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Quaternary deposits of the Büyük Menderes Graben in western Anatolia, Turkey: Implications for river capture and the longest Holocene estuary in the Aegean Sea

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ABSTRACT

The Büyük Menderes Graben is a seismically active depositional basin in the N–S extensional tectonic region of western Anatolia, Turkey. It extends in an E–W direction and is bounded by the Aegean Sea to the west. The infill of this tectonic basin comprises *ca* 850 m and 245 m thick clastic sequences of Neogene and Quaternary, respectively and the Quaternary part of the basin-fill is presented here by the help of seismic sections and boreholes. Results show that the studied succession was made of unconsolidated, mostly fine-grained clastic sediments of marine and continental sequences interfingered with each other. The marine counterpart forms three relatively short (approx. 30 km) and one long (approx. 100 km from modern coastline) sediment wedges representing sea transgressions onto the graben. The last one was a rapid incursion that occurred in the Middle Holocene, forming the longest estuary of the Aegean Sea in western Anatolia. The filling of this estuary caused the decline of some historical harbours and settlements in the region. While marine-based events occurred in the west of the graben, alluvial and fluvial processes produced marginal and axial deposits in the east of graben, respectively. In general, the continental succession of Quaternary is thinner than its marine equivalent, probably due to sea-level fluctuations. In addition, the sedimentation rate increased suddenly during deposition of the last marine sequence (estuarine deposits) in the Holocene. It is likely that this was the result of enlargement of the drainage area of the River Büyük Menderes due to a river capture that occurred in the latest stages of Pleistocene.

1. Introduction

The Büyük Menderes Graben (BMG) is an E–W trending seismically active depression in western Anatolia lying 175 km inland from the Turkish coasts of the Aegean Sea (Fig. 1). Among others initiated in Neogene (Fig. 1), it is the longest continental basin of western Turkey. The River Büyük Menderes (RBM; the river Maiandros of antique times), the longest stream of the region, drains and also fills this depression. Miletos, Priene and some other ancient settlements have been affected by sediments of the RBM and so they are all now land-locked harbours in western Anatolia (Fig. 2). Hence, the western end of the BMG is an important area for cultural, particularly maritime archaeological purposes (Franco, 1996; Brückner et al., 2002; Marriner and Morhange, 2007). In addition, the area is significant for its abundance of historical records on siltation and the seismic hazards of ancient settlements (Erol, 1976; Kayan 1999).

The Neogene infill of the BMG basin is well exposed, particularly along the northern margin of the graben, and together with the bedrocks belongs to the Menderes massif owing to successive faultings (Figs. 1, 3). A reliable stratigraphy has been erected dependent on not only lithofacies and fossil assemblages but also magnetostratigraphy (Sözbilir and Emre, 1990; Seyitoglu and Scott, 1992; Ünay et al., 1995; Sarıca, 2000; Saraç, 2003; Şen and Seyitoglu, 2002, 2009). The oldest unit was a clastic succession associated with lacustrine limestone of Early Miocene and the overlying units of Pliocene and Quaternary consisted of clastic sediments of alluvial origin (Fig. 3). As a matter of fact, sedimentary facies and chronostratigraphies of the extensional western Anatolian basins, included the BMG, resemble each other with only minor differences (Sözbilir and Emre, 1990; Alçiçek et al., 2007). Thus, the BMG is a convenient area to investigate the geological evolution of Anatolia together with the eastern Mediterranean, and various attempts have already been made, producing different interpretations (e.g. Dewey and Şengör, 1979; Seyitoglu and Scott, 1991; Westaway, 1994; Bozkurt, 2000, 2003; Purvis and Robertson, 2005; Rojay et al., 2005).

The main debate is about basin development and the causes and timing of crustal extension (Seyitoglu and Scott, 1992; Bozkurt, 2000; Yılmaz et al., 2000; Seyitoglu et al., 2002; Şen and Seyitoglu, 2009). On the other hand, information, hence interpretations about the Quaternary evolution of the BMG and other basins, is scarce due to lack of exposure. The sedimentary characteristics of the graben-fill of

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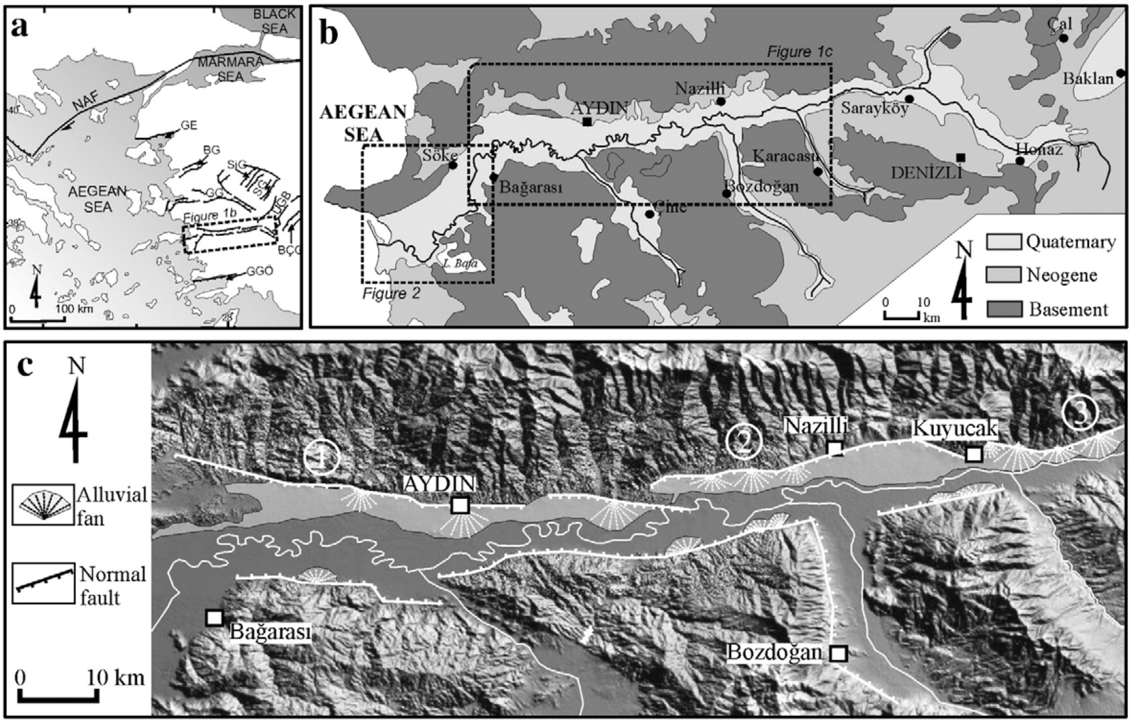

Fig. 1. Location (a), geology (b) and morphotectonic (c) maps of the Büyük Menderes Graben. Note Figs. 1b, 1c and 2 are inset. GGO Gökova graben, BÇG Baklan-Çivril graben, UGB Uşak graben, SG Selendi graben, GG Gediz graben, BG Bakırçay graben, GE Edremit graben. 1 Aydın segment, 2 Nazilli Kuyucak segment, 3 Buharkent segment of the Büyük Menderes fault.

Pleistocene have not been well described. This was the initial reason behind the present study.

The current knowledge about the BMG and its developments comes mainly from seismic records in the Aegean Sea (Aksu et al., 1987, 1990). According to results of these offshore surveys, the River Büyük Menderes formed four superimposed deltas, or a delta complex with four deltas in the Aegean Sea during the Late Pleistocene, the new one occurring just after the last glacial period (Aksu et al., 1987) (Figs. 2, 4). During and after the formation of the last delta, the Aegean coasts gained their present morphology by unifying the effects of various agents, *i.e.* tectonism, climate, and sea-level changes (Erinç, 1955, 1978; Göney, 1973; Erol, 1976; Shröder and Bay, 1996; Bruckner, 1997; Hakyemez et al., 1999; Ergin et al., 2007).

The ancient settlements Miletos, Dydima, Myus, and Priene increased the scientific interest for the Holocene evolution of the region, but the real geological data from onshore are restricted, except for some geomorphologic observations (Göney, 1973, 1975; Erol, 1996). For example, the number and areal limits of marine incursions have not been verified yet, as pointed out by Shröder and Bay (1996). However, there have been attempts to describe historical marine coastlines using morphology and radiometric data (Göney, 1975; Mullenhoff et al., 2004) (Fig. 2). Finally, the inequality between a large drainage area of the RBM (24 300 km^2) and relatively thin sediment sequence of the Quaternary (250 m) in the graben has not been explained so far (Figs. 3, 5, 6). River capture which may be a process to enlarge the catchment could create such an inequality (Roy and Sinha, 2005; Maher et al., 2007).

