

Geology of the Ören and Surrounding Areas, SW Anatolia

ÖMER FEYZİ GÜRER¹ & YÜCEL YILMAZ²

¹ University of Kocaeli, Engineering Faculty, Department of Geological Engineering, Vinsan,
TR-41 100 Kocaeli - TURKEY (e-mail: ofgurur@kou.edu.tr)

² Istanbul Technical University, Faculty of Mines, Department of Geological Engineering, Maslak,
TR-80626 İstanbul - TURKEY

Abstract: On the Lycian Nappes of SW Anatolia, Neogene basins developed along two different trends in different periods. NNE-trending basins formed during the Early-Middle Miocene period as exemplified by the Ören and Yatağan grabens. These graben fills consist of three distinct rock units. At the base are (1) coarse clastics, sourced from elevated areas adjacent to the basin-bounding faults. These are linear river-valley fills. They give way upward to (2) alternating coal-bearing sandstone and limestone as the graben valleys were gradually widened, and the surrounding mountains were reduced by erosion. Finally, lake environment formed, invading the region during the advanced stage of graben development. In the lakes were deposited (3) extensive marls and limestones. The lake deposits gradually overlapped the graben shoulders. The NE-trending grabens extend SW toward the shore of the SW-NE-trending Kale-Tavas basin. The lake and the sea basin were apparently connected as evidenced by several marine incursions from the south into the Ören basin. The marine units wedge out to the north. On the graben shoulders, the Lower-Middle Miocene sediments were overlain unconformably by red, brown coarse clastic sediments as linear and axial fluvial deposits during Late Miocene time when N-S extensional tectonics began. Under this tectonic regime, some of the N-S-trending faults were reactivated as oblique-slip faults with a dip-slip component. Later, the fluvial deposits were replaced by sediments of a new lake environment, in which extensive lacustrine limestones were deposited. The extents of the lakes were regional, stretching far beyond the limits of the grabens. The E-W-trending faults bordering the northern margin of the Gökova graben cut and postdate the Upper Miocene-Lower Pliocene lacustrine units. The Lower to Upper Miocene sequences were elevated on the graben shoulders. Along the northern edge of Gökova graben, more than 400 m of coarse fluvial conglomerates and debris were formed in front of this elevated region. The Gökova graben, mostly offshore, is about 150-km-long and enlarges westward from 5 to 30 km. The western margin of the graben rises steeply to over 1000 m, but the southern margin is less marked. The coastline has many bays and small offshore islands.

Key Words: Ören, Gökova, Neogene basin, extensional tectonics

Ören ve Çevresinin Jeolojisi, Güneybatı Anadolu

Özet: Güneybatı Anadolu'da, Likya Napları üzerinde iki farklı zamanda ve iki farklı yönde Neojen havzaları gelişmiştir. KKD gidişli, Ören ve Yatağan havzaları Erken-Orta Miyosen döneminde gelişmiştir. Bu grabenlerde üç farklı kaya topluluğu vardır; tabanda faylı havza sınırına komşu alanlardan derlenmiş kaba klastikler yer alır. Bunlar çizgisel akarsu vadi dolgularıdır. Bu çökeller, graben vadisinin giderek genişlemesi ve çevre yükseltilerin erozyonla aşındırılması ile kömür ara katkılı içeren kumtaşı, silttaşı ardalanmasına geçer. Graben gelişiminin ileri evresinde göl ortamı oluşmuş ve bölgeyi kaplamıştır. Göllerde başlıca kireçtaşı ve marn çökelmiştir. Göl çökelleri tedrici olarak graben omuzlarını aşmıştır. KD yönlü grabenler, GB-KD yönlü Kale-Tavas havzasının GB kıyasına doğru genişlemiştir. Göl ve denizel havzalar, Ören havzasının güneyinde denizin bu graben içine doğru birkaç kez ilerlemesi ile kısmen birleşmiştir. Bu alanda denizel birimler kuzeye doğru kamalanmaktadır. Kahverengi-bej renkli, kömür arakatmanlı gölsel ince detritikler ve marnlar temel üzerinde uyumsuzlukla çökelmiştir. Graben omuzlarında, Alt-Orta Miyosen çökelleri üzerine, Geç Miyosen'de, K-G gerilmeli tektonikle başlayan lineer ve aksiyal fluvial ortamda, kırmızı, kahve renkli klastikler çökelmiştir. Bu tektonik rejim ile K-G yönlü faylardan bazıları, eğim atım bileşenleri olan oblik faylar şeklinde yeniden hareket geçirmiştir. Daha sonra, fluvial birimler yerlerini yeni bir gölün kireçtaşlarına bırakmıştır. Gölün yayılımı bölgesel olup K-G grabenlerin sınırlarını aşmıştır. Gökova grabeninin kuzey kenarını sınırlayan D-B doğrultulu faylar, Üst Miyosen-Alt Pliyosen gölsel çökellerini kesmektedir. Alt ve Üst Miyosen istifleri graben omuzlarında yükselmiştir. Gökova grabeninin kuzey kenarı boyunca, yükselen bloğun önünde, 400 metre'den daha kalın iri akarsu çakıltaşları ve moloz birikmiştir. Gökova grabeni, büyük bölümü deniz içinde, 150 km uzunluğunda ve batıya doğru 5 km'den 30 km'ye kadar genişleyen bir grabendir. Grabenin kuzey kenarında, batı ucu 1000 m'yi aşan yükseltilere ulaşmaktadır. Güney kenarında ise, bir çok küçük koy ve adaların oluştuğu, daha az belirgin bir morfoloji ve kıyı çizgisi gelişmiştir.

Anahtar Sözcükler: Ören, Gökova grabeni, Neojen havzası, gerilmeli tektonik

Introduction

There is a controversy concerning the age of development of the E-W-trending graben basins of western Anatolia (Figure 1). The two main views are: (1) the E-W grabens began to form during the Late Oligocene-Early Miocene, and have been continuously evolving ever since (Seyitoğlu & Scott 1991); and (2) the E-W grabens are rather young tectonic features, and began to form in Late Miocene time (McKenzie 1972; Şengör & Yılmaz 1981; Mercier *et al.* 1989; Paton 1992; Yılmaz *et al.* 1997, 2000; Koçyiğit *et*

al. 1999, Bozkurt 2000; Sarıca 2000). The proposed synthesis of previously available data (Şengör *et al.* 1985; Walcott 1988) or (commonly) of inadequate data was mostly obtained from the rocks cropping out along the immediate borders of the grabens (Seyitoğlu & Scott 1992, 1996; Cohen *et al.* 1995). To test and compare the two models, we undertook a field-mapping project to study the Ören area (Figure 2) because there and in the surrounding regions, morphologically active and distinct young faults of various trends, together with thick

