tectonostratigraphic rock series show ages ranging from Triassic to Cretaceous (Çakmakoğlu 2007). These marble-dominated units belonging to Lycian Nappes rest tectonically on top of metaolistostromal formations and marble sequences of the Cycladic Massif (Güngör and Erdoğan 2001; Rimmelé et al. 2006).

Miocene Units

Söke Formation Although geological studies on the Söke Formation goes back to the beginning of the twentieth century, back to Philippson (1911), the unit is mainly studied in the mid-1950s largely due to its coal content. The unit is firstly addressed as Söke formation by Ercan et al. (1986) referring to all detritic and carbonate units between Kuşadası and Söke. Later geological studies are conducted by Ünay and Göktaş (1999) and Gürer et al. (2001). The most detailed study on the formation is by Sümer et al. (2013). These authors subgroup the formation under three members from bottom to top: (1) the lowermost Kemalpaşa Conglomera Member that is made of coarse grained sediments, (2) Şeytan Member that is characterized by fine grained sediments and economic coal seams, and (3) the uppermost Maden Limestone Member that is dominantly made of carbonate rocks (Fig. 3). The unit unconformably rests over the rocks of the Cycladic Massif. The total thickness of the formation that is distributed over an 8-km^2 area around Söke and surroundings is reported as 250 m (Sümer et al. 2013). The sedimentological characteristics of the Söke Formation points to alluvial fans, conjunctive alluvial plains, fresh water lakes and lake margin swamp environments, and shallow carbonate lacustrine environment (Sümer et al. 2013). There are three dating studies from the Formation. While Ünay and Göktaş (1999) and Sarıca (2000)—referring to their micromammal (rodent) findings—indicate that the unit has parts represented by MN4 mammal zone (late early Miocene), Akgün and Akyol (1999) has suggested a middle Miocene age according to their palynological findings in the coals observed in the formation. Ostracod fauna in the formation also shows a similar age host (Tuncer and Tunoğlu 2015). All these age data suggest that the formation's geological age is early-middle Miocene.

Davutlar Conglomerates This unit is at first described as upper series of the Miocene sediments by Nebert (1955) and later redefined as Dededağ Formation (Ünay and Göktaş 1999) and Davutlar Conglomerate (Gürer et al. 2001). The formation is later studied by Sümer et al. (2013), who described it as composed of pebble stones and characterized by fine detritic sediments upwards. The formation outcrops between Davutlar and Söke and has an approximate thickness of 200 m. The unit unconformably overlies the Söke Formation and metamorphic basement rocks of the Cycladic Massif. The unconformable contact between the Söke Formation and Davutlar Conglomerate has been discussed with the help of paleomagnetic data in Uzel et al. (2017). The sedimentological characteristics of the formation point to a deposition environment dominated by alluvial fans (Sümer et al. 2013). Ünay and Göktaş (1999) and Sarıca (2000) indicate that the micromammal (rodent) fauna they obtained from the formation are made of forms representing the MN4-MN6 mammal zone (Fig. 3). According to these data, a middle Miocene age may be accepted for the Davutlar Conglomerate.

Kuşadası Formation Although the best outcrops of this formation are located between Kuşadası and Söke, the formation is spread on a large area ranging from the southwesternmost part of BMG to the northwest border of Küçük Menderes Graben. Nebert (1955) had described these units inside the upper series of Miocene sediments. The first denomination of these units as Kuşadası Formation was done by Ünay and Göktaş (1999). In a later detailed study, Sümer et al. (2013) had described the formation to be made up of minor to moderate sandstone, mudstone, calcareous siltstone, marlstone, and dominantly clayey limestone, calcareous claystone, and limestone. The total thickness of the unit is approximately 200 m. The sedimentological, lithological, and faunal components of the unit points to a fresh water carbonate lacustrine environment and the geological age is constrained as late Miocene, due to its gastropod and ostracod fauna content (Becker-Platen 1970; Tuncer and Tunoğlu 2014). Additionally, Tuncer and Tunoğlu (2014) also report a certain abundance of marine forms.

Hisartepe Volcanics First determined by Ercan et al. (1986), Hisartepe Volcanics comprises dark gray-black–colored trachyandesitic, basaltic andesitic, andesitic, and to a lesser extent, latitic and rhyodacitic lava and dome facies volcanic rocks with characteristic hexagonal cooling cracks (Sümer et al. 2013). One of the important geosite proposals in this study is related with these volcanic rocks (Fig. 3). They outcrop along an approximately NE–SW trend in 4 different main zones with approximately 60 m thickness and usually shows dome facies characteristics. Random metamorphic rock xenoliths are common in these rocks. A pepperitic contact between the Kuşadası Formation and these volcanic rocks is visible at the Hisartepe. This contact relation suggests existence of a contemporaneous volcanism in the basin along with the sediment deposition. $^{40}Ar/^{39}Ar$ ages from these volcanic rocks yield ages between 11.66 and 12.85 Ma (Sümer et al. 2013; Uzel et al. 2017).

Fevzipaşa Formation The Fevzipaşa Formation is studied firstly by Nebert (1955). He defined the formation as cardium-bearing sands within the Pliocene sediments. Becker-Platen and Löhnert (1972) indicates that these forms are *Cardium edule* and the fine grained sandstones and claystones may be deposited in an environment related with the Aegean Sea during Pliocene or Pleistocene. The formation is later named as Savulca (Ünay and Göktaş 1999) and Fevzipaşa Formation (Gürer et al. 2001). Sümer et al. (2012) consider the formation under 3 main packages that are separated with 2 allostratigraphic unconformities. The formation comprises deposits of alluvial fan, deltaic facies, and freshwater lacustrine environments and additionally present 2 remarkable tuff layers within 7 sedimentary facies assemblages (Sümer et al. 2012). Using the micromammal (rodent) fauna, Ünay and Göktaş (1999) and Sarıca (2000) indicate that the age of the formation is late Pliocene-Pleistocene (Fig. 3). Sümer et al. (2012) also report K/Ar ages from the tuffs, that ranges from 2.4 ± 0.3 to 0.95 ± 0.15 Ma. A more detailed description of the formation is beyond the scope of this paper, and readers are referred to Sümer et al. (2012) for further information.

