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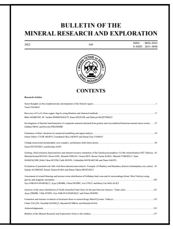

Some thoughts on the morphotectonic development of the Denizli region

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Research Article

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ABSTRACT

The Denizli region is located to the east of the Buldan Horst. Although they follow the same trends as the Büyük Menderes and Gediz Grabens, the Denizli region has undergone semi-independent evolution during the Quaternary. The essential morphotectonic elements of the area are the Denizli Basin and the surrounding Babadağ and the Güzelpınar Horsts. The Babadağ Horst is the most distinct morphotectonic element of the region. It is bounded in the north by the Denizli fault, a listric normal fault, and possibly a major detachment fault. The Laodicea and Güzelpınar Horsts located within the downthrown block of the fault may be regarded as antithetic structures.

1. Introduction

A recent research project on the ancient rock quarries of western Anatolia has allowed a closer look at the major structures and morphotectonic features of the Denizli region. This paper is based on the data derived from the study. We hope that the views presented initiate future research to test the model proposed.

Essential morphotectonic elements of the Denizli region are the Denizli basin and the surrounding Babadağ (2308 m) Horst and the Güzelpınar (Çökelez Mt 1840 m) Horst (Figure 1a). The region is delimited in the west by the Buldan Horst representing the eastern end of the Bozdağ Mountains (the Bozdağ Horst), which define a plunging anticline (Figures 1a and 1b). The surrounding two large and actively enlarging grabens of western Anatolia, the Büyük Menderes graben and the Gediz graben (Erinç, 1954; McKenzie, 1978; Şengör, 1979; Şengör and Yılmaz 1981; Yılmaz et al., 2000) converge to the east (Figure 1a) (for detailed descriptions of the grabens, a reader is referred to Şengör, 1979; Şengör and Yılmaz, 1981; Seyitoğlu and Scott, 1991, 1996; Yılmaz et al., 2000; Bozkurt ve Sözbilir, 2004; Seyitoğlu et al., 2004; Yılmaz 2017*a, b*; Sümer et al., 2020). The grabens fragmented the Menderes Massif, which is considered to have been elevated as a core complex along a major detachment-breakaway- fault (Şengör and Yılmaz, 1981; Bozkurt and Park, 1994; Hetzel et al., 1995; Emre and Sözbilir, 1997; Gesner et al., 2001; Lips et al., 2001; Van Hinsbergen, 2010).

Two ridges dissect the eastward continuation of the grabens. These are Kadıköy ridge in the north and Gencelli ridge in the South (KR and GR; Figure 1a). Further east, a 50 km long and 20 km wide Denizli basin (Figures 1b and 2) (Westaway, 1993; Çakır, 1999) lies along with the grabens. There is a thin NW-SE trending horst in the southeastern part of the Denizli basin. The horst is located in the ancient city of Laodicea. Therefore, I call it here the Laodicea Horst (the Karakova horst of Hançer, 2013). The

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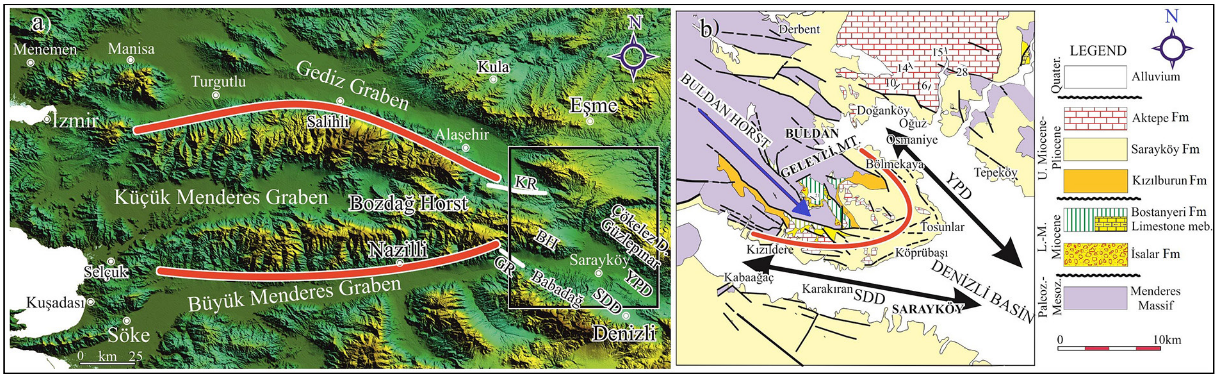

Figure 1- a) Morphotectonic map of the Bozdağ Horst and the surroundings, the central-western Anatolia. The black square shows the location of the map displayed in Figure 1b. Abbreviations for Figures 1a and 1b. GR: The Gencelli Ridge, YPD: The Yenicekent-Pamukkale depression or the Çürüksu graben, SDD; The Sarayköy-Denizli depression, b) simplified geology map of the eastern part of the Bozdağ horst (modified after Bozcu, 2010). Blue arrow; easterly plunging anticline (horst), Black arrows; axes of the graben depressions, red line with black hue; axis of the Neogene fold curving around eastern plunge of the Buldan anticline.

horst divides the Denizli basin into two unequal depressions; the Yenicekent-Pamukkale depression (the Çürüksu graben of Şimşek, 1984) in the north and the Sarayköy-Denizli depression in the south (YDP and SDD; Figures 1a and 2).

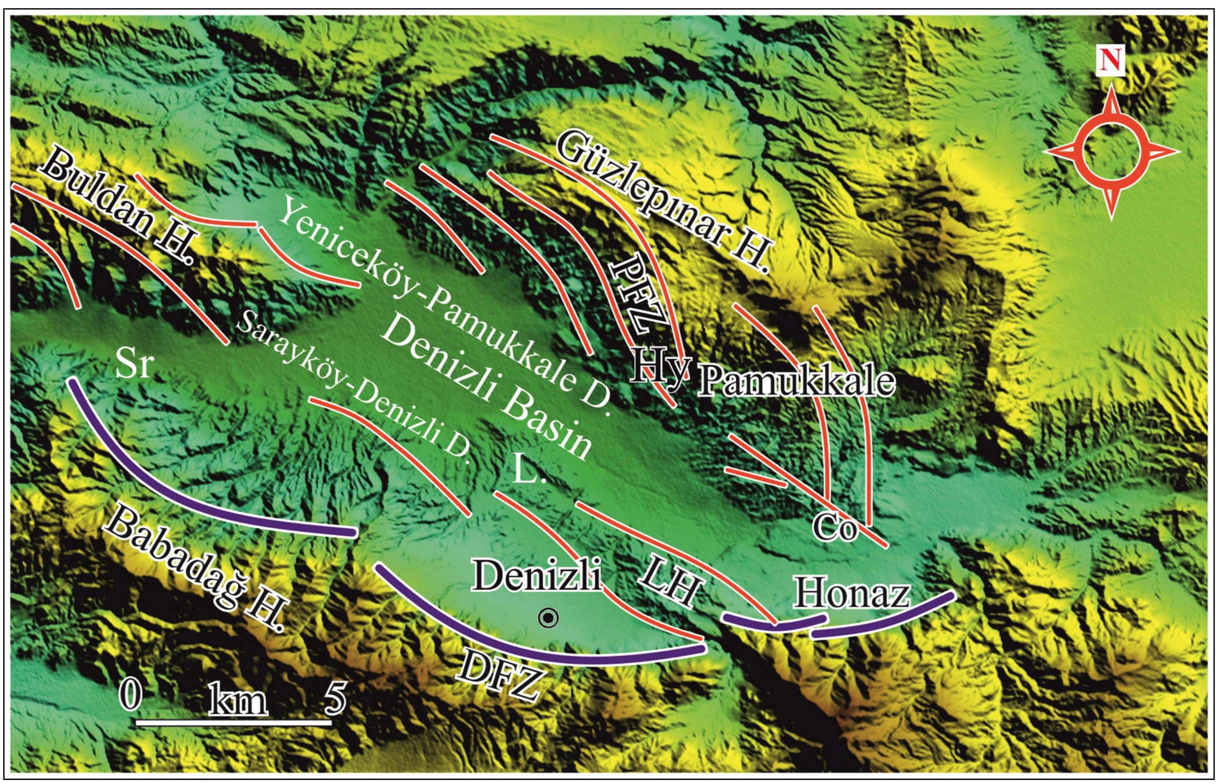

Figure 2- Morphotectonic map of the study area showing the Güzelpınar (Çökelez Mountain), Babadağ (Babadağ Mountain) Horsts, and the Denizli basin. The narrow Laodicea Horst (LH) divides the basin into unequal size depressions; the Yeniceköy-Pamukkale depression (YPD) and the Sarayköy-Denizli depression (SDD). Abbreviations; settlements: Sr: Sarayköy, L: Laodicea antique city, Co: Colossae antique city, Hy: Hierapolis antique city, D: depression, H: horsts, LH: Laodicea Horst, F: faults, DF: the Denizli fault zone, PF: Pamukkale fault zone. The arcuate red lines are gravity faults. Straight red lines extending along boundaries of the grabens and the Laodicea horst are oblique-slip faults with significant strike-slip displacement. Black lines with white hues are listric normal faults, possibly a detachment fault that elevated the metamorphic rocks against the Neogene and Quaternary successions.