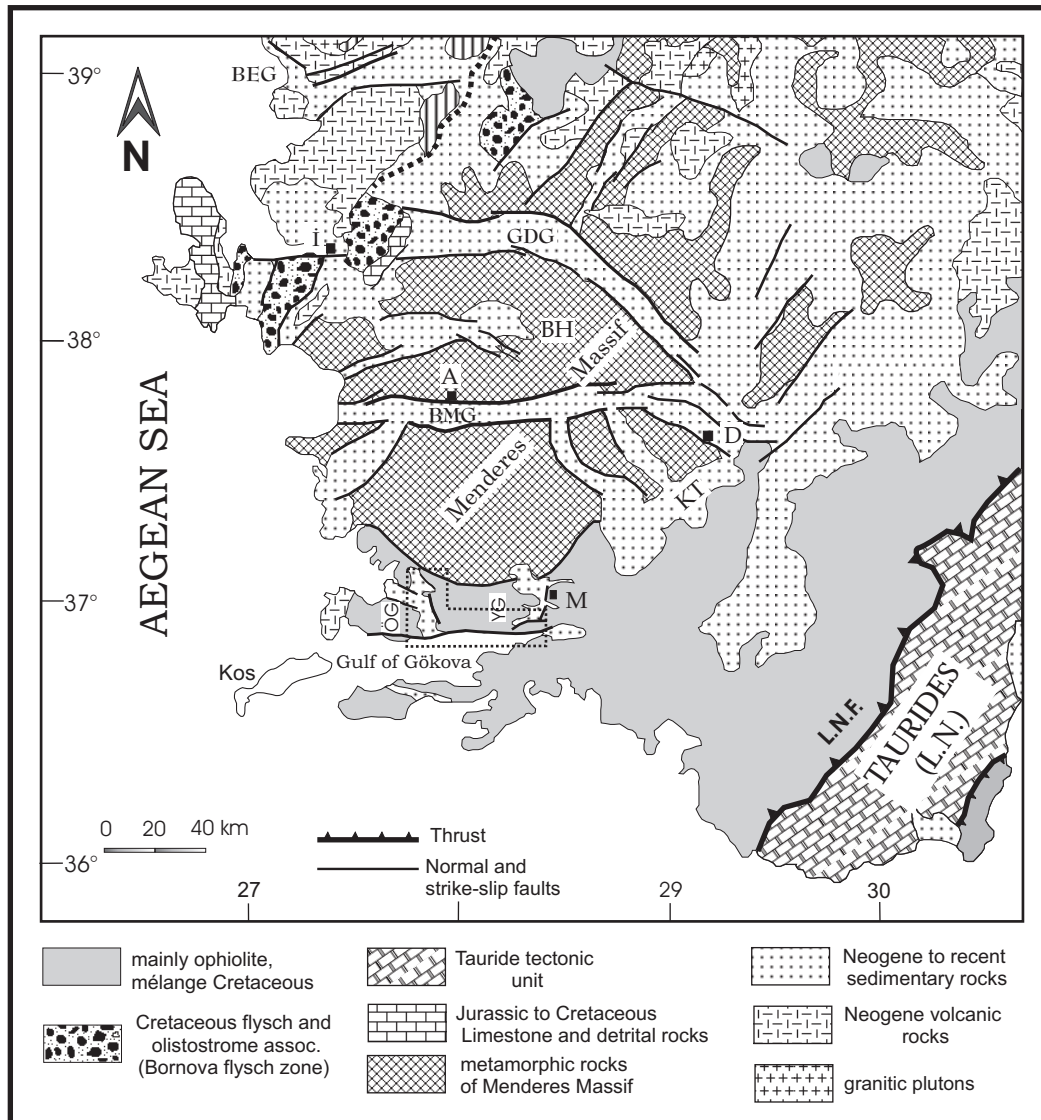


Figure 1. Geological map of western Anatolia (modified from Yılmaz *et al.* 2000). BEG– Bergama graben; GDG– Gediz graben, BMG– Büyük Menderes graben; KT– Kale-Tavas basin, LN– Lycian Nappes; LNF– Lycian Nappe front; BH– Bozdağ horst; ÖG– Ören graben; YG– Yatağan graben. A, D, I and M are cities of Aydın, Denizli, İzmir and Muğla, respectively. Inset shows the location of the study area.

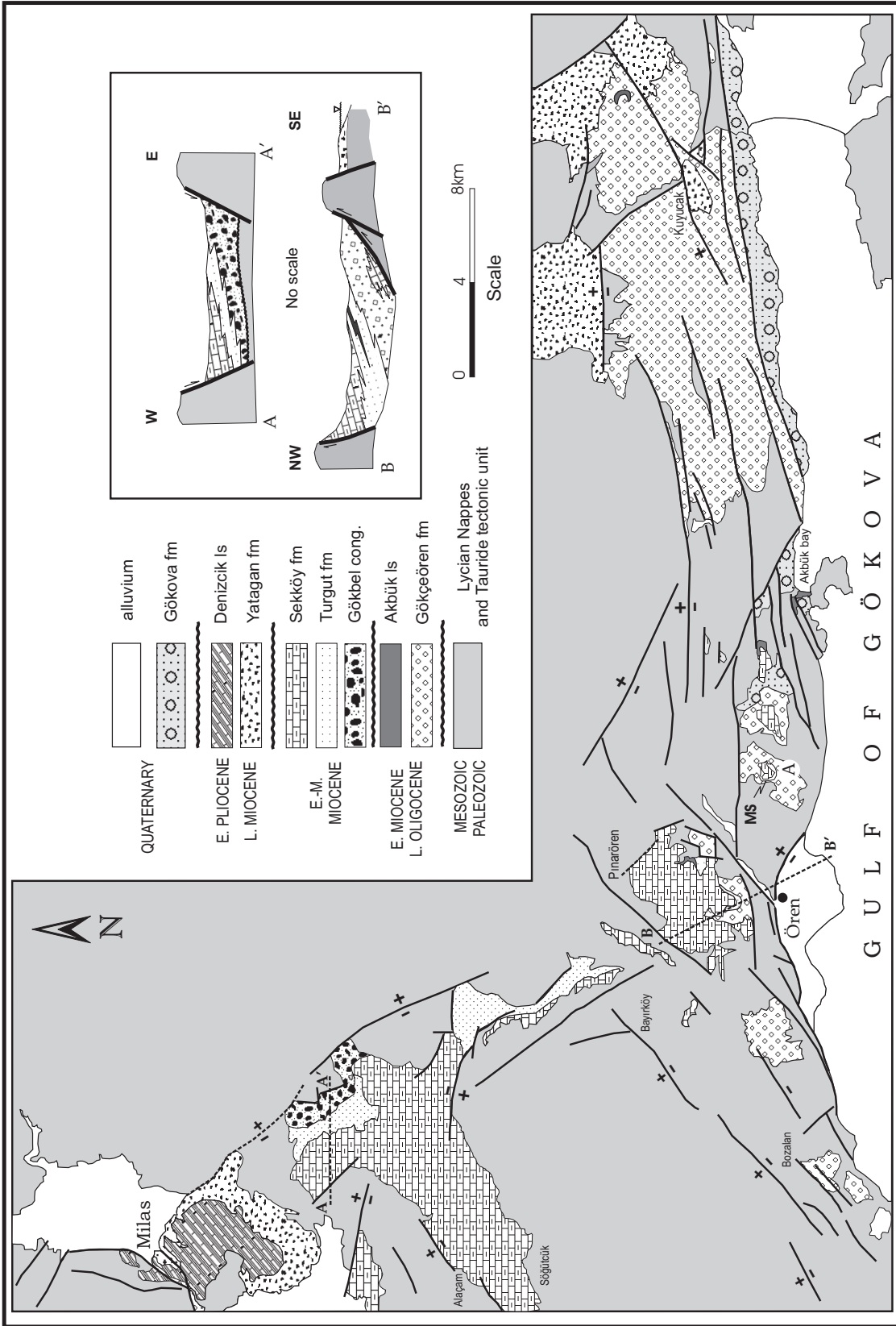


Figure 2. Simplified geological map of the Ören graben (modified from Yılmaz *et al.*, 2000) and associated cross sections: MS– measured stratigraphic section (Figure 4), A– Akkılıse.

