geodiversitas

2021 • 43 • 13

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art. 43 (13) — Published on 28 June 2021
www.geodiversitas.com

PUBLICATIONS SCIENTIFIQUES
MUSÉUM NAL HIST NATURELLE

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CP 41 – 57 rue Cuvier F-75231 Paris cedex 05 (France)
Tél. : 33 (0)1 40 79 48 05 / Fax : 33 (0)1 40 79 38 40
diff.pub@mnhn.fr / http://sciencepress.mnhn.fr

ISSN (imprimé / *print*) : 1280-9659/ ISSN (électronique / *electronic*) : 1638-9395

Oligocene larger benthic foraminifera and sedimentation of the Burdur Basin, SW Anatolia, Turkey

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Submitted on 16 October 2019 | accepted on 27 February 2020 | published on 28 June 2021

urn:lsid:zoobank.org:pub:7EB95293-B048-41D0-9237-F66CBFDD43E5

Gedik F. & Karadenizli L. 2021. — Oligocene Larger Benthic Foraminifera and sedimentation of the Burdur Basin, SW Anatolia, Turkey. *Geodiversitas* 43 (13): 377-389. https://doi.org/10.5252/geodiversitas2021v43a13. http://geodiversitas.com/43/13

ABSTRACT
This study focuses on the Oligocene successions that contain predominantly siliciclastic, limestones with larger benthic foraminifera in the Burdur Basin of southwest Anatolia, Turkey. The Burdur-1 and Burdur-2 sections in the Oligocene deposits are described sedimentologically and were sampled for lithology, biostratigraphy, microfacies analysis and fossil content. Larger benthic foraminifera were mainly recovered from limestones in the upper part of the Burdur-2 section. Thin-section analysis of the larger benthic foraminiferal assemblage reveals that the upper part of the Burdur-2 section includes *Nummulites fichteli* Michelotti, 1841, *Operculina complanata* (Defrance, 1822), *Nephrolepidina praemarginata* (Douvillé, 1908), *Eulepidina* sp., *Planorbulina* sp., *Amphistegina* sp., and *Asterigerina* sp. This foraminiferal association represents the Shallow Benthic Foraminifera Zone 22 (SBZ 22) of Rupelian-early Chattian age. Sedimentological analysis in the Burdur-1 and Burdur-2 sections has revealed an association of massive-unorganized conglomerate, parallel-bedded sandstone, massive mudstone, graded-massive conglomerate, graded-massive sandstone, well-sorted organized conglomerate, well-sorted parallel-bedded sandstone and microfossil-bearing parallel-bedded limestone facies. Alluvial fan / river, fan-delta, beach and shallow shelf carbonate facies communities were identified by lateral and vertical correlation of facies. It is concluded that the large Burdur Fan developed in a graben basin that opened and was flooded by a branch of the Tethyan Ocean that invaded southwest Anatolia during the Oligocene.

KEY WORDS
Oligocene,
Turkey,
Burdur,
larger foraminifera,
micropalaeontology,
sedimentology.

RÉSUMÉ
Grands foraminifères benthiques de l'Oligocène et sédimentation du bassin de Burdur, sud-ouest de l'Anatolie, Turquie.
Cette étude se concentre sur les successions de l'Oligocène du bassin de Burdur, au sud-ouest de l'Anatolie (Turquie), qui contiennent principalement des calcaires siliciclastiques avec de grands foraminifères benthiques. Les coupes des niveaux oligocènes de Burdur-1 et de Burdur-2 sont décrites et ont été échantillonnées pour la lithologie, la biostratigraphie, l'analyse des microfaciès et le contenu paléontologique. Les plus grands foraminifères benthiques ont été principalement échantillonés dans les calcaires de la partie supérieure de la coupe de Burdur-2. L'analyse des lames minces de l'assemblage de grands foraminifères benthiques révèle que la partie supérieure de la coupe de Burdur-2 contient *Nummulites fichteli* Michelotti, 1841, *Operculina complanata* (Defrance, 1822), *Nephrolepidina praemarginata* (Douvillé, 1908), *Eulepidina* sp, *Planorbulina* sp., *Amphistegina* sp. et *Asterigerina* sp. Cette association de foraminifères représente la Zone de foraminifères benthiques peu profonds n°22 (SBZ 22) d'âge Rupélien-Chattien inférieur. L'analyse sédimentologique des coupes de Burdur-1 et Burdur-2 a révélé une association de conglomérat massif non organisé, de grès à litages parallèles, de mudstone massif, de conglomérat massif, de grès massif, de conglomérat organisé bien trié, de grès à lits parallèles bien trié et de faciès calcaire à lits parallèles contenant des microfossiles. Les communautés de faciès carbonatés de type éventail alluvial/rivière, fan-delta, plage et plateforme peu profondes ont été identifiées par corrélation latérale et verticale des faciès. Il en est déduit que le cône alluvial de Burdur s'est développé dans un bassin de Graben qui s'est ouvert et a été inondé par une branche de l'océan Téthys qui a envahi le sud-ouest de l'Anatolie pendant l'Oligocène.

