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Neotectonic Characteristics and Seismicity of the Reşadiye Peninsula and Surrounding Area, Southwest Anatolia

Reşadiye Yarımadası ile Çevresinin Neotektonik Özellikleri ve Depremselliği, Güneybatı Anadolu

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ABSTRACT

The NW-trending Datça Graben, E-W trending Reşadiye Horst, Gökova and Hisarönü Grabens are the most important morphologic and structural units of the Southwest Anatolia on which, tectonic evolution was controlled by NW-SE, NE-SW and E-W trending faults. The Datça Graben has been started to develop as a half graben on the Lycean Nappes of the central part of the Reşadiye Peninsula under the control of NW-trending southern marginal fault during early Pliocene. Lagoonal-fluvial environment connected with shallow marine has evolved its evolution as a graben till late Pliocene (late Piacenzian). E-W trending Gökova Graben and Hisarönü Graben, started to develop under the effect of N-S directed extension, ends the development of the Datça Graben. The Gökova Graben is about 140 km long and enlarges from about 5 km to 30 km westward, and active Yali and Nisyros volcanic centers are located at the western tip of the peninsula. E-W trending southern marginal faults of this graben and northern marginal faults of the Hisarönü Graben cut the late Pliocene deposits of Datça Graben, forming Reşadiye Horst between these two grabens. This is an important evidence for the development of Gökova and Hisarönü Grabens starting from early Quaternary.

This region is one of the seismically active regions of the southeast Aegean Sea. The records of historic and instrumental period shows the presence of the strong earthquakes with magnitudes of 7.7 (Ms) and intensity of X, and the effect of important tsunamies in the region. Based on the focal depth and fault plane solutions of the earthquakes (Ms≥4) occurred in the region between 2000-2006, it is observed that shallow earthquakes associate with E-W trending normal fault planes, where as the deep earthquakes associate with oblique to strike-slip fault planes. The concentration of earthquake epicenters in the central and northern part of Gulf of Gökova is an important evidence for the seismic activity of the central part and northern margin of the Gökova Graben. However, the increase in the density of deep focused earthquakes at the south and SW of Reşadiye Peninsula must be related with northward subduction along the Aegean trench. Based on the earthquakes of the historic period and seismic activity of the region, we can conclude that the seismic risk and tsunami probability of the region is still very high.

Key Words: Datça, Gulf of Gökova, neotectonic, Reşadiye Peninsula, seismicity, southeast Aegean Sea, southwest Anatolia

ÖZET

Tektonik gelişimi KB-GD, KD-GB ve D-B doğrultulu faylar tarafından kontrol edilen güneybatı Anadolu'daki en önemli morfolojik ve yapısal unsurlar, KB-gidişli Datça Grabeni, D-B doğrultulu Reşadiye Yükselimi, Gökova Grabeni ve Hisarönü Grabeni'dir. Temelini Likya Napları'nın oluşturduğu Reşadiye Yarımadası'nın orta kesiminde yer alan Datça Grabeni, Erken Pliyosende KB-gidişli güney kenar fayı kontrolünde yarı-graben olarak gelişmeye başlamıştır. Graben, geç Pliyosen'e (geç Piyasensiyen) kadar sığ denizle bağlantılı lagün-akarsu ortamında gelişimini sürdürmüştür. Erken Kuvaternerde K-G doğrultulu genişlemeye bağlı olarak gelişmeye başlayan Gökova Grabeni ve Hisarönü Grabeni, Datça Grabeni'nin gelişimini sonlandırmıştır. Yaklaşık 120 km uzunluğunda olan Gökova Grabeni batıya doğru 5 km genişlikten yaklaşık 30 km genişliğe ulaşır ve en batı ucunda aktif Yali ve Nisyros volkanik merkezleri yer alır. Grabenin güney kenarını sınırlayan yaklaşık D-B gidişli kenar fayları ve Hisarönü Grabeni'nin kuzey kenar fayları Datça Grabeni'nin geç Pliyosen yaşlı çökellerini keser ve Reşadiye Yükselimi bu iki graben arasında yükselir. Bu durum Gökova ve Hisarönü Grabenlerinin erken Kuvaternerde gelişmeye başladığının önemli bir kanıtıdır.

Bölge, güneydoğu Ege Denizi'nin sismik aktivitesi en yüksek olan yerlerinden biridir. Tarihsel ve aletsel dönemlerdeki kayıtlar, bölgede şiddeti X, büyüklüğü (Ms) 7,7'ye ulaşan depremlerin ve tsunamilerin varlığını göstermektedir. Bölgede 2000–2006 yılları arasında meydana gelen depremlerin (Ms≥4) odak derinlikleri ve fay düzlemi çözümleri incelendiğinde sığ depremlerin D-B doğrultulu normal fay, derin odaklı depremlerin ise oblik karakterli fay düzlemleriyle ilişkili olduğu görülmektedir. D-B doğrultulu normal faylarla ilişkili sığ depremlerin Gökova Körfezi ortalarında ve kuzeyinde yoğunlaşması Gökova Grabeni'nin orta kesimlerinin ve kuzey kenarının da halen aktif olduğunun önemli bir kanıtıdır. Reşadiye Yarımadası'nın güneyinde ve GB'sında yoğunlaşan derin odaklı depremler ise kuzeye dalan Ege yitim zonundaki hareketlerden kaynaklanmalıdır. Tarihsel dönemdeki depremler ve bölgedeki sismik aktiviteler göz önüne alındığında bölgede tsunami üretecek büyüklükteki depremlerin olma olasılığının oldukça yüksek olduğu görülmektedir.

Anahtar Kelimeler: *Datça, Gökova Körfezi, güncel tektonik, Reşadiye Yarımadası, depremsellik, güneydoğu Ege Denizi, güneybatı Anadolu*

INTRODUCTION

The geology and geomorphology of the Reşadiye Peninsula and surrounding region, located at Southwest Anatolia, to the Northeast of the Aegean Arc (Figure 1) have attracted the earth scientists, starting from the beginning of 20th century (Philippson, 1915; Chaput 1947, 1955; Tintant 1954; Rossi 1966; Orombelli et al. 1967; Becker-Platen 1970; Erol 1968, 1976, 1983).

The studies are mostly concentrated on the volcanism, geomorphology and tectonics of the peninsula and surrounding areas. The Pliocene-Quaternary volcanism of the region has been studied by Ercan (1980), Ercan et al. (1984). Based on the age obtained by Ar/Ar dating, Smith et al. (1996) suggest that the age the volcanic activity affecting Kos Island and surrounding region is 161 ka. Allen and Cas (2002) examined the pyroclastics exposing around the Kos island, Bodrum and west of Reşadiye Peninsula. They put forward the idea that the origin of these pyroclastics is the same with the pyroclastics formed 161 ka ago. According to these authors, these pyroclastic flows have reached to the neighboring islands, Bodrum and Reşadiye Peninsula after this volcanic activity. Kayan and Tuna (1985) studied the geomorphology of the Reşadiye Peninsula and discussed the natural environmental characteristics affecting the old Knidos settlement. Kayan (1988) studied the sea level changes of late Holocene at west Anatolia and mentioned importance of these changes. Ersoy (1990, 1991) investigated the stratigraphy and tectonics of the Reşadiye Peninsula. Based on their detailed studies, Görür et al. (1995) discussed the origin of rifts around Gökova region. Kurt et al. (1999) pointed out the presence of submarine active tectonism in the Gulf of Gökova by using multi-channel seismic reflection data. They also pay attention to the role of southern marginal faults of Gökova Graben during the formation of the graben.

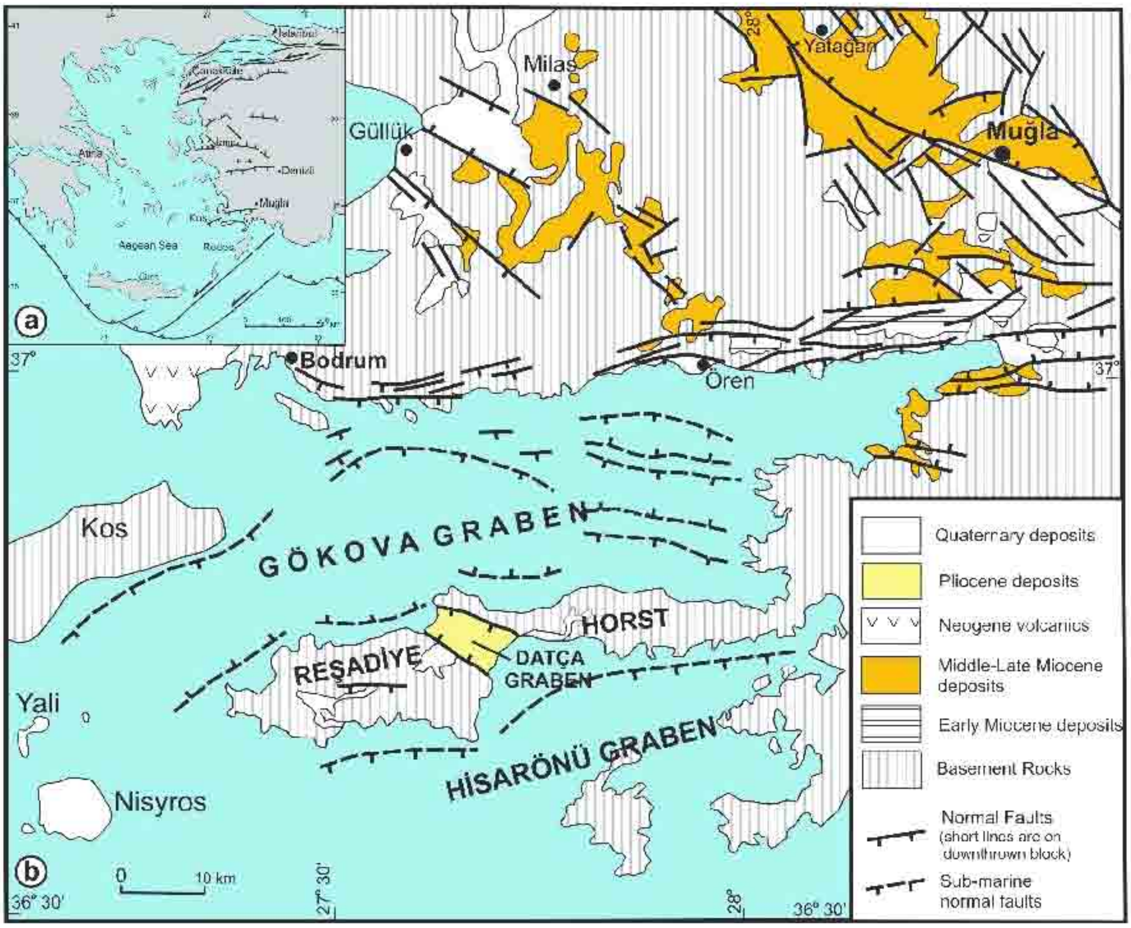

Figure 1. (a) Simplified tectonic map of the Aegean region, (b) General tectonic map of the Reşadiye Peninsula and surrounding regions (modified from Görür et al. 1995 and Kurt et al. 1999).