Neogene successions, are present. In this paper, the new data resulting from this study are first presented and then the data are discussed to shed light on the geological evolution of these Neogene basins.

The Gökova graben is one of the major E-W-trending grabens of western Anatolia. (Figure 2). The Ören area is located to the north of the Gökova graben where there are large Neogene outcrops. This Neogene is commonly referred to as the Ören basin, which extends from the Gulf of Gökova in the south to Milas in the north (Figure 2). The Ören Neogene basin is bounded, for the most part, by steeply dipping oblique-slip faults with considerable amount of normal slip component.

Geology of the Basins

In the Gökova region, basins of various ages and orientations have been identified. The oldest basin, the Kale-Tavas molasse basin of Şengör & Yılmaz (1981), is orientated ENE-WSW. The youngest basin is the modern Gökova graben. Between the development of these approximately ENE-WSW or E-W basins, roughly N-S-trending basins formed during the Early Miocene and Late Miocene. The major geological characteristics of these basins are briefly described below.

The Kale-Tavas Basin

The Kale-Tavas is the oldest basin of the region, and its sedimentary fill ranges from Upper Oligocene to Lower Miocene. The fill of the Kale-Tavas basin is best-observed in the area that extends from northeast of Denizli in the east to the Gökova graben in the west (Figure 2).

The Kale-Tavas basin units rest on the Lycian Nappes along an angular unconformity. The lowermost unit of the basin is a red, thick, massive to poorly-bedded and poorly-sorted coarse conglomerate assigned to the Gökçeören formation. This conglomerate unit is devoid of fossils, and is composed predominantly of ophiolitic materials derived from the underlying ophiolite, which forms the uppermost tectonic slice of the Lycian Nappes. These materials, which were accumulated to the north of an approximately NE-SW-trending fault zone, are mainly debris flow and fluvial deposits, sourced from these fault-induced structural highs. Clast imbrication indicates an approximately southeast to northwest palaeocurrent

direction. Grain size decreases toward the north, where the red clastic sediments pass laterally and vertically into grey conglomerates, which in turn, pass vertically and laterally into grey, well-sorted sandstones with some limestones lenses. Locally these pass laterally into grey shales containing lignite beds. These shales are lagoonal and shallow-marine clastic sediments which contain gastropods, bivalves and benthic foraminifers of Late Oligocene-Early Miocene age (Becker-Platen 1970; Koçyiğit 1984; Hakyemez 1989; Akgün & Sözbilir 2001). The sandstones are overlain by a flysch-like sequence, composed mainly of alternating sandstones and marls. This sequence has numerous fluvial channel deposits, ranging in thickness from a few meters to a few tens of meters; these were emplaced as turbidite deposits which incised the underlying soft sediments and also disturbed their original attitudes. Therefore, locally developed unconformities were formed in the succession. Upward in the section, the high energy of the depositional environment decreases, as evidenced by fining-upward profiles, and eventually the clastic sediments are gradually replaced by limestones of the Kale formation. Fauna from the limestones yield Aquitanian-Burdigalian ages (Hakyemez 1989; Görür *et al.* 1995; Akgün & Sözbilir 2001).

The Ören Basin

The Ören and Yatağan basins are subparallel basins trending approximately NNW-SSE (Figures 1 and 2). These basins display identical strata of Early to Middle Miocene age. Typically, the basin units rest unconformably on the slightly metamorphosed rocks of the western Taurides. In places, the lowermost clastic rocks rest unconformably on the fossiliferous marine limestones of the Kale-Tavas basin. Development of the Ören and Yatağan basins was controlled by oblique-slip fault systems, having major dip-slip components coupled with a subordinate dextral strike-slip component. The basin sediments and their substrate are disrupted by E-W-trending normal faults around the Gulf of Gökova.

The Ören basin fill consists mainly of two rock units (Figure 3). The lower unit is composed predominantly of clastic rocks of the Gökbel conglomerate. This unit is a massive to poorly bedded and poorly sorted grey, coarse conglomerate with well-rounded clasts derived from the

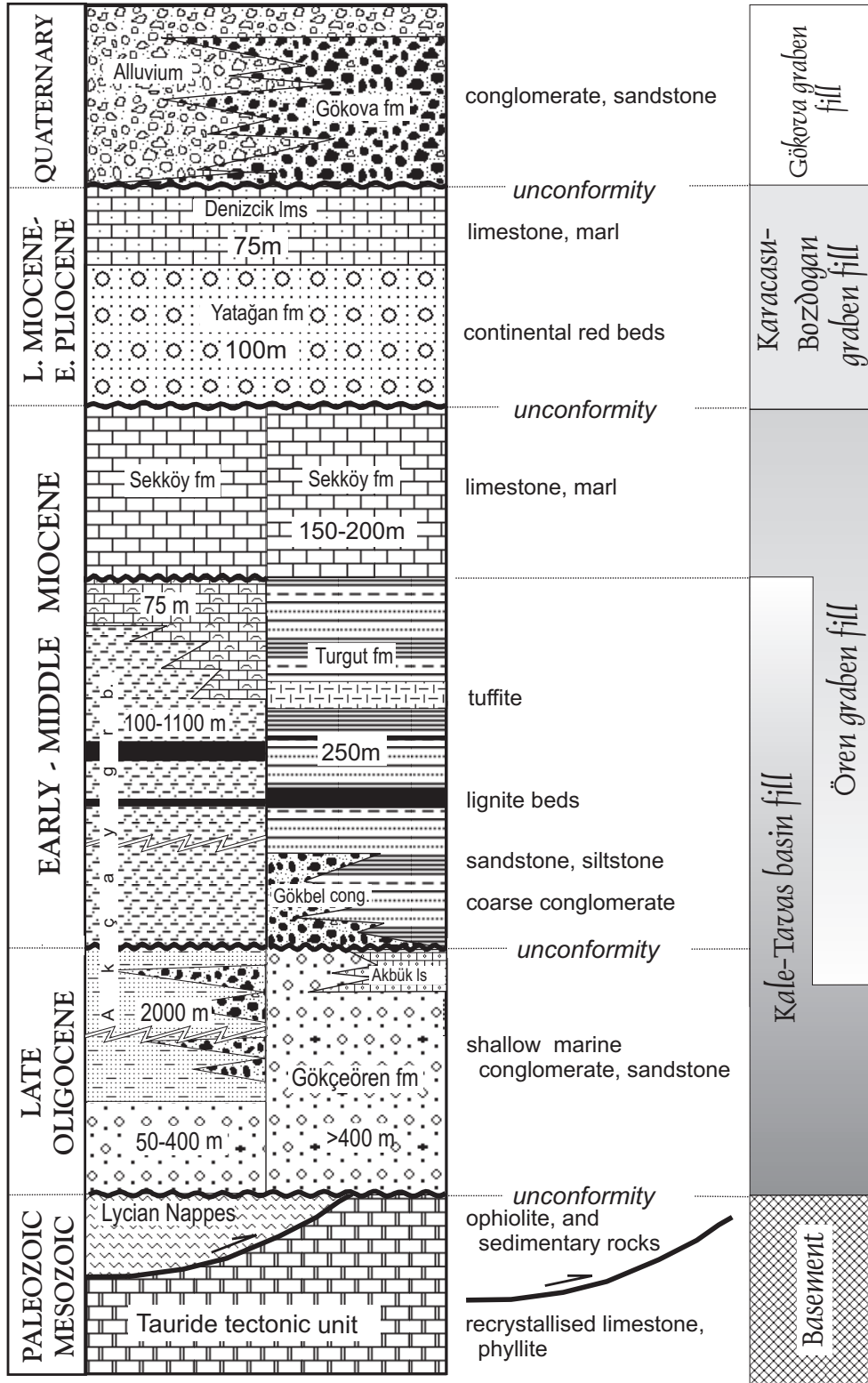


Figure 3. Generalized stratigraphic section of the Milas-Ören area.

underlying recrystallized limestones and phyllites. The conglomerates are of debris flow and fluvial origin. Upward in the succession, the coarse conglomerates are replaced by sandstones of the Turgut formation. The upper unit is a shale-marl-dominated, fine clastic succession having a number of lignite beds. The top of the sequence is a white marl and limestone unit called the Sekköy formation (Atalay 1980).