Büyük Menderes Graben Basin-Fill Units

These units are the youngest sedimentary deposits within the BMG. These deposits consist of less consolidated sedimentary rocks and/or still depositing sediments of Holocene or Quaternary age. These sediments may be grouped under 3 main depositional packages according to their areas of distribution, borders of observation, morphologies, and the modern environmental characteristic they reflect; (1) alluvial fan and plain deposits, (2) marine fan-delta deposits, (3) Büyük Menderes marine river delta deposits (Sümer 2013). The stratigraphic unconformity between the alluvial fan and plain deposits and older rock units of the marine fan-delta deposits is especially observed at the westernmost point of the BMG and at the north of the basin. The detailed characteristics of the deposits of the Karina marine fan-delta complex, which is directly related with the scope of this paper, will be addressed under the chapter introducing the new geosite candidates in this study.

Geoheritage and Geosites

Previous Geosite Candidates from the Region Listed in the JEMİRKO's Provisional Inventory of Geological Heritage of Turkey

Kazancı et al. (2015) indicate that one of the considerable dangers for geosites, geological heritage, and geological conservation is the attribution of different meanings to these terms and they further remark that suggestion and acceptance of a geosite depends on rules. There are 10 basic categories (groups) defined by the ProGEO (ProGEO Group 1998) for description/determination of geosites; however, this rough categorization is not a final grouping and branched in a much detailed Geosite Framework List (cf. Kazancı et al. 2015 and the references therein). JEMİRKO (The Turkish Association for the Conservation of the Geological Heritage) is a non-governmental organization (NGO) on the geological heritage and geoconservation, which has been founded in 2000. The organization is a member of UNESCO National Committee of Turkey and representative of the European association for the conservation of the geological heritage (ProGEO). The main objectives of JEMIRKO are (1) to make inventories of the geosites, (2) to promote the geological heritage elements detected, and (3) to produce, conduct, and encourage any projects in the aspects given above. To achieve its first goal, JEMIRKO tries to follow the principals of the Geosite Framework List by ProGEO.

In a pursuit of a reliable methodology, several international meetings and attempts were made for a common framework list for classifying its geosites and creating a geosite inventory (cf. ProGEO Group 1998; Theodossiou-Drandaki et al. 2004; Brilha et al. 2005; de Lima et al. 2010). Commonly, every country is called on to create its own framework list in concordance with neighbor countries' framework lists; not like a country inventory but rather like a stensil to work with (cf. Kazancı et al. 2015). From the beginning of the inventory studies, JEMİRKO has tried to follow these steps later described by Kazancı et al. (2015) in detail. JEMİRKO is focused on a rather non-official registration procedure for candidacy, which includes filling up of a descriptive registration form to propose a "geosite" and a following evaluation process by a relevant subject committee of expert geologists of the field including field studies (Kazancı et al. 2012). In this study, we followed the Geosite Framework List for Turkey (GFLT), outlined by Kazancı et al. 2015, which includes 85 titles in 10 main categories (Groups A to J—Table 1), the Stratigraphic (Group A) and Volcanic-Metamorphic-Sedimentary Petrology (Group C) categories being the richest. This list is based on the tenfold category Framework List (FL) by ProGEO (cf. ProGEO Group 1998; Theodossiou-Drandaki et al. 2004).

There are currently four geosite candidate entries in the preliminary provisional Inventory of Geological Heritage Elements of Turkey by JEMİRKO from the region (JEMİRKO 2002; http://www.jemirko.org.tr/turkiye-jeolojik-miras-envanteri/). These entries included (1) several of the grabens of western Anatolia (Gediz, Büyük Menderes, Fig. 4a, and Küçük Menderes; Group E in GFLT), (2) the interesting tafoni structures forming due to weathering of the augen-gneiss located to the south of Menderes Massif (east of Bafa Lake; Group F in GFLT), (3) the peculiar Anatolian diaspore crystals (a.k.a. zultanite) northeast of İlbirdağı (Küçükçamlık-Kurudere-Selimiye region; Group D in GFLT) and (4) the Camızağılı-Çine tourmaline (dravite) crystals (Group D in GFLT). The final version of the geosite inventory has not been published yet either in paper or online.

The characteristics and importance of the geology of the Büyük Menderes Graben (BMG; Figs. 1 and 2) have already been given in this paper, in the chapter summarizing the geological setting of the BMG, hence will not be resummarized here.

Alkanoğlu (1984) had introduced the tafoni in the augen-gneiss to the east of Bafa Lake for the first time (Figs. 1 and 2). Tafoni (singular: tafone) can loosely be defined as a weathering product in coarse-grained siliceous or crystalline rocks. The term comes from Corsican dialect and used to define either (a) a honeycomb structure formed by cavernous weathering on the face of a cliff in a dry region or along the seashore or (b) granitic or gneissic blocks of boulders hollowed out by cavernous weathering (Bates and Jackson 1987). The tafoni described from the east of Bafa Lake corresponds to the latter definition. The region lying between Yatağan and Çine is also dominated by this type of structures (Fig. 4b). Detailed geology of this region has been studied by several authors (e.g., Bozkurt 2004; Erdoğan and Güngör 2004; Koralay et al. 2012). Gül and Uslular (2017) summarized the various landforms that can be encountered in the region as dome-bald hill (inselberg-bornhardt and tor structures), pillar structures, boulder-block corestones, weathering pits, polygonal cracks, tafoni, honeycomb weathering (alveoli), spheroidal weathering, flared slopes, and onion skin-exfoliation cracks.

The Anatolian diaspores (Zultanites) present transparent crystals showing vitreous luster and perfect to good cleavages (Hatipoğlu 2010). The crystal sizes may sometimes reach up to 35 cm and are still being exploited from a single deposit located at the Küçükçamlık-Kurudere-Selimiye region (İlbir Mountains) to the northwest of Milas (Muğla, SW Turkey) (Hatipoğlu 2010).

Unfortunately, it is not possible to find any direct scripts on the Camızağılı-Çine tourmaline (Dravite) crystals in the literature. However, Oyman (2006) indicates existence of dravite end-member of the schorl-dravite solid solution series in the Sinancılar-Kemalpaşa district tourmalines located in the southern horst of the Gediz Graben (northernmost one of the WAG group) and schorl end-member of the schorl-dravite series in the Mandıra Hill located approximately 9 km east of Çine (Fig. 1).

New Geosite Candidates Within the BMG and Surroundings

Below, we present new potential geosite locations within the BMG and its vicinity and correlate them with the Geosite Framework List for Turkey.

Yavansu Fault (Geosite 1)

The Yavansu Fault is a unique E–W trending and south dipping normal fault. It is located to 5 km south of Kuşadası city center. The suggested geosite is easily accessible by public (bus or shuttle) and private transport and can be visited on foot. The fault juxtaposes Quaternary sediments in the hanging wall against marbles of the Cycladic Massif in the footwall (Fig. 4c).