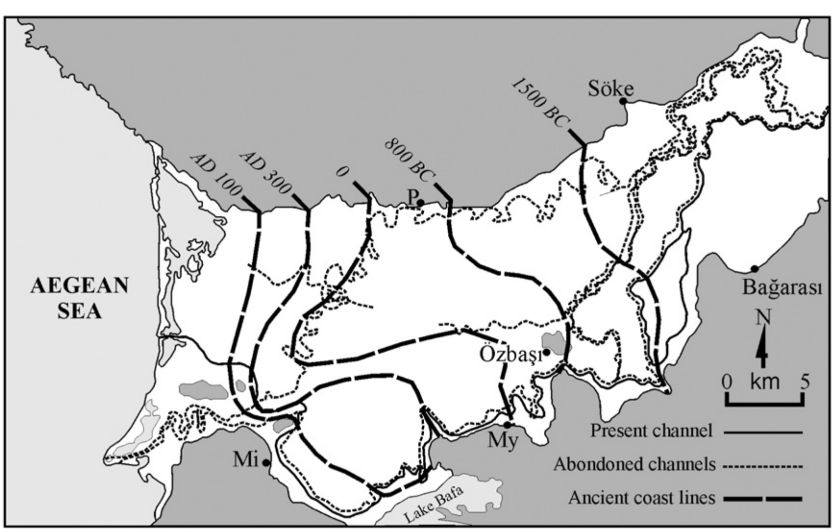

Fig. 2. Present and abandoned channels of the River Büyük Menderes and palaeoshorelines in delta plain. There was no delta formation beyond Söke–Bağarası line. Possible places and dates of ancient coasts are from Göney (1975) and Mullenhoff et al. (2004). Mi Milet, My Myous and P Prienne are historical harbours.

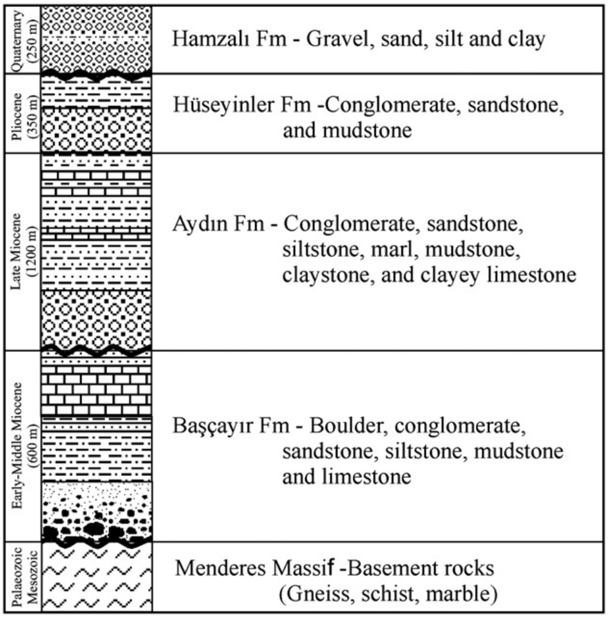

Fig. 3. Simplified stratigraphic section of the graben basin-fill (mostly from Yılmaz et al., 2000 and Yazman et al., 2004).

The aim of this study is to present the Quaternary evolution of this tectonically active graben based on sedimentary records obtained by boreholes and geophysical surveys. To achieve it, the Quaternary succession of the basin-fill will be analysed, the possible marine transgressions will be defined and the sedimentation rate in the Holocene will be estimated using the sediment load of the modern River Büyük Menderes. The sedimentary succession to be presented here could also be a useful data for the interpretation of sedimentary responses to sea-level changes on developments of fluvial and alluvial facies in a graben.

2. Geological and geographical setting

Western Anatolia in Turkey is an active extensional area where pervasive crustal extension in the Neogene and Quaternary led to the development of extensional grabens trending NW–SE, NE–SW, and E–W (Bozkurt, 2003; Bozkurt and Rojay, 2005; Açıkalın and Ocakoğlu, 2006). So, the graben basins of western Anatolia, some of which are known as the Büyük Menderes, Küçük Menderes, Gediz, Alaşehir, Denizli, Uşak, Güre, Çivril, Baklan, Dinar and Acıgöl grabens, are part of a broad complex of horst and graben systems (Fig. 1). Nearly all of them have a thick, sometimes fossiliferous Neogene infill showing their occurrences before Quaternary (Lutting and Steffens, 1976). The setting of the Büyük Menderes Graben (BMG) and the graben basin will be outlined here.

2.1. Morphology and tectonics

The BMG is one of longest tectonic depressions of western Anatolia with an 8–12 km width and *ca* 175 km length bounded by horsts up to a height of 1500 m (Fig. 1b, c). So, it has a hoe-like morphology. At the western end (the head of hoe; in the Söke area), the meeting place of the graben with the Aegean Sea, the BMG goes toward the NE up to 25 km and then it turns to an E–W direction (in the Aydın–Kuyucak area) and it meets the Baklan and Denizli grabens at the eastern end. The town of Sarayköy is close to the end of the graben (Fig. 1a–c).

However, some regional NW–SE trending faults and the locally changing thickness of the basin-fill suggest that Büyük Menderes Graben ended near the town Kuyucak (Sarı and Şalk, 2006; G. Seyitoglu; personnel commun., 2008). The morphology and seismic profiles indicate clearly that the BMG is a full graben. However, presently the northern margin has been much more active, comprising four fault segments apart from some small fractures (the İncirliova–Aydın, Sultanhisar–Nazilli, Kuyucak and Buharkent segments; Figs. 1c, 7) (Şaroğlu et al., 1992).

Proximal and medial parts of alluvial fans here were deeply incised. Similarly, the relative increased channel depth of the RBM in the Kuyucak–Sarayköy area can indicate that fault activity in the eastern part of the graben by the Kuyucak and Buharkent segments is higher than that of the western part of the graben (Arpat and Şaroğlu, 1975). The other characteristic of the graben is that the river course has been forced to migrate toward the southern margin, most probably by progradations of alluvial fans that were initiated from gorges of the northern margin of the BMG (Fig. 1c). On the other hand, there is no terrace along the river. Probably terraces were modified by anthropogenic activities, or even not formed at all.

2.2. Stratigraphy

The BMG and its surroundings have been previously mapped in detail and a stratigraphic framework has been proposed (Kastelli, 1971; Akdeniz et al., 1986; Sözbilir and Emre, 1990). In addition, magnetostratigraphy and the mammalian fossil content of the Neogene and Quaternary infill of the graben has been studied since 1993, and the results of this strengthen the proposed stratigraphy (Ünay et al., 1995; Sarıca, 2000; Saraç, 2003; Şen and Seyitoğlu, 2009).

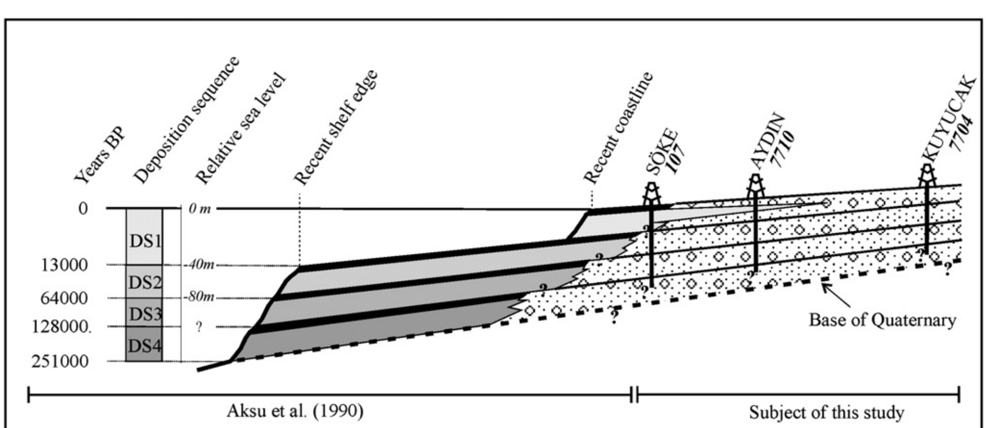

Fig. 4. Sequential evolution of the Büyük Menderes Delta complex (from Aksu et al., 1990) and its continental counterpart investigated by this study. They represent longitudinal section of the Quaternary basin-fill.