The NW-SE-trending basin fills are composed generally of sediments deposited in a continental environment. Toward the south where the ENE-WSW-trending, partly coeval, marine Kale-Tavas basin was located, a number of marine incursions into the N-S troughs occurred intermittently, as evidenced by the presence of marine-fossil-bearing sandstone layers interbedded with the lacustrine sediments (Figure 4). The marine beds wedge out toward the north. The age of these rock units has been variously assigned to the Aquitanian (Tchihatcheff 1869), the Aquitanian-Burdigalian (Nebert 1957), or the Oligocene-Lower Miocene (Erentöz & Öztemur 1964).

The lacustrine limestone is overlain unconformably by a 100- to 200-m-thick, brown to red continental conglomerate and sandstone unit, the Yatağan Formation. In places, the red clastic sediments rest directly on the Lycian Nappes. The red beds yield a rich mammalian fauna that ranges in age from Middle Astracian to Turolian in the Muğla region (Atalay 1980). The Yatağan formation is composed of fluvial and debris-flow deposits, laid down within fault-bounded, approximately N-S-trending troughs. At top of the sequence is white lacustrine limestone of the Denizcik formation. The limestones are not confined to the limits of the fault-controlled depressions where the clastic rocks accumulated; they cover a vast region as a capping limestone that extended from the gulf areas in the west to the Denizli area in the east. This distribution indicates that the N-S graben depressions were filled and lost their topographic expression before deposition of the limestones.

The Gökova Graben

This is the southernmost graben of western Anatolia. It is 150-km-long, and widens westward from 5 to more than 30 km (Figure 1). A major part of the graben is offshore,

forming the Gulf of Gökova. The northern margin is bounded by a linear mountain front, which rises steeply to >1000-m. E-W-trending listric normal faults, together with a set of N60°-80°E-trending oblique-slip faults, characterise the northern margin. The E-W-striking faults commonly cut and offset the oblique-slip faults. The southern margin of the graben is topographically less steep and marked by many bays and small offshore islands.

The graben-bounding faults of the Gökova graben have apparently controlled deposition of a thick post-Miocene-Pliocene sedimentary sequence which constitutes the Gökova Formation. The E-W faults cut the N-S-trending graben bounding faults and the rock groups of the Miocene grabens. The sediments, deposited along the margin of the Gökova graben, consist of coarse clastic sediments, formed as scree deposits, unconsolidated slope debris and lateral fan deposits. Their source is undoubtedly the uplifted horst block lying in the immediate vicinity. The graben fill is rotated gently (10°-15°) northward due to rotation on the major E-W-trending, south-dipping listric faults. The age of the unconsolidated sediments in the graben may be inferred to be post-Pliocene from stratigraphic evidence, insofar as debris from rocks of Late Miocene-Early Pliocene age sourced from the adjacent horst blocks have been incorporated into the present graben fill.

Geological Evolution

In the light of the data presented above the major stages of the geological evolution of this region may be summarised as follows.

First Stage

The first stage corresponds to the period when the Lycian Nappes, as a nappe package, consisting of slices of the western Taurus metamorphic basement and the overlying Mesozoic platform carbonates, together with the dismembered ophiolites that form the uppermost nappe, travelled southward during Early Miocene time. The nappes were finally emplaced onto the Lower Miocene basin fill of the Antalya basin before the Late Miocene time (Figure 5) (Robertson 2000).

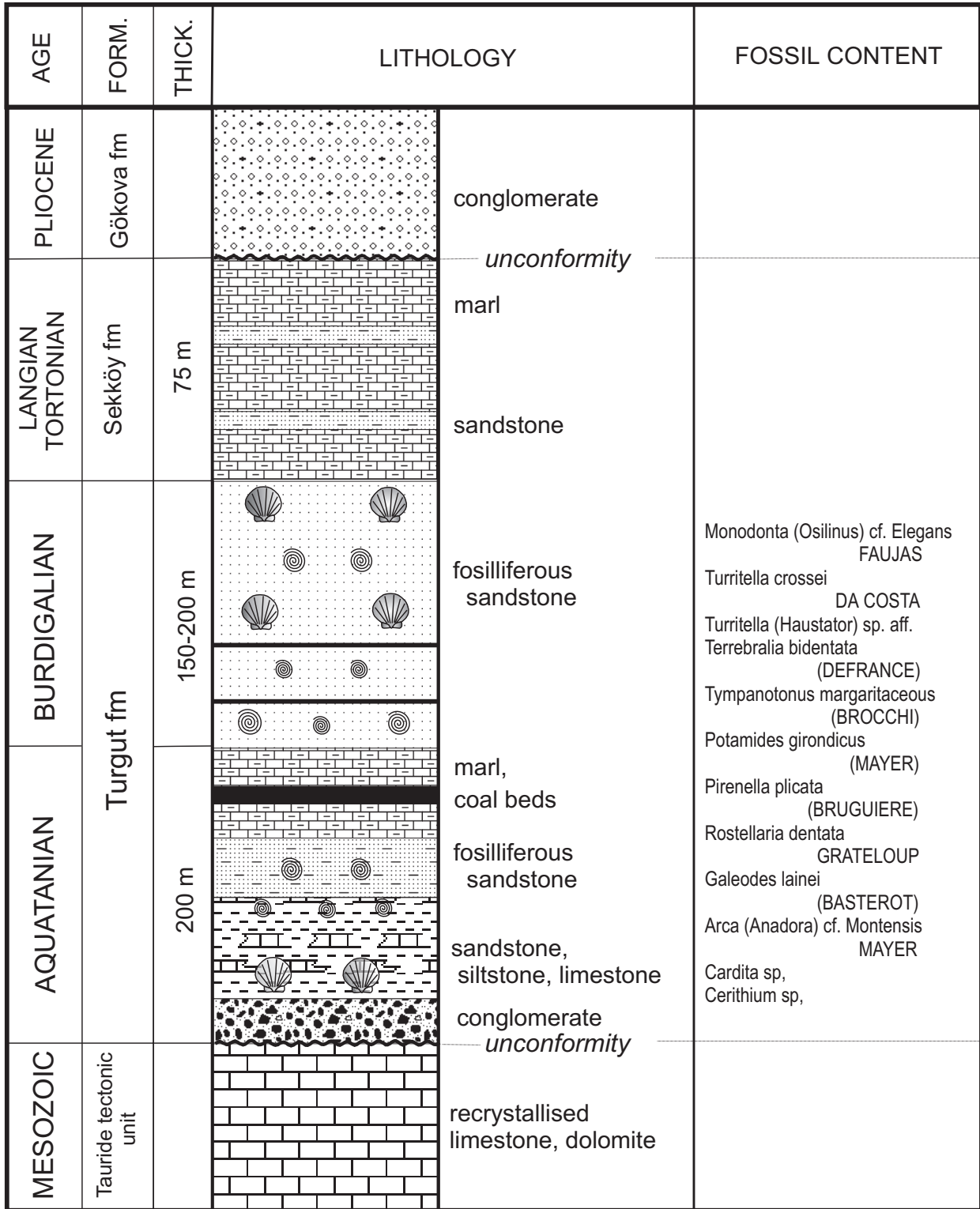


Figure 4. Measured stratigraphic section of the Turgut and Sekköy formation (in the north of Alakilise town) (Modified from Nebert 1957)