Şekil 1. *(a) Ege'nin basitleştirilmiş tektonik haritası, (b) Reşadiye yarımadası ve civarının genel tektonik haritası (Görür vd. 1995 ve Kurt vd. 1999'dan değiştirilerek alınmıştır).*

Based on their studies around Ören (Muğla) and surrounding regions, Gürer and Yılmaz (2002) try to explain the origin of Ören and Gökova Grabens. Kapan Yeşilyurt and Taner (2002), examined the stratigraphy and gastropoda-pelecypoda fauna of Datça and surrounding regions, and they indicate that this fauna characterize the late Piacenzian. Altunel et al. (2003) suggest the presence of two seismic activities in ancient Knidos. Dirik et al. (2003) examined the relationship between the geomorphology-neotectonics and settlement-development of old civilizations in the central part of Reşadiye Peninsula.

The earthquakes of 3-4 August 2004 and 10-11 January 2005 with magnitudes of 5.2, 5.1 and 5.0, 5.1 and hundreds of aftershocks hit the Gökova bay and caused to increasing the interest of the scientists over the region. The main objective of this paper is to discuss the active tectonics and seismicity of the region, based on the recent studies of the author and the latest earthquakes occurred in the region.

STRATIGRAPHIC OUTLINE OF THE REGION

The rock units exposing in the Reşadiye Peninsula are divided into basement rocks and a cover sequence. The rock units older than Pliocene are considered to be basement rocks and their Plio-Quaternary cover is considered to be cover sequence (Figures 2 and 3).

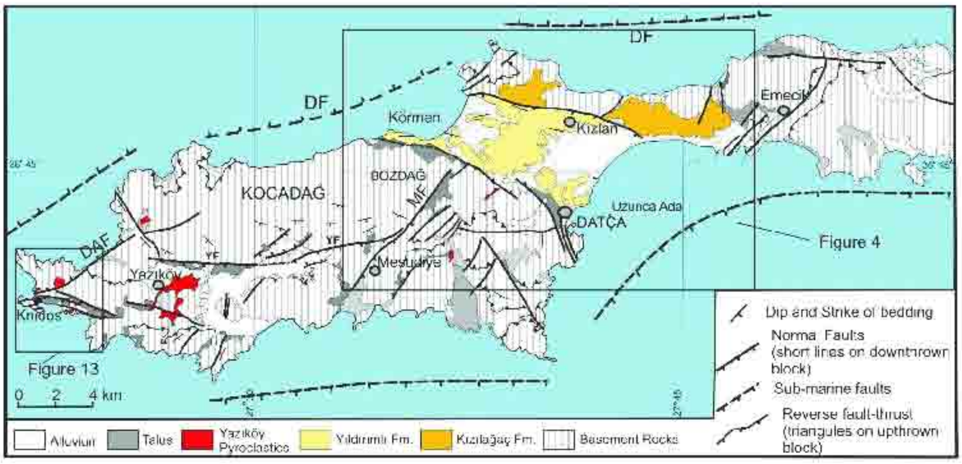

Figure 2. Geologic map of the western part of Reşadiye Peninsula. DF: Datça fault, MF: Mesudiye fault, YF: Yakaköy fault, DAF: Damlaca fault.

Şekil 2. *Reşadiye Yarımadası batı kesiminin jeolojik haritası. DF: Datça fayı, MF: Mesudiye fayı, YF: Yakaköy fayı, DAF: Damlaca fayı.*

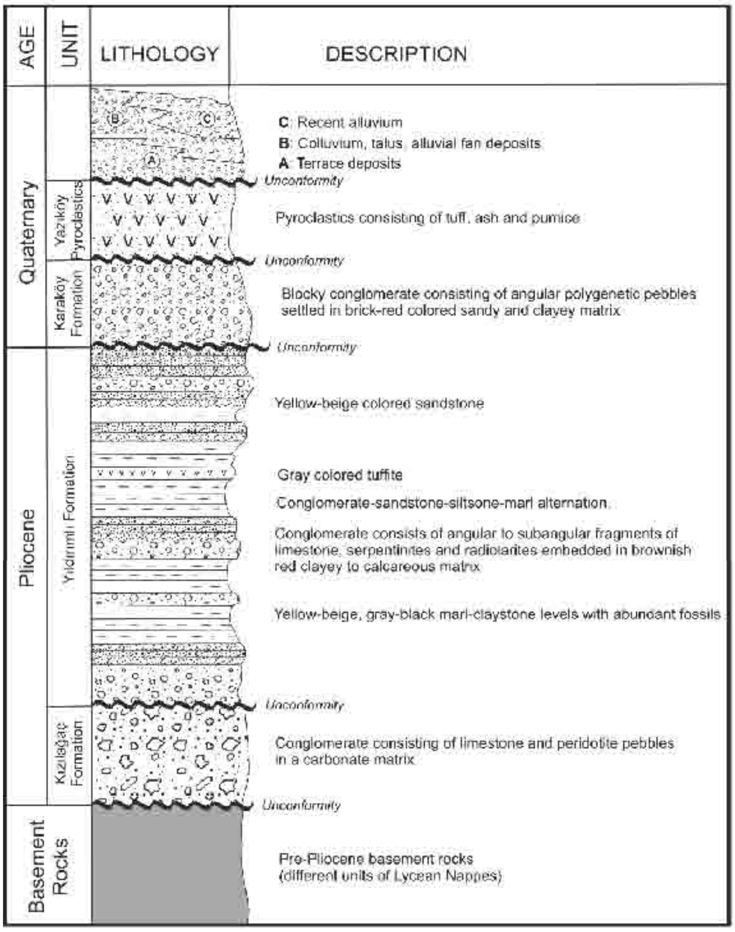

Figure 3. Generelized stratigraphic columnar section of the study area.

Şekil 3. *Çalışma alanının genelleştirilmiş stratigrafik dikme kesiti.*

Basement Rocks

The basement rocks consist of different units of Lycean Nappes including: ophiolites and ophiolitic mélange, early Jurassic massive carbonates, middle-late Jurassic radiolarite, cherty limestone and overlaying early Maestrichtian clayey biomicrite and marl levels and blocky flysch of Late Cretaceous-early Eocene (Ersoy 1990, 1991).

Plio-Quaternary Cover Sequence

There is very important time gap between Plio-Quaternary cover sequence and pre-Eocene rock units in the Reşadiye Peninsula. The early Pliocene conglomerate, sandstone and pebbly limestone (Kızılağaç formation); the Latest Pliocene (Piacenzian) fluvial-lacustrine to shallow marine sandstone, conglomerate, marl, claystone, oolitic limestone alternation with thin tuff intercalations (Yıldırımlı formation), unconformably overlies all of the older rocks. The Yıldırımlı formation is unconformably overlain by Karaköy formation in marginal facies character. Yazıköy pyroclastics, terrace deposits, colluviums, talus, alluvial fans, beach rock, beach sand and gravel, and alluvium constitute the younger cover units.

Kızılağaç Formation

This unit is observed at the north and northeast of Datça Graben (Figure 2) and first named in this study. The sequence starts with conglomerate consisting of limestone and peridotite pebbles in a carbonate matrix. Locally it consists of pebbly limestone. Based on its stratigraphic the early Pliocene age was attributed to this unit by Ersoy (1990).

Yıldırımlı Formation

This unit, displaying great lithologic variations vertically and laterally, is first named by Rossi (1966) as Yıldırımlı Formation and Pliocene age is attributed to this unit by this author. Later, Görür et al. (1995) named the same unit as Datça formation, but because of its priority, the Yıldırımlı Formation term is used here. The unit has wide spread around Reşadiye, Hızırşah, Kızlan and Körmen vicinities (Figures 2, 4).

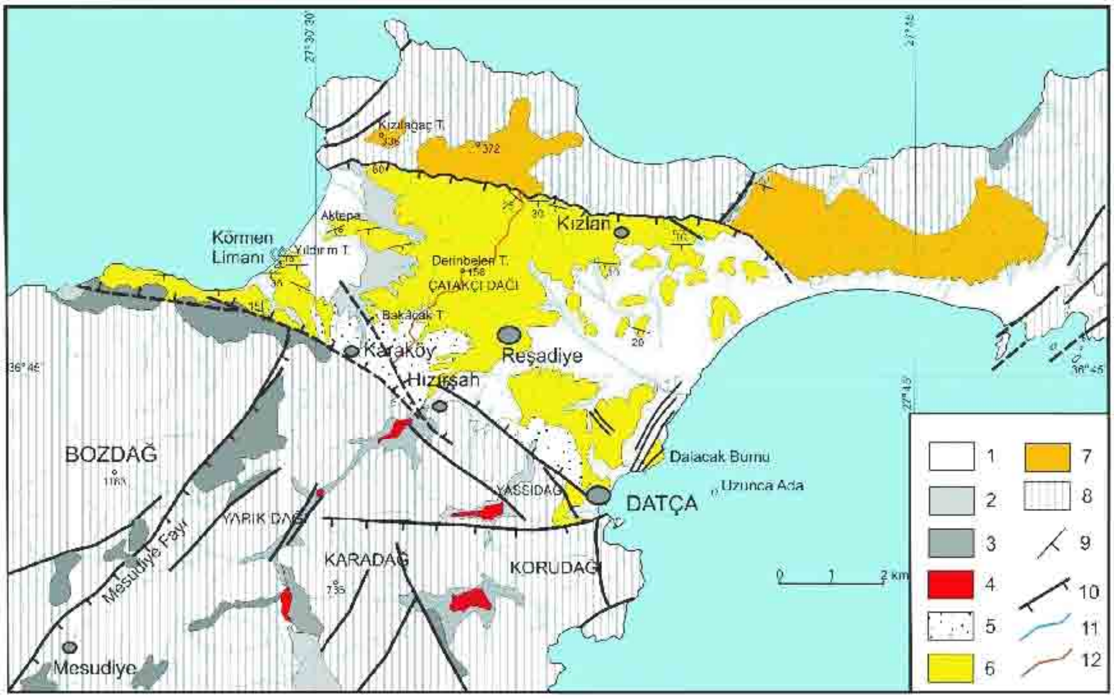

Figure 4. Neo-tectonic map of the Datça Graben and surrounding regions. 1. Alluvium, 2. Alluvial fan, 3. Talus, 4. Yazıköy pyroclastics, 5. Karaköy formation, 6. Yıldırımlı formation, 7. Kızılağaç formation, 8. Basement rocks, 9. Dip and strike of bedding, 10. Faults, 11. Creeks, 12. Water-shed line.