The first denomination of the fault was done by Hancock and Barka (1987) who also described the kinematic architectural elements of the fault. According to the authors, the fault length is elongated roughly 25 km on the mainland Turkey to the east and extends 20 km under the Aegean Sea towards the

Table 1 The proposed Geosite Framework List of Turkey (summarized from Kazancı et al. 2015)

Code	Group/subgroup name			Some examples
Group A	Stratigraphic	A1	Quaternary	Marine coastal deposits; Pleistocene caliches and calcretes
		A2	Phanerozoic	Neogene and Paleogene basins, and their secessions; reference stratigraphic sections of Neogene and Paleogene stages; sedimentary and biological characteristics of time-boundaries; Mesozoic and Paleozoic succession and their basins related sedimentary sequence
		A3	Proterozoic	Precambrian rocks
Group B	Paleoenvironmental			Trace fossils, fossiliferous sedimentary beds; Footprints on volcanites; Bouma turbidite sequences, and other sedimentary and volcanic facies assemblages
Group C	Volcanic, metamorphic and sedimentary petrology, textures and structures, events and provinces			Any kind of volcanisms and metamorphisms and related facies and textures; metamorphic core complexes; ophiolites and island arcs; nappes and ophiolite complexes
Group D	Mineralogical, economical			Evaporitic mineral beds; valuable stones and gemological minerals
Group E	Structural			Seismically active fault zone and related basins; tectonic creeps, structural features and landforms
Group F	Geomorphological features, erosional and depositional processes, landforms and landscapes			Recent eolian deposits; Evaporite karsts modern lakes; wetlands and geomorphological landforms and related deposits
Group G	Astroblems			
Group H	Continental or oceanic scale geological features, plate relationships			Foreland, Hinterland, Forearc basins; fold thrust belts in Afro-Arabian plate
Group I	Submarine			
Group J	Historical and cultural			Antique marble and ore mines; the sites where the geological terms firstly defined; local and specific building stones

Samos Island. The researchers suggested that the western part of this fault ranging to the Aegean Sea is responsible for many historical and instrumental earthquakes. Şaroğlu et al. (1992) showed this fault as an active one in the 1992-dated Active Fault Map of Turkey. Although Gürer et al. (2001) claims that the Kuşadası fault they described in their study is the Yavansu fault of Hancock and Barka (1987), it is clear from their data that the fault they describe is another fault to the north of Yavansu which crosses along the Kuşadası city center. Duman et al. (2011), in the renewed Active Fault Map of Turkey, considered the Yavansu Fault within the Kuşadası Fault Zone which is 19 km in length and comprises 4 main faults. Sümer et al. (2013) described the Yavansu fault as an approximately 2.5 km long E–W trending and south-facing range front fault. This former study and the study by Hancock and Barka (1987) include most of the kinematic and structural data on the fault.

The Yavansu fault includes many classical elements of the normal fault kinematics and may definitely be considered one of the most beautiful complete examples of normal faulting architecture in the WAEP (Fig. 4d). Several colleges in Turkey that offer minor and major degrees in earth sciences periodically organize field trips to this fault in order teach the elements of structural geology (Fig. 4e). Hence, it is considered an open-air classroom for earth-science education. The scientific and educational value of the Yavansu fault is significant and it may be clearly regarded as a geosite candidate within the Group E (structural group) of the proposed Geosite Framework List for Turkey (cf. Kazancı et al. 2015) that encompasses the seismically active normal and transform faults, structural landforms, and tectonically active basins.

Feeder Dome of the Hisartepe Volcanics (Geosite 2)

Details of the geological studies on the Hisartepe Volcanics have been given in the chapter on the geological setting of this text. This geosite candidate is easily accessible by private transport and can be visited on foot. These volcanic rocks are generally formed in the dome facies and present significant peaks in the modern morphology (Fig. 5a).

Besides being the only example of Miocene volcanism in the BMG and the surroundings, the economically exploitable nature of the Hisartepe Volcanics allows us to access the remnants of the mining operations and gives us the opportunity to observe very good outcrops for geological observations. The second geosite suggested in this study stands exactly in such an area, in an old open-pit mining site that was abandoned in the 1980s both due to the legal changes and its close proximity