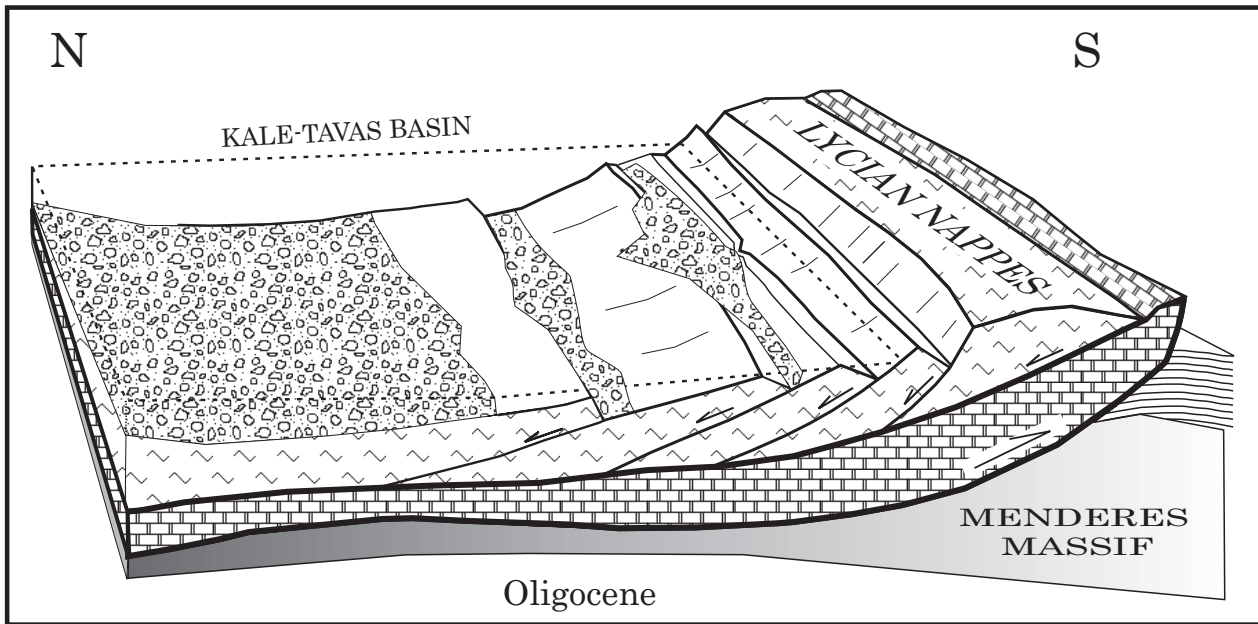


Figure 5. Pre-extension stage and development of the Kale-Tavas basin. The Lycian Nappes were moving south while a piggy-back basin, the Kale-Tavas basin, developed above the Lycian Nappes during Oligocene time. The listric normal faults controlled the southern edge of the basin, and the consequent coarse clastic deposition.

The Kale-Tavas basin began to form during this period. Within this basin, sediment deposition started during the Late Oligocene, indicating that this graben began to form slightly earlier than the N-S grabens. Mostly ophiolite-derived, coarse clastic materials at the base of the Kale-Tavas basin were sourced from a structural high formed from the Lycian Nappes. The high was located to the south of the basin. The southern margin of the basin, bounded by this structural high was characterised by NE-SW-trending normal faults. For this reason, the Kale-Tavas basin, which was situated above the contemporaneously southerly advancing Lycian Nappe package, may be regarded as a piggy-back basin (Yılmaz *et al.* 2000).

The N-S trending Ören and Yatağan grabens, that are generally bounded by the oblique-slip faults, possibly developed in a N-S compressional stress field (Figure 6) in that the southern as well as the northern parts of western Anatolia suffered N-S compressional deformation during this period (Yılmaz & Polat 1998; Yılmaz *et al.* 2000; Robertson 2000)

The E-W Extension Stage

The earlier stage of the N-S extension. N-S extension began during Late Miocene time. During this period the E-W-trending Bozdağ horst, located in the middle of the Menderes Massif, was elevated (Yılmaz *et al.* 2000). Low-angle detachment faults are recognised along both the southern and northern flanks of the Bozdağ horst. The detachment faults appear to have been active mainly during Late Miocene time (Hetzl *et al.* 1995; Emre 1996; Koçyiğit *et al.* 1999; Yılmaz *et al.* 2000; Bozkurt 2001; Sözbilir 2001) in that the Upper Miocene fluvial lateral fan deposits derived from the horst were transported into the surrounding low topography as coarse clastic material. Away from the structural high the clastic rocks gave way gradually to lacustrine limestones. This situation suggests that the horst was possibly surrounded by interconnected lake basins (Figure 7).

Farther away from the horst, to both the south and north, approximately N-S-trending accommodation faults began to develop on the upper plates of the detachment faults. These grabens were long, narrow troughs bounded by the oblique-slip faults which controlled the

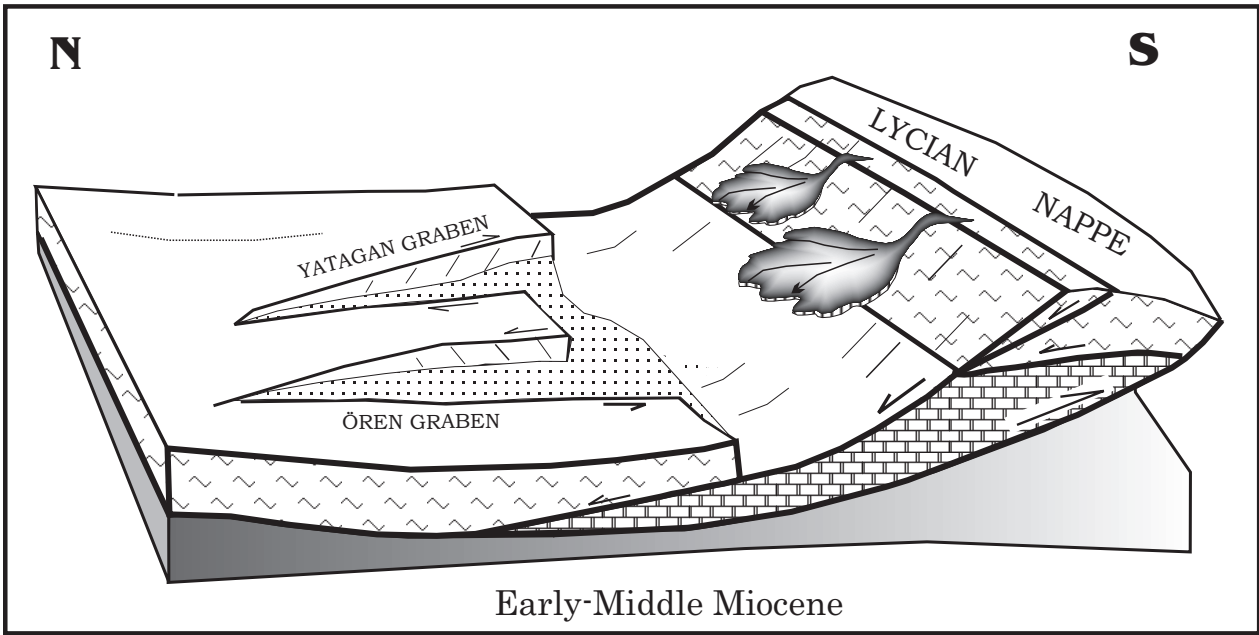


Figure 6. Differential stretching within the piggy-back basin areas formed N-S-trending faults and narrow grabens.