2. Stratigraphy

In the Denizli region, four tectonostratigraphic units separated by unconformities may be distinguished (Batı et al., 1998; Yılmaz et al., 2000; Şenel, 1997, 2010; MTA, 2002 (Figures 1b and 3)). These are; 1) basement associations consisting of two rock groups, a) metamorphic rocks (M, ML; Figure 3), and b) overlying weakly metamorphosed Mesozoic limestone succession t2K, J2K; Figure 3). Some limestones belong to the Lycian nappes (Yılmaz, 2017*a*). The metamorphic rocks represent parts of the Menderes Massif that cover large areas in western Anatolia, extending from the Taurus Mountains in the south to the İzmir-Ankara suture zone in the north (Yılmaz, 2017*a, b*). The basement rocks are mostly exposed in the Babadağ and the Buldan areas (Figures 2 and 3). 2) A Lower-Middle Miocene terrestrial coarse to a fine clastic sedimentary sequence. Rock units of the sequence are defined and described in the Buldan area by Bozcu (2010). The sequence begins with thick (< 500 m) red conglomerates (Figure 1b), which transit to fine-grained detrital rocks (Figure 3). 3) Lacustrine marl, claystone, and limestone alternation of the Upper Miocene (Şimşek, 1984; Göktaş, 1990; Taner, 2001; Alçiçek, 2007; Alçiçek et al., 2013, 2019) - Lower Pliocene (Taner, 2001; Alçiçek, 2010; Alçiçek et al., 2019) age range. They overlie the underlying rocks with a distinct angular unconformity in the Buldan area (Figure 1a). The lacustrine sequence represents western Anatolia's most extensive rock group (Yılmaz, 2017*a*) (Figure 3). 4) The Quaternary coarse clastic rocks. They were developed as fanglomerates along horst fronts and fluvial conglomerates deposited in valleys (Hakyemez et al., 1999; Figure 3).

3. Structural Geology

The study area is situated around the eastern plunge of the Bozdağ Dome-Horst (Figure 1b; Bozcu, 2010) (black square; Figure 1a) (for a detailed description of the structural elements of the region, a reader is referred to Hançer, 2013).

The Upper Miocene medium to coarse-grained red clastic sediments wrapping around the plunge of the dome (curvilinear red line in Figure 1b) rest on the approximately N-S trending Early- Middle Miocene graben fill with a distinct angular unconformity (Figure 1b; Bozcu, 2010). The rise of the dome began during the Late Miocene because it supplied clastic materials to the surrounding lateral fans (Bozcu, 2010).

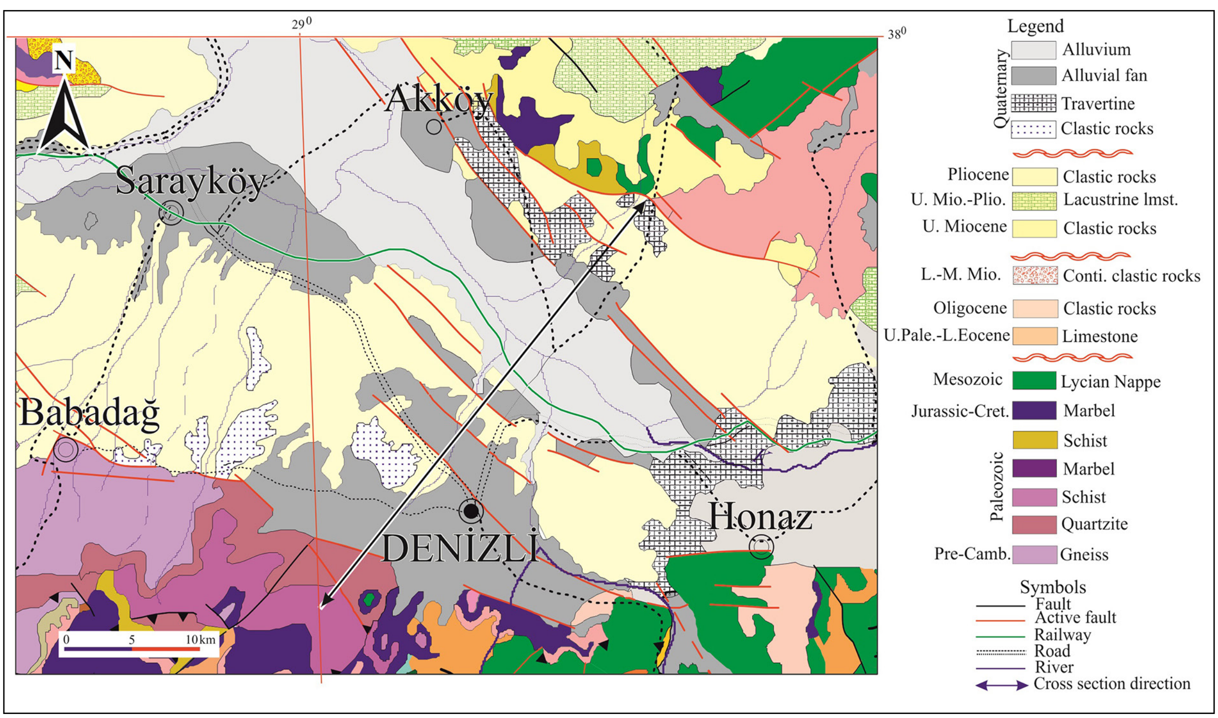

Figure 3- Geology map of the Denizli region (modified after Denizli sheet of the MTA geology map of Türkiye on the scale of 1/500.000).

Two ridges separate the Gediz and Büyük Menderes grabens from the depressions along with their eastward extension (Figure 1a). Hançer (2013) identified the northern ridge. However, the time and mechanism of development of the ridges have long remained unknown. They are morphologically distinct and control the present drainage system (Figures 1a, 4a, 4b, and 4c). The geological and morphological data also reveal that the ridges are bounded by strike-slip faults, which displaced the basement rocks and the overlying Neogene-Quaternary sedimentary sequences, sinistrally in the North (Figures 4a and 4b, and dextrally in the South (Figures 4a and 4c).

Between the two strike-slip fault zones of opposite shear sense, the eastern region of the Bozdağ dome (BH; Figure 4a) appears to have been forced to rotate in the anti-clockwise sense (Figure 4a). The motion is in harmony with the southwesterly advance of the Anatolia Plate (McKenzie, 1978; Şengör and Yılmaz, 1981; McKenzie and Yılmaz, 1991; Mc Clasky et al., 2000; Reilenger et al., 2006, 2010).

The morphotectonic panorama of the Denizli region may be summarized as an NW-SE trending depression, the Denizli basin (graben) surrounded by the Babadağ Horst in the south (Figure 2) and the Güzelpınar Horst in the north (Figures 1a and 2; Hancer, 2019). The present landform of the Denizli region is young (Erinç, 1954), formed during the Quaternary (Yılmaz et al., 2000; Sarıca, 2000; Sümer et al., 2013; Hançer, 2013; Yılmaz, 2017*b*, Alçiçek et al., 2019; Özpolat et al., 2020).