MOTS CLÉS
Oligocène,
Turquie,
Burdur,
grands foraminifères,
micropaléontologie,
sédimentologie.

INTRODUCTION

Turkey is part of the Orogenic Belt of the Alpine-Himalayan Mountain Range (Fig. 1). The geological evolution of southwestern Turkey is unique in the Mediterranean region since several well-preserved tectonic units exemplify the whole tectonic history of the Alpine orogen (Şengör & Yılmaz 1981; Şenel 1997; Collins & Robertson 1998, 2003). The rock succession outcropping in the western Taurids (SW Anatolia), was placed into the following four tectonic units by Collins & Robertson (1998, 2003): Menderes Massif, Bey Dağları platform, Lycian thrust sheets and melanges, and supra-allochton sediments. As shown by Poisson (1977), Özcan *et al*. (2009), and several workers, the Oligocene-Miocene development of the region is characterized by both the emplacement of Lycian Allochthon over the Bey Dağları platform in the foreland and the development of extensional basins in the hinterland. Although a very tentative foraminiferal composition of the Oligo-Miocene units of both autochthonous and supra-allochthonous units was documented by several workers (Dizer 1962; Poisson 1977; Göktaş *et al*. 1989; Örçen 1991; Şenel 1997), updated palaeontological studies with zonal precision are lacking. Gedik & Karadenizli (2007) and Karadenizli *et al*. (2009) presented unpublished detailed palaeontological and biostratigraphical data for the Oligocene deposits in the Burdur region. The most recent studies of larger foraminifera from the Burdur area include Özcan *et al*. (2009) and Matsumaru *et al*. (2010). Özcan *et al*. (2009) studied the Korkuteli (Antalya) and Tavas-Burdur basins, and presented a detailed foraminiferal inventory of both Oligo-Miocene units from the Bey Dağları platform and coeval supra-allochthonous units (piggy-back basin units of Sözbilir 2002). The latter units are deposited in an extensional tectonic regime.

Matsumaru *et al*. (2010) focused their study on the Karabayır Formation in the Korkuteli Basin, which was deposited in a shallow-marine regime well-marked by lower Miocene transgressive sediments, which in turn are overlain by basinal units of the Karakuştepe Formation that developed prior to the emplacement of the Lycian Nappes (Poisson & Poignant 1974; Poisson 1977; Şenel 1997; Robertson 2000). These authors have hypothesized that tectonics were the most influential control on the depositional history of the Bey Dağları foreland basins during the Oligocene-Miocene.

The marine Oligocene units of southwestern Anatolia, deposited under different tectonic regimes, are important in interpreting the regional palaeogeography of the Neotethys (Şenel *et al.* 1989; Karadenizli *et al*. 2009, 2017). During the Oligocene, thick siliciclastic sediments with limestones formed on the basement belonging to the Lycian Nappes in the Burdur Basin (Şenel *et al.* 1989; Karadenizli *et al*. 2009, 2017). These limestones contain diagnostic larger foraminifera such as nummulitids and lepidocyclinids, which are of great value for biostratigraphic dating and regional correlation (Karadenizli *et al*. 2009, 2017).