Şekil 4. *Datça Grabeni ve civarının güncel-tektonik haritası. 1. Alüvyon, 2. Alüvyon yelpazesi, 3. Yamaç molozu, 4. Yalıköy piroklastikleri, 5. Karaköy formasyonu, 6. Yıldırımlı formasyonu, 7. Kızılağaç formasyonu, 8. Temel kayalar, 9. Tabaka eğim ve doğrultusu, 10. Faylar, 11. Dereler, 12. Su bölüm çizgisi.*

At the west of Körmen, the lower part of the unit is characterized by conglomerate-sandstone and marl alternation. The pebbles of loose conglomerate were derived from serpantinite, gabbro and radiolarites. The sandstone beds interlayer with yellow-beige, gray-black marl-claystone levels with abundant fossils (Figure 5). The unit contains thin gray colored tuff layers around Yıldırım Tepe. The Yıldırımlı Formation juxtaposes with serpantinites along the WNW-trending northern margin of Datça Graben. Along this margin, the Yıldırımlı Formation is characterized by conglomerate which consists of angular to sub angular fragments of limestone and serpentinites embedded in brownish red clayey to calcareous matrix. Additionally, along the northern margin the formation displays great lithological variations starting from bottom to top (Ersoy, 1990). At the north of Kızlan village, the bottom levels are characterized by fluvial conglomerates which their pebbles has been derived from ophiolites and limestones and embedded in a sandy, clayey matrix. The bottom strata more eastwards is characterized by lacustrine thick bedded, white colored oolitic limestone which includes ophiolite and chert fragments in further east. At the most eastern side, the lithology changes into oolitic, pisolithic and concretional limestones (Ersoy, 1990). Upward, this sequence grades into the lacustrine sediments consisting of conglomerate, sandstone, claystone, marl and, rare limestones and dolomite. At the Dalacak Burnu, located to the northeast of Datça (Figure 4), the Yıldırımlı formation unconformably overlies highly brecciated, gray colored recrystallized limestones. At this locality the sequence starts with the conglomerates, which angular fragments have been derived mostly from gray colored limestone, rarely from sandstones, and cemented with a calcareous material. It continues upward with polygenetic blocky conglomerate and grades to conglomerate-red colored silty sandstone-clay alternation.

Based on the gastropoda-pelecypoda fauna, the late Piacenzian age was attributed to the Yıldırımlı formation by Kapan-Yeşilyurt and Taner (2002). According to ESR (Electron Spin Resonance) dating, the age of the unit is 1.891-1.998 Million years (Kapan-Yeşilyurt and Taner, 2002). Great lateral, vertical lithologic variations and fossil descriptions (Ersoy 1990; Kapan-Yeşilyurt and Taner 2002) indicate rapid marine transgression following fluvio-lacustrine deposition and finally sudden regression in the Datça Graben.

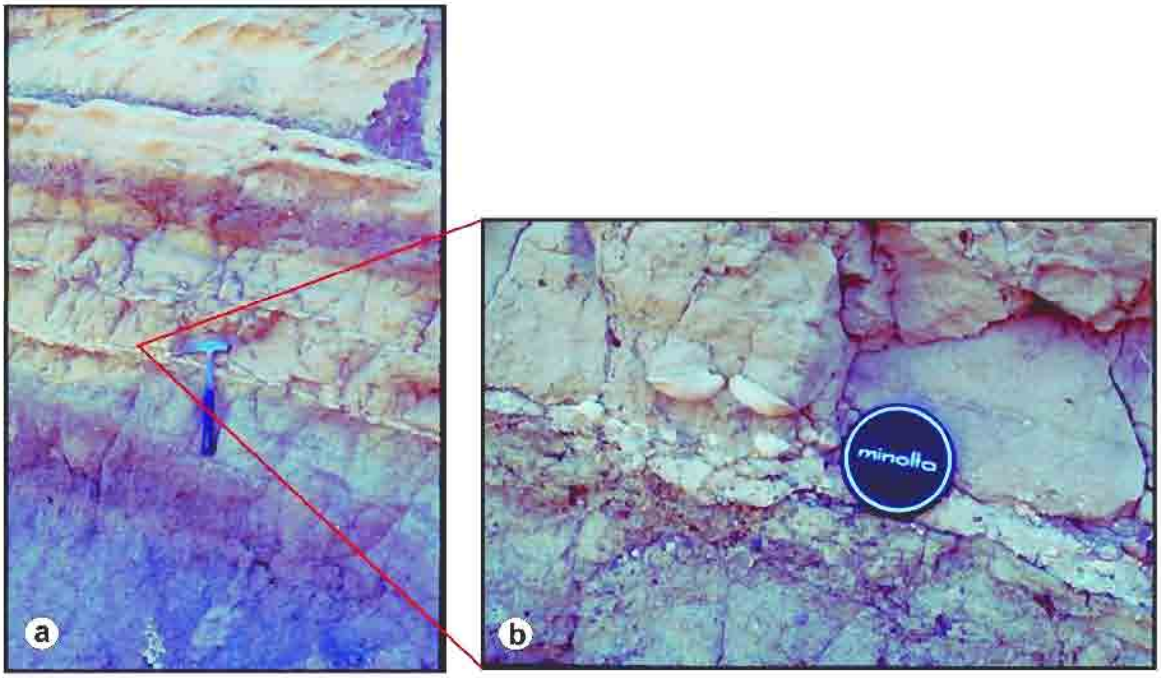

Figure 5. General (a) and close up (b) view of fossiliferous level of the Yıldırımlı formation (West of Yıldırımlı *Tepe)*.

Şekil 5. *Yıldırımlı formasyonunun fosilli seviyelerinin genel (a) ve yakın (b) görünümü (Yıldırımlı Tepenin batısı).*

Karaköy Formation

This formation is well exposed around Karaköy and northwest of Datça along the southern margin of Datça Graben (Figure 4). It is firstly named in this study. Karaköy formation is characterized by its red color. Nearly horizontal Karaköy formation unconformably overlies underlying Yıldırımlı formation. It has developed as marginal facies of graben due to rapid uplift and erosion of the western part of the Reşadiye horst, and characterized by blocky conglomerate consisting of angular polygenetic pebbles settled in brick-red colored sandy and clayey matrix. Away from the margin, the grain size decreases and the unit grades into the red sandstone, green-yellow claystone-mudstone alternation. Since it unconformably overlies the late Piacenzian Yıldırımlı Formation, the age of the Karaköy formation must be early Quaternary.

Yazıköy Pyroclastics

The Yazıköy pyroclastics, consisting of tuff, ash and pumice, are well exposed in the valleys and coastal sections of western part of Reşadiye Peninsula (Figures 2, 6 a,b,c,d). It is first named in this study. The source for these pyroclastics lies at the eastern end of the modern Aegean volcanic arc which extends from the Greek mainland to Turkey (Figure 1a) (Dewey and Şengör, 1979; Ercan et al., 1984; Allen and Cas, 2002). Allen and Cas (2002) named these rocks as the Kos Plateau Tuff (KPT). According to these authors, the source of the KPT was between Kos and Nisyros (Figure 1B) and the KPT pyroclastic flows probably crossed open sea to the south and east of the source in the eastern Aegean Sea. Single-crystal Ar-Ar analysis of sanidine crystals dated the KPT as 161 ka (Smith et al. 1996).

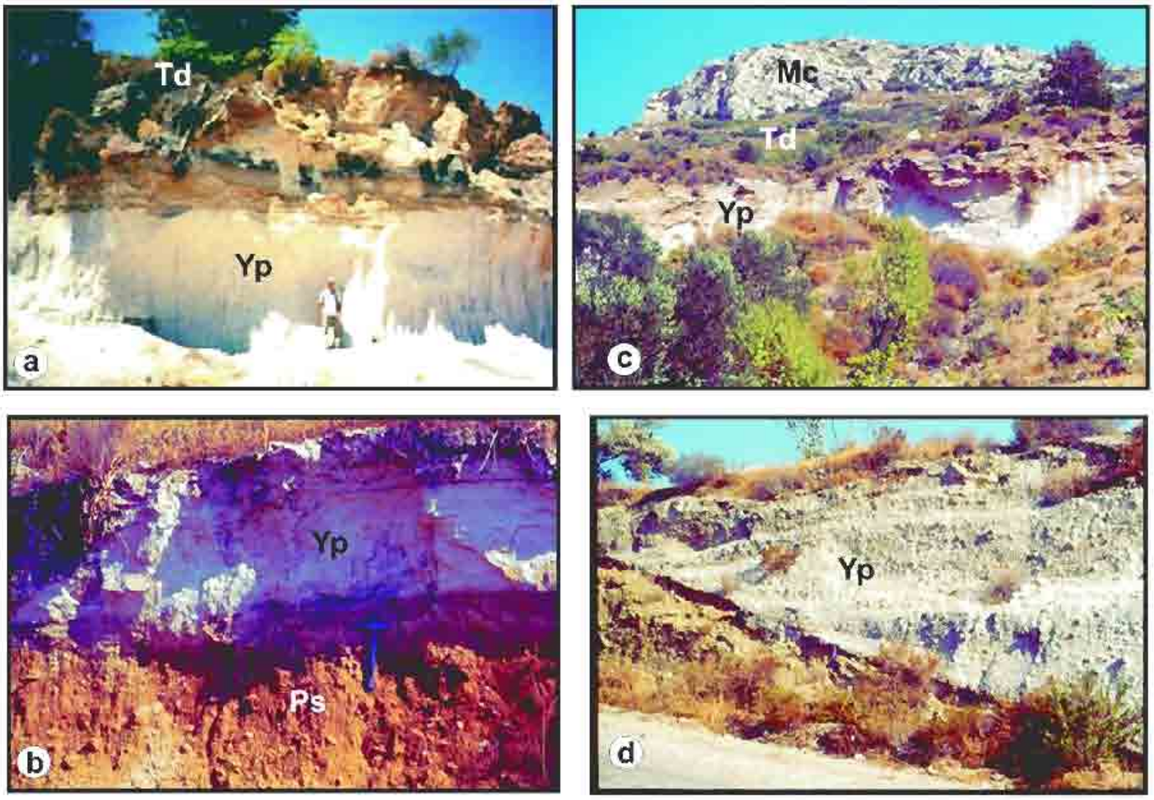

Figure 6. (a) General view of Yazıköy pyroclastics in a quarry (SW of Karaköy); (b) View of pyroclastics flowing on paleo-soil (south of Yazıköy); (c) General view of pyroclastics beneath hanging terrace deposits (SW of Hızırşah); (d) Pyroclastic flow over the basement rocks (south of Yazıköy). Td: Terrace deposits, Py: Yazıköy pyroclastics, Ps: Paleo-soil, Mc: Mesozoic carbonates.