The Babadağ Horst is the major morphotectonic element of the region (Figure 2). The Denizli fault (the Babadağ-Honaz fault of Hançer, 2013) defines its northern boundary (DF; Figure 2). It is a normal fault having many branches, which may be traced

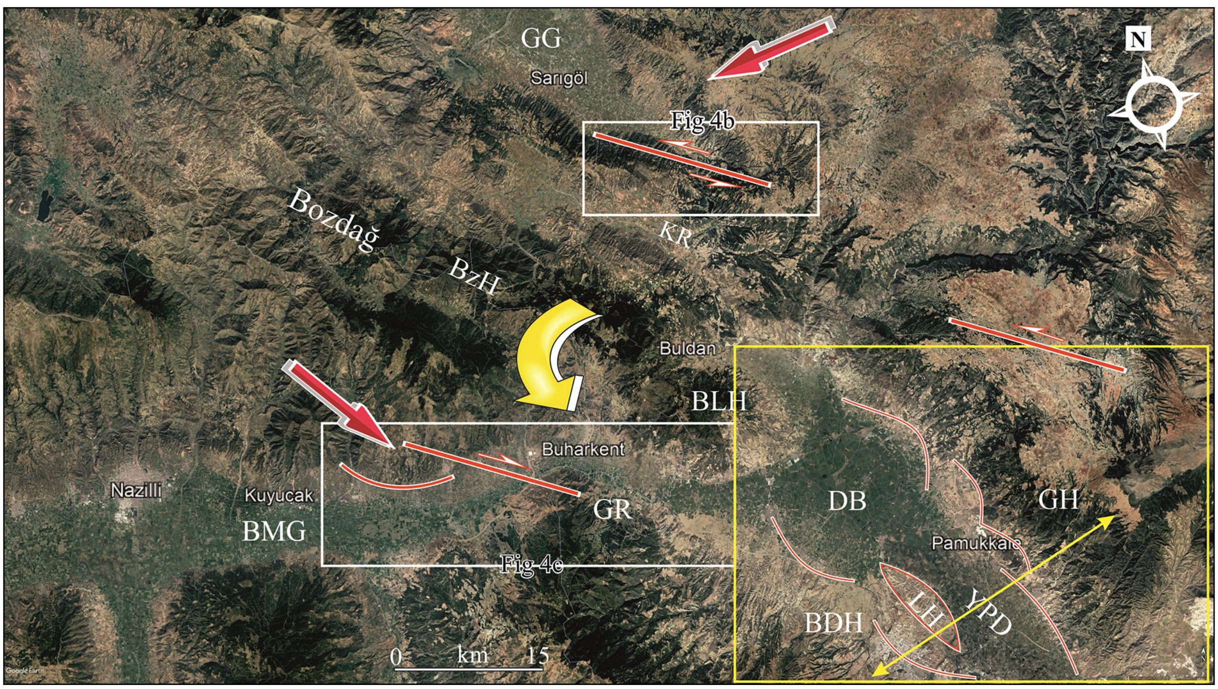

Figure 4- a) Google satellite image showing the Bozdağ Mountains and the surrounding regions. Rectangles show the locations of Figures 4b and 4c. White arrows indicate the motion directions due to the southwesterly advance of the Anatolian Plate. The circler arrow indicates the rotation of the block bounded by the strike-slip faults of opposite shear sense. The strike-slip faults (red lines); are left lateral in the north and right lateral in the south. Abbreviations, GG: Gediz Graben, BMG: Büyük Menderes Graben., BzH; Bozdağ Horst, Blh; Buldan Horst., KR: Kadıköy Ridge, GR: Gencelli Ridge, BDH: Babadağ Horst, GH: Güzelpınar Horst, LH: Laodicea Horst, DB: Denizli Basin, YPD: Yenicekent-Pamukkale Depression, SDD: Sarayköy-Denizli Depression, red line with white hue; major normal fault (detachment fault), b) Google satellite image of area 4b in Figure 4a, showing the strike-slip faults defining the boundary of the Kadıköy ridge (the northern ridge) along which significant imprints of the left-lateral displacements are observed in the morphology, c) the Google satellite image of the Gencelli ridge (the southern ridge; 4c in Figure 4a). The right-lateral offset along the boundary faults is visible in the morphology.

interruptedly more than 50 km from Babadağ in the west to Honaz in the east (Figures 2, 3, and 4a) (the eastern part of the fault was previously described by Bozkuş, 2001 and Özkaymak, 2015).

The fault plane of the Denizli fault is well exposed around Denizli city (Figure 5). It displays a concave map pattern, and the dip angle changes from about 75° to 40° (Figure 2), indicating that it is steeper near the surface and flattens with depth (Figure 5). The flattening manifests its listric normal fault character. The rotational motion of the hanging wall along the concave fault plane causes back tilting, which generated side valleys trending sub-parallel to the central depression (Figure 6).

The Denizli fault is active (Westaway, 1993; Bozkuş et al., 2001; Emre et al., 2018). One of the western branches was reactivated around Denizli city in 1965 (M= 5.7), and in 2008 earthquakes (the Denizli earthquake 4.8) (Atabey et al., 1982; Tan et al., 2008; Hançer, 2013).

The Denizli basin is subdivided into two semi-independent depressions by the Laodicea Horst (LH;

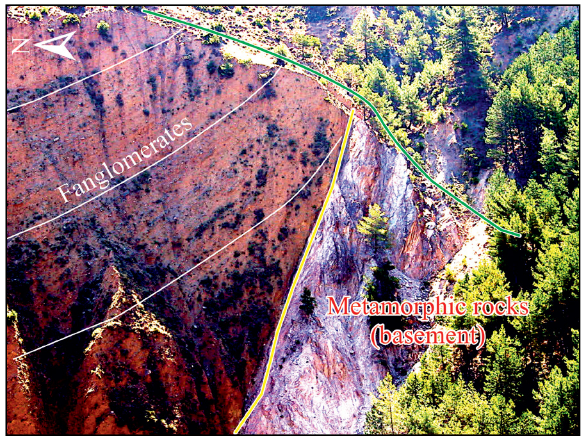

Figure 6- Photo showing the listric normal fault in the south of the Babadağ town, which separates the basement metamorphic rocks from the Neogene continental red beds. Note the stream valley (green line) on the back-tilted slope.

Figures 2, 7, 8, 9, and 10). The sequence elevated above the Laodicea Horst is terrace deposits and fluvial clastic sediments of the Quaternary age (Figure 9). The data reveals that the Laodicea Horst is younger than the Babadağ Horst, which began to rise during the late Miocene (Alçiçek et al., 2013; Hançer, 2019).

Figure 5- A view of Denizli city and the surroundings from the north. The fault plane of the steeply dipping major normal fault along which the Denizli horst was elevated is clearly observed. The flat-lying erosional surface (the broken lines) may be noted above the horst. A deeply carved lateral alluvial fan (defined by the broken green line) indicates that the rise of the horst is continuing.

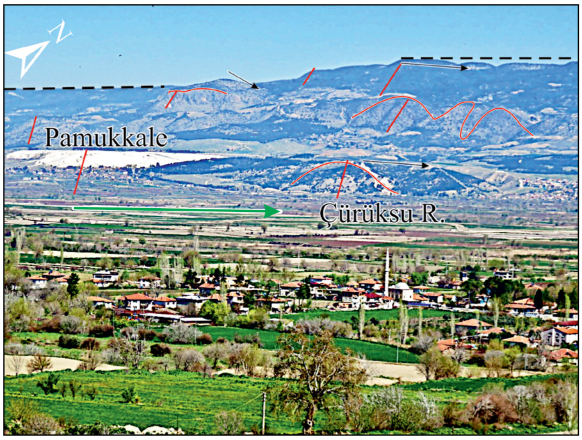

Figure 7- A panoramic view of the southern slope of the Güzelpınar Horst and the Çürüksu river valley (the Yenicekent-Pamukkale depression-graben). Steep slopes-escarpments (thick red lines) correspond to fault planes (thin red lines) of a series of sub-parallel gravity faults formed in response to the rise of the horst. Backward tilting of the downthrown blocks (black arrows) and a progressive increase in the tilting angle toward the valley reveal the listric character of the Pamukkale fault. The green arrow indicates the north-tilted valley floor of the Çürüksu river (Çürüksu R.) toward the Güzelpınar Horst. The white unit on the horst block is the Pamukkale travertine deposit near the Pamukkale town, the ancient city of Hieropolis. The black broken lines are traces of the fragmented erosional surface that remained on the horst blocks. The erosional plains are on the Upper Miocene-Lower Pliocene lacustrine units in the low land along the horizon.

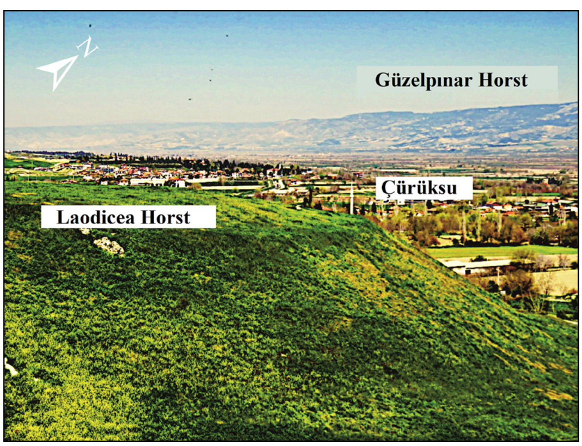

Figure 8- A northerly view from the Laodicea horst to Güzelpınar horsts. On the horizon, the gradual elevation of the flat-lying erosional plains may be noted from low land to the hills.

The Laodicea Horst is bounded by many oblique-slip faults with significant strike-slip coupled with dip-slip components (Figure 2). The discoidal map pattern of the faults (Figure 2) reveals that the horst may also be defined as a tectonic wedge that wedged into the depression (Figure 2).