Oligocene sediments outcrop in the Burdur area along the Burdur Lake (Fig. 1A) where are situated the sections Burdur-1 and Burdur-2. Their geographic coordinates are 37°48'22"N, 30°06'31"E and 37°47'38"N, 30°07'33"E, respectively. In this study, the stratigraphy of the region was re-examined and correlated with the Acıgöl region. The Oligocene units consist of the Çardak and Hayrettin formations (Göktaş *et al*. 1989). Their sedimentological characteristics are interpreted to represent the development of Oligocene sedimentary environments in the Burdur Basin. Micropalaeontologic studies and facies analysis were carried out in the Burdur-1 (840 m)

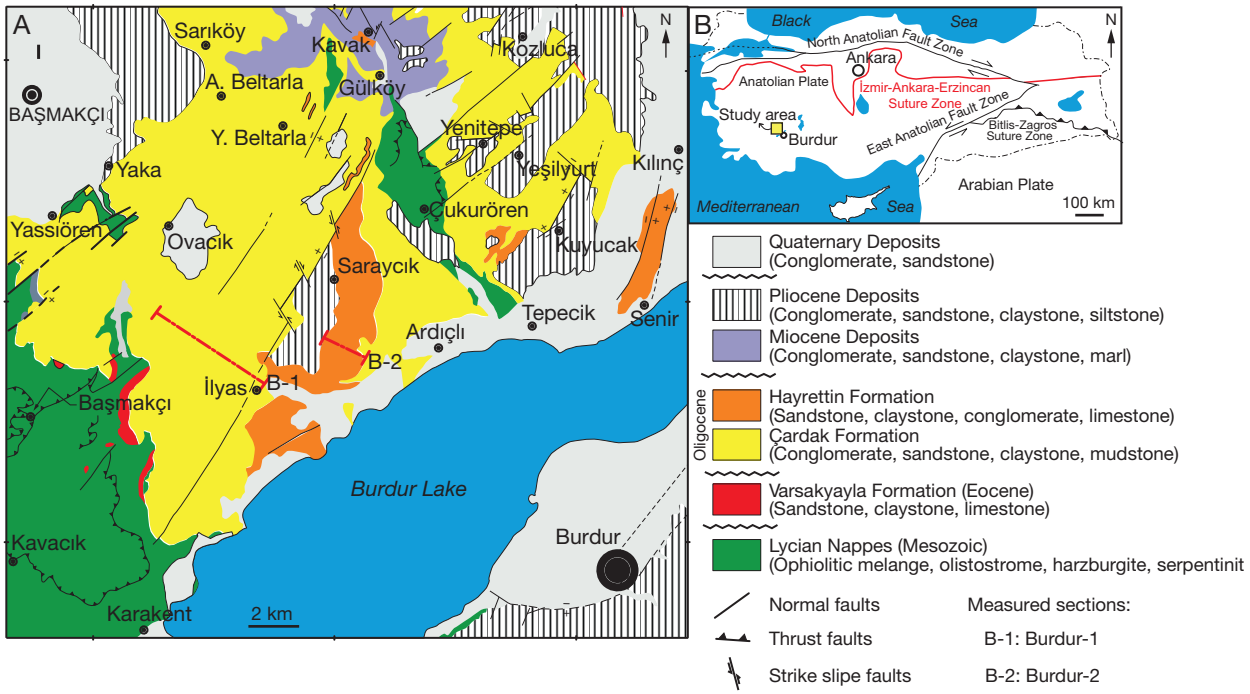

FIG. 1. — **A**, **B**, Geological map of the studied area with generalized stratigraphic section (modified from Şenel 1997).

and Burdur-2 (140 m) sections to interpret the sedimentary environments (Figs 1A; 2). Large foraminifera were analysed from the shallow shelf carbonates of the Hayrettin Formation, in the upper 20 m of the Burdur-2 section.

MATERIAL AND METHODS

Two stratigraphic sections, in total about 1000 m, were logged. The foraminiferal assemblages were mainly recovered from limestones in the upper part of the Burdur-2 section. Taxonomic identification of the benthic foraminifera was performed on randomly oriented sections. Integrated sedimentology and micropalaeontology have enabled lateral and vertical interpretation of the facies, allowing recognition of four facies associations and their sedimentary environments.

For systematic study of foraminifera, the classification of Loeblich & Tappan (1987) is followed. All the non-oriented and oriented thin sections are deposited in the collection of the General Directorate of Mineral Research and Exploration (MTA), Ankara, Turkey, under the numbers shown in Figures 4 and 5.

GEOLOGICAL SETTING AND STRATIGRAPHY

The southwestern Anatolian region was initially under the influence of a compressive regime until the late Eocene (Şenel 1997). It was later influenced by an extensional regime (Seyitoğlu & Scoot 1991, 1992, 1996; Karadenizli *et al.* 2009, 2017). The basement Lycian Nappes are settled over the continental crust as a result of the collision of the oceanic crust to the continental crust during the Cretaceous (Şenel 1997). The region was later influenced by the extension regime that is explained by various tectonic models such as back-arc expansion, tectonic escape, orogenic collapse and episodic two-stage graben formation.