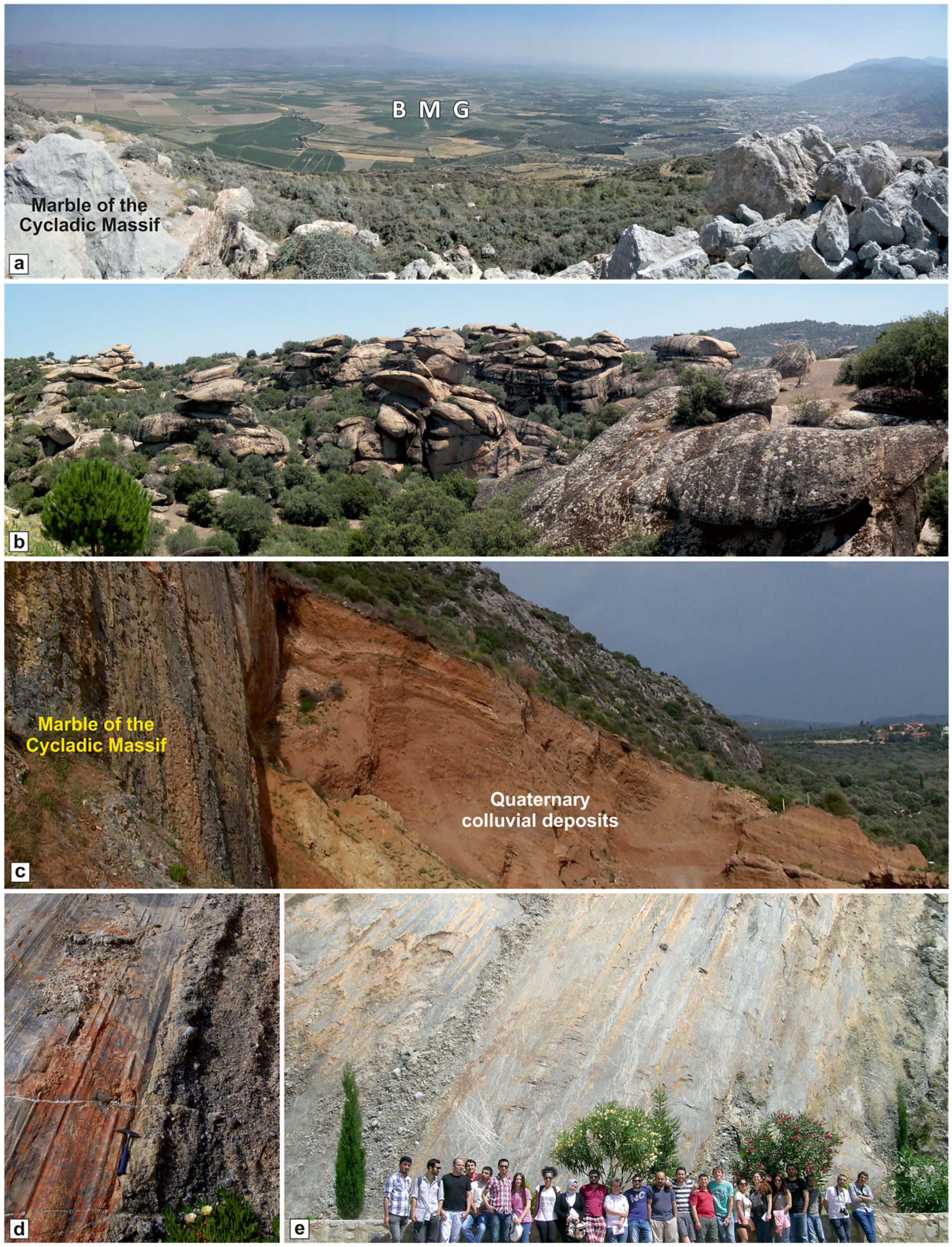

Fig. 4 (a) Panoramic view of the Büyük Menderes Graben from the top of the Oyukdağ Mountain. (b) View from tafoni on augen-gneiss of the Menderes Massif. (c) The Yavansu Fault juxtaposes Quaternary colluvial sediments and marbles of the Cycladic Massif. (d) Some of the structural elements and kinematic indicators of the polished high-angle fault surface, e.g., slickenlines, spall marks, extensional cracks, and compact fault breccia. (e) Photo taken during the geological field trip with undergraduate students in front of the Yavansu Fault

to the borders of Dilek Peninsula Büyük Menderes Delta National Park. The site is currently available for public visit. The location is characterized by an outcrop exhumed by an open-cut of 250 width and 150 m height (Fig. 5b). The internal structure and emplacement mechanism of the feeder dome can clearly be observed in this location. The hexagonal cooling joints reaching up to 1.5 m (Fig. 5c) are approximately in horizontal orientation implying the direction of the intrusion during emplacement of the feeder dome. Characteristics of this feeder dome are unique not only for BMG and its surroundings but also the western Anatolia. The educational and scientific importance of this feeder dome and its beautiful hexagonal columnar joints encourages us to nominate this location as an ideal geosite candidate within the Group C of the proposed Geosite Framework List for Turkey (cf. Kazancı et al. 2015).

Karina Marine Fan-Delta Complex (Geosite 3)

The Quaternary basin fill of the BMG has been subject of many studies (e.g., Eisma 1978; Takahashi 1997; Hakyemez et al. 1999; Müllenhoff et al. 2004; Süzen and Rojay 2005; Kazancı et al. 2009). The Karina marine fan-delta complex is located at the northern margin of the BMG and comprises the westernmost deposit assemblage juxtaposed to the Aegean

Fig. 5 (a) Remarkable morphologic pinnacle hill belonging to the Hisartepe Volcanic feeder "dome". (b) Panoramic view of the Geosite 2 inside of the feeder dome. (c) Prismatic cooling joints. (d) Road-cut section of the fan-deltaic sediment. (e) Distribution of the Karina fan-delta complex represents the subaerial fan-delta top and subaqueous fan-delta front environments. Yellow squares on photographs b and e match position of photographs c and d, respectively

Sea. The geosite suggested is easily accessible by private transport and can be visited on foot.

Currently, the most extensive study on these deposits is given in Sümer et al. (2013). In this study, the authors present mostly the sedimentary facies of the fan-delta and the geomorphological data on the drainage basins belonging to the Cycladic Massif. The sediment association in this location is located in a fan complex with 3 apex. The length of the complex is approximately 1.5 km and its width is around 350 m. Its expansion area on the land is approximately 0.5 km^2. The sediment thickness in the land area locally reaches up to 20 m (Fig. 5d). Karina fan-delta complex represents the subaerial fan–delta/fan–delta top environments, while the Karina Lagoon and the sand bars represent the subaqueous fan–delta/fan–delta front environments (Fig. 5e). The southernmost part of the fan-delta on the other hand interfingers with the Büyük Menderes river delta.

The Karina marina fan-delta complex comprises the only clearly observable modern fan-delta deposits in the western Anatolia. Moreover, it is a great chance that the expansion area of these deposits is located within the Dilek Peninsula Büyük Menderes Delta National Park (Figs. 1 and 2) which means that they are under legal protection (both directly and indirectly by laws no. 6831, 3194, 3621, 5177, 2872, 2873, 2634, and 2863; Kazancı et al. 2012, the full text of the laws are available from the Turkish Legislation Information System

Table 2 Summary of the geosite candidates presented in this study

Potential geosites introduced in this study		Coordinates (long/lat)		Framework category (cf. Kazancı et al. 2015)
1	Yavansu Fault unique fault surface	37° 49′ 32″ N	27° 16′ 00″ E	Group E (structural group)
2	Hisartepe Volcanics feeder dome and columnar jointed lava flows	37° 42′ 55″ N	27° 15′ 46″ E	Group C (volcanic, metamorphic, and sedimentary petrology, textures and structures, events and province group)
3	Karina marine fan-delta complex	37° 37′ 57″ N	27° 7′ 45″ E	Group A (Stratigraphic group, A1-Quaternary subgroup)

website; https://www.mevzuat.gov.tr/Default.aspx). Sampling for scientific studies can be done by special permission from the General Directorate of Protection of Natural Assets (Tabiat Varlıklarını Koruma Genel Müdürlüğü). The modern deltas are usually covered by clastic deposits and present insufficient section thicknesses offering little allowance for geological/sedimentological inspections. However, the uplift of these deposits with the Priene-Sazlı Fault (PSF; Fig. 1) makes it possible for direct observations on the units. In the aspect of science and education, the location is considered unique and especially important in evaluation and teaching of Quaternary geological events. Hence, the Karina marine fan-delta complex seems suitable as a geosite candidate within the Group A (Stratigraphic group, A1-Quaternary subgroup) of the proposed Geosite Framework List for Turkey (cf. Kazancı et al. 2015).

