

## Paleobathymetric evolution of the Miocene deposits of the Gömbe sector of the Lycian Foreland and Aksu basins in Antalya, Turkey

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**Abstract:** The evolution of the Lycian Foreland and Aksu basins are associated with the Africa-Eurasia convergence and collision of intervening continental blocks. Both basins developed around the Beydağları, a Mesozoic carbonate platform, which constitutes the main component and western limb of the Isparta Angle. The Gömbe Basin is an integral part of the Lycian Foreland Basin that comprises mainly Eocene to Late Miocene turbidites, onto which the allochthonous Lycian and Antalya nappes thrust over. The Aksu Basin, however, developed in the inner part of the Isparta Angle and is bounded by the Aksu Thrust in the east. During their evolution, these basins experienced significant bathymetric changes, possibly due to vertical motions and variations in the sediment supply. This study provides a detailed analysis of the paleobathymetric evolution of these basins. This conducted paleobathymetric study was based on the determination of the depositional depth by the abundance ratio of planktonic versus benthic foraminifera, which is the function of the water depth. The percentage of planktonic foraminifera relative to the total foraminifer population (%P) increases from shallow to deep water. However, some benthic foraminifera species are directly affected by the oxygen level of the bottom water, rather than by paleobathymetry, i.e. stress markers, and were discarded in the calculation. Additionally, the dissolution of the foraminifera has the potential for miscalculations, since planktonic foraminifera are more prone to dissolution than benthic ones. Nevertheless, the obtained quantitative results were verified and validated qualitatively by specific benthic depth markers that lived at specific depth ranges. Aksu Basin had a shallowing trend, and the sedimentation rate exceeded the subsidence in the middle of the section. Calculated depths for the Gömbe Basin indicated depths around 1000 m, which was contrary to the high sedimentation rates indicated by the turbiditic facies of the basin infills.

**Keywords:** Foraminifera, paleobathymetry, Lycian foreland Basin, Aksu Basin, Isparta Angle

### 1. Introduction

Throughout the Cenozoic Era, convergence between Africa and the Eurasian plate led to the gradual closure of the Neotethyan oceanic basins, and resulted in the present tectonic scheme of the eastern Mediterranean region. The Aegean and Cyprus arcs, 2 subduction systems, appeared in the eastern Mediterranean. The Isparta Angle is defined as a junction of these morpho-tectonic structural units (Blumenthal, 1963). The Antalya Basin, located within the Isparta Angle, was formed on the Mesozoic (para) autochthonous carbonate platform in the western Taurides. Terminal closure of the Neotethyan Ocean signified the deformation history from Mesozoic to Early Cenozoic, which comprised thrusting of the Lycian Nappes and associated ophiolitic units over the Beydağları and Geyikdağı paraautochthonous units (Dumont et al., 1972; Özgül, 1976, 1984; Poisson et al., 2003a; Van Hinsbergen et al., 2010).

The Antalya Basin comprises 3 subbasins, namely the Aksu, Köprüçay, and Manavgat basins, which are located in the eastern part of the Beydağları Platform (Akay et al., 1985; Flecker et al., 1998; Glover and Robertson, 1998; Poisson et al., 2003a; 2011; Flecker et al., 2005). These basins are associated with the evolution of the Central Taurides (Gutnic et al. 1979; Özgül, 1984) and developed in response to the development of the Isparta Angle and Aksu Thrust. The Lycian nappes thrust from the northwest and the Tauride from the east on the Beydağları platform. Aside from the Lycian Nappes, the emplacement of the Antalya and Alanya Nappes placed a distinct unit within the Isparta Angle (Figure 1). The Lycian Foreland Basin began to develop in the Early Miocene, and it was under a compressional regime due to thrusting of the Lycian Nappes over the Beydağları Platform toward the Langhian (Flecker et al. 1998; Poisson et al., 2003b; Flecker et al., 2005; Poisson et al., 2011).

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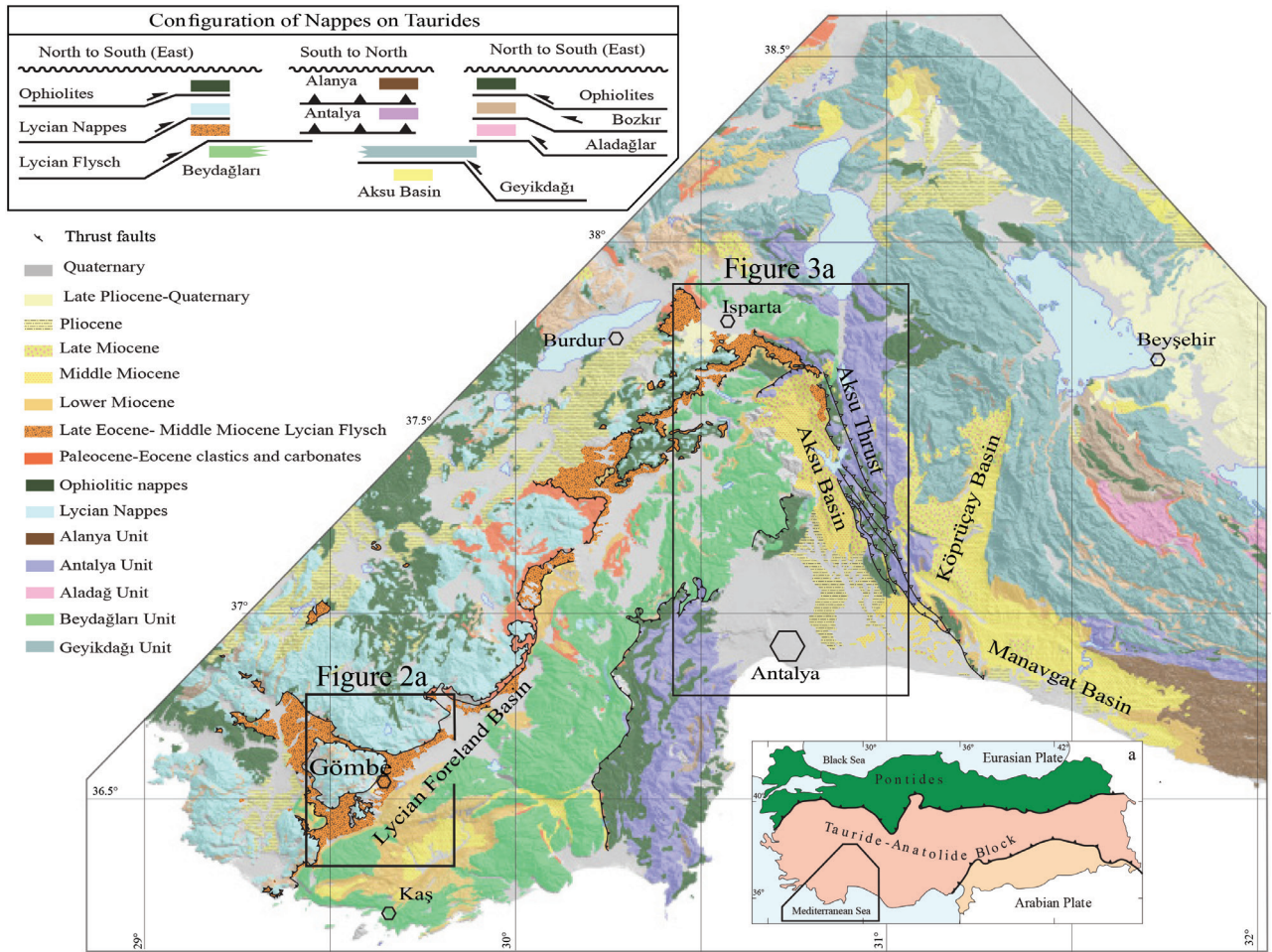


Figure 1. Major tectonic units and Neogene sedimentary basins in the Isparta Angle (modified from Kaymakçı et al., 2018).