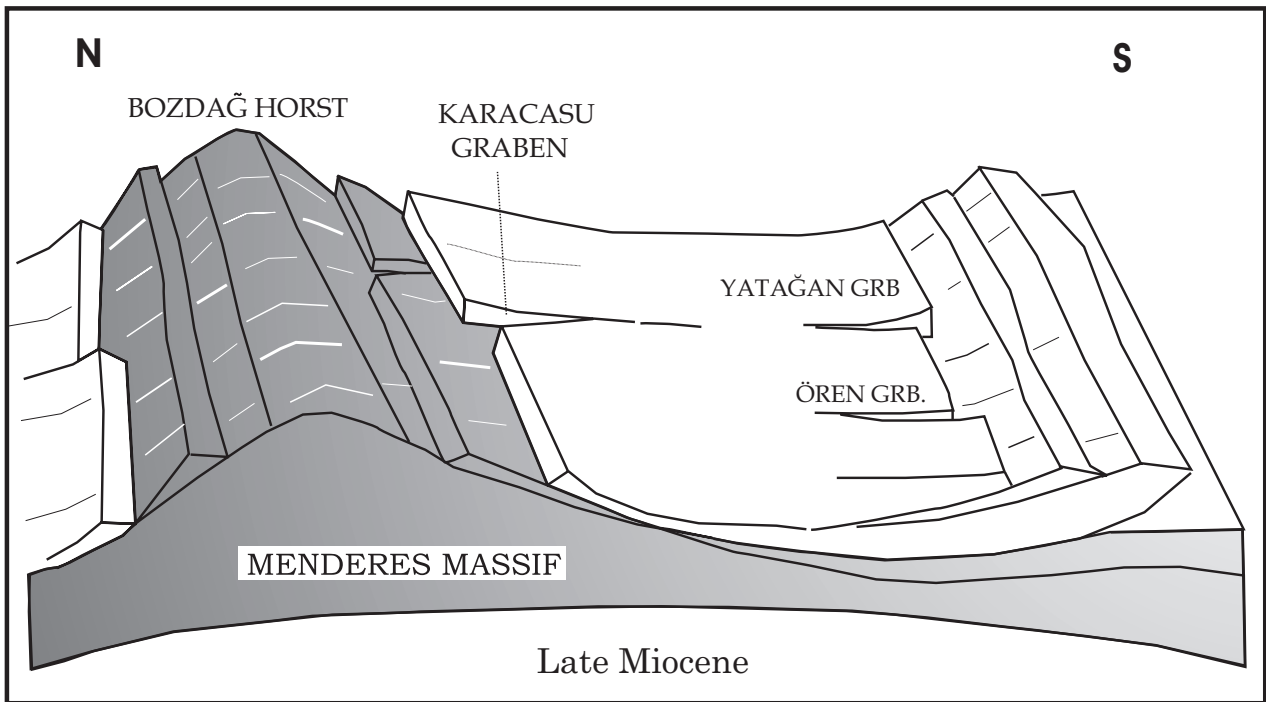


Figure 7. During the Late Miocene, N-S extension began. The Bozdağ horst was elevated and major breakaway faults were formed. Above the detachment surfaces, approximately N-S-trending grabens began to form as cross-grabens.

deposition of Upper Miocene sediments. Some of these faults appear to have been spatially associated with the Early Miocene basin-bounding fault system, an example of this being the Ören graben.

Finally, a new lake developed during Late Miocene-Early Pliocene time. This new lake basin covered the entire northern area and extended into present offshore areas (Figure 8).

The interruption stage of the N-S extension. N-S extension appears to have been interrupted at the end of Late Miocene-Early Pliocene period when a regionwide, low-relief erosional surface formed on rocks as young as Early Pliocene. The limestones and red clastic rock of Late Miocene-Early Pliocene age, flat or tilted, were eroded and lie below this surface.

The later stage of the north-south extension. Following the development of the erosional surface, N-S extension was reactivated and the E-W-trending grabens began to form. As a result, the erosional surface, as well as the older structures and the Miocene-Lower Pliocene strata, were cut by faults that bound the east-west grabens. The low-relief erosional surfaces on the plateaux

have a sharp boundary with a steep slope of the newly developed graben valleys (Figure 9) (Yılmaz *et al.* 2000).

The present morphology of the region formed later, during the development of a set of E-W-trending faults in Quaternary time (Figure 10).

Conclusions

Structures and sediments in the northern Gökova region suggest different episodes of basin development.

1. The E-W-trending Kale-Tavas basin began to form during Oligocene time above the contemporaneously southerly-transported Lycian Nappe package, as a piggy-back basin.
2. The N-S-trending Ören basin formed slightly later during Early Miocene time, under an E-W extension, N-S compression. The Ören and Kale-Tavas basins were interconnected.
3. A new group of basins developed along reactivated NNW-SSE-trending faults during Late Miocene time when N-S extension began, and possibly survived into Early Pliocene time. The basins were filled and lost their morphological expression at the end of Late Miocene time.

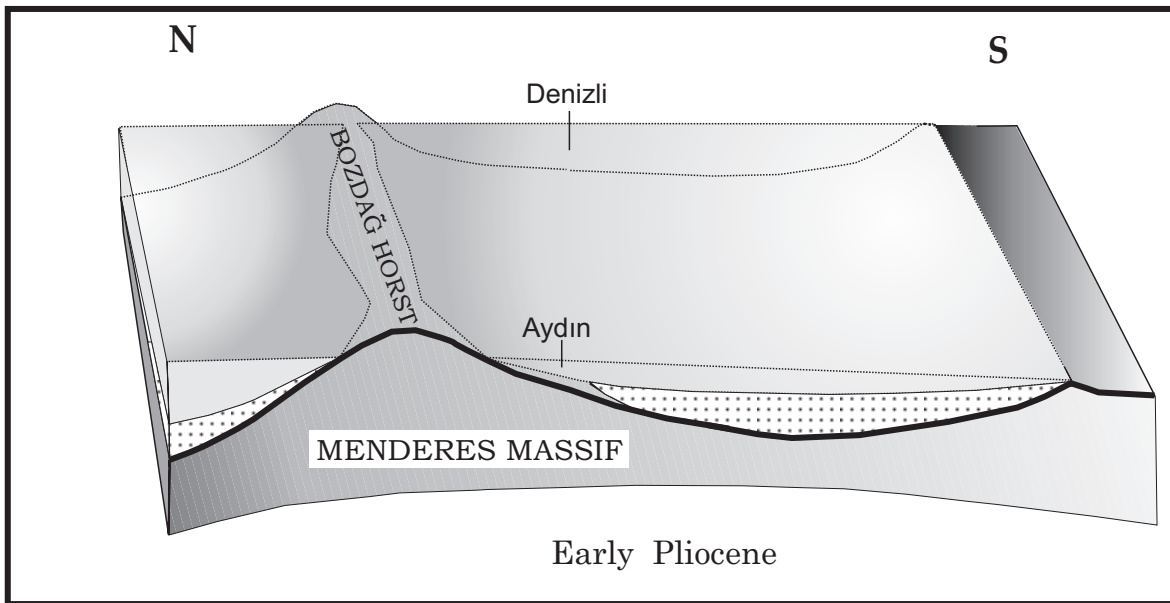


Figure 8. A new lake was developed during latest Miocene-Early Pliocene time, and it gradually invaded the flanks of the previously elevated Bozdağ horst.