Şekil 6. *(a) Yazıköy piroklastiklerinin bir ocak içindeki görünümü (Karaköy'ün GB'sı); (b) Eski-toprak üzerine akan piroklastiklerin görünümü (Yazıköy'ün güneyi); (c) Asılı taraça çökellerinin altında yüzeyleyen piroklastiklerin genel görünümü (Hızırşah'ın GB'sı); (d) Temel üzerine yerleşmiş olan piroklastiklerin genel görünümü (Yazıköy'ün güneyi). Td: Taraça çökelleri, Py: Yazıköy piroklastikleri, Ps: Eski-toprak, Mc: Mezozoyik karbonatları.*

Terrace Deposits

These are abandoned old valley bottom deposits and mostly observed on the valley walls, 20-25 meters above the present valley floors to the west of Hızırşah (Figure 6b, 7a). They consist of the rounded to subrounded pebbles of limestone, sandstone, and serpentinite and directly overlie the pyroclastic units. This indicates that following the filling of the explosion to the valleys, the new valley floors have been developed along the valleys. Due to activity along E-W trending fault during Quaternary, the valley-fill deposits were raised and formed hanging terrace deposits by vertical erosion.

Colluvium, Talus and Alluvial Fans

Talus deposits were formed over steep slopes of limestone outcrops and at their foot. They consist of loosely cemented angular fragments of limestone. Colluvium consists of angular fragments cemented by brownish calcareous cement. They are also formed at the foot of vertical cliffs of limestone (Figure 7b). Alluvial fans were formed at the mouth of rivers in different size depending on the amount of material carried by the river or creeks.

Beach rock

These rocks are formed by cementing of the beach sand and pebbles by carbonate cement. They are found along both north and south coasts of the peninsula.

Hanging beach rock

These are raised beach rocks seen along the shores of the peninsula, which are important evidence of the sea level changes. At the north of Kızlan, they are observed at levels of about 10-15 meters and at the south of Emecik at the levels of 20-25 meters above present shore line.

Beach sand and gravel

This material is consists of uncemented sand and small pebbles, observed along the north and south of the peninsula.

Alluvium

The unconsolidated silt, sand, clay and pebbles constitute the alluvium. These deposits fill the flood plains of streams.

STRUCTURES

Two groups of structures are exposed in the region. These are the contractional paleotectonic structures, such as thrusts, folds and the extensional neotectonic structures such as normal faults and grabens.

Contractional Paleotectonic Structures

The reverse and thrust faults are important structures of the paleotectonic period (Figure 2). Since these structures are out of the scope of this article, they are not studied in detail. However, these structures are well studied and analysed by Ersoy (1990, 1991).

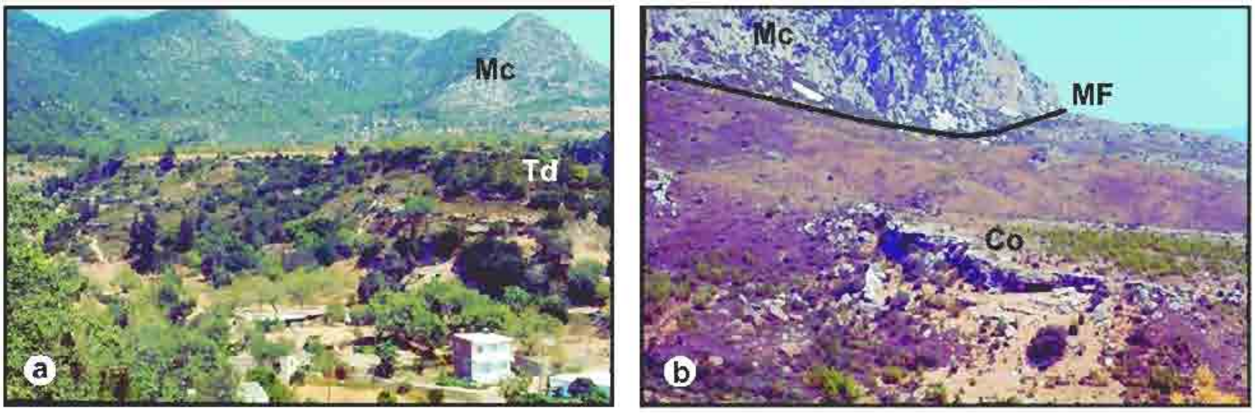

Figure 7. (a) General view of hanging terrace located in the tectonic trough to the south of Kocadağ (view to north); (b) general view of colluvium along the scarp of Mesudiye fault (MF) (east of Bozdağ, view to NE). Td: Terrace deposits, Co: Colluvium, Mc: Mesozoic carbonates.

***Şekil 7.** (a) Kocadağ'ın güneyindeki tektonik oluk içinde yer alan asılı taraça (bakış kuzeye); (b) Mesudiye fayı (MF) dikliği boyunca gelişmiş kolüvyon (Bozdağ'ın doğusu, bakış KD'ya). Td: Taraça çökelleri, Co: Kolüvyon, Mc: Mezozoyik karbonatları.*

According to Ersoy (1991), the EW- trending fold axis and reverse-thrust faults are the dominant compressional structures in the western part of Datça Graben. However, NE- trending reverse-thrust faults and asymmetric, overturned folds are the important compressional structures in the eastern part of Kızlan. Therefore these structures are the important evidence of the presence of an approximately NS- and NW-directed compressional forces in the region during the paleotectonic period.

Extensional Neotectonic Structures

SW Anatolia and Aegean Sea form one of the most active and rapidly extending region in the world (Jackson and McKenzie, 1984; Taymaz, et al., 1991, Reilinger et al., 1997; Bozkurt, 2001). It is currently experiencing an approximately, N-S continental extension at a rate of 30-40 mm/year (Oral et al., 1995; Le Pichon et al., 1995). Two different graben systems of different ages and orientations are observed in the region (Figures 1, 2 and 4). The first system is represented by NW-SE oriented grabens (Figure 1), filled with Astaracian to Turolian (about 15 to 5 Ma) sedimentary rocks intercalated locally with volcanic rocks (Görür et al. 1995, and references therein). However, the age of sedimentary rocks filling the Datça Graben is late Pliocene. The second system cuts across the first one, and is characterized by the large east-west trending Gökova and Hisarönü Grabens.

Although the scientists agree on the extensional nature of basins present in the Aegean region, the cause and origin of crustal extension in the Aegean has long been debated, and proposals fall into four different models (Bozkurt, 2001): (1) 'Tectonic escape' model: the westward extrusion of the Anatolian block along its boundary structures since the late Serravalian (12 Ma) (Şengör, 1979; Şengör et al., 1985; Şengör, 1987; Dewey and Şengör, 1979). (2) 'Back-arc spreading' model: back-arc extension caused by the south-southwestward migration of the Aegean Trench system (McKenzie, 1978; Meulenkamp et al., 1988; Le Pichion and Angelier, 1979); However, there is no consensus on the inception date for the subduction roll-back process and proposals range between 60 Ma and 5 Ma (McKenzie, 1978; Meulenkamp et al., 1988; Le Pichion and Angelier, 1979, 1981). (3) 'Orogenic collapse' model: the extension is induced by the spreading and thinning of over-thickened crust following the latest Paleocene collision across Neotethys during the latest Oligocene-early Miocene (Seyitoğlu and Scott, 1991, 1992). (4) 'Episodic' a two-stage graben model that involves a Miocene-early Pliocene first stage (orogenic collapse), and a Plio-Quaternary second phase (westward escape of the Anatolian block) of N-S extension (Koçyiğit et al., 1999).

The age of the grabens is also controversial and proposal fall into three major categories (Bozkurt 2001): (1) the grabens began to form during the Tortonian (Şengör and Yılmaz, 1981; Şengör et al., 1985; Şengör, 1987). (2) The basins started to form during the Early Miocene and continued their evolution since then (Seyitoğlu and Scott, 1991, 1992). (3) The grabens are Plio-Quaternary structures (Koçyiğit et al., 1999; Bozkurt, 2000; Yılmaz et al., 2000).

Datça Graben

E-W trending, 65 km long, only a few km wide Reşadiye Peninsula is located on the southwestern tip of the Anatolian coast (Figures 1, 8, 9). In central part of this peninsula, approximately WNW-ESE trending, 5 km-wide, 9 km-long depression, seems as a very characteristic structure. Two natural bays surround this depression, Körmen bay at the NW, and Datça bay at the SE (Figures 2, 8). This depression was first named as Datça Isthmus by Chaput (1947). But later, since the northern and southern boundaries of this depression are faulted, this tectonic depression has been named as Datça Graben (Ersoy 1990). The hills and ridges with maximum elevation of about 120 meters are located in the central part of the depression (Figure 4). This topographically high area is underlain by the late Pliocene deposits, and the layers of this unit incline to the south at about 20° forming questa ridges. The small creeks run in NE-SW direction in the north of Datça Graben by cutting across the Çatakçı Dağı. Thus the drainage pattern close to Körmen bay creates an asymmetry in the depressional area. The valleys and ridges of the northwestern part of this section are shorter and their slopes are rather steep. However, the valleys and ridges that lie in the Datça bay direction are less steep and longer. The 100-120 meters high erosional surface that cuts the late Pliocene deposits is one of the most important geomorphologic characteristics of the Datça Graben. The cut and fill terraces, seen at the mountainous regions of Reşadiye peninsula which are connected to the mountain cliffs