Miocene to Pliocene stratigraphy and kinematic evolution of the Antalya and Lycian Foreland basins have been studied in detail by various researchers (e.g. Özgül, 1976; Hayward and Robertson, 1982; Hayward, 1984; Akay et al., 1985; Çiner et al., 2008). The earliest biostratigraphic studies in the region were conducted by Bizon et al. (1974) and Gutnic et al. (1979). They were followed by İslamoğlu (2001), İslamoğlu and Taner (2002, 2003), Poisson et al. (2003b), Şenel (2004), and Sagular (2009), and included planktonic foraminifera, nannoplanktons, molluscs, and corals. Tectonic evolution and paleoenvironmental characteristics of the region were addressed by Akay and Uysal (1988), Flecker et al. (1998), Glover and Robertson (1998), Flecker et al. (2005), Karabıyıkoglu et al. (2005), Poisson et al. (2011), Üner et al. (2015), and Koç et al. (2016). However, no published studies exist on the paleobathymetric evolution of these basins, in terms of changes in the accommodation space and vertical block movements in the region.

The geometry, facies distributions, paleobathymetry, and environment of deposition were mainly controlled by tectonic regimes, as well as global sea level fluctuations. Paleobathymetric studies have provided important insight into understanding the development of the accommodation space, sediment supply, and interplay between tectonics and sedimentation (Allen and Allen, 1990). In this context, the main purpose of this contribution was to understand the paleobathymetric evolution of the Aksu and Gömbe sector of the Lycian Foreland Basin using the change in the ratio of planktonic versus benthic foraminiferal present within the infills of these basins. This will shed some important light on the development history of these basins, especially on how the accommodation space and water depth changed during emplacement of the Lycian Nappes from the west and the Antalya Nappes along the Aksu Thrust Fault from the east over the Beydağları Platform during the Neogene. The evolution of the basins is closely linked with the Africa-Eurasia convergence and

collision of intervening continental blocks (Flecker et al., 2005; Çiner et al., 2008; Üner et al., 2015; Koç et al., 2016). Therefore, the information obtained from these basins will provide constraints on the evolution of the eastern Mediterranean basins over the last ~15 my.

## 2. Geological setting

Convergence between African and the Eurasian plates resulted in partial closure of the different branches of the Neotethyan oceanic basin. The southern Aegean and Cyprus arcs are 2 subduction systems along which the oceanic crust at the northern edge of the African Plate, which constitutes the remnant oceanic crust of the eastern subducting below Anatolia at the southern edge of Eurasia. Various slab-edge processes during the Late Cretaceous and onwards gave way to the formation and total destruction of various sedimentary basins on the overriding plate. The remnants of these basins are exposed partly in various locations in southwestern Anatolia. These basins include very thick Eocene to recent marine, to continental deposits (Hayward and Robertson, 1982; Hayward, 1984; Glover and Robertson, 1998; Flecker et al., 2005; İşler et al., 2005; Alçiçek et al., 2006 and 2013; Faccenna et al., 2006; Çiner et al., 2008; Mackintosh and Robertson, 2009; Ten Veen et al., 2009; Hall et al., 2014).

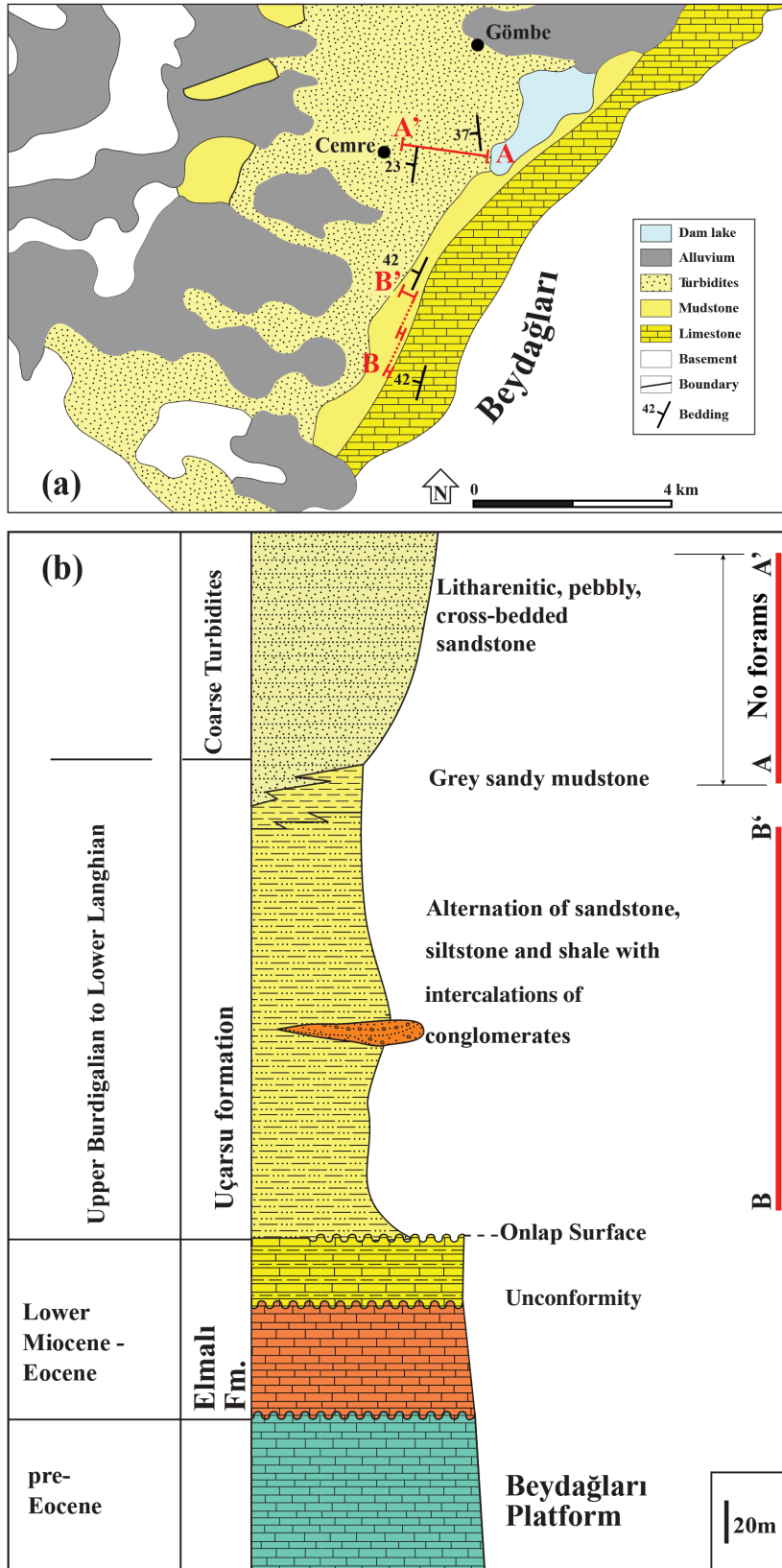
The basement of most of these basins belongs to Mesozoic autochthonous carbonate platform units composed of various accreted and stacked nappes, most of which derived from the north, from the İzmir Ankara-Erzincan Suture zone, while the source of the other nappes is still under debate. Three contrasting sources have been proposed for the origin of these nappes. According to the first scenario, all of the Tauride nappes were derived from a northerly located oceanic basin (Ricou et al., 1975), which was most probably the northern branch of the Neotethys ocean (Şengör et al., 1984). The second scenario was proposed by Ricou et al. (1979), which was a modified version of the first scenario. They considered that all of the nappes were derived from the north, but the Antalya Nappe on the eastern margin of the Beydağları Platform first emplaced during the Late Cretaceous, and moved northwards along a sinistral strike-slip fault zone and thrust over the central Tauride autochthon. According to the third scenario, the nappes located north of the Taurides were derived from the north, while the nappes located south of the Taurides were derived from the south (Dumont et al., 1972). The last scenario implicitly required more than one Mesozoic basin south of the Taurides, as proposed by Poisson (1984) and Nemeč et al. (2018).