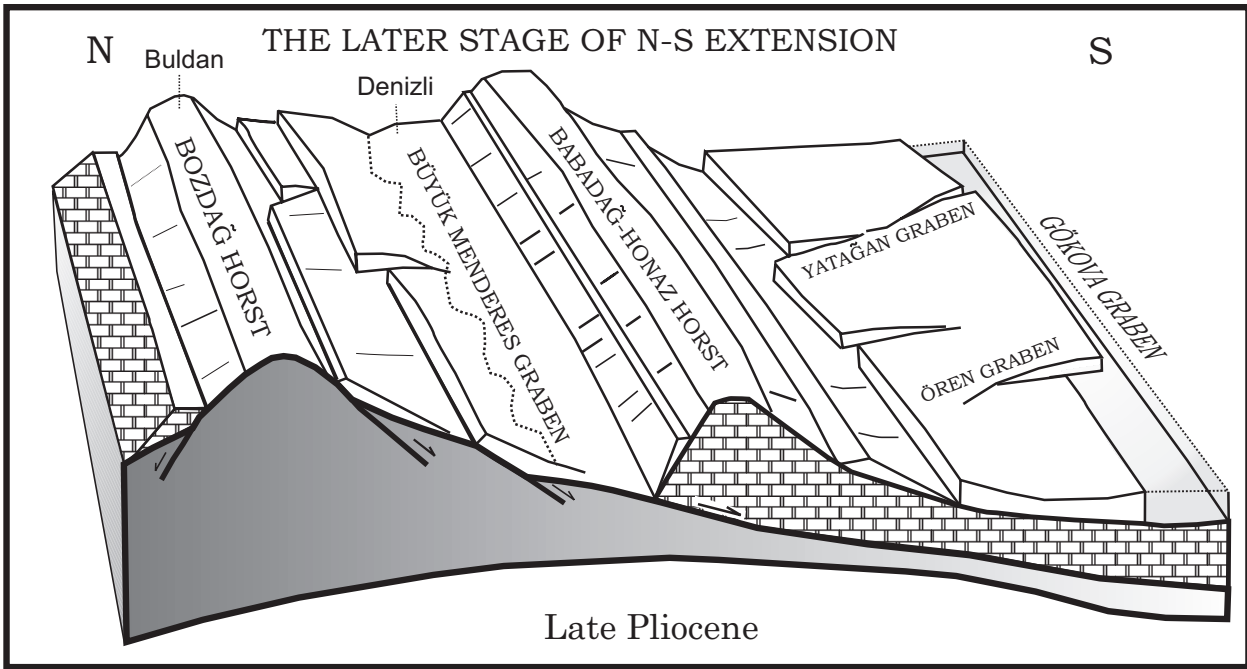


Figure 9. Following the development of erosional surface, the N-S extension was reactivated and the E-W grabens began to form.

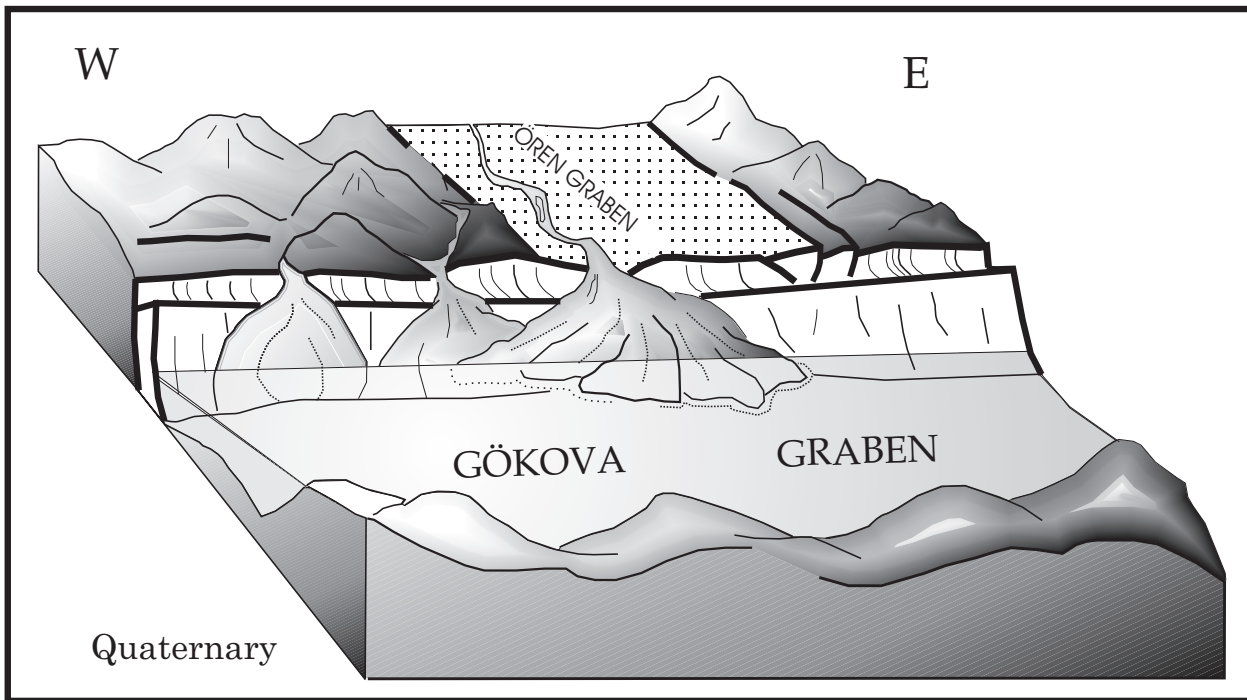


Figure 10. Present morphology of the Gökova region formed along E-W-trending faults possibly during Quaternary time. Then newly formed E-W-trending normal faults have localized the width of the shallow depressions into the present graben valleys.

4. The modern Gökova graben developed later along E-W-trending normal faults which cut and truncate the older units and their associated structures.