Concluding Remarks

A geosite is a scientific documentation of the area it is located and/or processes of formation it is related. They are composed of natural occurrences such as rocks, fossils, minerals, or sedimentary-structural-volcanic/magmatic features. In theory, a geosite is expected to reveal an event/process or occurrence during the evolution of the Earth (cf. Wimbledon 1996; ProGEO Group 1998; Kazancı et al. 2015). Geosites are usually proposed by people from the relevant field. In this study, we have introduced and determined three more geosite candidates in addition to the already listed inventory geosites on the provisional Geological Heritage Inventory of Turkey (cf. JEMIRKO 2002), also correlating them with the categories in this proposed FL for Turkey. The introduced candidates' contents, geographical coordinates, and related FL category are re-summarized in Table 2. We think that all of these three locations are very good examples for some of the basic subjects/concepts in geology (structural geology, volcanology and sedimentology) and have high scientific and educational value for the earth science. Current provisional inventory by JEMİRKO includes geosites from framework Groups D, E, and F. The currently suggested geosites encompassing Groups A (A1), C, and E will enrich the geological heritage value of the region. Furthermore, being in a complementary location and combining several of physical and social science assets, these remarkable locations and geological features are already visited by several academics and enthusiastic students from various universities and branches of science all around Turkey and the world. Simulated by the 1-day field trip during this study, geographically juxtaposed locations of all of these three geosites also makes this region very suitable for short educational field trips. Application for these mentioned new potential geosites for their acceptance in the JEMİRKO provisional inventory will also be formally completed in the upcoming days via the registration process described above.

Acknowledgments The authors thank to the editor-in-chief and co-editors for their editorial handling of the paper and also thank to the anonymous reviewers for their constructive criticism. The authors also grateful to Dr. Uğur İNCİ and Dr. Şükrü TÜL for their previous detailed and inspiring studies on the area and the subject.

References

Akgün F, Akyol E (1999) Palynostratigraphy of the coal bearing Neogene deposits in Büyük Menderes Graben, western Anatolia. Geobios 32: 367–383

Akyol İH, Pamir HN (1929) Tepeköy-Torbalı-İzmir Zelzelesi. Darülfünun Jeoloji Enstitüsü neşriyatıdan 1:1–72

Alkanoğlu E (1984) Menderes masifindeki tafoniler. Yeryuvarı ve İnsan 8(4):11–13

Arabu N (1923) L'Asie Mineure occidentale d'après les travaux de A. Philippson. Ann Geogr 32(176):126–141

Arpat E, Bingöl E (1969) The rift system of western Turkey; thoughts on its development. Bull Min Res Exp 73:1–9

Bates RL, Jackson JA (1987) Glossary of geology. American Geological Institute, Alexandria, Virginia

Becker-Platen JD (1970) Lithostratigraphische Unterschungen im Kanozoikum Südwest Anatoliens (Türkei) – Känozoikum und Braunkohlen der Turkei. 2 Beihefte zum Geologischen Jahrbuch 97:1–244

Becker-Platen JD, Löhnert E (1972) Über Cardium-Funde aus dem Känozoikum der Umgebung von Söke (west Türkei). Beihefte zum Geologischen Jahrbuch B2:55–63

Bozcu M (2010) Geology of Neogene basins of Buldan-Sarıcaova region and their importance in Western Anatolia neotectonics. Int J Earth Sci 99:851–861

Bozkurt E (2000) Timing of extension on the Büyük Menderes Graben, western Turkey, and its tectonic implications. In: Bozkurt E, Winchester JA, Piper JDA (eds) Tectonics and magmatism in

Turkey and the surrounding area, Geological society, London, special publications, vol 173, pp 385–403

Bozkurt E (2004) Granitoid rocks of the southern Menderes Massif (southwestern Turkey): field evidence for tertiary magmatism in an extensional shear zone. Int J Earth Sci (Geol Rundsch) 93:52–71

Bozkurt E, Park RG (1997) Evolution of a mid-tertiary extensional shear zone in the southern Menderes Massif, western Turkey. Bull Soc Géol France 168:3–14

Bozkurt E, Satır M (2000) The southern Menderes Massif (western Turkey): geochronology and exhumation history. Geol J 35:285–296

Bozkurt E, Sözbilir H (2004) Tectonic evolution of the Gediz Graben: field evidence for an episodic, two-stage extension in western Turkey. Geol Mag 141:63–79

Bozkurt E, Park RG, Winchester JA (1993) Evidence against the core/cover interpretation of the southern sector of the Menderes Massif, west Turkey. Terra Nova 5:445–451

Brilha J, Andrade C, Azerêdo A, Barriga FJAS, Cachão M, Couto H, Cunha PP, Crispim JA, Dantas P, Duarte LV, Freitas MC, Granja MH, Henriques MH, Henriques P, Lopes L, Madeira J, Matos JMX, Noronha F, Pais J, Piçarra J, Ramalho MM, Relvas JMRS, Ribeiro A, Santos A, Santos V, Terrinha P (2005) Definition of the Portuguese frameworks with international relevance as an input for the European geological heritage characterisation. Episodes 28:177–186

Brunn JH, de Graciansky PC, Gutnic M, Juteau T, Lefevre R, Marcoux J, Poisson A (1970) Structures majeures et corrélations stratigraphiques dans les Taurides occidentales. Bull Soc Géol France 7:515–556

Çağlayan AM, Öztürk EM, Öztürk Z, Sav H, Akat U (1980) Some new data southern Menderes massif and structural interpretation. J Geol Eng 10:9–17

Çakmakoğlu A (2007) Dilek Yarımadası, Söke ve Selçuk çevresinin Neojen öncesi tektonostratigrafisi. MTA Dergisi 135:1–17

Candan O, Dora OÖ, Kun N, Akal C, Koralay E (1992) Allochthonous metamorphic units at the southern part of Aydın Mountains, Menderes Massif. TAPG Bulletin 4:93–110

Candan O, Dora OÖ, Oberhänsli R, Oelsner F, Durr S (1997) Blueschist relics in the Mesozoic cover series of the Menderes Massif and correlations with Samos Island, Cyclades. Schweiz Mineral Petrogr Mitt 77:95–99

Candan O, Koralay OE, Akal C, Kaya O, Oberhänsli R, Dora OÖ, Konak N, Chen F (2011a) Supra-pan-African unconformity between core and cover series of the Menderes Massif/Turkey and its geological implications. Precambrian Res 184:1–23

Candan O, Oberhänsli R, Dora OÖ, Koralay OE, Çetinkaplan M, Rimmelé G, Fukun C, Akal C (2011b) Menderes Masifi'nin Pan-Afrikan Temel ve Paleozoyik–Erken Tersiyer Örtü Serilerinin Polimetamorfik Evrimi. MTA Dergisi 142:123–165