The Antalya basin within the Isparta Angle includes the Aksu, Köprüçay, and Manavgat basins (Koç et al., 2016). They were developed by the Lower Miocene, on the Antalya and Alanya Nappes, and in the west they onlap

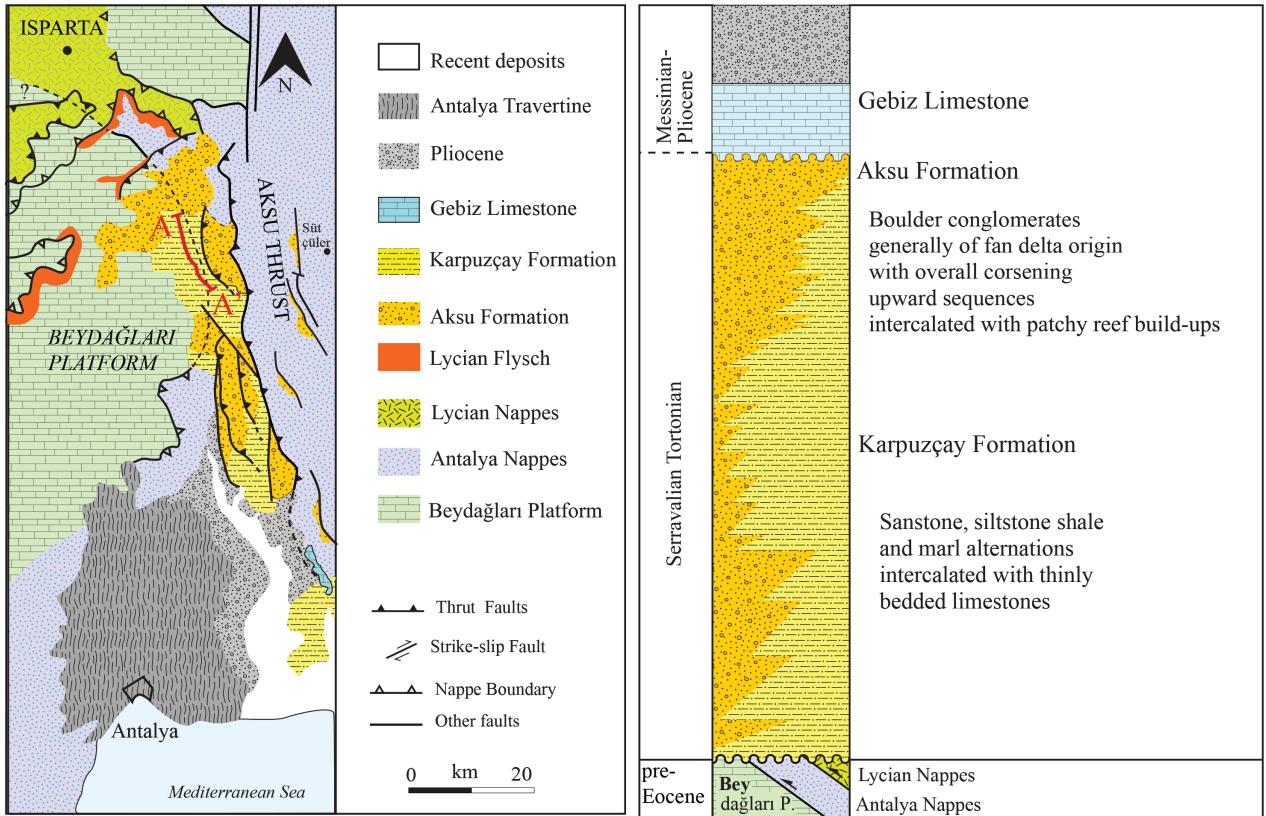
onto the Beydağları Platform. However, the Gömbe sector of the Lycian Foreland Basin developed progressively on the Beydağları Platform, as the Lycian Nappes advanced eastwards and thrust over the Beydağları platform from the west during the Eocene to Middle Miocene (Hayward, 1984). The Beydağları Platform, together with the Geyikdağı Unit, constitutes the central axis of the Taurides, since they are structurally the lowest units in the belt. They are considered as paraautochthonous units and comprise thick Mesozoic carbonates spanning from the Paleozoic to Late Cretaceous. Carbonate deposition on the Beydağları Platform continued until the Early Miocene in various places (Hayward, 1984). The Alanya Nappes contain Permian and Triassic high-pressure metamorphic rocks with peak metamorphism that took place around the Santonian and was characterized by eclogite to blueschist facies rocks overprinted by younger medium-grade greenschist facies metamorphism (Çetinkaplan et al., 2016). The Antalya Nappes contain various volcanic and volcanoclastic rocks, ophiolitic fragments belonging to different depths of an oceanic crust, as well as various sedimentary units belonging to different tectonic and depositional environments. This is typical for colored mélanges, implying that it developed in an accretionary wedge environment, which was possible at the southern margin of the northward subducting Pamphylia Ocean of Şengör and Yılmaz (1981) (Çetinkaplan et al., 2016). It was thrust over during the Late Cretaceous by the Alanya Nappes, both of which together thrust over the Geyikdağı Unit.

The Gömbe Basin, constituting an integral part of the Lycian Foreland Basin, comprises 2 lithostratigraphic units, namely the Elmalı and Uçarsu formations (Şenel, 2004). The Elmalı Formation overlies the Beydağları Platform, and it is overlain by the Uçarsu Formation, between Elmalı and Kaş (Figures 1 and 2). The thickness of the Elmalı Formation is more than 1000 m (Şenel, 2004). It was named by Şenel (2004), and is exposed between Kaş and Isparta. The Uçarsu Formation is tectonically overlain by the Lycian Nappes from the west, and it is up to 220 m thick. It is characterized by green, greenish-grey mudstone, siltstone, sandstone and conglomerate alternations, and sandy limestone intercalations. The section includes gastropod and coral fragments, and echinoids. It also contains planktonic foraminifera, such as *Globigerinoides* sp. and *Globigerina* sp., and the age of this formation is Late Burdigalian to Early Langhian (Şenel, 2004).