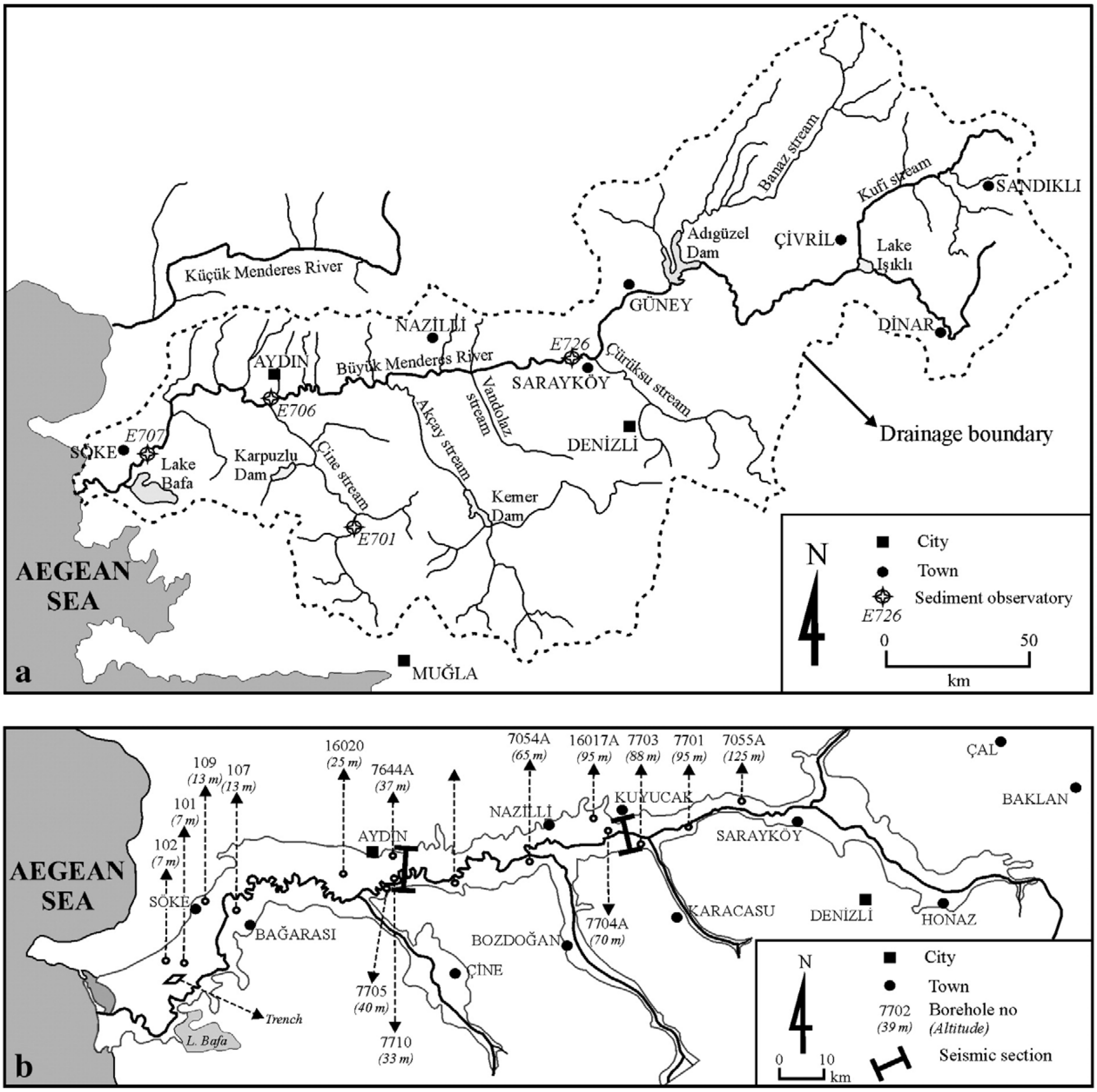

Fig. 5. (a) The River Büyük Menderes and its tributaries. Note meandering nature of the main channel in different localities. Compare the lower course with Fig. 1c for morphology; (b) distribution of Quaternary sediments and locations of boreholes, seismic sections and a trench. Altitudes are for surface positions of boreholes.

Based on present knowledge, the graben basins, including the BMG of western Anatolia, were opened on the Palaeozoic–Mesozoic rocks of the Menderes massif and Lycian nappes in Early Miocene, hence the basement of the BMG basin is allochtonous and mostly metamorphic rocks of pre-Neogene, exposed at the northern and southern margins of the graben (Kastelli et al., 1971; Akdeniz et al., 1986; Yılmaz et al., 2000; Bozkurt, 2000, 2003) (Fig. 1). They are overlain by basin-fill deposits.

Recently, completely new stratigraphic names have been proposed, based on geophysical and borehole data between the towns of Aydın and Nazilli (Yazman et al., 2004) (Fig. 3). The latter described four continental and mostly clastic formations as follows in ascending order: Beşçayır Fm (600 m) of Early–Middle Miocene, Aydın Fm (800–1200 m) of Late Miocene, Hüseyinciler Fm (350 m) of Pliocene and Hamzalı Fm (180 m) of Quaternary. Bouger gravity profiles in accordance with the 2D inversion technique display 2–4 km sediment thickness in different localities of the graben supporting the proposed stratigraphy (Sarı and Şalk, 2006). The youngest, Quaternary, unit is the main interest of this study and will be described in the next chapters in detail (Fig. 3). The presence of the Quaternary unit in the graben has been verified by both boreholes and seismic records (DSI, 1975; Yazman et al., 2004). Fossils indicate that it was formed in Middle and Late Pleistocene (Ünay and Göktaş, 2000; Saraç, 2003), despite the fact that its marine equivalent was deposited in last 240 ka, based on radiometric dates (Aksu et al., 1987, 1990).

2.3. The Büyük Menderes River and its sediment load

The BMG is occupied by the lower course of the River Büyük Menderes (RBM) (*ca* 200 of 584 km) (Fig. 1). The river has a typically meandering channel in the graben. Moreover the term “meandering river” in geology is derived from the old name for this river, the “maiandros”. The meandering channel is due to both a low lying and a large graben floor up to 12 km (Fig. 1). The gradient of the graben floor is less than 0.6%. The altitude at the 20th km, 75th km and 175th km from the sea coast is only 13 m, 37 m and 100 m respectively. The low lying characteristic of this graben floor is due to not only alluvial and fluvial sedimentation but also tectonism during the Late Quaternary.

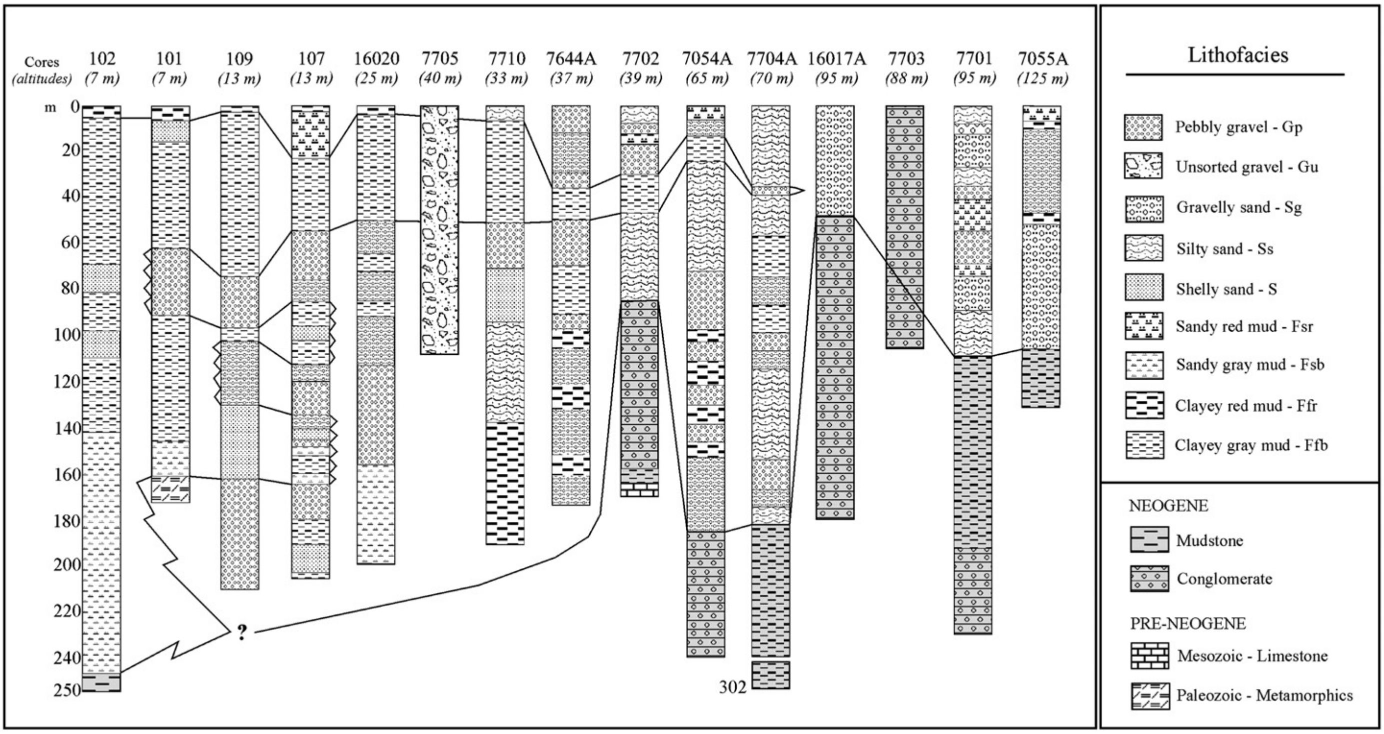

Fig. 6. Facies associations and their distributions within the Quaternary deposits. Note the three marine layers (ML2–4) are observed within limited cores but the last one went further. See Figs. 5, 7 for location and facies details.