The rise of the Laodicea Horst caused the northward tilting of the Çürüksu river valley (Figure 7). Consequently, the riverbed migrated toward the Güzelpınar horst (Figures 7 and 8). The historical and instrumentally recorded earthquakes reveal the dynamic character of the faults associated with the Laodicea Horst (Hançer, 2013).

The Güzelpınar Horst surrounding the Denizli graben in the south is also represented by a set of normal faults collectively known as the Pamukkale fault (Figure 7) (Altunel and Hancock, 1993; Altunel and Barka, 1996; Koçyiğit, 2005; Kaymakçı, 2006; Dilsiz, 2006; Van Noten et al., 2013; Hançer, 2013; Emre et al., 2018). Morphotectonic features in and around the fault zone reveal its listric fault character (Figure 7). Among the normal fault branches, oblique-slip displacement with strike-slip and dip-slip offsets are also common (Çakır, 1999; Van Noten et al., 2013).

Hot springs sipping along the faults of the Pamukkale fault zone generated many travertine deposits (Figure 7) (Şimşek, 1984; Altunel and Hancock, 1993; Altunel, 1996, 2000; Dilsiz, 2006; De Filippis et al., 2012; Alçiçek et al., 2013). The antique Roman city of Hierapolis was built on a back-tilted hanging wall of one of these normal faults (Figure 7) (Altunel and Hancock, 1993; Şimşek et al., 2000; Özkul et al., 2013; Alçiçek, 2007; Kele et al., 2011; Kaypak and Gökkaya, 2012; Alçiçek et al., 2013; Van Noten et al., 2013).

Many other travertine deposits associated with the young faults may also be observed in the Denizli region (Özkul et al., 2013; Van Noten et al., 2019; Aratman et al., 2020 and the references therein) (for the various geological features of the travertine deposits, a reader is referred to as Altunel and Hancock (1993), Altunel (2000), Özkul et al. (2013), Kele et al. (2011), Van Noten et al. (2013), Hançer (2013), Toker et al. (2015).

According to historical records, Hierapolis was destroyed several times by earthquakes (Altunel and Hancock, 1993; Altunel and Barka, 1996; Piccardi,

Figure 9- Southerly view from the Laodicea horst to the Babadağ Horst. The terrace deposits at the base of the ancient monument of the antique city of Laodicea and the perfectly planar, flat-lying erosional surfaces on the Laodicea Horst (about 270 m) may also be noted above the Babadağ Mountains (< 2000 m). The graben boundary faults cut and dissect the continuity of the erosional surface during the Quaternary.

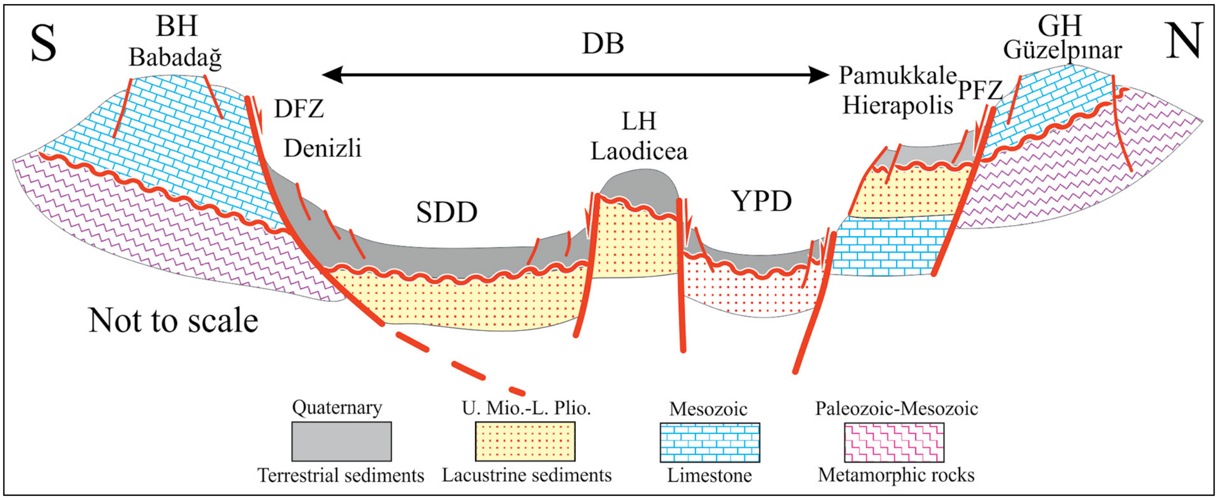

Figure 10- A sketch geological cross-section across the Denizli region showing the Babadağ Horst as a major listric normal fault (detachment fault) and the Laodicea and the Güzelce Horsts as antithetic structures developed on the downthrown block. The horizontal distance across the Denizli basin (DB) is about 7 km. Abbreviations. BH: Babadağ Horst, SDD: Sarayköy-Denizli graben (depression), DF: Denizli fault, LH: Laodicea Horst, YDP: Yenicekent-Pamukkale graben (depression), PF: Pamukkale fault, GH: Güzelpınar Horst.

2007; Tan et al., 2008; Utku, 2009). A magnitude six earthquake in BC 60 damaged the ancient city severely (Atabey et al., 1982; Hançer, 2013 and the references therein). The Denizli region's earthquakes have relatively shallow focal depths ranging from 5 to 10 km (Aydan et al., 2005; Kaypak and Gökkaya, 2012).

4. Discussion

Back-arc extension of the Hellenic Trench (McKenzie, 1978; Le Pichon and Angelier, 1979; Meulenkamp et al., 1988) due to its southward retreat and the consequent delamination are considered the mechanisms responsible for the rapid extension of western Anatolia (Wortel and Spakman, 2000; Faccenna et al., 2004; Dilek and Altunkaynak, 2007; Agostini et al., 2008; Jolivet et al., 2013; Philippon et al., 2014; Ring et al., 2017; Yılmaz, 2017*b* and the references therein). The N-S extension generated detachment fault(s) and the associated metamorphic core complexes. The Menderes Massif, one of the good representatives of the core complexes, was partly exposed before the Late Miocene. Evidence for this is metamorphic rock clasts incorporated into the Upper Miocene terrestrial sediments (Yılmaz et al., 2000). The metamorphic rocks cropping out in the Babadağ horst may be regarded as the southeastern part of the Menderes Massif (Yılmaz, 2017*b*, Figure 2).

For the last five-six decades, geological research in western Anatolia has enlightened various geological aspects of the Neogene grabens and the surroundings (Yılmaz, 2017*a, b*; Alçiçek et al., 2019 and the references therein). However, comprehensive studies correlating the basins along and across western Anatolia are few (Yılmaz, 2000; Alçiçek, 2010; Ersoy et al., 2011, 2014). The views on the time and mechanism of the grabens having trends deviating from E-W are also quite diverse (Şengör, 1987; Genç and Yılmaz, 2000; Yılmaz et al., 2000; Genç et al., 2001; Gürer et al., 2001, 2009; Gürer and Yılmaz, 2002; Bozkurt, 2003, 2009; Seyitoğlu et al., 2004; Kaymakçı, 2006; Koçyiğit and Deveci, 2007; Ten Veen et al., 2009; Gürer et al., 2009; Ersoy et al., 2011; Özburan and Gürer, 2012; Şaroğlu and Gürer, 2020; Seyitoğlu et al., 2022; Gürer, 2023).

On the enlargement of the west Anatolian grabens, the views gradually changed through time. The earlier views favored uninterrupted growth since they began in the late Oligocene-early Miocene (Seyitoğlu and Scott, 1996; Bozkurt, 2000; Sözbilir, 2005). Later studies support the development in pulses (Lips et al., 2001; Purvis and Robertson, 2004; Bozkurt and Rojay, 2005; Beccaletto and Steiner, 2005; Lacassine et al., 2007; Emre and Sözbilir, 2007; Chatzaras et al., 2011; Yılmaz, 2017*a, b*; Alçiçek et al., 2019). The regional angular unconformities separating the three rock groups of the Neogene-Quaternary age (Yılmaz, 1997; Koçyiğit et al., 1999; Yılmaz et al., 2000; Yılmaz, 2017*b*) favor interrupted extension.