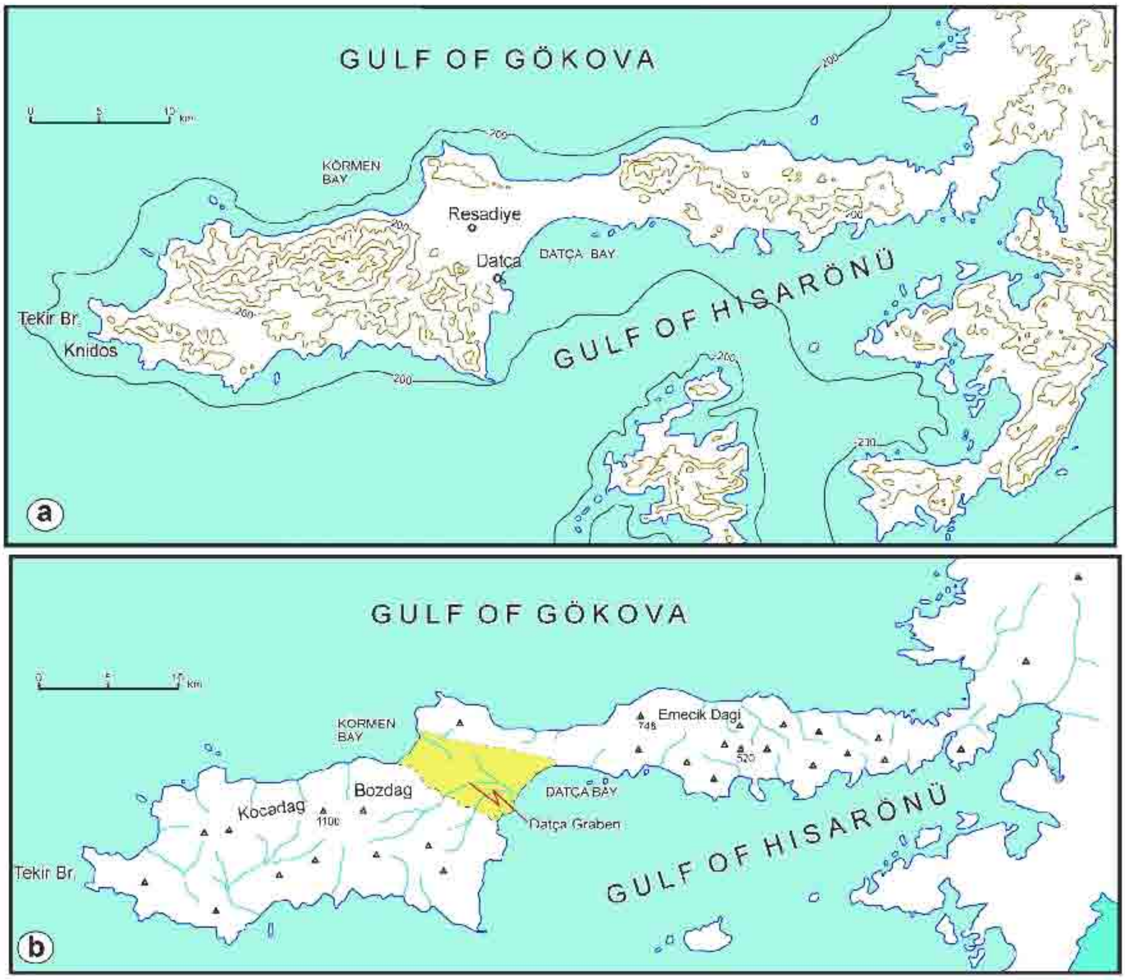

Figure 8. (a) Elevation map of the Reşadiye Peninsula (contour interval is 200 m.); (b) Drainage map of the Reşadiye Peninsula.

Şekil 8. *(a) Reşadiye Yarımadası'nın yükselti haritası (Eşyükselti eğrileri 200 m de bir geçirilmiştir. Eşderinlik eğrilerinden sadece -200 m çizilmiştir), (b) Datça Yarımadası'nın drenaj haritası.*

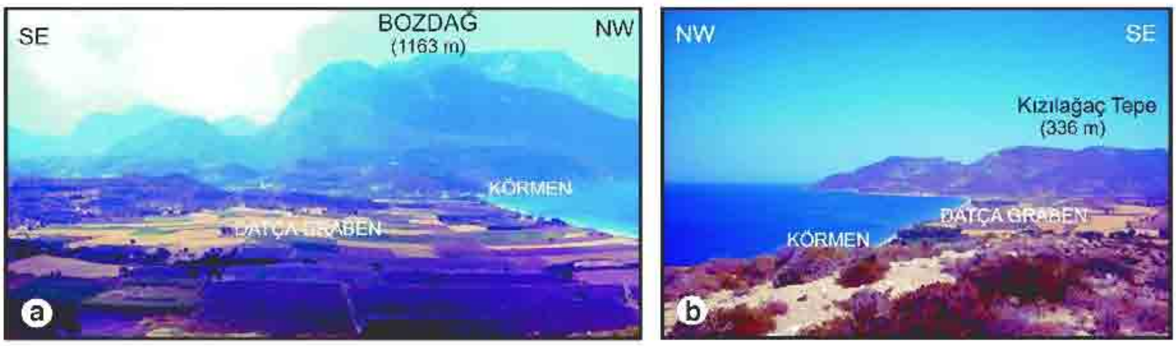

Figure 9. (a) General view of the SW boundary of the Datça Graben (view from northern boundary); (b) General view of the NE boundary of the Datça Graben (view from SW boundary).

Şekil 9. *(a) Datça Grabeni'nin GB sınırının genel görünümü (bakış kuzey kenardan); (b) Datça Grabeni'nin KD sınırının genel görünümü (bakış güney kenardan).*

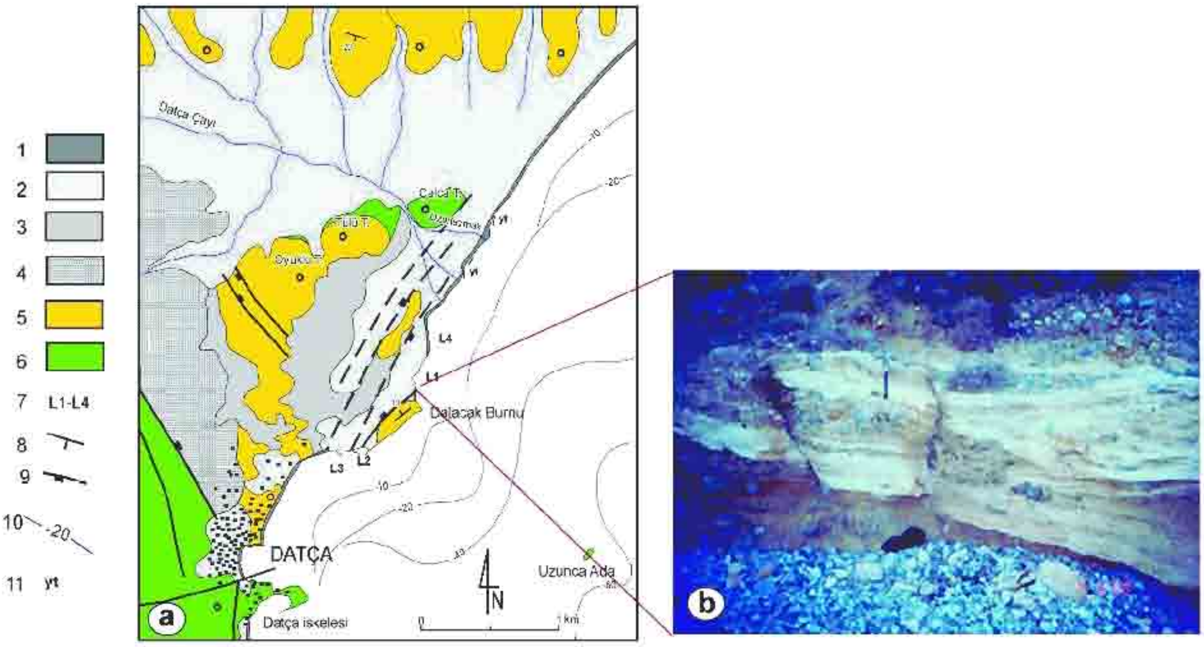

Figure 10. (a) Geologic map of the north of Datça. 1) Beach, 2) Alluvium, 3) Colluvium, 4) Karaköy formation, 5) Yıldırımlı formation, 6) Pre-Pliocene Basement rocks, 7) Ancient Knidos ports, 8) Dip and strike of bedding, 9) Normal fault, theet on downthrown block, 10) submarine contours, 11) Beach rock. (b) NE-trending normal faults (view to SE).

Şekil 10. *(b) Datça'nın kuzey kesiminin jeolojik haritası. 1) Kumsal, 2) Alüvyon, 3) Kolüvyon, 4) Karaköy formasyonu, 5) Yıldırımlı formasyonu, 6) Pliyosen öncesi Temel kayaları, 7) Eski Knidos limanları, 8) tabaka eğim ve doğrultusu, 9) Normal fay, diş düşen blokta, 10) Eş derinlik eğrisi, 11) Yalı taşı. (b) KD-gidişli normal fayların görünümü (bakış GD'ya).*

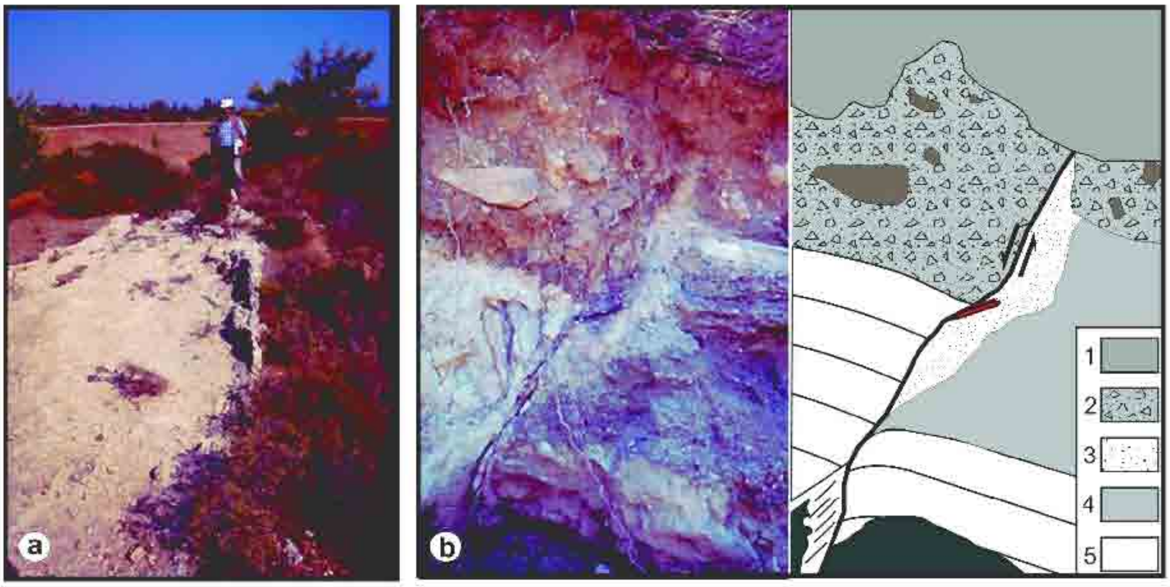

Figure 11. (a) Travertine occurrence formed along 110°-trending fracture (east of Kızlan). (b) 085°-trending very active fault cutting both Yıldırımlı formation and soil (West of Körmen). 1) recent soil, 2) soil with pebbles, 3) sandy levels, 4) Marl, 5) Clayey limestone.