The whole catchment of the BMR covers about 24.300 km^2. However it includes two dams and one natural lake, so, the net precipitation area has recently decreased to 11900 km^2 (Fig. 5). The main tributaries are the Banaz and Kufi streams at the east, north of Çivril town. The Akçay and Çine streams come from the southern side of the graben (Fig. 5). Interestingly, a majority of tributaries have also meandering channels, as they are found in local depressions. The numbers of dams on tributaries have increased in recent years. According to our observations the Çine stream carries the most chaotic and coarse-grained load as its longitudinal profile is relatively steeper (Fig. 5).

The water discharge of the BMR has gradually decreased in the last 20 years because of intensive use of water for irrigation purposes and dry weather in the period of 1998–2005. Annual discharges were 154 m^3/s, 90 m^3/s and 40 m^3/s in 1984, 1990 and 2005, respectively (EIE, 1986; 1993, 2006). Unfortunately there was no water at all in the lower course of the river in the summer of 2007. Parallel to this, the sediment load has decreased in time. The suspended sediment load of the river was 3 kg/m^3 in the late seventies, providing 23300 to 38800 ton/day (or 8.5–14 million tons annually) of sediment to the sea according to records at observatory EIE 707 near Söke town (EIE, 1986; this observatory had to move to a site close to Aydın town in 1990 because of the low water discharge) (Fig. 5). This was such a large amount of sediment that it could be compared with that of the Rhone River and it was noted that such a large load was probably effective in deepening the graben (Westaway, 1994). Presently three sediment stations of EIE are working on the river (Fig. 5) and, combining their records with those of station EIE 706, the mean sediment load of the RBM is about 1089 ton/day with a mean water discharge of 59.9 m^3/s between 1950 and 1996 (EIE, 2000).

2.4. The Büyük Menderes Delta

The Büyük Menderes Delta is a confined delta as it was formed by the confined BMR in a graben (Fig. 1). Its morphology does not resemble that of classical river deltas in the literature (*i.e.* Morgan, 1970; Broussard, 1975, Colella and Prior, 1990). Hence, the amount of progradation and the area of the subaerial delta plain are different in various investigations, estimating the progradation from 50 to 20 km (Göney, 1975; Aksu et al., 1987, 1990; Erol, 1996; Shröder and Bay, 1996; Brückner, 1997, Brückner et al., 2002; Mullenhoff et al., 2004; Ergin et al., 2007). The delta progradation in real marine conditions is *ca* 5 km in the south margin (Büyük Menderes Burnu) in the bay, from the bedrocks where the coastal cliffs begin to enlarge in a N–S direction (Fig. 2). The delta plain is characterized by many ponds and lagoons and abandoned channels. Altitudes are only 7 m at 20 km inland (sites boreholes 101 and 102) and 13 m at 40 km near the town of Söke (site boreholes 107 and 109) (Figs. 1, 5).

The depositional circumstances of the delta are wave-dominated associated by a microtidal environment (Aksu et al., 1987; Ergin et al., 2007). It has a subaqueous prodelta platform 1–2.5 km wide and less than 10 m deep with a steep prodelta slope (1:50) in a shelf break that occurred in water depths between 100 and 120 m (Aksu et al., 1987). Seismic profiling on the subaqueous delta shows that the BMR delta was a delta complex comprising four depositional delta sequences (Fig. 4). The youngest one has formed in the last 6000 years (Aksu et al., 1987). The submarine delta has an E–W trending submarine canyon or valley-like morphological feature that extends from a depth of about 70 to 200 m, possibly representing the underwater continuation of the RBM bed cut in the lowstands of sea levels during the Late Quaternary (Ergin et al., 2007). Combined with archaeological data, the submarine delta sequences demonstrate that the sea level raised the maximum water level and/or present day level 6000–5500 years ago. So the latest delta sequences represent the Holocene delta (Aksu et al., 1987; Shröder and Bay, 1996; Brückner, 1997; Mullenhoff et al., 2004).

3. Materials and methods

The Quaternary deposits of the graben have been partly examined in 1999, 2000 and 2006. Together with the middle and upper courses of the river, the river catchments were visited in 2007 in order to display river morphology and sediment sources. Satellite images and air-photos using a 1/35000 scale were used to observe the modern

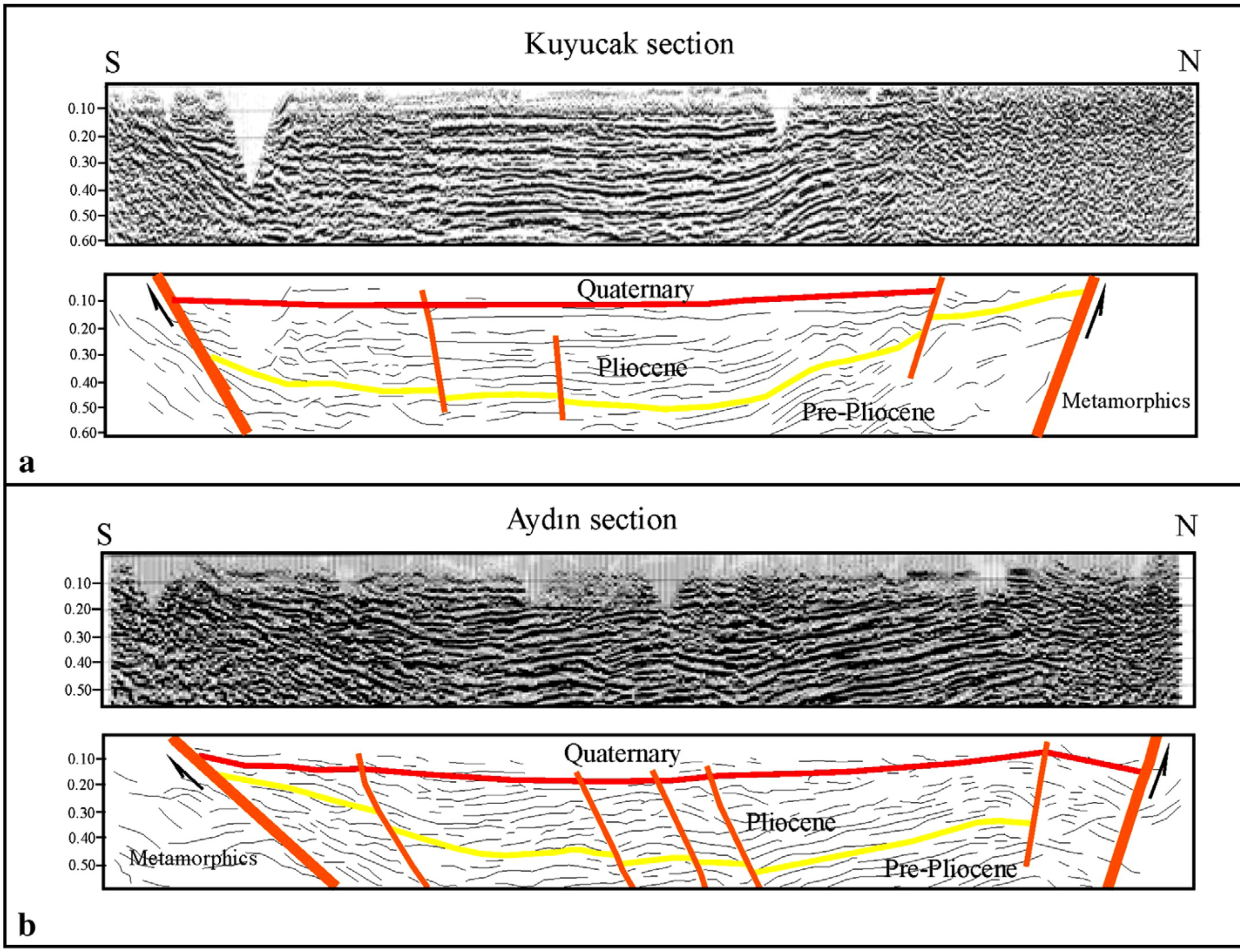

Fig. 7. Seismic sections and their geological interpretations. See Fig. 5 for locations.