The low energy lacustrine sequence reveals that interconnected lakes cover the entire western Anatolia during the late Miocene-Early Pliocene (Becker-Platen, 1970; Benda, 1971; Benda et al., 1974, 1977; Luttig and Stevens, 1976; Yılmaz, 2017*a, b*; Alçiçek et al., 2019). Alçiçek et al. (2019), based on the detailed paleoenvironment analyses, show that the lakes were dried out, and marsh-swamp deposits at the top of the lacustrine succession remained till the Pleistocene. The region suffered a severe erosional stage during the same period, which generated a flat-lying erosional plain above the lake deposits and the underlying rocks. Both events reveal that the region was relatively quiet during the late Miocene-late Pliocene. The development of the present E-W grabens followed the quiet period in the Pleistocene (Angelier et al., 1981, 1982; Yılmaz, 1997; Yılmaz et al., 1999; Sarıca, 2000; Rojay et al., 2005; Westaway et al., 2005; Bozkurt et al., 2011; Yılmaz, 2017*a, b ;* Alçiçek et al., 2019; Maddy et al., 2020). Fragments of the flat-lying erosional plains were then elevated to different heights, which is also observed on the horsts surrounding the Denizli Graben (Figures 5, 7, 8, and 9). This key stratigraphic horizon may be used to differentiate the pre and post-erosional geological events and give them a relative age.

In the Denizli region, however, the development of the Babadağ horst possibly began during the Late Miocene (Alçiçek et al., 2019) or Early Pliocene (Taner, 2001) when the interconnected lakes were still covering the surrounding regions (MTA, 2002). Evidence for this is the coarse terrestrial conglomerates of the elevating Babadağ horst interfingering with the lacustrine sediments (Alçiçek, 2007). During this stage the Denizli basin may thus be regarded as a half-graben (Alçiçek et al., 2019).

The Gediz and the Büyük Menderes grabens were possibly extended to the Denizli region during the initial stage of development because the infill of the grabens in both areas shares a similar coeval stratigraphy (Koçyiğit, 2005; Ergin et al., 2007; Alçiçek, 2007; Çiftçi and Bozkurt, 2009, 2010; Alçiçek et al., 2019). When the KR and GR ridges formed, the grabens collapsed (Ocakoğlu, 2020) and were separated. From this period onward, the eastern and the western grabens have experienced independent evolutions.

The dominant morphotectonic element of the Denizli region is the Babadağ Horst (Özpolat et al., 2020). The Denizli fault delimits the horst in the North, which may be regarded as a detachment-breakaway fault along which the deeply buried metamorphic rocks were elevated to the levels of the Neogene and Quaternary successions. The fault may thus be considered as a part of the major detachment fault of western Anatolia (Bozkurt and Park, 1994; Hetzel et al., 1995; Emre and Sözbilir, 1997; Gessner et al., 2001, 2013; Sözbilir, 2005; Çemen et al., 2006; Öner and Dilek, 2011, 2012; Buscher et al., 2013; Wölfler et al., 2017; Heineke et al., 2019; Asti et al., 2019). In the adjacent Büyük Menderes graben, the transition from low to high-angle normal faulting was estimated to have taken place during the latest Pliocene-early Quaternary (Öner and Dilek, 2011; Sümer et al., 2020). Future seismic studies will unravel tectonic nature of the Denizli fault at deeper levels.

The Güzelpınar and Laodicea Horsts are young structures that were formed during the Quaternary (Alçiçek, 2007; Hançer, 2013, 2019; Van Noten et al., 2013, 2019, and the references therein). The development of the Denizli fault appears to have exerted substantial tectonic control in their formation because they are located within the downtown block, similar to many antithetic faults of varying sizes that also formed during this period.

5. Results

The low-energy lacustrine sequence reveals that interconnected lakes covered western Anatolia throughout the late Miocene and Early Pliocene. A regionwide erosional stage that formed a flat-lying erosional plane accompanied this phase. The smooth topography was fragmented when the E-W trending major grabens began to open during the Pleistocene. The eastern and western grabens of the Denizli region were possibly united until this period. The Kadıköy and Gencelli ridges, when formed, separated the grabens during the Quaternary. Development of the ridges may be the consequence of the southwesterly motion of the Anatolian Plate, and the shear stress originated from this rotation. From this time onward, the Denizli Region has undergone a semi-independent evolution.

Major morphotectonic elements of the Denizli region are the NW-SE trending Babadağ and the Güzelpınar horsts. They define the Denizli basin. There is also a thin and narrow Laodicea horst in the basin's southeastern part, dividing it into two depressions of unequal size.

The most distinct morphotectonic entity of the Denizli Region is the Babadağ Horst. The Denizli fault delimits the horst in the north and may be regarded as an eastern extension of the detachment fault along which the Menderes massif was exhumed.

The development of the Denizli fault has possibly controlled the formation of the Laodicea and Güzelpınar Horsts located within the downthrown block. Partly coevally, many other antithetic faults of varying sizes, genetically associated with the young horsts, were also formed.

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References

Alçiçek, M. C. 2007. Tectonic development of an orogen-top rift recorded by its terrestrial sedimentation pattern: the Neogene Eşen Basin of southwestern Anatolia, Turkey. Sedimentary Geology 200, 117–140.

Alçiçek, H. 2010. Stratigraphic correlation of the Neogene basins in southwestern Anatolia: regional palaeogeographical, palaeoclimatic, and tectonic implications. Paleogeography, Palaeoclimatology, Palaeoecology 291, 297–318.

Alçiçek, M. C., Brogi, A., Capezzuoli, E., Liotta, D., Meccheri, M. 2013. Superimposed basin formation during Neogene–Quaternary extension in SW-Anatolia (Turkey): insights from the kinematics of the Dinar fault zone. Tectonophysics 608, 713–727.

Alçiçek, M. C., Mayda, S., Ten Veen, J. Y., Boulton, S. J., Neubauer, T. A., Alçiçek, H., Tesakov, A. S., Saraç, G., Hakyemez, Y. H., Göktaş, F., Murray, M. A., Titov, V. V., Jiménez-Moreno, G., Büyükmeriç, Y., Wesselingh, F. P., Bouchal, J. M., Demirel, A., Kaya, T. T., Halaçlar, K., Bilgin, M., Van den Hoek Ostende, L. 2019. Reconciling the stratigraphy and depositional history of the Lycian orogen-top basins, SW Anatolia. Paleaobiodiversity and Paleoenvironments 99, 551-570.

Altunel, E. 1996. Pamukkale travertenlerinin morfolojik özellikleri, yaşları ve Neotektonik önemleri. Bulletin of the Mineral Research and Exploration 118, 47-64.

Altunel, E. 2000. Hierapolis ve yakın çevresinde tarihsel deprem aktivitesi (Lattivita Sismica a Hierapolise Nelle Zone Limitrofe). Ricerche Archeologiche Turche Nella Valle Del Lykos, Lykos Vadisi Türk Arkeoloji Araştırmaları, 229-325.

Altunel, E., Hancock, P. L. 1993 Active fissuring and faulting in Quatemary travertines at Pamukkale, Western Turkey. Stewart, I. S., Vita-Finzi, I. C., Owen, L. A. (Ed.). Neotectonics and Active Faulting. Zeitschrift Geomorphologie Supplementary 94, 285-302.

Altunel, E., Barka, A. 1996. Evaluation of archaeoseismic damages at Hierapolis. Geological Bulletin of Turkey 39, 65-74.

Angelier, J., Dumont, J. F., Karamanderesi, İ. H., Poisson, A., Şimşek, Ş., Uysal, Ş. 1981. Analyses of fault mechanism and expansion of southwestern Anatolia since Late Miocene. Tectonophysics 75, T1–T9.

Angelier, J. N., Le Pichon, L. X., Barrier, E., Huchon, P. 1982. The tectonic development of the Helennic Arc and the Sea of Crete: a synthesis. Tectonophysics 86, 159–196.

Aratman, C., Özkul, M., Swennen, R., Hollis, C., Erthal, M. M., Zahra Mohammadi, H. C. E. 2020. The giant quaternary Ballık travertine system in the Denizli basin (SW Turkey): a paleoenvironmental analysis (Le système de travertin quaternaire géant de Ballik dans le bassin de Denizli (sud-ouest de la Turquie): une analyse paléoenvironnementale. Quaternaire 31(2).

Asti, R., Faccenna, C., Rossetti, F., Malusà, M. G., Gliozzi, E., Faranda, C., Lirer, F., Cosentino, D. 2019. The Gediz supradetachment system (SW Turkey): magmatism, tectonics, and sedimentation during crustal extension. Tectonics 38(4), 1414-1440.

Atabey, E., Ateş, R. C., Bayülken, N. 1982. The 19 August 1976 Denizli, Turkey, earthquake: evaluation of the strong motion accelerograph record. Bulletin of the Seismological Society of America 72(1982), 1635-1649.

Agostini, S., Ryan, J. G., Tonarini, S., Innocenti, F. 2008. Drying and dying of a subducted slab: coupled Li and B isotope variations in Western Anatolia Cenozoic volcanism. Earth Planetary Science Letters 272, 139-147.