References

- AKGÜN, F. & SÖZBİLİR, H. 2001. A palynostratigraphic approach to the SW Anatolian molasse basin: Kale-Tavas molasse and Denizli molasse. *Geodinamica Acta* **14**, 71-93
- ATALAY, Z. 1980. Muğla-Yatağan ve yakın dolayısı karasal Neojenin stratigrafisi araştırması. *Geological Society of Turkey Bulletin* **23**, 93-99 [in Turkish with English abstract].
- BECKER-PLATEN, J.D. 1970. Lithostratigraphische Untersuchungen im Känozoikum Südwest-Anatoliens (Türkei). *Beihefte zum Geologischen Jahrbuch Heft* **97**, Hannover.
- BOZKURT, E. 2000. Timing of extension on the Büyük Menderes Graben, western Turkey, and its tectonic implications. In: BOZKURT, E., WINCHESTER, J.A. & PIPER, J.D.A. (eds) *Tectonics and Magmatism in Turkey and the Surrounding Area*. Geological Society, London, Special Publications **173**, 385-405.
- BOZKURT, E. 2001. Late Alpine evolution of the central Menderes Massif, western Turkey. *International Journal of Earth Sciences* **89**, 728-744.
- COHEN, H.A., DART, C.J., AKYÜZ, H.S. & BARKA, A.A. 1995. Syn-rift sedimentation and structural development of the Gediz and Büyük Menderes grabens, western Turkey. *Journal of the Geological Society, London* **152**, 629-638.
- EMRE, T. 1996. Geology and tectonics of Gediz graben. *Turkish Journal of Earth Sciences* **5**, 171-185 [in Turkish with English abstract].
- ERENTÖZ, L. & ÖZTEMÜR, C. 1964. Aperçu général sur la stratigraphie du Néogène de la Turquie et observations sur ses limites inférieures et supérieures, Institute 'Lucas Maldada' C.S.I.C. (España) Cursillos Conferencias, Madrid **9**, 259-266.
- GÖRÜR, N., ŞENGÖR, A.M.C., SAKIÇ, M., TÜYSÜZ, O., AKKÖK, R., YİĞİTBAŞ, E., OKTAY, F.Y., BARKA, A.A., SARICA, N., ECEVİTOĞLU, B., DEMİRBAĞ, E., ERSOY, Ş., ALGAN, O., GÜNEYSU, C. & AKYOL, A. 1995. Rift formation in the Gökova region, southwest Anatolia: implications for the opening of the Aegean Sea. *Geological Magazine* **132**, 637-650.
- HAKYEMEZ, Y. 1989. Geology and stratigraphy of the Cenozoic sedimentary rocks in the Kale-Kurbalık area. Denizli-southwestern Turkey. *Mineral Research and Exploration Institute of Turkey (MTA) Bulletin* **109**, 1-14.
- HETZEL, R., RING, U., AKAL, C. & TROESCH, M. 1995. Miocene NNE-directed extensional unroofing in the Menderes Massif, southwestern Turkey. *Journal of the Geological Society, London* **152**, 639-654.
- KOÇYİĞİT, A. 1984. Güneybatı Türkiye ve yakın dolayında levhaiçi yeni tektonik gelişim. *Geological Society of Turkey Bulletin* **27**, 1-16 [in Turkish with English abstract].

Acknowledgements

We would like to thank anonymous reviewers for their constructive comments that improved the earlier version of the text. Steven K. Mittwede helped with the English.

- KOÇYİĞİT, A., YUSUFOĞLU, H. & BOZKURT, E. 1999. Evidence from the Gediz graben for episodic two-stage extension in western Turkey. *Journal of Geological Society, London* **156**, 605-616.
- MCKENZIE, D.P. 1972. Active tectonics of the Mediterranean region. *Geophysical Journal of the Royal Astronomical Society* **30**, 109-185.
- MERCIER, J.L., SOREL, D. & VERGELY, P. 1989. Extensional tectonic regimes in the Aegean basins during the Cenozoic. *Basin Research* **2**, 49-71.
- NEBERT, K. 1957. *Die braunkohlenvorkommen von Oeren*. Mineral Research and Exploration Institute of Turkey (MTA) Report, No. 3011, 21 p [unpublished].
- Paton, S. 1992. Active normal faulting, drainage patterns and sedimentation in southwestern Turkey. *Journal of the Geological Society, London* **149**, 1031-1044
- ROBERTSON, A.H.F. 2000. Mesozoic-Tertiary tectonic-sedimentary evolution of a south Tethyan oceanic basin and its margins in southern Turkey. In: BOZKURT, E., WINCHESTER, J.A. & PIPER, J.D.A. (eds) *Tectonics and Magmatism in Turkey and the Surrounding Area*. Geological Society, London, Special Publications **173**, 353-384.
- SARICA, 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**, 1-24.
- SEYİTOĞLU, G. & SCOTT, B. 1991. Late Cenozoic crustal extension and basin Formation in west Turkey. *Geological Magazine* **128**, 155-166.
- SEYİTOĞLU, G. & SCOTT, B.C. 1992. The age of Büyük Menderes Graben (west Turkey) and its tectonic implications. *Geological Magazine* **129**, 239-242.
- SEYİTOĞLU, G. & SCOTT, B.C. 1996. The cause of N-S extensional tectonics in western Turkey: tectonic escape vs back-arc spreading vs orogenic collapse. *Journal of Geodynamics* **22**, 145-153.
- ŞENGÖR, A.M.C. & YILMAZ, Y. 1981. Tethyan evolution of Turkey: a plate tectonic approach. *Tectonophysics* **75**, 181-241.
- ŞENGÖR, A.M.C., GÖRÜR, N. & ŞAROĞLU, F. 1985. Strike-slip faulting and related basin Formation in zones of tectonic escape: Turkey as a case study. In: BIDDLE, K. & CHRISTIE-BLICK, N. (eds) *Strike-slip Faulting and Basin Formation*. Society of Economic Paleontologists and Mineralogists, Special Publication **37**, 227-264.

- SÖZBİLİR, H. 2001. Geometry of macroscopic structures with their relations to the extensional tectonics: Field evidence from the Gediz Detachment, western Turkey. *Turkish Journal of Earth Sciences* **10**, 51-67.
- TCHIHATCHEFF, M. L. 1869. Asie Mineure Description Physique de cette contrée, **8**, Geologie, Paris.
- YILMAZ, Y. & POLAT, A. 1998. Geology and evolution of the Thrace volcanics, Turkey. *Acta Volcanologica* **10**, 293-303.
- YILMAZ, Y., GENÇ, Ş.C., GÜRER, Ö.F., ELMAS, A., KARACIK, Z., ALTUNKAYNAK, Ş. & GÜLEÇ, N. 1997. *Ayvalık-Dikili-Çandarlı-Bergama Arasında (Edremit-Bergama Grabenleri Çevresinde) Genç Mağmatizmanın Jeolojik ve Petrolojik Araştırılması*. YDABÇAG-228/G, YDABÇAG-420/G, Proje Raporu, 75 p [Turkish with English abstract, unpublished].
- YILMAZ, Y., GENÇ, Ş.C., GÜRER, Ö.F., BOZCU, M., YILMAZ, K., KARACIK, Z., ALTUNKAYNAK, Ş. & ELMAS, A. 2000. When did the Western Anatolian grabens begin to develop? In: BOZKURT, E., WINCHESTER, J.A. & PIPER, J.D.A. (eds) *Tectonics and Magmatism in Turkey and the Surrounding Area*. Geological Society, London, Special Publications **173**, 353-384.
- WALCOTT, C.R. 1988. *The Alpine Evolution of Thessaly (NW Greece) and Late Tertiary Aegean Kinematics*. Geologic Ultraiectina. Mededelingen van de Faculteit Aardwetenschappen Universiteit Utrecht **162**, 176 p.

Received 26 February 2001; revised typescript accepted 19 October 2001