The Aksu Basin is delimited in the east with the Aksu Thrust and onlaps onto the eastern margin of the Beydağları Platform (Figure 3). It comprises 3 Miocene formations, namely the Aksu Formation, Karpuzçay Formation, and Gebiz Limestone. Pliocene and Quaternary units overlie these units in various places. The Aksu Formation is



**Figure 2.** (a) Map showing the location of the Gömbe Section A-A', B-B' (see Figure 1 for its location). (b) Generalized columnar section Gömbe sector of the Lycian Foreland Basin (modified from Collins and Robertson, 1998; Şenel, 2004).



**Figure 3.** (a) Geological map of the Aksu Basin and location of the sampled section, A- A'. (b) Generalized columnar section of Aksu Basin (modified from Deynoux et al., 2005, Çiner et al. 2008).

mainly characterized by conglomerates, and thinly bedded sandstones, mudstones, and marl intercalations with occasional limestone blocks.

Çiner et al. (2008) divided the Aksu Formation into 3 subunits, as the Kapıkaya Conglomerate, Karada Conglomerate, and Kargı Conglomerate. The best outcrops of the Karpuzçay Formation were observed along roads cut along the Antalya-Isparta Highway. It laterally grades into Aksu and Karpuzçay and is overlain by Pliocene deposits. Its thickness was measured as 2050 m (Akay et al., 1985). The formation is characterized by sandstone and mudstone alternations with coarse conglomerate intercalations at the upper levels. Mudstones are grey, green, and yellow in color, and the sandstones are generally lighter in color. Thin to thick sandstone beds, which show fining and coarsening upward sequences, alternate with laminated and thinly bedded mudstones (Çiner et al., 2008). It contains planktonic foraminifera and nannofossils, such as *Globorotalia peripheronda*, *Praeorbulines*, *Orbulines*, *Globigerinoides trilobus*, *Globigerinoides sacculifer*, *Globigerinoides extremus*, *Globorotalia mayeri*, *Globigerinita* sp., *Globoquadrina* sp., *Globigerinoides obliquus*; *Sphenolithus*

*heteromorphus*, *Cyclicargolithus abisectus*, *helicosphaera carteri*, *Cyclococcolithus macintyreii*, *Reticulofenestra psedoumblica*, *Sphenolithus abies*, *Helicosphaera euphratis*, *Discoaster exilis*, and *Discoaster deflandrei*. The age of the formation was assigned as Serravalian to Tortonian (Akay et al., 1985; Çiner et al., 2008). Gebiz limestone unconformably overlies the Antalya Nappes and the Karpuzçay Formation. Its thickness was measured as 40 m (Akay et al., 1985). Poisson et al. (2011) assigned the Messinian age for the Gebiz Limestone according to the most recently acquired nannoplankton data. The post-Miocene units include Pliocene and Quaternary deposits. The Pliocene units comprise the Eskiköy Formation, Yenimahalle Formation, and Alakilise Formation. The Quaternary units comprise the Antalya Tufa and alluvial cover.

### 3. Material and methods

#### 3.1. Material

In the Gömbe Basin, 2 composite sections were measured, one of which was along the turbidities at the top, and 94 samples were collected from a 630-m thick section. The collected samples were coded as GB. The average sampling

interval was 7 m in this section. However, due to the fact that most of the units consisted of sand-sized material, foraminifera were not identified in the washed samples. These discarded samples were characterized by quartz and highly abundant rock fragments. The other subsection, below the GB section, was coded as GÖM. This section consisted of an alteration of mudstone and limestone. Collected samples along this section came from mudstone. A total of 22 samples were collected from a 220-m thick section. The average sampling interval was 10 m in this section. Samples 1, 3, 14, and 15 were discarded from in this section due to the absence of foraminifera. Samples, 4, 5, 7, 9, 10, 13, and 16 indicated an anoxic environment, and were discarded from the analyses as well.

In the Aksu Basin, samples were collected from a 1620-m section belonging to the Karpuzçay Formation. The section started in the core of the anticline, and it was characterized by an average 2-m mudstone and 50-cm sandstone alternation. Near the top of the section, the grain size became coarser, and it turned into a sandstone-conglomerate alternation. The average sampling interval was 10 m in this section when the nonexposed parts were excluded. Samples, 3, 5, 9, 12, 17, 27, 34, 35, 38, 43, 44, and 48 indicated an anoxic environment and were discarded because of the absence of depth markers, and other samples in which foraminifera were absent were also discarded.

### 3.2. Methods

Paleobathymetry studies concern the depositional depth estimation of marine basins. The uplift and subsidence history can be understood via the paleobathymetric evolution of the marine basins, taking into account global sea level changes (Van der Zwaan et al., 1990). As paleodepth estimations become more precise, understanding the history of the vertical movements of basin floors can become more comprehensive. Palaeontology, based mainly on foraminifera, plays a vital role in paleobathymetry estimations that cannot be fulfilled with another tool (Allen and Allen, 1990). Qualitative bathymetry studies are conducted with benthic foraminifera species. Each benthic foraminifera species has its own habitat, and one of the controlling factors of this habitat is water depth.

Each species indicates a depth interval and these can overlap each other, or they may intersect or not. This creates faunal zones consisting of benthic species and allows estimation of the depth range (Phleger, 1951; Bandy, 1953; Bandy and Arnal, 1960). Extant benthic foraminifera species can be used directly as a proxy for paleobathymetric studies. On the other hand, extinct species are only reliable within certain error margins, since their paleobathymetric range is deduced from comparisons and analogy with living taxa. However, the paleodepth range of benthic fossils, which have no recent counterparts, has to be ascertained by comparing the

species with living taxa. Another problem is the existence of heterobathyal species, living at different depth ranges at different locations (Bandy and Chierici, 1966).

Moreover, when the number of benthic species decreases, it is more difficult to obtain a precise depth range. In this case, the uncertainty of the obtained results may be hundreds of meters. Under these circumstances, quantitative studies have become more important. The planktonic foraminifera, in this case, are used for paleobathymetric studies, as well as their biostratigraphical applications (Bandy and Chierici, 1966; Wright, 1978; Van der Zwaan et al., 1999; Kouwenhoven, 2000; Kouwenhoven et al., 2006; Van Hinsbergen et al., 2005).

The standard methodology proposed by Van Hisbergen et al. (2005) was used herein for the Late Cenozoic, using the general notion of Van der Zwaan et al. (1990). It was based on a systematic relation between P/B (the ratio between the planktonic and benthic foraminifera) ratio and the depth of recent sediments (Phleger, 1951). The proportion of the planktonic foraminifera to the total foraminifer population increases from shallow water to deep water (Grimsdale and Van Morkhoven, 1955; Smitho; 1955). Paleodepths can be derived from the regression function, depending on distributions of recent foraminifera by performing %P.

$$\text{Depth (m)} = e^{3.58718 + (0.03534 * \%P)}$$

Here, %P indicates the percentage of planktonic foraminifera in relation to the total foraminifer assemblage. However, deep infaunal benthic species were considered as stress markers, and the %P value was calculated as  $\%P = 100 * (P / (P + B - S))$ , where P is the number of planktonic foraminifera, B is the number of benthic foraminifera, and S is the number of stress markers. The depth of the sediment affects available food and oxygen for the benthic foraminifera (Jorriksen et al., 1995). Infaunal benthic species, which were used as a stress marker, were affected by the oxygen level rather than the water depth. These species caused a disturbance in the %P distribution. Anoxic environments determine the presence/absence of epifaunal benthic species, living on the seafloor, used as a depth marker. If the sample is dominated by infaunal species, then it becomes difficult to find epifaunal benthic species in the anoxic environment (Van der Zwaan, 1990; Jorriksen et al., 1995; Van der Zwaan et al., 1999; Den Dulk et al., 2000; Van Hinsbergen et al., 2005; Kouwenhoven and Van der Zwaan, 2006; Nguyen and Spejler, 2014). According to previous studies, species of *Valvulineria*, *Bulimina*, *Globobulimina*, and *Bolivina* were used as stress markers. Species of *Uvigerina*, with the exception of *Uvigerina peregrina*, were also used as stress markers, and as a result, it was determined that species of *Uvigerina* tolerate low-oxygen environments (Schweizer, 2006).