Çetinkaplan M (2002) Tertiary high pressure / low temperature metamorphism in the Mesozoic cover series of the Menderes Massif and correlation with the Cycladic Crystalline Complex. Dissertation, Dokuz Eylül University

Çifçi G, Pamukçu O, Çoruh C, Çopur S, Sözbilir H (2011) Shallow and deep structure of a supradetachment basin based on geological, conventional deep seismic reflection sections and gravity data in the Buyuk Menderes Graben, western Anatolia. Surv Geophys 32: 271–290

Çiftçi NB, Bozkurt E (2010) Structural evolution of the Gediz Graben, SW Turkey: temporal and spatial variation of the graben basin. Basin Res 22:846–873

Cohen HA, Dart JC, Akyüz HS, Barka A (1995) Syn-rift sedimentation and structural development of the Gediz and Buyuk Menderes graben, western Turkey. J Geol Soc 152:629–638

Collins AS, Robertson AH (1997) Lycian melange, southwestern Turkey: an emplaced Late Cretaceous accretionary complex. Geology 25: 255–258

Coney PJ (1980) Cordilleran metamorphic core complexes: an overview. In: Crittenden MD, Coney PJ, Davis GH (eds) Cordilleran metamorphic Core complexes, Geological Society of America Memoir, vol 153, pp 7–31

Davis GH (1980) Structural characteristics of metamorphic core complexes, southern Arizona. In: Crittenden MD, Coney PJ, Davis GH (eds) Cordilleran metamorphic Core complexes, Geological Society of America memoir, vol 153, pp 35–78

de Graciansky PC (1972) Recherches géologiques dans le Taurus Lycien occidental. Université Paris Sud, Dissertation

de Lima FF, Brilha JB, Salamuni E (2010) Inventorying geological heritage in large territories: a methodological proposal applied to Brazil. Geoheritage 2:91–99

Dora OÖ (1976) Die Feldspäte als petrogenetischer Indikator im Menderes Massiv/West Anatolien. Neu Jahrb Min Abh 127:289–310

Duman TY, Emre Ö, Özalp S, Elmacı H (2011) 1:250 000 scale active fault map series of Turkey Aydın (NJ35–11) quadrangle, 7. General Directorate of Mineral Research and Exploration (MTA), Ankara

Dumont JF, Uysal Ş, Şimşek Ş, Karamanderesi İH, Letouzey J (1980) Formation of the grabens in southwestern Anatolia. Bull Min Res Exp 92:7–18

Eisma D (1978) Stream deposition and erosion by the eastern shore of the Aegean. In: Brice WC (ed) The environmental history of the Near and Middle East since the last ice age. Academic Press, London, pp 67–79

Emre T, Sözbilir H (1997) Field evidence for metamorphic core complex, detachment faulting and accommodation faults in the Gediz and Büyük Menderes grabens, western Anatolia. IESCA-1995 Proceedings 1:73–93

Ercan T, Akat U, Günay E, Savaşçın Y (1986) Söke–Selçuk–Kuşadası dolaylarının jeolojisi ve volkanik kayaçların petrokimyasal özellikleri. MTA Dergisi 105:15–38

Erdoğan B, Güngör T (2004) The problem of the core-cover boundary of the Menderes Massif and an emplacement mechanism for regionally extensive gneissic granites, western Anatolia (Turkey). Turk J Earth Sci 13:15–36

Evirgen MM (1979) Metamorphism in northern part of Menderes Massiff, Turkey (Ödemiş-Bayındır-Turgutlu region) and some rare mineral paragenesis. Bull Geol Soc Turk 22:109–116

Gessner K, Ring U, Lackmann W, Passchier CW, Gungör T (1998) Structure and crystal thickening of the Menderes massif, Southwest Turkey, and consequences for large-scale correlations between Greece and Turkey. Bull Geol Soc Greece 32:145–152

Gessner K, Piazolo S, Güngör T, Ring U, Kröner A, Passchier CW (2001a) Tectonic significance of deformation patterns in granitoid rocks of the Menderes nappes, Anatolide belt, Southwest Turkey. Int J Earth Sci 89:766–780

Gessner K, Ring U, Johnson C, Hetzel R, Passchier CW, Güngör T (2001b) An active bivergent rolling-hinge detachment system: Central Menderes metamorphic core complex in western Turkey. Geology 29:611–614

Gessner K, Collins AS, Ring U, Güngör T (2004) Structural and thermal history of poly-orogenic basement: U–Pb geochronology of granitoid rocks in the southern Menderes Massif, Western Turkey. J Geol Soc 161:93–101

Gessner K, Ring U, Güngör T (2011) Field guide to Samos and the Menderes Massif: along-strike variations in the Mediterranean Tethyan Orogen. Geological Society of America Field Guide 23: 1–52

Gül M, Uslular G (2017) Çine (Aydın)-Yatağan (Muğla) Arası Menderes Masifi'nde Gözlenen Jeomorfolojik Yapılar. Mavi Gezegen 22:38–47

Güngör T, Erdoğan B (2001) Emplacement age and direction of the Lycian nappes in the Söke-Selçuk region, western Turkey. Int J Earth Sci 89:874–882

Gürer FÖ, Bozcu M, Yılmaz K, Yılmaz Y (2001) Neogene basin development around Söke-Kuşadası (western Anatolia) and its bearing on tectonic development of the Aegean region. Geodin Acta 14:57–69

Gürer FÖ, Sarıca-Filoreau N, Özburan M, Sangu E, Doğan B (2009) Progressive development of the Büyük Menderes Graben based on new data, western Turkey. Geol Mag 146:652–673

Gutnic M (1979) Géologie des taurides occidentales (Turquie). Mémoires de la Société Géologique de France 137:1–112

Hakyemez YH, Erkal T, Göktaş F (1999) Late Quaternary evolution of the Gediz and Büyük Menderes grabens, Western Anatolia, Turkey. Quat Sci Rev 18:549–554

Hamilton WJ, Strıckland HE (1841) On the geology of the Western part of Asia Minor. Transactions of the Geological Society of London 6: 1–39

Hancock PL, Barka A (1987) Kinematic indicators on active normal faults in western Turkey. J Struct Geol 9:573–584

Hatipoğlu M (2010) Gem-quality diaspore crystals as an important element of the geoheritage of Turkey. Geoheritage 2:1–13

Hetzel R, Passchier CW, Ring U, Dora ÖO (1995) Bivergent extension in orogenic belts: the Menderes massif (southwestern Turkey). Geology 23:455–458

Hetzel R, Romer RL, Candan O, Passchier CW (1998) Geology of the Bozdag area, central Menderes massif, SW Turkey: Pan-African basement and Alpine deformation. Geol Rundsch 87:394–406