channels and for mapping old and recent sediments. The Quaternary deposits of the BMG are mostly covered by recent sediments and modern soils and thus they could not be examined without subsurface data. Hence this study is based on records of boreholes and geophysical measurements provided from the unpublished archives of various institutes. The boreholes, 96 records of which were investigated, had been drilled at different times and in different localities, mostly by the State Office for Water Works (DSI) and partly by the municipalities of Aydın, Nazilli and Kuyucak towns for irrigation purposes (both surface and groundwater are vital for this region as the graben is very populated; two cities (Aydın and Nazilli), ten moderate size towns and up to 350 villages are found here and groundwater is important partly for domestic use and mostly for irrigation purposes). The majority of the DSI's borehole records were also supported with gamma rays and electric logs which were useful to distinguish compacted and uncompacted layers. The lithological logs of 15 of the DSI cores are illustrated here, chosen as relatively representative ones for marginal and axial deposits in the graben (Figs. 5, 6). Unfortunately, the core sediments of many of the boreholes in the DSI Izmir and Ankara archives were heavily disturbed and in such cases we had to turn to the log records. Additionally, in order to compare the actual succession with the log records, a five meter deep trench was dug near the site of core 101, *ca* 10 km north of Lake Bafa (Figs. 2, 5). Here the thickness of the modern soil and the brownish fluvial sediment below it was 4.10 m, and then below that the bluish grey, plastic mud with fossils started, as described in the original record of core 101. Hence, log correlations and facies descriptions were started with examination of cores 101 and 102, using the terminology and methods of Miall (1977, 1978, 1984).

The seismic records of the BMG had been measured by the Turkish Petroleum Company (TPAO) between 1987 and 2000 and most of them were used for a reliable report (Yazman et al., 2004). Only two seismic lines, which had not been included into the above-mentioned report, are used here to illustrate the basin-fill stratigraphy (Figs. 5, 7). The seismic waves have been adopted as 1500 and 1544 m/s in log interpretation and these wave values could be checked by the sediment thickness of two of the DSI's boreholes (7710 and 7644A) which nearly cut the Aydın seismic section (Fig. 5). The used ages for sediments are from the literature, primarily Aksu et al. (1987) for the Pleistocene delta complex and from Shröder and Bay (1996) for the Holocene delta.

4. Results

Modern and older Quaternary deposits of the Büyük Menderes Graben (BMG) are so similar that sometimes it is hard to differentiate between them visually. Satellite images and air-photos became useful for mapping, particularly on the differentiation of modern alluvial fans and fluvial deposits (Fig. 1c). Subsurface data was essential in this study. The investigation results are as follows.

4.1. Borehole and seismic records of the graben-fill

Fifteen borehole logs and facies distributions are shown in Fig. 6. Two cores (101 and 7702) have most likely reached pre-Neogene bedrocks, while seven of the others (7702, 7054-A, 7704-A, 7701, 16017-1, 7703, 7055-A) cut the Neogene deposits and the rest already terminated in the Quaternary succession of the graben (Fig. 6). From the point of view of thickness, the Quaternary deposits form a low sediment prism enlarging toward the west. The sedimentary characteristics of the succession are described later.

Two normal seismic sections of the graben's prolongation, near the towns of Aydın and Kuyucak, have been examined and two of them are illustrated here (Figs. 5, 7). The pattern of seismic reflections apparently differs in the upper and lower parts of the seismic records (sections). The uppermost, parallel and condensed reflections represent the Quaternary succession, while the oblique and subparallel reflections are the Neogene part of the infill (Fig. 7a, b). From here one can reconstruct that the whole Quaternary succession is about 200 m thick. This thickness matches the borehole results that show a distribution within 80–240 m from east to west (Fig. 6). In the E–W sections, reflections have been inclined westward, most probably due to repetitive secondary faults in the graben.

Seismic records clearly indicate that the largest part of the graben-fill was formed in Neogene times; moreover, magnetostratigraphic data show that the exact opening time of the BMG was Early Miocene (Şen and Seyitoglu, 2009). Exposures of the Neogene deposits were displayed well between Adın and Nazilli and also between Kuyucak and Sarayköy towns (at the northern margin of the BMG) but they do not cover a complete section of the infill (Fig. 1b). Fault-bounded boundaries between bedrocks and infill are clear, both in the field and in the seismic records (Figs. 1, 7). Infill thickness varies from 800 to 1700 m due to many synsedimentary faultings in the Nazilli area, as has been already shown by the core log of a deep borehole (Yazman et al., 2004). The whole graben-fill was divided into four subunits by unconformities and these have been interpreted as deposits of the Middle Miocene, Late Miocene, Pliocene and Quaternary, in ascending order (Figs. 3, 7). The youngest unconformity, which is between the Neogene and the Quaternary, is sometime angular, while others are paraconformities or slight truncations (Fig. 7a, b). Angular unconformity was most likely the tectonic result of a long deposition gap between the Pliocene and the Late Pleistocene. However such unconformity is also possible when new sediments rest on inclined sequences towards the master fault. Finally, subsurface data indicate clearly that the BMG is a roughly symmetrical tectonic depression between the towns of Aydın and Kuyucak at least, probably resulting from the see-saw-like activities of the master and secondary faults since Early–Middle Miocene (Fig. 7b).

4.2. Sedimentary characteristics of the Quaternary basin-fill

The Quaternary part of the basin-fill in the BMG contains both modern sediments which formed probably in Late Holocene, approximately in the last three thousands years and older sediments of Quaternary (Late Pleistocene–Holocene). The latter is emphasized here as real Quaternary deposits in order to avoid any misunderstanding due to a lack of exact dates within these sediment sequences.

4.2.1. Modern sediments

The modern sediments in the BMG could be broadly categorized into two groups as marginal formations which were typified by the dominance of alluvial and colluvial processes and axial formations that occurred as a result of fluvial processes. Both groups can differ from the older (Quaternary) equivalents by apparent depositional morphologies, relatively light colours of sediments and less plant coverage. The lithology of these sediments can be observed at road cuts. The marginal formations are mostly gravel-dominated alluvial fans in the northern margin of the graben, the largest one being in the Nazilli area (Fig. 1c). Depositional morphologies of alluvial fans are seen clearly, thanks to fault-lines and fault scarps. However, not only gorges but also all valleys on the northern margin could form alluvial fans with random huge blocks due to the sharp and high topography of the bedrocks up to 1400 m (Fig. 1). Hence, nearly the whole northern side of the BMG is covered by alluvial sediments pushing the axial sediments toward the south (Hakyemez et al., 1999) (Fig. 1). Colluvium cones and screes are observed between Kuyucak and Sarayköy towns in front of steep bedrocks. Mapable marginal sediments are relatively rare in the southern margin of the graben except for a few alluvial fans (Fig. 1c).

The axial and/or fluvial sediments are directly produced by the BMR in the flood plain, abandoned channels, ox-bow lakes, ponds, over banks, point bars and active meandering channels. It is noteworthy that even the upper and middle courses of the BMR consist of meandering channels, even if most are low sinusoidal (the upper course in the Sandıklı and Banaz alluvial plains, the middle course in the Dinar and Baklan areas) (Fig. 5a). The RBM is stepping in these plains and grabens along its longitudinal profile and it has a high-sinusoidal channel system in the lower course in the Büyük Menderes Graben (Figs. 1, 2, 5). Sometime boundaries of fluvial sediments and distal alluvial fans prograded from margins (mostly northern margin) are not clear due to a low topography. However, the active progradation of fans forces the fluvial formation to move towards the south (Figs. 1, 3). The southern margin contains abundant colluvial cones and some short-headed alluvial fans, since active river channels prevent the progradation of fans and cones on this side. The overall thicknesses of the recent marginal and axial deposits including modern soils are between 15–40 m and 2–10 m, respectively. They are becoming thicker towards the margins.

Overall, the whole modern depositional area of the graben (=graben floor) is *ca* 1720 km^2 from the coastal zone to the town of Sarayköy (Figs. 1, 5). The Söke area is 670 km^2 with fine-grained-alluvial fans covering 320 km^2 of it, particularly along the Söke–Priene line in the northwestern margin (Figs. 1, 2). The rest is occupied by fluvial deposits. In the Aydın–Kuyucak area (*ca* 1050 km^2), nearly half of the graben floor (530 km^2) has been used by an active fluvial system.