Confidence limits of the calculation were defined by comparing the observed depth value of the recent samples

and predicted depth values based on the equation as 99% P, corresponding to 1200 m, where the lower confidence limit was 860 m and the upper was 1650 m. For 50% P, which corresponded to 430 m, the lower confidence limit was 310 m and the upper was 590 m. The standard error was greater at the deeper estimations (Van der Zwaan et al., 1990). Limits of the calculation by Van der Zwaan et al. (1990) were between 36 and 1238 m according to the values of %P, which ranged from 0% to 100%.

Extraction of foraminifera from rocks is easy in loosely consolidated material. Generally, using tap water is an adequate fast method. Nevertheless, water was not adequate for some lithified rocks, in which case, the freeze-thaw method of Kennedy and Coe (2014) was used with some modifications, such as rapid heating, detergent, and ultrasound stages, which were sufficient for extraction in this study. In order to use a size fraction of 125 and 595  $\mu\text{m}$  for counting, dried samples were sieved and then divided in equal quantities with a micro splitter. Samples were spread on a picking tray and counted until at least 300 planktonic and benthic species were obtained (Gibson, 1989).

Some unexpected results, such as outlier data points, may occur due to downslope transportation, reworking, and carbonate dissolution. Hence, the samples should be checked for these factors after washing (Gibson, 1989; Van der Zwaan et al., 1990; Van Hinsbergen et al., 2005). While reworking can be better understood from biostratigraphical studies, downslope transportation can be recognized by comparing depth markers. Shallower benthic species may be found in deeper parts where they are not expected to live with deeper benthic species (Bandy and Arnal, 1960). First, the transported depth markers are discarded. After calculation of %P, discarding of the samples depends on the taxonomic checks with the depth markers.

Moreover, samples are discarded that contain size sorting of foraminifera and sediment grains, or high amounts of quartz grains or rock fragments, which are evidence of transportation. Carbonate dissolution affects foraminifera differently because the resistance of shells differs from one taxon to another. Recognition and determination of the benthic species are adequate for the analysis of samples.

## 4. Results

### 4.1. %P and depth results

The results of the %P obtained from the GÖM section were used in the depth equation of Van der Zwaan et al. (1990). Figure 4 shows the relation with the stratigraphic section. In this section, the %P of all of the counted samples was greater than 95%, and the calculated depth ranges were between 1070 m and 1150 m. The %P and depth graphs of the stratigraphic sections from Aksu (IS) are shown in

Figure 5. In the Aksu section, the general trend of the sea level shallowed with respect to the %P, while the grain size of the sediments coarsened upward towards the top of the section.

### 4.2. Taxonomic check

Benthic species showing a wide depth range occurrence are not useful for paleobathymetry (Perez-Asensio et al., 2012). Van Hinsbergen et al. (2005) reported the depth range of marker species that were common in the Mediterranean (Figure 6). Species of *Gyroidina* may show occurrence from the outer neritic to lower bathyal depth, from 100 to 5000 m (Perez-Asensio et al., 2012), and these species were present in both the Gömbe and Aksu sections; hence, they were not useful for any correlations. Neither of the genera *Anomalinoidea* or *Lenticulina* were useful for paleobathymetry since they have wide bathymetric ranges.

In the Gömbe section, the calculated depth was always above 1000 m. Depth ranges that were derived from depth markers confirmed the depth from the %P. Moreover, the presence of *Cibicides italicus* narrowed down the range of depth, due to the fact that it indicated a depth deeper than 1000 m (Schweizer, 2006). At the top and middle of the Gömbe section (GB), the paleobathymetry could not be constructed due to the absence of the foraminiferal fauna. This part was dominated by quartz and rock fragments, and well sorting was observed in some of the levels indicating current deposition. Calculated depth levels of the base of the GÖM section were deeper than 1000 m.

In the Aksu section, the sample coded IS-31 was discarded due to the fact that it contained carbonate dissolution, which is not possible in a depth result of less than 200 m, according to the depth marker content. Although samples coded IS-49 and IS-52 were within the confidence limit, they had to be deeper when compared to the depth derived from the %P, because the upper depth limit of *Cibicides italicus* is around the 1000 m. At the bottom of the Aksu section (IS), the paleodepth was in the middle bathyal range. The paleodepth extended to 1000 m, to the lower bathyal range, at some levels, where *Cibicides italicus* was present. In the middle bathyal range, *Cibicides kullenbergi*, *Oridorsalis stellatus*, *Siphonina reticula*, and *Planulina arminensis* cooccurred. The depositional depth range changed from the middle bathyal to upper bathyal. The upper bathyal range contained *Planulina arminensis*, *Cibicides pachyderma*, *Cibicides ungerianus*, *Cibicides pseudoungerianus*, *Cibicides dutemplei*, and *Casudulina levigata*. At the top of the section, the size distribution was coarser, and turbiditic activity increased. Depth results could not be obtained from the bottom levels. Nevertheless, it can be deduced from the general trend that the depositional depth was shallower from bottom to top.