The back-arc expansion model involves subduction of the African Plate under the Anatolian Plate along the Aegean-Cyprus zone, and this caused crustal expansion behind the subduction zone in the Aegean and western Anatolian regions (McKenzie 1978; LePichon & Angelier 1979, 1981; Jackson & McKenzie 1988).

The tectonic escape model suggests collision of the Arabian Plate and the Eurasian Continent, which resulted in the formation of the Anatolian wedge during the late Serravallian (Middle Miocene), bordered by the North Anatolian and East Anatolian strike-slip faults (Fig. 1), with westward tectonic escape of the Anatolian Plate and the beginning of the expansion regime in Western Anatolia (Şengör 1979, 1982, 1987; Dewey & Şengör 1979).

The orogenic collapse model considers that the collision between the northern Sakarya Continent and southern Anatolite-Tauride Platform resulted in the closure of the Neotethys Ocean, and caused a crustal thickening along the Izmir-Ankara-Erzincan suture zone during the late Paleogene. The later thinning of the crust along this suture zone by orogenic collapse leds to the extensional regime in Western Anatolia during the late Oligocene-early Miocene (Dewey 1988; Seyitoğlu & Scoot 1991, 1992, 1996).

The episodic two-stage graben model claims that none of the above models are satisfactory to explain the origin and age of the crustal expansion, and suggests that the expansion regime evolved in two different structural styles (Koçyiğit *et*

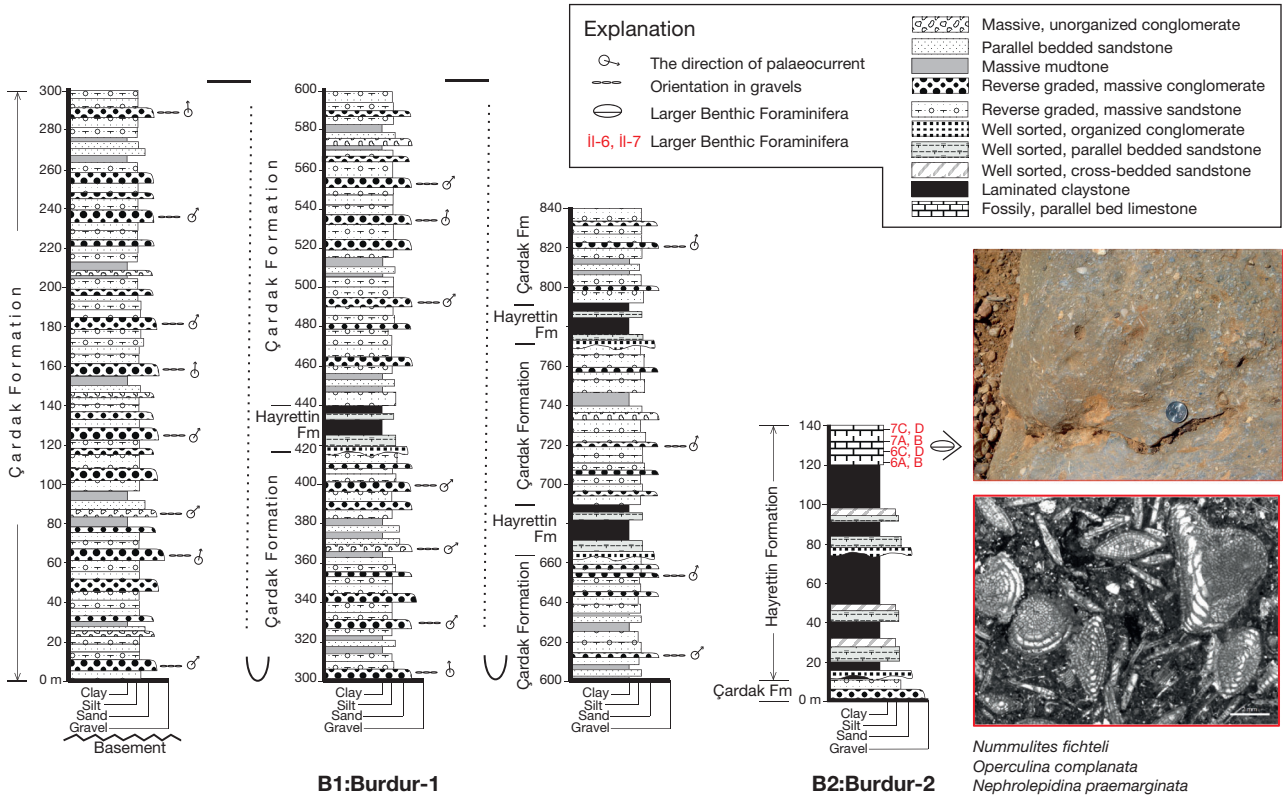

FIG. 2. — Details of the measured sections. Columns at right show the dominance of the facies throughout the successions.