İzdar E (1971) Introduction to geology and metamorphism of the Menderes massif of western Turkey. The Petroleum Exploration Society of Libya 1:495–500

JEMİRKO (2002) Türkiye Jeolojik Miras Ögeleri Envanteri. JEMİRKO, Ankara

JEMİRKO Jeolojik Mirası Koruma Derneği (The Turkish Association for the Conservation of the Geological Heritage) http://www.jemirko.org.tr/turkiye-jeolojik-miras-envanteri/. Accessed 07.12.2018

Kazancı N, Dündar S, Alçiçek MC, Gürbüz A (2009) Quaternary deposits of the Büyük Menderes Graben in western Anatolia, Turkey: implications for river capture and the longest Holocene estuary in the Aegean Sea. Mar Geol 264:165–176

Kazancı N, Şaroğlu F, Doğan A, Mülazımoğlu NS (2012) Turkey. In: Wimbledon WAP, Smith-Meyer S (eds) Geoheritage in Europe and its conservation. ProGEO, Oslo, pp 366–377

Kazancı N, Şaroğlu F, Suludere Y (2015) Geological heritage and framework list of the geosites in Turkey. Bull Min Res Exp 151:259–268

King GCP, Bailey GN (2010) Dynamic landscapes and human evolution. In: Sintubin M, Stewart IS, Niemi TM, Altunel E (eds) Ancient Earthquakes. Geological Society of America Special Papers 471, Boulder, pp 1–19

King G, Bailey G, Sturdy D (1994) Active tectonics and human survival strategies. J Geophys Res 99:20063–20078

Koçyiğit A (2015) An overview on the main stratigraphic and structural features of a geothermal area: the case of Nazilli-Buharkent section of the Büyük Menderes Graben, SW Turkey. Geodin Acta 27:85–109

Koçyiğit A, Yusufoğlu H, Bozkurt E (1999) Evidence from the Gediz Graben for episodic two-stage extension in western Turkey. J Geol Soc 156:605–616

Konak N, Şenel M (2002) Geological map of Turkey in 1:500 000 scale: Denizli sheet. Mineral Research and Exploration Directorate of Turkey, Ankara

Koralay OE, Candan O, Chen F, Akal C, Oberhänsli R, Satır M, Dora OÖ (2012) Pan-African magmatism in the Menderes Massif: geochronological data from leucocratic tourmaline orthogneisses in western Turkey. Int J Earth Sci 101:2055–2081

Lips AL, Cassard D, Sözbilir H, Yılmaz H, Wijbrans JR (2001) Multistage exhumation of the Menderes massif, western Anatolia (Turkey). Int J Earth Sci 89:781–792

Loos S, Reischmann T (1999) The evolution of the southern Menderes Massif in SW Turkey as revealed by zircon dating. J Geol Soc 156: 1021–1030

Müllenhoff M, Handl M, Knipping M, Brückner H (2004) The evolution of Lake Bafa (Western Turkey): sedimentological, microfaunal and palynological results. Coastline Reports 1:55–66

Nebert K (1955) Söke-Kuşadası linyit havzası. General Directorate of Mineral Research and Exploration (MTA) report no 3021, Ankara

Oberhänsli R, Monie P, Candan O (1998) The age of blueschist metamorphism in the Mesozoic cover series of the Menderes Massif. Schweiz Mineral Petrogr Mitt 78:309–316

Oberhänsli R, Candan O, Wilke F (2010) Geochronological evidence of Pan-African eclogites from the Central Menderes Massif, Turkey. Turk J Earth Sci 19:431–447

Okay A (2001) Stratigraphic and metamorphic inversions in the central Menderes Masif: a new structural modal. Int J Earth Sci 89:709–727

Oyman T (2006) Batı Anadolu'da Metamorfikler içindeki Granit ve Pegmatitlere ait Turmalinlerin Kristal Kimyası. DEUFMD 8(2): 47–65

Özer S, Güngör T, Sarı B, Sagular EK, Görmüş M, Özkar-Öngen İ (2017) Cretaceous rudist-bearing platform carbonates from the Lycian Nappes (SW Turkey): Rudist associations and depositional setting. Cretac Res 79:122–145

Paréjas E (1939) Le flysch cretace des environs de Smyrne. Publ Inst Geol Univ İstanbul 4:194–199

Paréjas E (1940) La tectonique transversale de la Turquie. Rev Fac Sc Univ d'İstanbul B5:133–244

Philippson A (1911) Reisen und Forschungen im Ewestlichen Kleinasien. Petermanns Mitt Ergazungsheft, Gotha

ProGEO Group (1998) A first attempt at a geosites framework for Europe — an IUGS initiative to support recognition of World heritage and European geodiversity. Geologica Balcanica 28:5–32

Purvis M, Robertson AHF (2005) Sedimentation of the Neogene-Recent Alaşehir (Gediz) continental graben system used to test alternative tectonic models for western (Aegean) Turkey. Sediment Geol 173: 373–408

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. https://doi.org/10.1029/2001TC901041

Rimmelé G, Oberhänsli R, Candan O, Goffé B, Jolivet L (2006) The wide distribution of HP–LT rocks in the Lycian Belt (Western Turkey): implications for accretionary wedge geometry. Geol Soc Lond, Spec Publ 260:447–466

Ring U, Gessner K, Güngör T, Passchier CW (1999) The Menderes Massif of western Turkey and the Cycladic Massif in the Aegean — do they really correlate? J Geol Soc 156:3–6

Ring U, Will T, Glodny J, Kumerics C, Gessner K, Thomson S, Güngör T, Monié P, Okrusch M, Drüppel K (2007) Early exhumation of higpressure rocks in extrusion wedges: cycladic blueschist unit in the eastern Aegean, Greece, and Turkey. Tectonics. 26. https://doi.org/10.1029/2005TC001872

Rojay B, Toprak V, Demirci C, Süzen L (2005) Plioquaternary evolution of the Küçük Menderes graben southwestern Anatolia, Turkey. Geodin Acta 18:317–331

Sarıca N (2000) The Plio-Pleistocene age of Büyük Menderes and Gediz grabens and their tectonic significance on N-S extensional tectonics in West Anatolia: mammalian evidence from the continental deposits. Geol J 35:1–24

Şaroğlu F, Emre Ö, Kuşçu İ (1992) Active fault map of Turkey. 1:2000 000 scale. Maden Tetkik ve Arama Genel Müdürlüğü, Ankara

Satir M, Friedrichsen H (1986) The origin and evolution of the Menderes Massif, W-Turkey: a rubidium/strontium and oxygen isotope study. Geol Rundsch 75:703–714