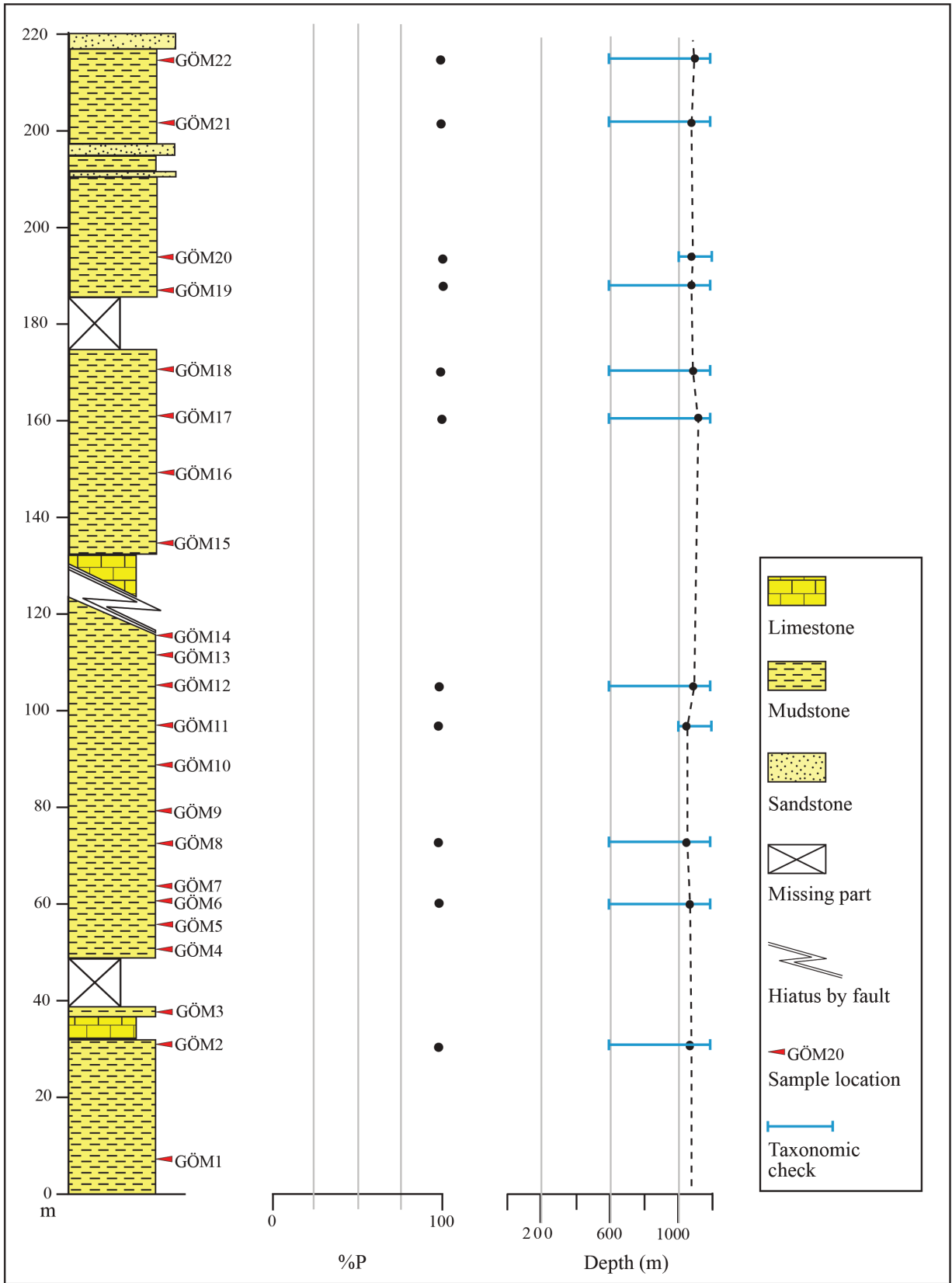


Figure 4. Stratigraphy and %P depth graphic of the Gömbe (GÖM) section.



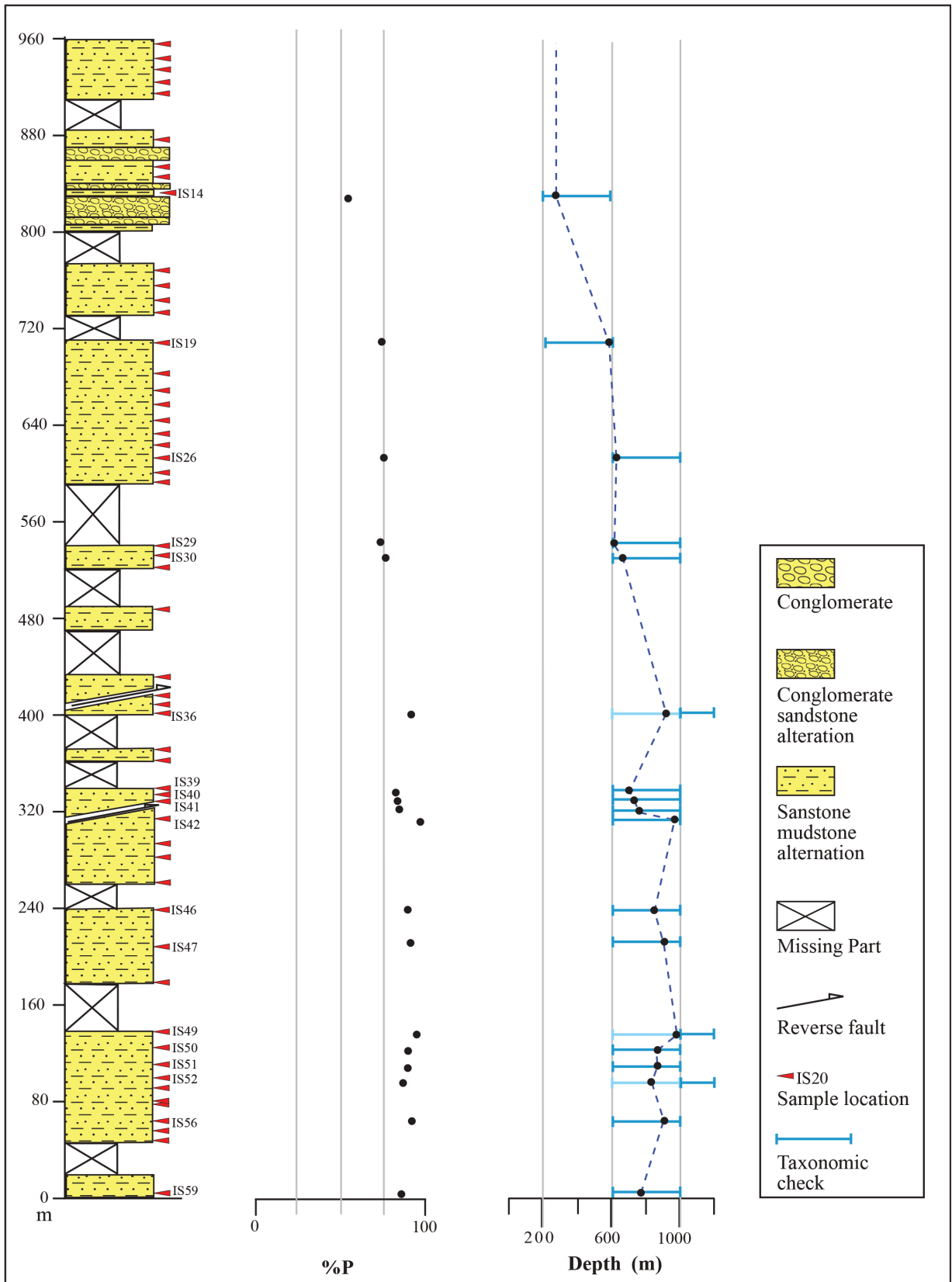
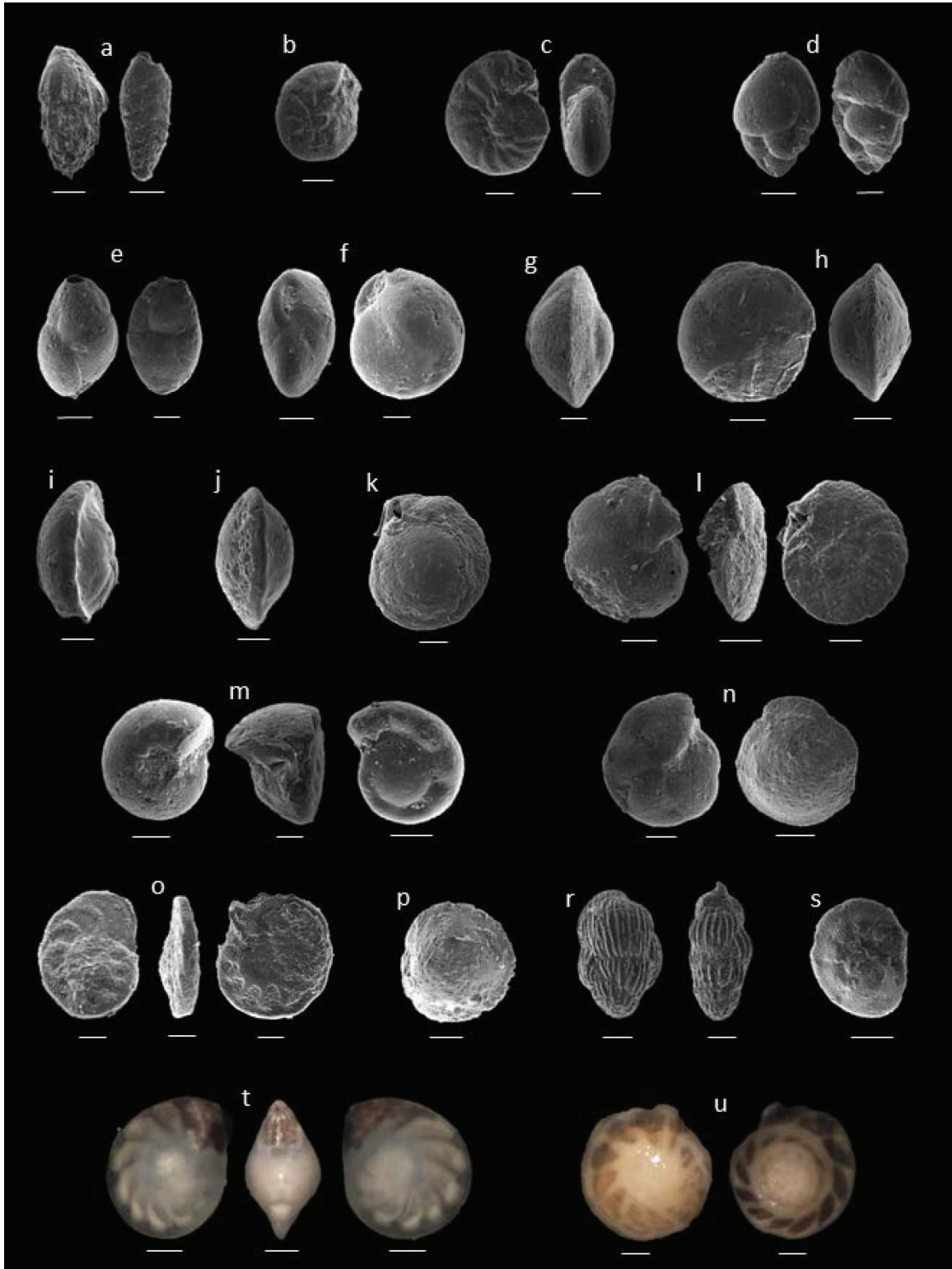