There is a well-developed watering system for irrigation purposes in the graben. In addition, many drainage channels along the river and a lot of superficial sediment banks along the main channels of the alluvial fans have been constructed to prevent floods. Consequently a modern soil 0.2–1 m thick has been formed on top of the basin-fill succession. The soil is thicker in the Söke area (western part of the graben), where the rate of modern sedimentation is low (Fig. 1). Farming is very extensive in the graben floor and unfortunately the area has become polluted due to the heavy use of fertilizers. In addition, many thermal springs along the fault-lines provide a good deal of boron, carbonates, sulphates and sulphurs to the streams, worsening the quality of usable water from the RBM. By the way, carbonate tufas and travertines form some patch-like sediments which are still developing through active geothermal and mineral water springs along the graben margins (Uysallı and Keskin, 1971; Şimşek, 1984), even though they are negligible in mapping. The most prominent of these formations is found in the Kızıldere village (10 km west of Sarayköy) which is the strongest target area of Turkey for geothermal energy as its surface temperature is 172 °C.

4.2.2. The older deposits

These are deposits of Late Pleistocene–Holocene ages in the Büyük Menderes tectonic depression (Fig. 1). The Quaternary part is easily differentiated from the Neogene part in seismic records, core logs and also in the field by rock types, morphology and structural deformation. In the seismic records the Quaternary succession is typified by intense and continuous reflections (Fig. 7a, b). The maximum thickness is

245 m just in the graben centre near the Aegean Sea (core 102), while it is thinned toward the east. The other long cores cutting the Quaternary deposits are core 109 (210 m), core 107 (208 m) and core 16020 (198 m) (Fig. 6).

The seismic reflections of the Quaternary deposits are regular and continuous over long distances (Fig. 7a, b). Such a character of seismic reflections can indicate that fluvial deposits and alluvial fans are relatively young and hence they have not been much affected by recent graben tectonics yet. From here, one can say that the continental deposits of the Quaternary in this old graben were almost equivalent to those of the RBM delta and they are not older than the 250 ka age determined for the delta complex by Aksu et al. (1987) (Fig. 4).

The prominent characteristics of the Quaternary deposits are being unconsolidated in comparison to the underlying Neogene succession, and electric logs have clearly shown this (DSI, 1975). However some parts of both the Neogene and the Quaternary deposits are permeable, forming productive groundwater aquifers that have been used for years by many villages and towns.

The lithology of the Quaternary basin-fill is mainly mud and muddy sand (Fig. 6). Non-clastics deposits (carbonate tufas and travertines) are volumetrically minor. The lithofacies described within the clastics are as follows: 1 — Pebbly gravel (Gp), 2 — Unsorted gravel (Gu), 3 — Gravelly sand (Sg), 4 — Silty sand (Ss), 5 — Shelly sand (S), 6 — Sandy red mud (Fsr), 7 — Sandy grey mud (Fsb), 8 — Clayey red mud (Ffr), 9 — Clayey grey mud (Ffb). The individual features of facies are listed in Table 1. It should be remembered that the facies were identified from log records and consequently some sedimentary features, particularly stratification types could be missing from the data. Fig. 7 represents a mainly vertical facies distribution in cores. The most common facies within the Quaternary succession are Pebbly gravel (Gp), Silty sand (Ss), Sandy red mud (Fsr) and Sandy grey mud (Fsb) in descending order (Fig. 5). In addition, the gravely facies increase towards the east.

The underlying deposits are typically consolidated conglomerates and mudstones and they did not fall within the scope of this study (Fig. 6). Most probably they are parts of Gökkırantepe Fm or Hüseyinciler Fm of Neogene age (Sözbilir and Emre, 1990; Yazman et al., 2004). Moreover, the basement was cut at the bottoms of boreholes 101 and 7702 in the graben center (Figs. 5, 6).

Occurrences of some of the facies described above were probably in genetic relationships, since Facies 4 and 8 (Ss and Ffr), Facies 1, 6 and 8 (Gp, Fsr, Ffr), Facies 1 and 8 (Gp and Ffr), and Facies 7 and 9 (Fsb and Ffb) have been generally associated (Table 1, Fig. 6). As result, the facies of the Quaternary infill form two lithological assemblages called the continental facies association and the marine facies association. The third group consists of carbonates; however their thickness is negligible, as in modern deposits.

4.2.2.1. Continental facies association. This is composed of varicoloured, frequently yellowish red clastics of facies 1, 2, 4, 5, 7 and 9, representing a subaerial deposition of Quaternary in the BMG. The association was observed in the logs of all the cores except for core 101 (Fig. 6). In general, the mean grain size decreases from east to west. According to occurrences and the abundance of some facies in each core, four subassociations can be described. They are SFA-1 (fac. 1, 4, 8), SFA-2 (fac. 5, 7, 9), SFA-3 (fac. 1, 3, 4, 6, 8) and SFA-4 (fac. 2). The first two subassociations (SFA-1, SFA-2) are displayed mostly in cores 107, 16020, 7710, 7644-A, 7054-A, 7704-A, while the other two (SFA-3, SFA-4) are in cores 7705, 16017-A, 7055-A (Figs. 5, 6).

The subassociation 1 (SFA-1) which is an assemblage of gravelly and muddy sediments is found in cores mostly in the centre of the graben and they represent sediments of meandering channel floors, point bars and natural leves (*i.e.* Allen, 1983; Collinson, 1996). The SFA-2, an assemblage of fine-grained muddy sediments, is typical for flood plain environments (*i.e.* Fielding, 1984). The SFA-3, which is composed of gravel, sand and mud, is a good example of medial and distal parts

Table 1
Lithofacies characteristics of the Quaternary deposits in the BMG.

Code	Facies name	Description	Interpretation
1 — Gp	Pebbly gravel	A colourful, loose, clast-supported facies with medium to well-rounded clasts of 3 to 7 cm. Sand is less than 10%. Normal grading is usual. Pebble-size clasts are mostly radiolarite, limestone and gneiss in origin while sands are made of quartz.	Similar to mostly Gp and partly Gm facies of Miall (1977). It is likely to represent channel bars (Miall, 1978; Rust, 1978, 1979; Cant 1982).
2 — Gu	Unsorted gravel	A dark red facies formed by angular and rounded clasts of metamorphic rocks. Mean grain size is 5 cm. A muddy matrix can reach 15% in volume; however in some places matrix and clasts can constitute separate layers as well as rounded and angular clasts. This facies is seen only in one core.	Alternating grainflow and rock-fall deposits with subordinate debris flow deposits (Nemec and Kazancı, 1999). They all represent colluvium and/or high angle alluvial fan succeeded by flushy deposits (Blair, 1999).
3 — Sg	Gravely sand	Matrix-free sand with fine pebbles (15–30%). Maximum and mean grain size is 3 cm and 0.3 mm respectively. Pebble clusters are common. Resembles Miall's (1977) facies Sm and Sh(s).	One of the most common facies in the succession. Most probably they were sediments of sandy sheet floods (Cant, 1982; Allen, 1983; Collinson, 1996).
4 — Ss	Silty sand	Medium to fine-grained sand layers with yellow colour. It is generally clay-free but silt ratio is 15–30%. Root casts are common. Apart from individual layers, this facies is usually alternating with facies Ffr. Some bodies are completely grey-coloured and underlain by grey mud (Fsb). They also include shell fragments.	They represent point bar and overbank deposits (Allen, 1983; Collinson, 1996). Grey sands are probably sand ridges or sand waves (Reading and Collinson, 1996).
5 — S	Shelly sand	Medium to fine-grained size, grey grey-coloured, clean sands with fragments of marine shells. Quartz is more than 75% volumetrically.	Probably they represent the mouth bar deposits and/or shoreface sediments with low wave energy (Reading and Collinson, 1996).
6 — Fsr	Sandy red mud	A red coloured, thin bedded mud with sand grains up to 10–25%. Sands can be replaced locally by granules of 0.5 cm in diameter. Granules are mostly metamorphic rock fragments while sands are quartz grains. It is similar to facies Fl and Fm.	Probably it was deposited in flood plains (Rust, 1978, 1979; Collinson, 1996).
7 — Fsb	Sandy grey mud	Typically grey, blue and bluish grey-coloured, fossiliferous plastic mud. Sand is medium to fine-grained and its ratio is around 10–15%.	Fossils indicate that it was deposited in a marine environment with low energy. Probably they represent prodelta areas (Reading and Collinson, 1996).
8 — Ffr	Clayey red mud	Yellow and red coloured, thin bedded mud with a clay content of 55–70%. It sometimes includes lens-like coal seams. Facies are dominant lithology in core 7704-A, while sometimes interbedded with facies 5 (Ss) as in core 7701.	Facies formed in flooded areas of a delta plain associated with swamps. Coal seams are representative for these environments (Fielding, 1984).
9 — Ffb	Clayey grey mud	A bluish grey, plastic mud with marine fossil. Clay ratio decreases to 30% while increasing to 70% in some layers. Facies are typically abundant in cores 102, 107, 109 and 16020.	Probably it was deposited in low energetic areas like lagoons, embayments or prodelta (Reading and Collinson, 1996).

of alluvial fans that originated from graben margins (Nemec and Postma, 1993). The subassociation-4 (SFA-4) was found in core 7705 and it represents scree deposits and/or colluvium which could be a proximal part of an alluvial fan (Fig. 6). Such deposits are very common in front of high angle slopes in the tectonic zones of Turkey (Nemec and Kazancı, 1999).