Aydan, Ö., Kumsar, H., Tano, H. 2005. Multiparameter changes in the earth's crust and their relation to earthquakes in Denizli region of Turkey. Proceedings World Geothermal Congress, 24-29 April 2005, 1-10.

Batı, Z., Yazman, M., Özdemir, İ. 1998. Alkaşehir grabeni ve Alaşehir-1 prospektinin değerlendirme raporu. TPAO, Rapor No: 3864, 147.

Beccaletto, L., Steiner, C. 2005. Evidence of two-stage extensional tectonics from the northern edge of the Edremit Graben, NW Turkey. Geodinamica Acta 18, 283-297.

Becker-Platen, J. D. 1970. Lithostratigraphisce Untersuchungen im Känozoikum Südwest- Anatoliens (Türkei). Beihefte zum geologischen Jahrbuch, 97, 1–244.

Benda, L. 1971. Principles of the palynologic subdivision of the Turkish Neogene. Newsletters on Stratigraphy 1-3, 23–26.

Benda, L., Innocenti, F., Mazzuoli, R., Radicati, F., Steffens, P. 1974. Stratigraphic and radiometric data of the Neogene in northwest Turkey. Journal of Applied and Regional Geology 125(2), 183-193.

Benda, L., Meulenkamp, J. E., Schmidt, R. R., Steffens, P. 1977. Biostratigraphic correlations in the eastern Mediterranean Neogene. Correlation between sporomorph associations and marine microfossils from the Upper Oligocene-Lower Miocene of Turkey Newsletters on Stratigraphy 6, 1–22.

Bozcu, M. 2010. Geology of Neogene basins of Buldan-Sarıcaova region and their implications in western Anatolian neotectonics. International Journal of Earth. Science 99(4), 851-861.

Bozkurt, E. 2000. Timing of extension on the Büyük Menderes graben, Western Turkey, and its tectonic implications. Geological Society London of Special Publications 173, 385–403.

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

Bozkurt, E. 2009. Extensional contractional origin for the southern Menderes shear zone, SW Turkey: tectonics and metamorphic implications. Geological Magazine 144(1), 1-20.

Bozkurt, E., Park, R. G. 1994. Southern Menderes Massif: an incipient metamorphic core complex in Western Anatolia, Turkey. Journal of Geological Society of London 151, 213-216.

Bozkurt, E., Sözbilir, H. 2004. Tectonic evolution of the Gediz Graben: field evidence for an episodic, two-stage extension in Western Turkey. Geological Magazine 141(1), 63-79.

Bozkurt, E., Rojay, B. 2005. Episodic, two-stage Neogene extension and short-term intervening compression in western Turkey: field evidence from the Kiraz basin abd Bozdağ Horst. Geodinamica Acta 18(3), 299-316.

Bozkurt, E., Satır, M., Buğdaycıoğlu, C. 2011. Surprisingly young Rb/Sr ages from the Simav extensional detachment fault zone, northern Menderes Massif, Turkey. Journal of Geodynamics 52, 406–431.

Bozkuş, C., Kumsar, H., Özkul, M., Hançel, M. 2001. Seismicity of active Honaz Fault under an extensional tectonic regime. International Earth Sciences Colloquium on the Aegean Region, İzmir, Turkey, 7-16.

Buscher, J. T., Hampel, A., Hetzel, R., Dunkl, I., Glotzbach, C., Struffert, A., Akal, C., Rätz, M. 2013. Quantifying rates of detachment faulting and erosion in the central Menderes Massif. by thermochronology and cosmogenic. Journal of the Geological Society 170(4), 669-683.

Chatzaras, V., Xypolias, P., Kokkalas, S., Koukouvelas, I. 2011. Oligocene-Miocene thrusting in central Aegean: insights from the Cycladic island of Amorgos. Geological Journal 46(6), 619-636.

Çakır, Z. 1999. Along-strike discontinuity of active normal faults and its influence on Quaternary travertine deposition, examples from Western Turkey. Journal of Earth Sciences 8, 67–80.

Çemen, I., Catlos, E. J., Göğüş, O. 2006. Post collisional extensional tectonics and exhumation of the Menderes Massif in the Western Anatolia Extended Terrane, Turkey. Geological Society of America, Special Paper 409, 353-379.

Çiftçi, N. B., Bozkurt, E. 2009. Evolution of the Miocene sedimentary ll of the Gediz Graben, SW Turkey. Sedimentary Geology 216(3-4), 49-79.

Çiftçi, N. B., Bozkurt, E. 2010. Structural evolution of the Gediz Graben, SW Turkey: temporal and spatial variation of the graben basin. Basin Research, 22(6), 846-873.

De Filippis, L., Faccenna, C., Billi, A., Anzalone, E., Brilli, M., Özkul, M., Soligo, M., Tuccimei, P., Villa, M. 2012. Growth of fissure ridge travertines from geothermal springs of Denizli Basin, western Turkey. Bulletin of the Geological Society of America 124(2012), 1629-1645.

Dilek, Y., Altunkaynak, Ş. 2007. Cenozoic crustal evolution and mantle dynamics of post-collisional magmatism in western Anatolia. International Geology Review 49(5), 431-453.

Dilsiz, C. 2006. Conceptual hydrodynamic model of Pamukkale hydrothermal field, southwestern Turkey, based on hydrochemical and isotope data. Hydrology Journal 14, 562-572.

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. Proceedings of International Earth Sciences Colloquium on the Aegean Region, I, 73-93.

Emre, T., Sözbilir, H. 2007. Tectonic evolution of the Kiraz Basin, Küçük Menderes Graben: evidence for compression/uplift-related basin formation overprinted by extensional tectonics in West Anatolia. Turkish Journal of Earth Sciences 16(4), 441-470.

Emre, Ö., Duman, T. Y., Özalp, S., Şaroğlu, F., Olgun, Ş., Elmacı, H., Can, T. 2018. Active fault database of Turkey. Bulletin of Earthquake Engineering 16(8), 3229-3275.

Ergin, M., Kadir, S., Keskin, Ş., Turhan-Akyüz, N., Yaşar, D. 2007. Late quaternary climate and sea-level changes recorded in sediment composition of the Büyük Menderes Delta (eastern Aegean Sea, Turkey). Quaternary International 167-168, 162-176.

Erinç, S. 1954. Orta Ege Bölgesi'nin jeomorfolojisi. Maden Tetkik ve Arama Genel Müdürlüğü, Rapor No: 2217, Ankara (unpublished).

Ersoy, Y. E., Helvacı, C., Palmer, M. R. 2011. Stratigraphic, structural, and geochemical features of the NE–SW trending Neogene volcanosedimentary basins in western Anatolia: implications for associations of supra-detachment and transtensional strike-slip basin formation in extensional tectonic setting. Journal of Asian Earth Science 41, 159-183.

Ersoy, E. Y., Çemen, İ., Helvacı, C., Billor, Z. 2014. Tectono-stratigraphy of the Neogene basins in Western Turkey: implications for tectonic evolution of the Aegean extended region. Tectonophysics 635, 33-58.

Faccenna, C., Piromallo, C., Crespo-Blanc, A., Jolivet, L., Rossetti, F. 2004. Lateral slab deformation and the origin of the western Mediterranean arcs. Tectonics 23, TC1012.

Genç, Ş. C, Yılmaz, Y. 2000. Aliağa dolayının jeolojisi ve genç tektoniği (Geology and young tectonics of the Aliağa region). Batı Anadolu Depremselliği Sempozyumu (BAD-SEM) Bildiriler Kitabı, İzmir, 152-159.

Genç, C. Ş., Altunkaynak, Ş., Karacık, Z., Yazman, M., Yılmaz, Y. 2001. The Çubukludağ graben, south of İzmir: its tectonic significance in the Neogene geological evolution of the western Anatolia. Geodinamica Acta 14, 45-55.

Gessner, K., Ring, U., Johnson, C., Hetzel, R., Passchier, C. W., Güngör T. 2001. An active bivergent rolling-hinge detachment system: central Menderes metamorphic core complex in western Turkey. Geology 29(7), 611–614.

Gessner, K., Gallardo, L. A., Markowitz, V., Ring, U., Thomson, S. N. 2013. What caused the denudation of the Menderes massif: review of crustal evolution, litho-sphere structure, and dynamic topography in southwest Turkey. Gondwana Research 24(1), 243-274.

Göktaş, F. 1990. 1/25.000 ölçekli Denizli M22b1, b2 ve b3 paftalarının jeoloji haritası. Maden Tetkik ve Arama Genel Müdürlüğü, Ankara.

Gürer, F. Ö. 2023. A new look at the origin of N-S trending young basins of western Anatolia. Bulletin of the Mineral Research and Exploration 10.19111/bulletinofmre.1066949

Gürer, Ö. F., Yılmaz, Y. 2002. Geology of the Oren and surrounding areas SW Anatolia. Turkish Journal of Earth Sciences 11, 1–13.