Figure 5. Stratigraphy and %P and depth graphics of the Aksu Section, IS.



**Figure 6.** (a) *Bolivina* d'Orbigny, 1839. (b) *Ammonia beccarii* Linnaeus, 1758. (c) Genus *Anomalinoidea* Brotzen, 1942. (d) *Bulimina* d'Orbigny, 1826. (e) *Globobulimina* sp. Cushman, 1927. (f) *Cassidulina laevigata* d'Orbigny, 1826. (g) *Cibicides dutemplei* d'Orbigny, 1846. (h) *Cibicides italicus* Di Napoli Alliata, 1952. (i) *Cibicides kullenbergi* Parker, 1953. (j) *Cibicides pachyderma* Rzehak, 1886. (k) *Cibicides pseudoungerianus* Chusman, 1922 (l) *Cibicides ungerianus* d'Orbigny, 1846. (m) *Gyroidina* d'Orbigny, 1826. (n) *Oridorsalis stellatus* Silvestri, 1898. (o) *Planulina*

### 4.3. Vertical movement

The first sample level corresponding to the base of the section was used as a reference level and the sediment thickness was added to the calculated paleobathmetry for each datum. The reason for this was the shallowing effect of the sediment accumulation. However, the main complication of adding the sediment thickness was the variation between the initial and present thickness of the sedimentary rocks influencing the estimation of subsidence or uplift. (Van Hinsbergen et al., 2005) Correction of the compaction was applied to both the Gömbe and Aksu sections because of the lithology of the sections, which was mainly sandstone and mudstone. The reduction was taken as 20% on average (Perrier and Quiblier, 1974). Results were relative to the eustatic sea level change due to the wide time interval and absence of significant chronostratigraphic data (Figure 7).

### 5. Discussion

The depositional depth of the basins was derived from the %P from suitable samples. Confidence limits of these quantitative results were verified and validated using specific benthic depth markers. Resolution of the quantitative paleobathmetry was based on the number of samples covering a time interval; each sample provided a depth result from the %P and made drawing of the

paleobathmetry curve possible (Van Hinte, 1978). To obtain more detailed results, the numbers of samples can be increased for a given time interval (Van Hinsbergen et al., 2005). A total of 116 and 59 samples were collected, as indicated on the constructed stratigraphic sections. Discarding some samples decreased the resolution of the study.

Nevertheless, the obtained paleodepth results from the %P covered sections GÖM and IS. Moreover, one of the limitations of the study was that there was no significant chronostratigraphic correlation on the measured sections. The obtained paleodepth results were interpreted in compliance with this frame.

Above the GÖM section, the paleobathmetry was unable to be constructed due to the absence of foraminiferal fauna. This part was dominated by quartz and rock fragments, and well sorting was observed in some of the levels, indicating current deposition. Calculated depth levels at the base of the GÖM section were deeper than 1000 m and this was confirmed by the presence of *Cibicides italicus*.

Global eustatic sea level was falling, as indicated in Figure 8, from 20 Ma to 13.8 Ma (Burdigalian to Langhian) in a general trend (Haq et al., 1988). It has been suggested that there was no global sea level change during the Upper Burdigalian to Lower Langhian, and the