Şekil 11. *(a) 110°-gidişli bir yarıktan çıkan karbonatların oluşturduğu traverten (Kızlan doğusu). (b) Yıldırımlı Formasyonu'nu ve toprak oluşumunu kesen, 085°-gidişli aktif bir fay (Körmen batısı). 1) güncel toprak, 2) çakıllı toprak, 3) kumlu seviyeler, 4) Marn, 5) killi kireçtaşı.*

by pediments, join this erosional surface. The southwestern margin of Datça Graben is bounded by a mountain front, which consists of several hills reaching up to 1100 m elevations (Figure 9a). NW-trending linear to en echelon normal faults characterizes this margin. The Yıldırımlı formation, Karaköy formation and basement rocks (Mesozoic carbonates and blocky flysch) juxtaposes along this margin. The northeastern margin of the graben is topographically less steep (Figure 9b). Along this margin, Yıldırımlı formation juxtapose with Kızılağaç formation, Mesozoic carbonates, blocky flysch and ophiolitic rocks. Lower Pliocene Kızılağaç formation unconformably overlies older rocks at the north of the northern margin of the graben (Figure 4), indicating the half graben character of the depression during its initial stage. The lithologic characteristics and fossil content of the Yıldırımlı formation indicate that the lagoonal-fluvial environment connected with shallow marine has evolved in Datça Graben till late Pliocene (late Piacenzian). The presence of NNE trending normal faults around north of Datça (Figure 10), linear travertine occurrence along 110° -trending fracture at the east of Kızlan (Figure 11a) and very young fault cutting Yıldırımlı formation and soil at the south of Körmen (Figure 11b) are important evidences of the Quaternary activities in the Datça Graben.

Gökova Graben

The Gökova Graben is mainly an EW- trending depression with 150-km-long, and widens westward from 5 to 30 km, located between Bodrum peninsula to the north and Reşadiye peninsula to the south (Figure 1). It forms the Gulf of Gökova. The northern margin is bounded by a linear mountain front, which rises steeply to more than 1000 m. EW-trending normal faults characterize the northern margin of the graben. The southern margin of the graben is topographically less steep, but it is also controlled by submarine listric normal fault, named Datça fault by Kurt et al. (1999) (Figures 2, 12). The EW- trending Datça fault cuts the NW-trending boundary faults of Datça Graben and its late Pliocene fill. Therefore the age of the boundary faults and basin fill of Gökova Graben must be post Pliocene.

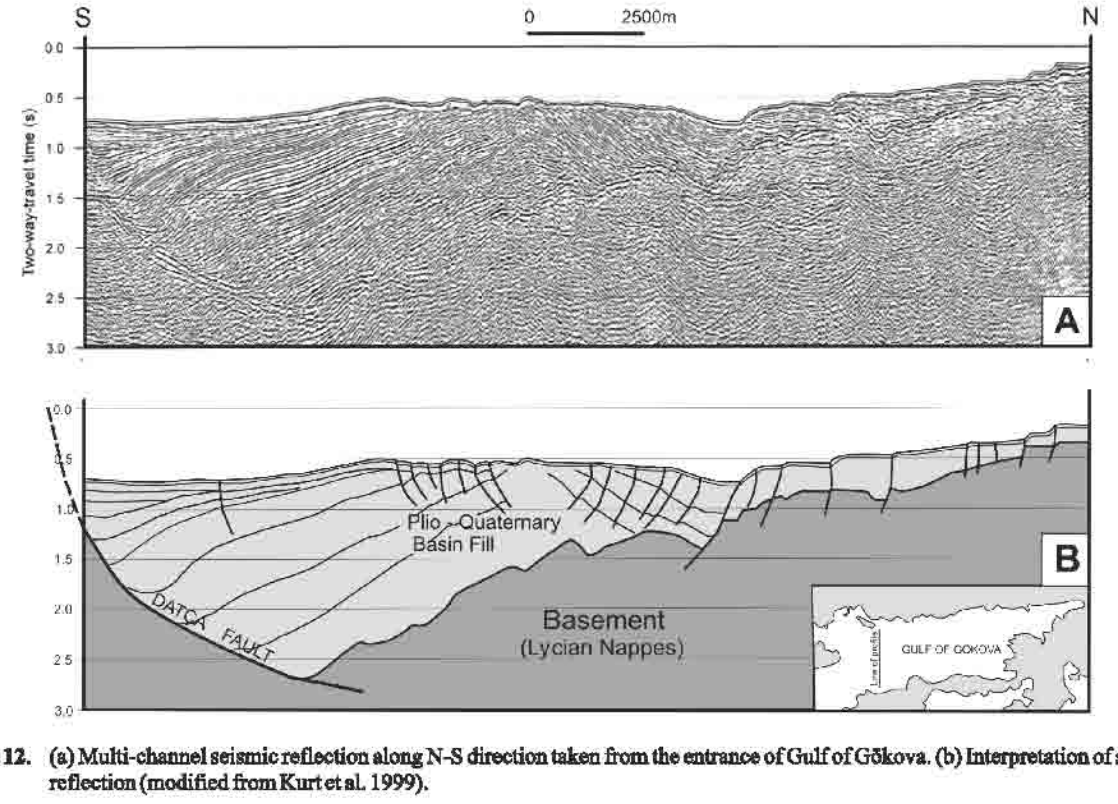

Figure 12. (a) Multi-channel seismic reflection along N-S direction taken from the entrance of Gulf of Gökova. (b) Interpretation of seismic reflection (modified from Kurt et al. 1999).

Şekil 12. *(a) Gökova Körfezi'nin girişinden K-G doğrultusunda alınan çok kanallı sismik refleksiyon). (b) Üstteki sismik refleksiyonun yorumu (Kurt vd. 1999'dan faydalanılmıştır).*

Normal Faults

The neotectonics and morphology of Reşadiye peninsula are both controlled by NE, NW, almost EW-trending normal faults (Figure 2).

NE-trending Faults

The most important faults of this group are Damlaca and Mesudiye faults.

Damlaca fault (DAF) is located on the western part of Reşadiye Peninsula (Figures 2, 13). On the eastern footwall of the fault, the carbonates were formed very steep fault scarps. Whereas, the Yazıköy pyroclastics and alluvial fan/talus deposits were protected on the downthrown block.

Mesudiye fault (MF) is SE dipping normal fault, extending between Mesudiye at south and south of Körmen at north (Figure 4). Triassic-Jurassic carbonates and Cretaceous wild flysch were juxtaposed along the fault. The Carbonates form very steep scarps and highland on footwall of the fault. A graben was formed at the east of Bozdağ (Figure 4). The colluvium (Figure 7b) and fluvial terrace deposits were formed in this depression.

EW-trending Faults

The Knidos fault, Yakaköy fault and submarine boundary faults of the Gökova Graben are the most important EW-trending faults of the region (Figures 2, 13).

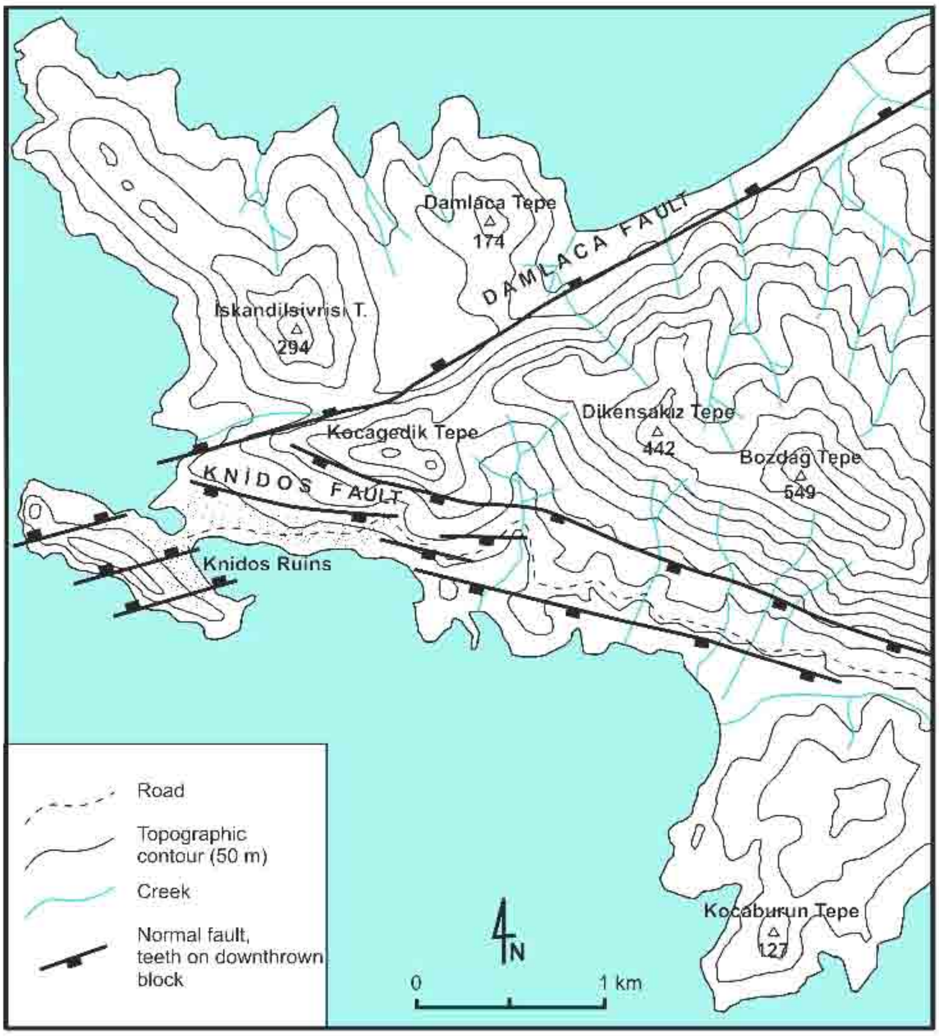

Figure 13. Normal faults shaping the western tip of Reşadiye Peninsula (modified from Altunel et al. 2000).

Şekil 13. *Reşadiye Yarımadasının en batı ucunu şekillendiren normal faylar (Altunel vd. 2000'den yararlanılmıştır).*

Knidos fault (KF) is a normal fault located in the western tip of Reşadiye Peninsula (Figure 13). It is characterized by a limestone scarp, 6-10 m in height, which forms a natural bluff on which the city walls of Knidos were built (Figure 14a). Along the trace of the fault, massive Jurassic limestone and Quaternary talus deposits are juxtaposed (Figures 14 b, c). The ancient site of Knidos lies directly on this active normal fault. The archaeological studies reveal the presence of at least two destructive earthquakes in the site (Altunel et al. 2003). Fresh geomorphic expression of a scarp defining the boundary between massive limestone and Quaternary, and archaeological evidences such as parallel fallen columns, tilted, offset or rotated structures are important evidence of the Holocene activity of this fault.

Yakaköy fault (YF) is an EW-trending, about 15 km long normal fault located on the southern margin of Kocadağ (Figure 2). It controls the northern boundary of EW-trending trough, filled with Yazıköy pyroclastics, colluvium and old alluvium. Cut and fill terraces are important morphologic feature of this trough (Figure 7a).