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

Gürer, Ö. F., Sarıca-Filoreau, N., Özburan, M., Sangu, E., Doğan, B. 2009. Progressive development of the Büyük Menderes Graben based on new data, western Turkey. Geological Magazine 146(5), 652–673.

Hakyemez, H. Y., Erkal, T., Göktaş, F. 1999. Late Quaternary evolution of the Gediz and Büyük Menderes grabens, western Anatolia, Turkey. Quaternary Science Reviews 18(4–5), 549-554.

Hançer, M. 2013. Study of the structural evolution of the Babadağ-Honaz and Pamukkale fault zones and the related earthquake risk potential of the Buldan Region in SW Anatolia, east of the Mediterranean. Journal of Earth Science 24(3), 397-409.

Hançer. M. 2019. Structural evolution of the northeast–southwest trending tectonic lineament and a model for graben formation in the Denizli region of Western Anatolian (west of the Zagros Fold-and-Thrust Belt). Tectonics 3, 83-100.

Heineke, C., Hetzel, R., Nilius, N. P., Zwingmann, H., Todd, A., Mulch, A., Wölfler, A., Glotzbach, C., Akal, C., Dunkl, I., Raven, M., Hampel, A. 2019. Detachment faulting in a bivergent core complex constrained by fault gouge dating and low temperature thermochronology. Journal of Structural Geology 127, 103865.

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

Jolivet, L., Faccenna, C., Huet, B., Labrousse, L., Le Pourhiet, L., Lacombe, O., Lecomte, E., Burov, E., Denèle, Y., Brun, J.-P., Philippon, M., Paul, A., Salaün, G., Karabulut, H., Piromallo, C., Monié, P., Gueydan, F., Okay, A., Oberhänsli, R., Pourteau, A., Augier, R., Gadenne, L., Driussi, O. 2013. Aegean tectonics: strain localization, slab tearing and trench retreat. Tectonophysics 597–598, 1–33.

Kaymakçı, N. 2006. Kinematic development and paleo stress analysis of the Denizli Basin (western Turkey): implications of spatial variation of relative paleo stress magnitudes and orientations. Journal of Asian Earth Sciences 27, 207–222.

Kaypak, B., Gökkaya, G. 2012. 3-D imaging of the upper crust beneath the Denizli geothermal region by local earthquake tomography, western Turkey. Journal of Volcanology and Geothermal Research 211–212, 47-60.

Kele, S., Özkul, M., Gökgöz, A., Fórizs, I., Baykara, M. O., Alçiçek, M. C., Németh, T. 2011. Stable isotope geochemical and facies study of Pamukkale travertines: new evidence of low-temperature non-equilibrium calcite-water fractionation. Sedimentary Geology 238, 191-212.

Koçyiğit, A. 2005. The Denizli graben-horst system and the eastern limit of western anatolian continental extension: basin fill, structure, deformational mode, throw amount and episodic evolutionary history, SW Turkey. Geodinamica Acta 18(3–4), 167-208.

Koçyiğit, A., Deveci, Ş. 2007. An N-S-trending active extensional structure, the Şuhut (Afyon) graben: commencement age of the extensional neotectonic period in the Isparta angle, SW Turkey. Turkish Journal of Earth Sciences 16, 391–416.

Koçyiğit, A., Yusufoğlu, H., Bozkurt, E. 1999. Evidence from the gediz graben for episodic two-stage extension in western Turkey. Journal of Geological Society of London 156, 605–616.

Lacassin, R., Arnaud, N., Leloup, P. H., Armijo, R., Meijer, B. 2007. Exhumation of metamorphic rocks in N Aegean: the path from shortening to extension and extrusion. Earth 2, 51–63.

Le Pichon, X., Angelier, J. 1979. The Hellenic Arc and trench system: a key to the Neotectonic evolution of the eastern Mediterranean area. Tectonophysics 60, 1-42.

Lips, A. L. W., Cassard, D., Sözbilir, H., Yılmaz, H. 2001. Multistage exhumation of the Menderes Massif, western Anatolia (Turkey). International Journal of Earth Sciences 89, 781-792.

Luttig, G., Steffens, D. 1976. Explanatory notes for the paleogeographic atlas of Turkey from Oligocene to Pleistocene. Bundesanstalt für Geowissenschaften und Rohstoffe, 64.

Maddy, D., Veldkamp, A., Demir, T., Aytaç, A. S., Schoorl, J. M., Scaife, R., Boomer, I., Stemerdink, C., Van DerSchriek, T., Aksay, S., Lievens, C. 2020. Early Pleistocene river terraces of the Gediz River, Turkey: the role of faulting, fracturing, volcanism and travertines in their genesis. Geomorphology 358, 107102.

McClusky, S., Balassanian, S., Barka, A. A., Demir, C., Ergintav, S., Georgiev, I., Gürkan, O., Hamburger, M., Hurst, K., Kahle, H., Kastens, K., Kekelidze, G., King, R., Kotzev, V., Lenk, O., Mahmoud, S., Mishin, A., Nadariya, M., Ouzounis, A., Paradissis, D., Peter, Y., Prilepin, M., Reilinger, R., Sanli, I., Seeger, H., Tealeb, A., Toksöz, M., Veis, G. 2000. Global positioning system constraints on plate kinematics and dynamics in the eastern Mediterranean and Caucasus: Journal of Geophysical Research 105(B3), 5695–5720.

McKenzie, D. P. 1978. Active tectonic of the Mediterranean belt, Aegean sea and surrounding regions. Geophysical Journal International 30(2), 109-185.

McKenzie, D., Yılmaz, Y. 1991. Deformation and volcanism in western Turkey and the Aegean. Bulletin Technical University of Istanbul Special Issues on Tectonics 44, 345-373.

Meulenkamp, J. E., Wortel, M. J. R., Van Wamel, W. A., Spakman, W., Strating, E. H. 1988. On the Hellenic subduction zone and the geodynamical evolution of Crete since the Late Middle Miocene. Tectonophysics 146, 203-215.

MTA. 2002. 1/500000 scale geology map of Turkey, Denizli Sheet. Maden Tetkik ve Arama Genel Müdürlüğü, Ankara, Turkey.

Ocakoğlu, F. 2020. Rapid Late Quaternary denudation of the Karacasu Graben in response to subsidence in the Büyük Menderes Corridor: Insights from morphotectonics and archaeogeology. Geomorphology, 107107.

Öner, Z., Dilek, Y. 2011. Supradetachment basin evolution during continental extension: the Aegean province of western Anatolia. Turkey. The Geological Society of America 123(11-12), 2115–2141.

Öner, Z., Dilek, Y. 2012. Fault kinematics in supradetachment basin formation, Menderes core complex of western Turkey. Tectonophysics 608, 1394-1412.

Özburan, M., Gürer, Ö. F. 2012. Late Cenozoic polyphase deformation and basin development, Kütahya region, western Turkey. International Geology Review 54(12), 1401-1418.

Özkul, M., Kele, S., Gökgöz, A., ChouShen, C., Jones, B., Baykara, O. M., Fórizs, I., Németh, T., Chang, Y., Alçiçek, M. Ç. 2013. Comparison of the Quaternary travertine sites in the Denizli extensional basin based on their depositional and geochemical data. Sedimentary Geology 294, 179-204.

Özkaymak, Ç. 2015. Tectonic analysis of the Honaz Fault (western Anatolia) using geomorphic indices and the regional implications. Geodinamica Acta 27(2-3).

Özpolat, E., Yıldırım, C., Görüm, T. 2020. The Quaternary landforms of the Büyük Menderes graben system: the southern Menderes Massif, western Anatolia, Turkey. Journal of Maps 16(2), 405-419.

Piccardi, L. 2007. The AD 60 Denizli Basin earthquake and the apparition of Archangel Michael at Colossae (Aegean Turkey). Masse, W. B. (Ed.). Geological Society of Special Publications 273, 95-105.

Philippon, M., Brun, J. P., Gueydan, F., Sokoutis, D. 2014. The interaction between Aegean back-arc extension and Anatolia escape since Middle Miocene. Tectonophysics 631, 176-188.

Purvis, M., Robertson, A. H. F. 2004. A pulsed extension model for the Neogene–Recent E-W-trending Alasehir Graben and the NE-SW-trending Selendi and Gordes Basins, western Turkey. Tectonophysics 391, 171–201.

Reilenger, R., McClusky, S., Vernant, P., Lawrence, S., Ergintav, S., Çakmak, R., Özener, H., Kadirov, F., Guliyev, I., Stepanyan, R., Nadariya, M. 2006. GPS constraints on continental deformation in the Africa-Arabia-Eurasia continental collision zone and implications for the dynamics of plate interactions. Journal of Geophysical Research: Solid Earth 111(B5).