al. 1999; Bozkurt & Rojay 2005). According to this model, the primary graben system developed, depending on the formation of the core complex, in an extensional tectonic regime during the early-middle Miocene, and this tectonic regime ended during the late Serravallian-early Tortonian interval with the start of a north-south compressive regime. The model then stated that the second graben formation occurred during the Pliocene-Quaternary time interval. Burdur Basin opened by normal faulting that developed mainly by extension tectonics. It supports the orogenic collapse model with the available tectonic data.

STRATIGRAPHY OF BURDUR BASIN

The Oligocene-Miocene marine units in the southwestern Turkey were defined with a variety of different names. We here adopt the lithostratigraphic nomenclature proposed by Şenel 1997) who also provided a geological map of the region. The oldest units in the study area are the Lycian Nappes that consist of ophiolitic melange, olistostrome, harzburgite, serpentinite, dunite, limestone, calciturbidite, volcanite, radiolarite, chert and shale (Fig. 1B). This basement unit is unconformably covered by the Varsakyayla Formation (Şenel 1997), which consists of Eocene sandstones, claystones and limestones. The Varsakyayla Formation is overlain disconformably by the Çardak and Hayrettin Formations that are the subject of the present study (Fig. 1).

The Çardak Formation was first defined by Göktaş et al. (1989) in an unpublished report, who divided it into four members. In this study, we observed that the Maymundağı Member of Göktaş *et al.* (1989), which consists of thick conglomerate-sandstone facies, constitutes the predominant lithofacies of the Çardak Formation while the other members reflect its lateral and vertical facies changes. All the members defined by Göktaş *et al.* (1989) are, consequently, grouped in a single unit in the present study, the Çardak Formation. In the Burdur area Yalçınkaya *et al.* (1986) distinguished this unit as the Ardıçlı Formation, and Şenel 1997) and Şenel *et al.* (1989) included it in the Acıgöl Group. The Hayrettin Formation was also first defined by Göktaş *et al.* (1989). It conformably overlies the Çardak Formation, and it is covered unconformably by Miocene sediments. The main lithologies of the Hayrettin Formation are sandstone and claystone, although locally conglomerates and fossiliferous limestones are also observed. Göktaş *et al.* (1989) dated this formation as "middle-late Oligocene" based on its invertebrate fossil association.

SEDIMENTOLOGY OF OLIGOCENE DEPOSITS

Facies analysis was carried out in the Burdur-1 (840 m) and Burdur-2 (140 m) sections that comprise almost entirely the Çardak and Hayrettin formations. Ten facies were identified using their lateral and vertical relations (Fig. 2). These are here grouped in four facies associations: alluvial fan-fluvial, fan-delta, beach and shallow water carbonate sediments.