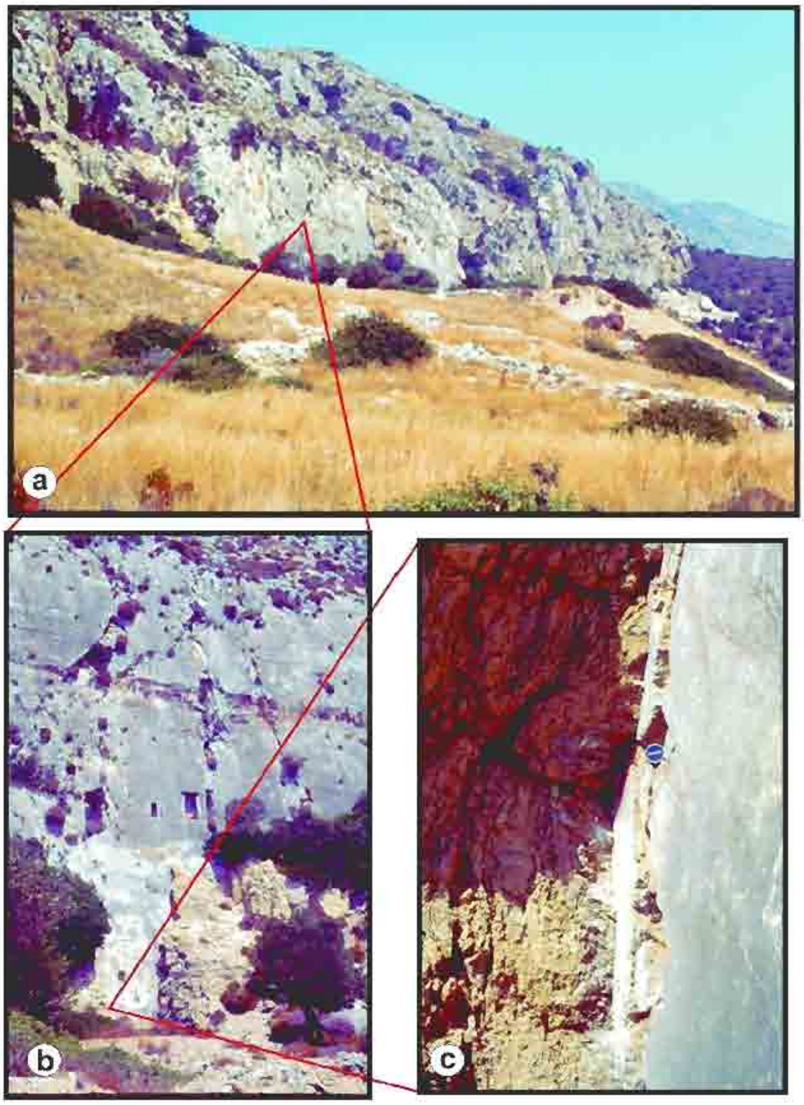

Figure 14. (a) General view of the fault scarp of the Knidos Fault (view to NE). (b,c) Close-up views of the same fault plane.

Şekil 14. *(a) Knidos Fayı fay dikliğinin genel görünümü (KD'ya bakış). (b,c) aynı fay düzleminin yakın görünümü.*

SEISMICITY OF THE REGION

The Reşadiye Peninsula and its surrounding region are located in one of the seismically most active region of the world (Figure 15). Several major destructive earthquakes have struck this region (Table 1, 2, 3; Figure 16). There are three main sources of earthquakes in the region: (1) the northward-moving African Plate, subducting below the southwest-moving Aegean block, and associated transcurrent faults, (2) Intense volcanic acticity along Aegean volcanic arc: west of the peninsula lay the active volcanic centers of Nisyros and Yali (Figure 16). Major eruptive activity has occurred on Nisyros in recent times (AD 1887, 1873 and possibly around 1422) and these violent volcanic events may have been associated with intense seismic activity (Stiros 2000 and references therein). (3) Another important source for the earthqukes of the region is the active submarine faults of the Gökova Graben. 4/08/2004 earthquakes (Table 3; Figure 16) are the important evidence of the seismic activity of the northern boundary and submarine faults of the Gökova Graben.

In addition to these potential earthquake sources the Knidos Fault, on which ancient Cnidos city is located, is important source for earthquakes.

When the figure 16 is analyzed carefully, the earthquakes can be grouped into two based on the fault plane solutions: (1) Approximately NE-trending oblique-slip faults with moderate to deep epicenters (45-165 km) concentrated in the southwestern part of the peninsula. (2) EW-trending normal faults with shallow depth (<15 km), concentrating in Gökova Graben (Table 3, Figure 15). This observation can be explained by: (1) to the south and southwest of the peninsula, the northward-moving African Plate is subducting below the southwest-moving Aegean block. This movement generates large earthquakes below the peninsula along the transcurrent systems parallel to Pliny-Strabo transform. (2) The roll-back process along the subducting slab generates extension near the surface resulting in earthquakes with shallow depth in and around the EW-trending Gökova Graben.

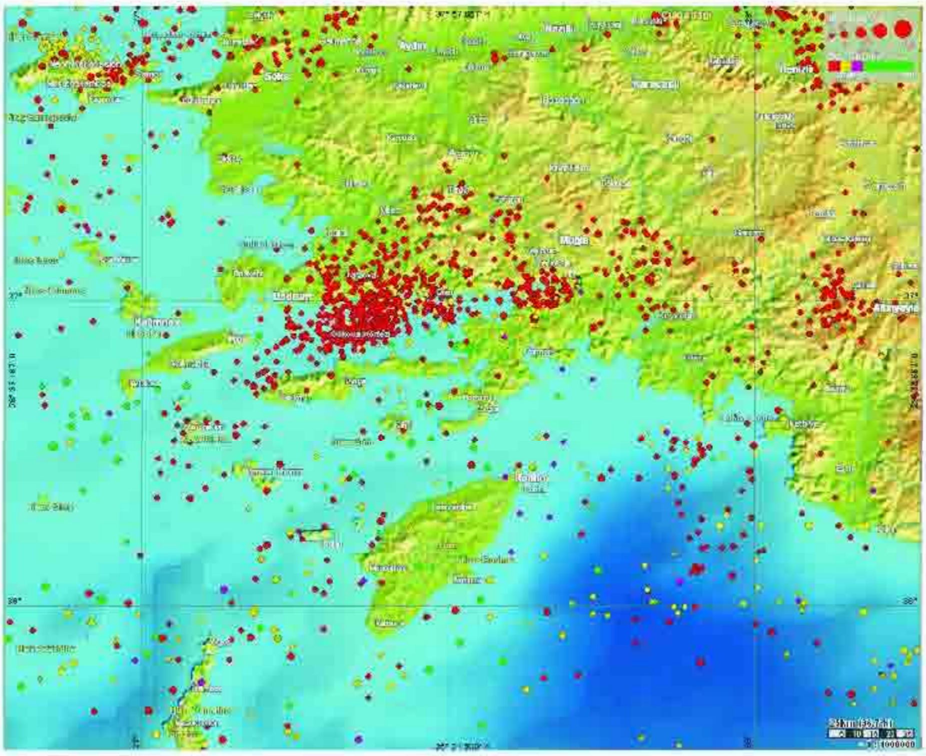

Figure 15. The epicenters of the earthquakes occurred in and around Gulf of Gökova between 2002-2007 (M=>3) (source: Earthquake monitor).

Şekil 15. *Gökova körfezinde ve civarında 2002-2007 yılları arasında meydana gelen depremlerin merkez üstleri (M=>3) (Kaynak: Deprem monitörü).*

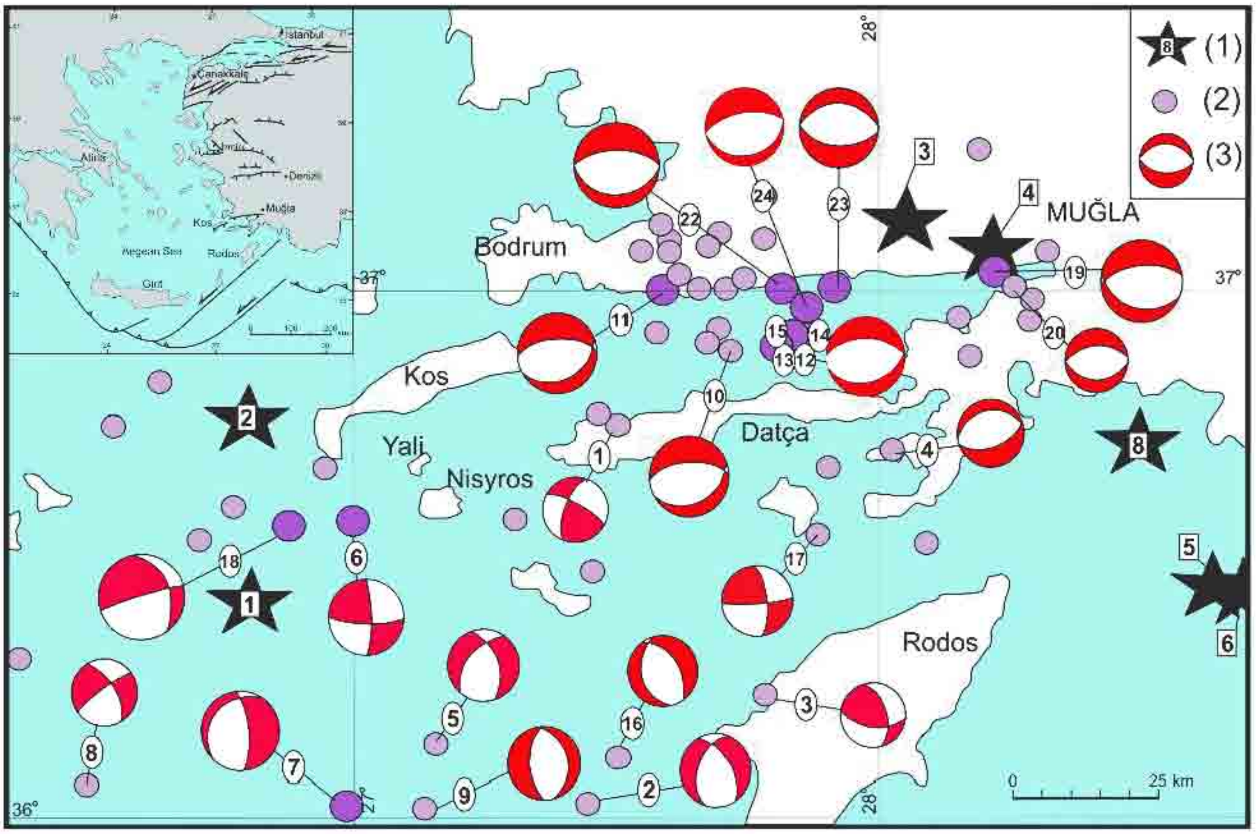

Figure 16. The epicenters of destructive earthquakes of instrumental period (1) and epicenters of the earthquakes (2) with fault plane solutions (3) occured between 2000-2006 in the region. See table 2 and 3 for details. (source: SED moment tensors and KOERİ).