Reilenger, R., McClusky, S., Paradises, D., Ergintav, S., Vernant, P. 2010. Geodetic constraints on the tectonic evolution of the Aegean region and strain accumulation along the Hellenic subduction zone. Tectonophysics 488, 22-30.

Ring, U., Gessner, K., Thomson S. 2017. Variations in fault-slip data and cooling history reveal corridor of heterogeneous back arc extension in the eastern Aegean Sea region. Tectonophysics 700, 108-130.

Rojay, B., Toprak, V., Demirci, C., Suzen, L. 2005. Plio-quaternary evolution of the Küçük Menderes Graben southwestern Anatolia, Turkey. Geodinamica 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. Geological Journal 35(1), 1–24.

Seyitoğlu, G., Scott, B. 1991. Late Cenozoic crustal extension and basin formation in west Turkey. Geological Magazine 128, 155-166.

Seyitoğlu, G., Scott, B. C. 1996. Age of the Alaşehir Graben (West Turkey) and its tectonic implications. Geological Journal 31(1), 1-11.

Seyitoğlu, G., Işık, V., Çemen, İ. 2004. Complete Tertiary exhumation history of the Menderes Massif, western Turkey: an alternative working hypothesis. Terra Nova 16, 358-363.

Seyitoğlu, G., Tunçel, E., Kaypak, B., Esat, K., Gökkaya, E. 2022. The Anatolian diagonal: a broad left-lateral shear zone between the North Anatolian Fault Zone and the Aegean/Cyprus. ArcTürkiye Jeoloji Bülteni 65(2), 93-116 .

Sözbilir, H. 2005. Oligo-Miocene extension in the Lycian Orogen: evidence from the Lycian molasse basin, SW Turkey. Geodinamica Acta 18, 255–282.

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. Journal of Geodynamics 65, 148–175.

Sümer, Ö., Sözbilir, H., Uzel, B. 2020. Büyük Menderes Grabeni'nin rolling hinge (yuvarlanan reze) modelinde supra-detachment (sıyrılma üstü) havzadan rift havzasına evrimi. Türkiye Jeoloji Bülteni 63, 241-276.

Şaroğlu, F., Güler, B. 2020. Batı Anadolu tektonik kaması'nın güncel deformasyonu: batıya doğru kaçıştan kaynaklanan blok hareketleri. Türkiye Jeoloji Bülteni 63(2), 161-194.

Şenel, M. 1997. 1/100000 scale geological map of Turkey, Denizli-J9 Quadrangle, and accompanying 18 page explanatory booklet. General Directorate of Mineral Research and Exploration, Ankara.

Şenel, M. 2010. 1:100.000 scale geological maps of Turkey Denizli N23 sheet. Mineral Research and Exploration Directorate of Turkey (MTA), Ankara.

Şengör, A. M. C. 1979. Türkiye'nin Neotektoniği'nin esasları. Jeoloji Kurumu Yayını, 30.

Şengör, A. M. C. 1987. Cross-fault and differential stretching of hanging walls in regions of low-angle normal faulting: examples from western Turkey. Coward, M. P., Dewey, J. F., Hancock, P. L. (Ed.). Continental Extensional Tectonics. Geological Society of London Special Publication 28, 575-589.

Şengör, A. M. C., Yılmaz, Y. 1981. Türkiye'de Tetis'in evrimi, levha içi tektoniği açısından bir Yaklaşım. Türkiye Jeoloji Kurultayı Özel Dizi.

Şimşek, Ş. 1984. Denizli-Sarayköy-Buldan alanının jeolojisi ve jeotermal enerji kaynakları. İstanbul Üniversitesi Yer Bilimleri Dergisi 3(1–2), 145-162.

Şimşek, Ş., Günay, G., Elhatip, H., Ekmekçi, M. 2000. Environmental protection of geothermal waters and travertines at Pamukkale, Turkey. Geothermics 29 (4-5), 557-572.

Tan, O., Cengiz, M., Tapırdamaz, A. Y. 2008. The earthquake catalogues for Turkey. Turkish Journal of Earth Science 17(2), 405-418.

Taner, G. 2001. Denizli Bölgesi Neojeni'ne ait katların stratigrafik konumlarinda yeni düzenleme. Türkiye Jeoloji Kurultayı Bildirisi, 54-79.

Ten Veen, J. H., Boulton, S. J., Alçiçek, M. C. 2009. From palaeotectonics to neotectonics in the NeoTethys realm: the importance of kinematic decoupling and inherited structural grain in SW Anatolia (Turkey). Tectonophysics 473, 261–281.

Toker, E., Kayseri-Özer, M. S., Özkul, M., Kele, S. 2015. Depositional system and palaeoclimatic interpretations of Middle to Late Pleistocene travertines: Kocabaş, Denizli, SW Turkey. Sedimentology 62(5), 1360-1383.

Utku, M. 2009. Etkinlik ve yığınsal etkinlik dönemlerine göre Denizli depremlerinin analizi**,** Bulletin of the Mineral Research and Exploration 138, 9-34.

Van Hinsbergen, D. J. J. 2010. A key extensional metamorphic complex reviewed and restored: the Menderes Massif of western Turkey. Earth-Sciences Reviews 102(1-2), 60-76.

Van Noten, K., Claes, H., Soete, J., Foubert, A., Özkul, M., Swennen, R. 2013. Fracture networks and strike-slip deformation along reactivated normal faults in Quaternary travertine deposits, Denizli Basin, western Turkey. Tectonophysics 588, 154-170.

Van Noten, K., Topal, S., Baykara, M. O., Özkul, M., Claes, H., Aratman, C., Swennen, R. 2019. Pleistocene-Holocene tectonic reconstruction of the Ballık travertine (Denizli Graben, SW Turkey): deformation of large travertine geobodies at intersecting grabens. Journal of Structural Geology 118, 114-134.

Westaway, R. 1993. Neogene evolution of the Denizli region of Western Turkey. Journal of Structural Geology 15(1), 37–53.

Westaway, R., Guillou, H., Yurtmen, S., Demir, T., Scaillet, S., Rowbotham, G. 2005. Constraints on the timing and regional conditions at the start of the present phase of crustal extension in western Turkey, from observations in and around the Denizli region**.** Geodinamica Acta 18, 209-238.

Wölfler, A., Glotzbach, C., Heineke, C., Nilius, N. P., Hetzel, R., Hampel, A., Akal, C., Dunkl, I., Christl, M. 2017. Late Cenozoic cooling history of the central Menderes Massif: timing of the Büyük Menderes detachment and the relative contribution of normal faulting and erosion to rock exhumation. Tectonophysics 717, 585–598.

Wortel, M. J. R., Spakman, W. 2000. Subduction and slab detachment in the Mediterranean-Carpathian region. Science 290, 1910-1917.

Yılmaz, Y. 1997. Geology of Western Anatolia. Theme 3: General Geology. Active Tectonics of Northwestern Anatolia-The Marmara Polyproject. A Multidisiplinary approach by Space–Geodesy, Hydrology, Geothermics and Seismology. vdf Hochschulverlag AG an der ETH, Zurich.

Yılmaz, Y., Genç, S. C., Gürer, Ö. F., Karacık, Z., Altunkaynak, S., Bozcu, M., Yılmaz, K., Elmas, A. 1999. Ege Denizi ve Ege Bölgesi'nin jeolojisi ve evrimi. Görür, N. (Ed.). Türkiye Denizleri, Devlet Planlama Teşkilatı. Türkiye Bilimsel ve Teknolojik Araştırma Kurumu, 211–337.

Yılmaz, Y., Genç, Ş. C., Gürer, Ö. F., Bozcu, M., Yılmaz, K., Karacık, Z., Altunkaynak, Ş., Elmas, A. 2000. When did the Western Anatolian Grabens begin to develop? Bozkurt, E., Winchester, J. A., Piper, J. D. A. (Ed.). Tectonics and Magmatism in Turkey and the Surrounding Area. Geological Society of London Special Publications 173, 353-384.

Yılmaz, Y. 2017*a*. Morphotectonic development of Anatolia and the surrounding regions. Çemen, İ., Yılmaz, Y. (Ed.). Active Global Seismology; Neotectonics and Earthquake Potential of the Eastern Mediterranean Region. Geophysical Monograph 225, American Geophysical Union, Wiley, New York, 11-91.

Yılmaz, Y. 2017*b*. Major problems of Western Anatolian geology. Çemen, İ., Yılmaz, Y. (Ed.). Active Global Seismology: Neotectonics and Earthquake Potential of the Eastern Mediterranean Region, Geophysical Monograph Book Series 225, 141-187.