Schuiling RD (1962) On petrology, age and structure of the Menderes migmatite complex (SW-Turkey). Bull Min Res Exp 58:71–84

Şen S, Seyitoğlu G (2009) Magnetostratigraphy of early–middle Miocene deposits from east–west trending AlaŞehir and Büyük Menderes grabens in western Turkey, and its tectonic implications. In: van Hinsbergen DJJ, Edwards MA, Govers R (eds) Collision and collapse at the Africa–Arabia–Eurasia subduction zone. London, Special Publications, London, Geological Society, pp 321–342

Şengör AMC, Satır 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

Seyitoğlu G, Scott B (1992) The age of the Büyük Menderes graben (western Turkey) and its tectonic implications. Geol Mag 129: 239–242

Sözbilir H (2002) Geometry and origin of folding in the Neogene sediments of the Gediz Graben, western Anatolia, Turkey. Geodin Acta 15:277–288

Sözbilir H, Emre T (1990) Neogene stratigraphy and structure of the northern rim of the Büyük Menderes graben. IESCA-1990 Proceedings 2:314–322

Sümer Ö (2013) Evolution of the Plio-Quaternary Söke–Milet Basin. Dokuz Eylül University, Dissertation

Sümer Ö (2015) Evidence for the reactivation of a pre-existing zone of weakness and its contributions to the evolution of the Küçük Menderes Graben: a study on the Ephesus Fault, Western Anatolia, Turkey. Geodin Acta 27:130–154

Sümer Ö, İnci U, Sözbilir H (2012) Tectono-sedimentary evolution of an Early Pleistocene shallow marine fan-deltaic succession at the western coast of Turkey. Geodin Acta 25:112–131

Sümer Ö, İnci U, Sözbilir H (2013) Tectonic evolution of the Söke Basin: extension-dominated transtensional basin formation in western part of the Büyük Menderes Graben, Western Anatolia, Turkey. J Geodyn 65:148–175

Süzen ML, Rojay B (2005) Active shoreline changes of Büyük Menderes River Delta in last 50 years. In: Özhan E (ed) Proceedings of the seventh international conference on the Mediterranean coastal environment MEDCOAST 05, 25–29 October 2005. Kuşadası, Turkey, pp 1309–1316

Takahashi M (1997) Geo-environmental analysis in the recent alluvial plains of the large Menderes and the small Menderes. Japon Rev 8:209–219

Taymaz T, Jackson J, McKenzie D (1991) Active tectonics of the north and central Aegean Sea. Geophysic J Int 106:433–490

Tchihatcheff P De (1867) Asie Mineure, Description Physique de cette contree. Quatrieme partie: Geologie I, Paris

Theodossiou-Drandaki I, Nakov R, Wimbledon WAP, Serjani A, Neziraj A, Hallaci H, Sijaric G, Begovic P, Sv P, Pl T, Todorov T, Zagorchev I, Antonov D, Sinnyovski D, Diakantoni A, Fassoulas C, Fermeli G, Galanakis D, Koutseveli A, Livaditi A, Papadopoulou K, Paschos P, Rassiou A, Skarpelis N, Zouros N, Grigorescu D, Andrasanu A, Hlad B, Herlec U, Kazancı N, Şaroğlu F, Doğan A, İnaner H, Dimitrijevic M, Gavrilovic D, Krstic B, Mijovic D (2004) IUGS Geosites project progress — a first attempt at a common framework list for south eastern European countries. In: Parkes MA (ed) Natural and cultural landscapes. The Geological Foundation, Royal Irish Academy, Dublin, Ireland, pp 81–89

Tül Ş, Sümer Ö, Ersoy Y (2009) Mythological expression and cultural approaches under geological and geomorphological aspects. In: Helvacı C, Tecim V, Aydın C (eds) IGCP 521 INQUA 0501 field trip guide book. DEÜ, İzmir, pp 37–42

Tuncer A, Tunoğlu C (2014) Ostracoda assemblage of the Middle-Late Miocene Kuşadası Formation, Söke Basin, Western Anatolia, Turkey. In: Beqiraj A, Ionescu C, Christofides G, Uta A, Beqiraj Goga E, Marku S (eds) Proceedings of the 20th Congress of the Carpathian-Balkan Geological Association, Buletini I Shkencave Gjeologjike Special Issue 2, September 24-26, Tirana, Albania, p 94

Tuncer A, Tunoğlu C (2015) Ostracoda fauna and paleoenvironmental characteristics of the late Early-Middle Miocene Söke Formation, Söke Basin, Aydın/Western Anatolia. Bulletin of the Earth Sciences Application and Research Centre of Hacettepe University 36:97–120

Ünay E, Göktaş F (1999) Late Early Miocene and Quaternary small mammals in the surroundings of Söke (Aydın): preliminary results. Geological Bulletin of Turkey 42:99–113

Ünay E, Göktaş F, Hakyemez HY, Avşar M, Şan Ö (1995) Dating of the sediments exposed at the northern part of the Büyük Menderes Graben (Turkey) on the basis of Arvicolidae (Rodentia, Mammalia). Geological Bulletin of Turkey 38:75–80

Üşümezsoy Ş (1988) Evolution of the NW Anatolian Pb-Zn deposits: litospheric detachment in compressional and extensional regime in NW Anatolian accretionary belt and magmatism and metallogenesis. Geosound 177:1–34

Uzel B, Sümer Ö, Özkaptan M, Özkaymak Ç, Kuiper K, Sözbilir H, Kaymakcı N, İnci U, Langereis CG (2017) Palaeomagnetic and geochronological evidence for a major middle Miocene unconformity in Söke Basin (western Anatolia) and its tectonic implications for the Aegean region. J Geol Soc 174:721–740. https://doi.org/10.1144/jgs2016-006

Weismantel O (1891) Die Erdbeben des vorderen Kleinasiens in geschichtlicher Zeit. Dissertation, Unirersitiät Matburg

Wimbledon WAP (1996) National site election, a stop on the road to a European Geosite list. Geologica Balcanica 26:15–27

Yılmaz Y, Genç ŞC, Gürer F, Bozcu M, Yılmaz K, Karacık Z, Altunkaynak Ş, Elmas A (2000) When did the western Anatolian grabens begin to develop? In: Bozkurt E, Winchester V, Piper JDA (eds) Tectonics and Magmatismin Turkey and the surrounding area, Geological society, London, special publications, vol 173, pp 353–384

Zeschke G (1954) Der Simav-Graben und seine Gesteine. Geological Bulletin of Turkey 1:179–189