Şekil 16. *Aletsel dönemdeki yıkıcı depremlerin merkezüstleri (1) ve 2000-2006 yılları arasında meydana gelen yıkıcı depremlerin merkezüstleri (2) ile fay düzlemi çözümleri (3). Detay için Tablo 2 ve 3'e bakınız (Kaynak: SED moment tensors ve KOERİ).*

Table 1. **Destructive historical earthquakes of the region (Source: KOERİ).**

Tablo 1. ***Bölgedeki yıkıcı tarihsel depremler (Kaynak: KOERİ).***

Date	Lat.	Long.	Location	Intensity
MÖ 222	36.50	28.00	Rodos-(Tsunami)	X
MÖ 185	36.00	28.00	Rodos,	IX
155	36.30	28.00	Rodos,Muğla,Fethiye	X
08 08 1304	36.50	27.50	Rodos,Girit	X
03 10 1481	36.00	28.00	Rodos,GB Anadolu-(Tsunami)	IX
18 08 1493	36.75	27.00	Istankoy Adası	IX
18 10 1843	36.25	27.50	Rodos,Ege Denizi	IX
12 10 1856	36.25	28.00	Rodos, Girit-(Tsunami)	X
22 04 1863	36.50	28.00	Rodos	IX
29 02 1885	37.20	27.20	Ege Denizi	IX

Table 2. Destructive earthquakes of instrumental period. For location see Figure 15 (Source: KOERİ).

Tablo 2. *Aletsel dönemde etkili olmuş yıkıcı depremler. Lokasyon için şekil 15'e bakınız (Kaynak: KOERİ).*

No	Date	Location	Intensity	Mag. (Ms)
1	26.06.1926	Rodos (Tsunami)	IX	7.7
2	23.04.1933	Gökova Körfezi	IX	6.4
3	23.04.1941	Muğla	VIII	6.0
4	13.12.1941	Muğla	VIII	6.5
5	24.04.1957	Fethiye-Rodos	IX	6.8
6	25.04.1957	Fethiye-Rodos	VIII	7.1
7	25.04.1959	Köyceğiz-Muğla	VIII	5.9
8	23.05.1961	Rodos-Marmaris	VII	6.3
9	05.10.1999	Marmaris-Muğla	VI	5.2

Table 3. The earthquakes occurred in the region between 2000-2005 (M>4). (Source: KOERİ)

Tablo 3. *Bölgede 2000-2005 yılları arasında meydana gelen depremler (M>4). (Kaynak: KOERİ).*

No	Date	Lat.	Long.	Magnitude			Depth
				Mw	Mb	Ms	(km)
1	16/9/2000	36.722	27.505	4.32	4.5		57
2	21/12/2001	36.002	27.447	4.71	4.5		9
3	02/10/2002	36.270	27.780	4.22	4.3		45
4	26/09/2002	36.667	28.028	4.41	4.5		18
5	30/01/2003	36.270	27.170	4.72	4.4		9
6	13/09/2003	36.629	26.918	4.99	5.2		153
7	7/02/2004	36.040	26.910	5.21	5.2	5.1	9
8	18/03/2004	36.081	26.475	4.38	4.5		90
9	25/05/2004	35.920	27.180	4.79	4.6		15
10	3/08/2004	36.884	27.703	4.81	4.5		9
11	3/08/2004	37.020	27.720	5.30	4.8		9
12	4/08/2004	36.833	27.815	5.64	5.1	5.2	9
13	4/08/2004	36.788	27.826	4.65	4.4	3.7	9
14	4/08/2004	36.843	27.850	5.26	5.2	4.8	9
15	4/08/2004	36.832	27.827	5.41	4.9	4.8	9
16	18/08/2004	36.130	27.520	4.63	4.3		12
17	20/08/2004	36.536	27.881	4.66	4.6		66
18	7/10/2004	36.429	26.796	5.61	5.7		165
19	20/12/2004	37.042	28.206	5.41	5.2	4.7	9
20	21/12/2004	37.060	28.210	4.16	4.2		9
21	28/12/2004	36.996	28.267	4.33	4.5		4
22	10/01/2005	37.017	27.804	5.55	4.9	4.8	9
23	10/01/2005	37.018	27.919	5.21	5.0		9
24	10/01/2005	36.917	27.867	5.20	5.1	4.4	15

CONCLUSIONS

Based on the studies done on the Reşadiye Peninsula and surrounding regions, we can conclude that:

The NW-SE, NE-SW and E-W- trending faults have conrolled the both morphology and neotectonics of the region.

The Datça Graben has been started to develop as a half graben on the Lycean Nappes of the central part of the Reşadiye Peninsula under the control of NW-trending southern marginal fault during early Pliocene. It has evolved its evolution as a graben and lagoonal-fluvial environment connected with a shallow sea till late Pliocene (late Piacenzian).

E-W trending Gökova and Hisarönü Grabens, started to develop under the control of N-S directed extension, end the development of the Datça Graben at the early Quaternary.

Based on the fault plane solutions and depth of the focus of the earthquakes occurred between 2000-2006, we can conclude that shallow depth earthquakes are associated with EW-trending normal faults in the Gulf of Gökova. However, moderate to deep earthquakes are associated with oblique to strike-slip fault planes at the south and southwestern part of Reşadiye peninsula. So, for the earthquakes of the region two sources can be proposed: (1) the northward-moving African Plate subducting below the southwest-moving Aegean block generates large and deep earthquakes below the peninsula along the transcurrent systems parallel to Pliny-Strabo transform. (2) The roll-back process along the subducting slab generates extension near the surface causing shallow earthquakes in and around the EW-trending Gökova Graben.

The concentration of shallow depth earthquakes in the Gökova Graben is an important evidence for the activity of boundary and submarine faults of graben.

Acknowledgements

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GENİŞLETİLMİŞ ÖZET

KB-gidişli Datça Grabeni, D-B doğrultulu Reşadiye Yükselimi, Gökova ve Hisarönü grabenleri güneybatı Anadolu'daki en önemli morfolojik ve yapısal unsurlardır. Reşadiye Yarımadası'nın orta-batı kesiminde yer alan kaya birimleri Pliyosen öncesi temel kayalar ve Plio-Kuvaterner örtü kayaları olmak üzere iki grupta incelenmiştir. Temel kaya birimleri, Likya Naplarının ofiyolit, ofiyolitik melanj, erken Jura masif karbonatları, orta-geç Jura radyolarit, çörtlü kireçtaşı ve bunları örten erken Maastrihtiyen marn ara seviyeli killi mikrit ve geç Kretase-erken Eosen bloklu filiş ile temsil edilir (Ersoy 1990, 1991). Örtü kayaları ise erken Pliyosen kumtaşı ve çakıllı kireçtaşı (Kızılağaç formasyonu); ince tüf arakatkılı en geç Pliosen (Piyasensiyen) akarsu-göl-sığ denizel kumtaşı, çakıltaşı, marn, kiltaşı, oolitik kireçtaşı ardalanması (Yıldırımlı formasyonu); kenar fasiyesi karakterli Karaköy formasyonu; Yazıköy piroklastikleri, taraça çökelleri, kolüvyon, yamaç molozu, alüvyon yelpazesi, yalı taşı, plaj kumu, çakılı ve alüvyon ile temsil edilir.

Çalışma alanında yüzeyleyen tektonik yapılar: bindirme, ters fay ve kıvrımlardan oluşan eski-tektonik sıkışma yapıları; normal faylarla sınırlı Reşadiye horstu, Datça, Gökova ve Hisarönü grabenleri ile bunlarla ilişkili normal faylardan oluşan yeni-tektonik genişleme yapıları ile temsil edilir.

Temelini Likya Napları'nın oluşturduğu Reşadiye Yarımadası'nın orta kesiminde yer alan Datça Grabeni'nin en yaygın birimi Yıldırımlı formasyonu'nun litolojik özellikleri grabenin geç Pliyosen'e (geç Piyasensiyen) kadar sığ denizle bağlantılı lagün-akarsu ortamında gelişimini sürdürdüğünü ortaya koymaktadır. Erken Kuvaternerde K-G doğrultulu genişlemeye bağlı olarak gelişmeye başlayan Gökova Grabeni ve Hisarönü Grabeni, Datça Grabeni'nin gelişimini sonlandırmıştır. Yaklaşık 120 km uzunluğunda olan Gökova Grabeni batıya doğru 5 km genişlikten yaklaşık 30 km genişliğe ulaşır ve en batı ucunda aktif Yali ve Nisyros volkanik merkezleri yer alır. Grabenin güney kenarını sınırlayan yaklaşık D-B gidişli kenar fayları ve Hisarönü Grabeni'nin kuzey kenar fayları Datça Grabeni'nin geç Pliyosen yaşlı çökellerini keser ve Reşadiye Yükselimi bu iki graben arasında yükselir. Bu durum Gökova ve Hisarönü Grabenlerinin erken Kuvaternerde gelişmeye başladığının önemli bir kanıtıdır.

Bölge, güneydoğu Ege Denizi'nin sismik aktivitesi en yüksek olan yerlerinden biridir. Tarihsel ve aletsel dönemlerdeki kayıtlar, bölgede şiddeti X, büyüklüğü (Ms) 7,7'ye ulaşan depremlerin ve tsunamilerin varlığını göstermektedir. Bölgede 2000–2006 yılları arasında meydana gelen depremlerin (Ms≥ 4) odak derinlikleri ve fay düzlemi çözümleri incelendiğinde sığ depremlerin D-B doğrultulu normal fay, derin odaklı depremlerin ise oblik karakterli fay düzlemleriyle ilişkili olduğu görülmektedir. D-B doğrultulu normal faylarla ilişkili sığ depremlerin Gökova Körfezi ortalarında ve kuzeyinde yoğunlaşması Gökova Grabeni'nin orta kesimlerinin ve kuzey kenarının da halen aktif olduğunun önemli bir kanıtıdır. Reşadiye Yarımadası'nın güneyinde ve GB'sında yoğunlaşan derin odaklı depremler ise kuzeye dalan Ege yitim zonundaki hareketlerden kaynaklanmalıdır. Tarihsel dönemdeki depremler ve bölgedeki sismik aktiviteler göz önüne alındığında bölgede tsunami üretecek büyüklükteki depremlerin olma olasılığının oldukça yüksek olduğu görülmektedir.

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