Overall, continental facies association includes two fluvial (channel and flood plain), one alluvial and one colluvial subassociations. Their occurrences and distributions are very similar to those of modern depositional environments in the graben. From here one can say that depositional patterns remained almost the same during the filling of the graben in Quaternary.

4.2.2.2. Marine facies association. This association is formed by the facies Shelly sand (S), Sandy grey mud (Fsb) and Clayey grey mud (Ffb) (Table 1). The joint features of these facies and the constructive characteristics of the association are the bluish grey colour of the lithology and the presence of marine fossils. So there is no doubt that these sediments are marine in origin. The association is found in all cores except for cores 16017-A, 7701 and 7055-A. Especially it is very thick in cores 101 and 102 (Fig. 5). Generally it has a wedge-like geometry, thinning towards the east. In core 107 it alternates with non-marine facies three times (Fig. 6). The most prominent feature of the association is the lithology, which consists of mostly bluish grey-coloured silty sand clayey mud. In few core logs silty sand layer is very thin or absent (Fig. 7). However, bluish grey muddy sediments are much more prominent in every core logs (Fig. 7). Most probably they represent a very stagnant environment, despite sandy facies formed by mouth bars of the Büyük Menderes Delta in the Söke area (Figs. 2, 4, 6).

The carbonates of tufas and travertines could be a third facies association of the Quaternary graben-fill, but their areal distributions are hardly mapable at the scale of 1/25 000. Similar to those of the Recent equivalents, Pleistocene tufas and travertines are seen as small but numerous patches and most are found together with recent carbonates on Neogene clastics (Uysalli and Keskin, 1971; Şimşek, 1984). The Pamukkale travertines in Sarayköy, which are laterally the equivalent of the Kızıldere travertines have been previously examined and dated to *ca* 550 ka BP by the thermoluminescence method (Altunel, 1996; Özkul et al., 2002). It is interesting that the formational time-span of the Pamukkale travertines is longer than that of the Büyük Menderes Delta (Fig. 4). In addition, the first *Homo erectus* fossil of Turkey and its surrounding region was found within the Denizli travertines, very near the Kızıldere area, and as a result the scientific interest in Quaternary carbonates in grabens has increased significantly (Kappelman et al., 2008).

5. Discussion

The Quaternary deposits of the BMG basin cover older units of the graben-fill, which are mostly Neogene in age, like a blanket. They have been surveyed by both seismic records and cores and a *ca* 240 m thick succession thinning inland was discovered. Facies analyses of this succession showed a well-developed, sequential infilling of the graben basin induced jointly by both sea-level changes and tectonism. Due to its development under the control of a continuous extensional tectonism, it could be a good example of Quaternary successions not only for other western Anatolian grabens but also for flat-bottom tectonic depressions elsewhere. However, the thickness of the Quaternary succession is not so great when compared to underlying Neogene units of the graben-fill. On the other hand, the RBM has discharged a good deal of clastic load to the graben and then to the sea even today. In this chapter the characteristics of marine incursions into the graben and the possible role and/or influences of tectonism on the continental deposition will be discussed.

5.1. Marine transgressions into the BMG

The distribution of the vertical facies clearly indicates that considerable marine deposition occurred within the Quaternary succession of the BMG (Fig. 6). They consist mostly of fossiliferous, bluish grey muds (facies 7, 9) and a smaller amount of shelly sands (facies 5) (Table 1). Marine deposits or marine layers (MLs) alternate with continental sediments three times, at least at core 102, representing four marine transgressions into the BMG from the west. However, the thicknesses of individual marine layers change in the cores, from 20 to 70 m thinning eastwards (Fig. 6). The oldest one and other successive sequences are found between 240–174 m, 170–116 m, 111–81 m and 72–4 m, respectively, at core 102 which is the nearest core site to the modern coasts on the modern delta plain (Figs. 4, 6). The lower three layers in the succession (ML2–4) could be also described at cores 107, 109 in the Söke area *ca* 20 km inland, while the youngest one (ML1) reached the Kuyucak area *ca* 120 km inland from the modern mouth of the RBM (Fig. 8).

The exact ages of the Quaternary deposits included marine sequences of the BMG, and thus the history of marine transgressions, are not known, even if they can be dated broadly, based on fossil

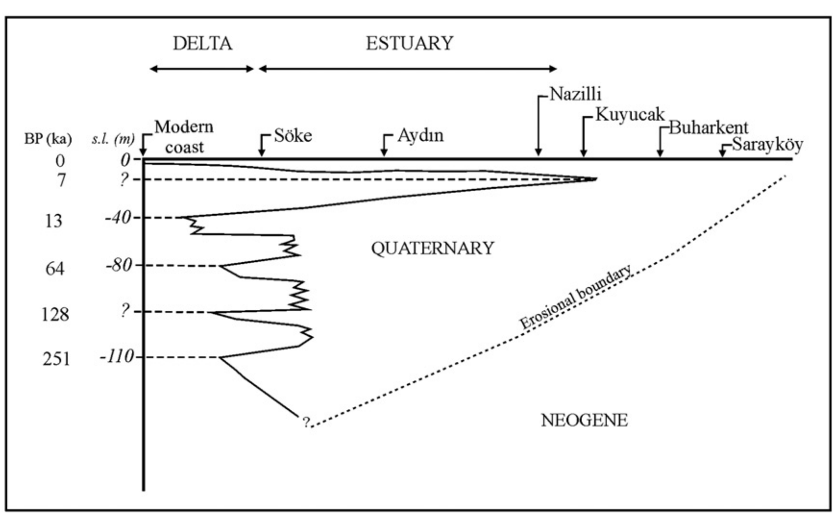

Fig. 8. Sea-level changes and their geographical limits of the marine incursions in the Büyük Menderes Graben. Compare with Figs. 1, 2 and 6.

descriptions, as Quaternary (Ternek, 1959; Ünay and Göktaş, 2000). However, Aksu et al. (1987) proposed a Late Pleistocene age for the formation of the Büyük Menderes Delta complex, based on a comparison with sapropel layers in the eastern Mediterranean Sea. Very soon after this proposal, western Anatolian river deltas including the Büyük Menderes Delta were interpreted to have been formed by four depositional sequences (DSs) under the light of seismic stratigraphy and depositional sequences were dated using organic matter within sediments by Aksu et al. (1990) (Fig. 4). The four-layer sequential pattern of the Büyük Menderes offshore delta complex [Aksu et al.'s (1990) DSs] seems to correlate with the four marine layers (MLs) in the graben (see above). One can say that ML 1–4 detected in the graben by this study was analogous to, and/or comprised time-equivalent sediments of, DS 1–4. If this is true, the first marine transgression and deltaic deposition (DS4, ML4) occurred between 250 and 128 ka ago while the second one (DS3, ML3) was 128–64 ka ago. The next layer (DS2, ML2) formed 64–13 ka ago but the last one (DS1, ML1) was only formed in the last 6 ka (Fig. 4) (Aksu et al., 1987, 1990). Finally, the first three transgressions reached as far as the Söke area but the last one exceptionally went further.

Marine layers represented by deltaic sequences indicate that the transgressions were very rapid and that deposition took place during the regressions. It should be noted that these fluctuations do not correspond to global sea-level changes in glacial periods, probably due to tectonism in the region (Flemming et al., 1998; Pirazzoli, 2005).

5.2. The longest estuary of the Aegean Sea

The youngest marine layer (ML1), which was the depositional result of the last and rapid marine transgression into the BMG, is a sedimentary wedge thinning inland (Figs. 4, 6, 8). It ends near the town of Kuyucak, *ca* 120 km away from the modern sea coast, representing a marine invasion (Fig. 8). The sedimentary result of this invasion was a thin succession of sand and underlying muddy deposits, *ca* 20 m out of the Söke area (Table 1; Fig. 6). The bluish-coloured muddy deposits show a contact of grey-coloured, fossiliferous silty sand (Ss) above and yellow red coloured sand and/or mud below. The bluish grey mud was deposited in an offshore area, below wave-base where only sands were probably deposited by gravity flows during storms (Reading and Collinson, 1996). The oxygenation of the bottom water was fairly poor as indicated by the bluish grey colour of the sediment, which is a consequence of dispersed pyrite in the sediment (Marjanac and Marjanac, 2007).