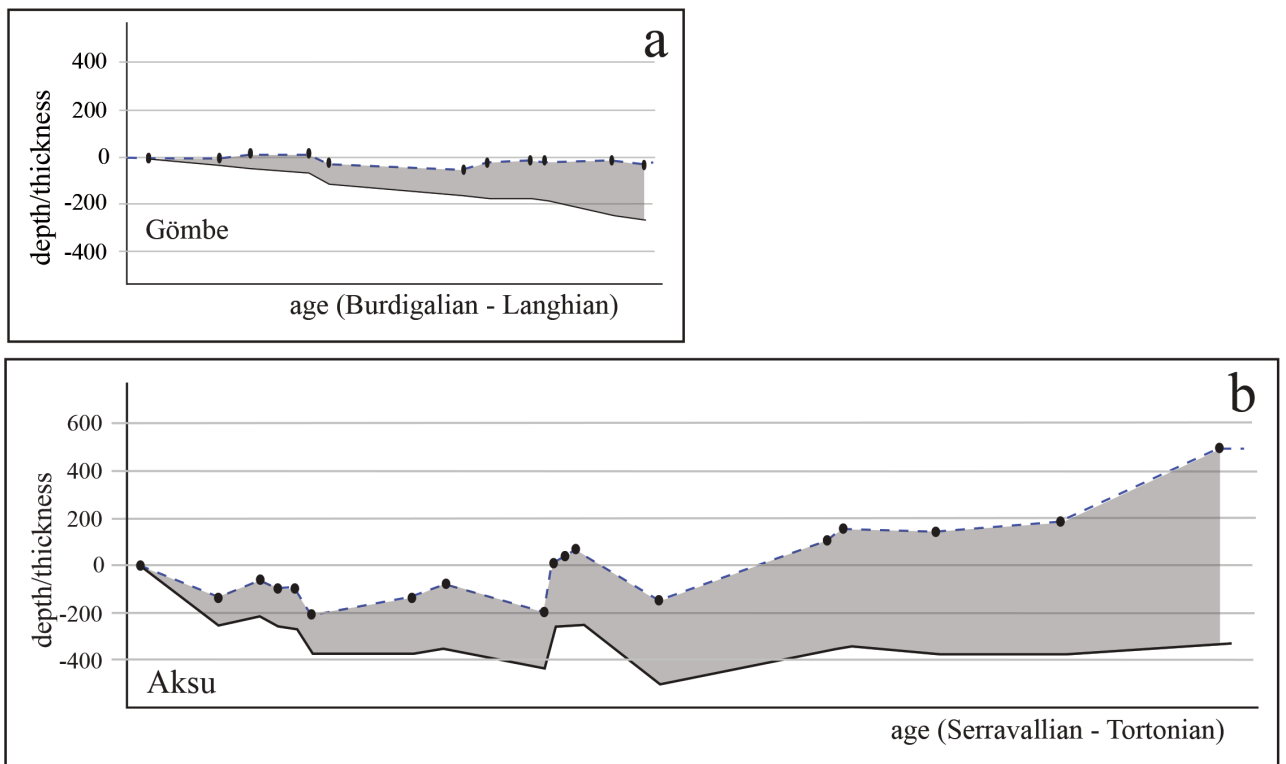
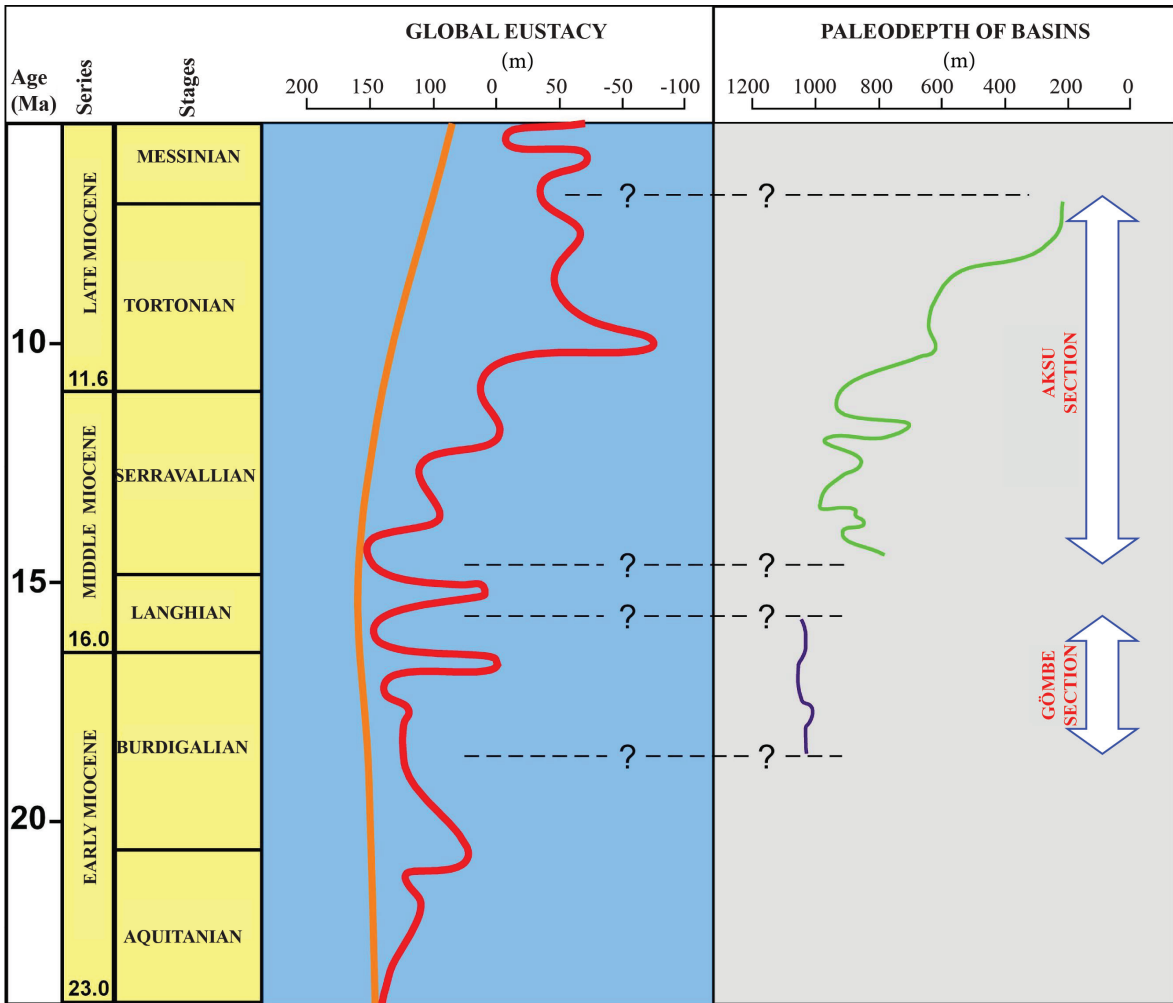


Figure 7. Diagrams depicting vertical motions of the (a) Gömbe and (b) Aksu basins.



**Figure 8.** Global eustatic sea-level change in the Miocene (Haq et al., 1988). Red line is short term, and the orange line is long term sea-level change (modified from Haq et al., 1988). Paleobathymetry curves of the Gömbe (purple line) and Aksu (green line) basins.

sedimentation rate was almost equal to the subsidence rate in the Gömbe Basin. This process then continued with a higher sedimentation rate, and turbidites were deposited until the end of the Langhian during the emplacement of the Lycian Nappes on the Beydağları platform (Hayward 1984, Poisson et al., 2003).

In the Aksu section, the calculated paleodepth results were at the lower, middle, and upper bathyal ranges. At the top of the section, the size distribution was coarser, and the turbiditic activity increased. Depth results could not be obtained from shallow levels. Nevertheless, it can be deduced from the general trend that the depositional depth was shallower from bottom to top.

Shallowing of the depositional depth was greater than the global eustatic sea level change, which is indicated in Figure 8, for the Aquitanian to Tortonian (Haq et al., 1988). Even if the global sea level change is taken into account during that time, the rate of sedimentation exceeded the

rate of subsidence in the middle and upper levels of the Aksu Basin. The rate of subsidence, related possibly with the Aksu Thrust, became slower during the Tortonian.

**6. Conclusion**

The main work performed in the context of this study produced the following conclusions:

Stratigraphy and paleobathymetry of the Gömbe indicated that the:

1. Depositional depths were deeper than 1000 m.
2. Paleo-depth did not change during the Late Burdigalian to Early Langhian time interval. This may have been due to:
  - a. the sedimentation rate having kept pace with the sea level rise in the case where no subsidence occurred, or
  - b. the sedimentation rate having increased to accommodate the sea level rise, and the total amount of subsidence.

3. Sequences located above the fossil-bearing sequence were dominated by turbidites, in which no significant fauna were found.

Stratigraphy and paleobathymetry of the Aksu basin indicated that the:

4. Depositional depth was shallowing as a general trend.

5. Shallowing of the depositional depth was more than the decrease in the eustatic sea level during the Serravallian to Tortonian.

6. Rate of sedimentation exceeded the rate of subsidence in the middle part of the Aksu Basin.

7. Subsidence rate decreased during the Tortonian.

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