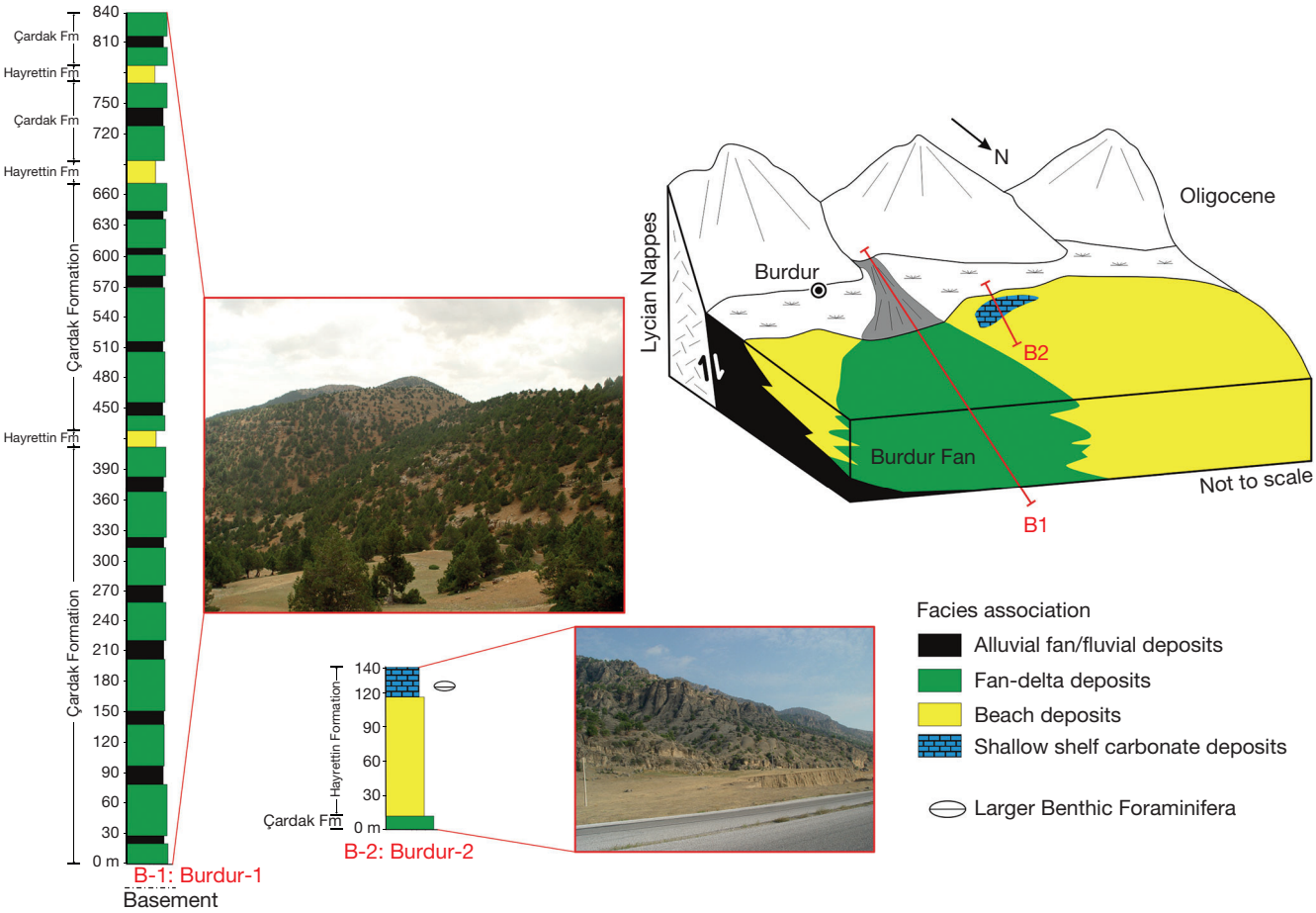

FIG. 3. — Stratigraphic and sedimentological cross sections and stratigraphic correlations of selected locations in the Burdur area. Oligocene palaeogeographic evolution of Burdur Fan.

FACIES

Massive-unorganized conglomerate

This facies consists of red 90-140 cm thick layers, with lateral continuation up to 250 m. The base does not show evidence for erosion, and the sorting is poor. Reverse grading is rare. Clasts are generally aligned along a north-south direction. The granular components are usually limestone, serpentine, radiolarite, derived from the underlying Lycian and ophiolite nappes. Although the average grain size is 5-8 cm, clasts may have dimensions up to 75-80 cm. The presence of thick and massive layers, locally reverse grading, poor grain sorting and large blocks is consistent with mass flow deposition facies (Bull 1977).

Parallel-bedded sandstones

These sandstones reveal parallel layers, and their thickness varies between 20-55 cm and they extend laterally for several hundred meters. Medium to coarse-grained sandstones are mostly lithic-wackes, and the cement is composed of clay. Despite their relatively thin beds, their lateral continuity suggests that they were formed at the end of the flooding period by the lateral accumulation of bed load in the form of sand flats (Rust 1978a, b).

These sandstones composed of middle-coarse sand grains are lithic and binding rocks. Although the thickness of beds is low, their lateral continuation is a sign of the accumulation of the bed burden at the end of the flood (Rust 1978a, b).