Even facies architecture of the succession suggests a delta progradation, with sedimentary features showing that a real delta formation was obtained only in the Söke area (Figs. 2, 6, 8). The depth of ML1's basal contact remains the same more or less from Söke (core 16020) to Kuyucak (core 7704-A). This implies that the bottom of the invasion was parallel to the modern graben surface. Most probably, there was a river in the graben during the sea invasion; such morphology is called an estuary in geography.

This is the longest marine incursion (or longest estuary) of the Aegean Sea in Holocene, at least as far as we know. However, Shröder and Bay (1996) previously suggested that during the last transgression of the Aegean Sea water could have reached up to the town of Aydın, *ca* 60–65 km beyond the present coasts. The present study indicates that the invaded area in the BMG was about 120 km long. The main reason for this long marine invasion is the flat-lying topography of the graben floor experiencing tectonic activities, particularly, of the Buharkent fault segment (Fig. 1). In addition, the investigated core logs in the DSI archives showed that the distribution of marine facies was very narrow between the towns of Aydın and Kuyucak, but fairly large between Söke town and Lake Bafa because of alluvial influences, as seen in geological and geographical maps (Figs. 1, 6).

When the spatial dimensions of ML1 are considered, it is possible to say that the Aegean Sea had a long, tongue-like estuary instead of a delta in the Büyük Menderes Graben during the Middle Holocene. Most probably the modern delta commenced in the Söke–Bağarası area following the disappearance of the estuary in Late Holocene (Fig. 2). The lithology, which mostly consists of the fossiliferous plastic mud of ML1, may support this interpretation (Table 1, Fig. 6). This tongue-like estuary was probably the largest marine feature not only of western Anatolia but also of the entire Turkish coasts in the Quaternary.

There is inadequate information about the exact time of marine transgression and events in Middle Holocene in Turkey, despite a general agreement that the first significant sea-level rise in Holocene took place just after the collapse of Laurentide Ice Sheet 8700–8160 years ago (Turney and Brown, 2007 and references therein). According to Kayan (1988, 1999) and Erol (1996), the last transgression of the Aegean Sea took place between 8000 and 6000 BP. Shröder and Bay (1996) suggested that the area between the towns of Aydın and Söke was covered by sea water between 7000 and 3500 BP. However, the possible coastlines of the Late Holocene Aegean Sea have been relatively well defined using historical and archaeological records (Göney, 1975; Shröder and Bay, 1996; Brückner, 1997; Mullenhoff et al., 2004). These investigations agree that the coastline was near Söke–Bağarası in 3500 BP and it prograded up to 20 km in the last 3500 years (Fig. 2). These scholars all followed the climate-basis interpretations of Eisma (1978) and Erinç (1978) about the causes of the last transgression and regression. However, an estuary *ca* 100 km long, emplaced into an area from Söke to Kuyucak, was filled in 7000–3500 BP. This is a relatively rapid infilling of a large estuary and a fast progradation of the delta plain when compared to the thickness of the pre-Holocene sequences in the Quaternary BMG. They may be the result of changes in the amount of river catchment as seen in modern and old sedimentary environments (Okay and Okay, 2002; Roy and Sinha, 2005; Maher et al., 2007).

5.3. Continental deposition in the graben

Core logs indicate that the occurrence and abundance of Quaternary alluvial and fluvial deposits in the BMG generally increase slightly towards the east and they reach a maximum thickness (188 m) in the Nazilli area (Fig. 6). There is no strict age data about these sediments; however, they could be seen as the lateral equivalent of marine layers, based on interfingering within two lithofacies associations (Figs. 4, 6, 8). Overall, the period of occurrence of the deltaic complex has been suggested as 250 ka BP by Aksu et al. (1990) and this was also the formation time of the continental deposits. Broadly speaking, marine sequences occurred beyond the Söke area except for sediments of the Holocene transgression (Figs. 6, 8).

Continental deposits, which are the main part of the graben-fill, were composed of subassociations of alluvial and fluvial facies (SFA1–4). In general, alluvial facies formed marginal deposits while fluvial ones constituted axial deposits, as in the present case. Essentially, the gutter-like morphology of the graben has influenced the environmental model of deposition (Fig. 2). However, modern alluvial fans that derived from the tectonically active northern margin were forced to shift the main course of the river towards the seismically passive southern margin. The vertical facies distribution of the Quaternary continental deposits in the graben (Fig. 7) indicates that the northern and southern margins behaved like a see-saw, producing repetitive sequences of alluvial and fluvial facies, even if the present morphology of the BMG suggests a half graben. Moreover, mud-dominated fluvial facies even in the eastern part of the graben show that the topographic position of graben floor remained the same more or less during the Late Pleistocene.

5.4. Possible changes in the drainage area

Seismic profiles clearly show that an unconformity occurred between deformed sequences of the Neogene and the parallel stratified deposits of Quaternary (Yazman et al., 2004) (Fig. 7). This unconformity also represents a relatively large gap of time of unclear duration. According to Aksu et al.'s (1990) dates on marine sediments, it lasted from the Late Pliocene to the Late Pleistocene representing a long erosion period. In other words, a 240–245 m thick clastic succession of Quaternary occurred during the last 250 ka. It seems to be of a relatively small thickness and low rate of sedimentation (app. 1 mm/a) for a large graben with a catchment of *ca* 24300 km^2. The relatively short time of occurrence could explain the small thickness of the continental deposits, but when taking into consideration the high modern sediment load of the RBM (see chapter 2c) and also the *ca* 50 m sediment thickness of the last, short-age (6–5 ka BP) depositional sequence of Holocene (DS 1 or ML 1), which corresponds to a sedimentation rate of 8–10 mm/a, the Pleistocene sequences are relatively thin and this needs to be explained.

In contrast, reasons for the high amount of sediment in the Holocene could be an explanation of this case. A rough calculation is possible using fluvial depositional areas, sediment thickness, sediment age and the modern sediment load of the RBM in order to show the extremely high sediment input into the graben in the Holocene. We think that the thinness of the Quaternary succession and/or the reason for the thicker Holocene sequence was a sedimentary response to two geological influences during the Late Pleistocene. One of them was related to a low rate of sediment production, since the drainage area of the RBM was nearly half that of the present case for a long time. The length of the RBM was short, having one third of the present course in the Pleistocene, except for the last 10–15 ka. Probably at the end of the last glacial period, the old RBM captured another drainage basin (the Işıklı–Çivril palaeolake which has been a fluvial plain presently and the catchment of that palaeolake) owing to river processes and fault activities. This capture made double catchments of the BMG and then sediment accumulation increased significantly in the graben. In contrast, the Işıklı–Çivril palaeolake turned to a fluvial plain occupied by a long meandering channel (upper course of the modern RBM; Fig. 5). Such a river process and the enlargement of catchments are not rare in continental environments (Okay and Okay, 2002; Roy and Sinha, 2005; Maher et al., 2007). The tectonic reasons for this event are beyond the scope of this study. The second influence on sediment thickness in the graben could be abrupt sea-level changes. When sea levels were falling, the river could trench its own bed rapidly; eroding a good deal of sediments and this event was repeated four times which correspond to the delta sequences. Incisions of the RBM imply a transportation of continental sediments into the sea. As result, marine sequences of the Quaternary succession became thicker than continental sequences, producing a wedge-like sedimentary prism in the graben.

6. Conclusions

The Büyük Menderes Graben, which has been bounded by the Aegean Sea, is the largest, seismically active depression of western Anatolia, Turkey (Figs. 1, 2). It has an 1100 m thick, mainly clastic basin-fill deposited during the Neogene and Quaternary (Fig. 3). The Quaternary part of the basin-fill (*ca* 250 m) is relatively thin in comparison with the present sediment load of the River Büyük Menderes and needs explanation. This younger part of the basin-fill is composed of unconsolidated alluvial and fluvial deposits intercalated with four layers of marine sediments (Figs. 4, 6, 7). The continental facies association thickens inland while the marine ones become dominant towards the Aegean Sea forming a wedge-like basin-fill geometry (Figs. 4, 7, 8). The marine layers correspond to four marine incursions and/or transgressions, the last one of which occurred 7000–3500 years BP. The last marine incursion also formed the largest, *ca* 120 km long estuary of the Aegean Sea in Holocene. This estuary was filled in a relatively short time (*ca* 3500 years) by intense siltation, most probably based on enlargement of the drainage area (Fig. 5). Local morphology indicates that the River Büyük Menderes captured the palaeolake Çivril–Işıklı in the latest Plesitocene under the control of both tectonic and surface processes and doubled its own drainage area. Following it, the Çivril–Işıklı palaeolake which has been the upper course of the River Büyük Menderes then (Fig. 5) turned to a flood plain. It is possible to say this capture is the most significant event in the development of the present morphology of the region. However, in order to display Quaternary evolution of the Büyük Menderes Graben in detail, the basin-fill and morphology of the catchment still need further studies.

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