Massive mudstone

The red mudstones display lateral continuity of hundreds of meters and contain grass, wood and coal fragments. The clayey part of the mudstones is formed from suspension while their silt component was deposited during the flooding stage from the mixture of suspended sediments and bed-load that settled as floodplain deposits (Miall 1987).

Reverse grading, massive conglomerates

This facies, which is most commonly found in the Burdur-1 section, varies in thickness from 70 to 175 cm and lateral continuity reaches several tens of meters. The matrix ratio increases upwards in each layer of conglomerates, displaying reverse grading. Water escape, load and flame structures are observed in some places. The average grain size is between 6-12 cm, while the maximum grain size reaches 60 cm, and preferred grain orientation is observed. The lateral orientation of grains, the increase of matrix rate upwards, load and flame

structures indicate that this facies settled as an underwater debris flow (Nemec & Steel 1988).

Reverse graded, massive sandstone
The green and grey sandstones are composed of fine to medium parallel layers with eroded upper surfaces. Medium to coarse-grained sandstones display reverse grading, water escape, load, deformation and obstrusion structures. The load, deformation and obstrusion structures observed in sandstones and conglomerates indicate that they settled in subaqueous conditions (Nemec & Steel 1988).

Well-sorted, organized conglomerates
Well-sorted and grain-supported conglomerates form 60-80 cm thick parallel layers, with coarse aggregates composed of disc or blade-shaped grains. The top of the sheets are convex upward. These conglomerates pass laterally into marine facies. This facies represents beach platform and berm environments (Postma & Nemec 1990; Bluck 1999).

Well-sorted, parallel-bedded sandstones
Well-sorted and parallel-bedded sandstone includes scattered medium to coarse-grained gravels and the layer thickness is between 15 to 55 cm. Fine gravels form pockets extending parallel to the stratification. These sandstones show lateral transition towards the terrestrial facies. This facies fits with Bluck's (1999) beach "outer-frame" or represents shore side/shore front transition in a coastal environment.

Well-sorted, cross-bedded sandstones
These green-grey sandstones have cross-bedding, and their thickness is between 12-20 cm, pre-set thickness 3.9 mm and cross-bedding dip between 10°-14°. The top surface of layers is eroded. Medium to fine-grained sandstones are well sorted and do not contain a clay matrix. This facies displays obstrusion and load structures. The presence of cross-bedding and bed-load transport in the lateral direction indicate that this facies is deposited by water flows (Rust 1978b). In addition, these well-graded sandstones are formed by wave-reworking of fan-delta deposits, and they may have formed beach and near-shore bars (Crowell & Link 1982).

Laminated claystones
Although these grey-green coloured claystones are usually laminated, they can also appear massive owing to amalgamation. The claystones contain benthic foraminiferal fragments. These claystones were formed by suspension sediments in a coastal marine environment. They are locally mixed with shore-derived silt and the presence of thin coal levels indicates periodic deposition in restricted marshlands.

Fossiliferous, parallel-bedded limestones
This facies is located in the uppermost parts of Burdur-2 section (Fig. 3). The yellow coloured limestones, which vary in thickness between 15 and 70 cm, locally alternate with claystones. Petrographic analysis indicates grainstone, packstone and wackestone fabrics with abundant benthic foraminifera. These limestones were formed in regions of minimal siliciclastic input in lagoons within a carbonate platform (Heckel 1974).

FACIES ASSOCIATIONS:
Based on lateral and vertical relations of the ten facies described above, four facies associations can be distinguished: alluvial fan-fluvial deposits, fan-delta deposits, beach deposits, and shallow shelf carbonate deposits (Fig. 3).

Alluvial fan and fluvial deposits
This facies association, including massive-unorganized conglomerates, parallel-bedded sandstones and massive mudstones, is observed at the Burdur-1 section (Fig. 1). It is included in the Çardak Formation (Fig. 1), and it indicates alluvial fan and fluvial depositional environments (Miall 1991, 1996).

Fan-delta deposits
This facies association consists of reverse grading, massive conglomerates and sandstone and is observed in the Burdur-1 section and in the basal part of the Burdur-2 section (Fig. 3). A large part of the Çardak Formation consists of this facies association. The term fan-delta was first used by Holmes (1965), followed by McPherson *et al*. (1988) and later defined by Nemec & Steel (1988).

Beach deposits
This facies association is composed of well-sorted conglomerates, bedded sandstones, cross-bedded sandstones and laminated claystones (Fig. 3). It constitutes most of the Hayrettin Formation and is especially widespread in the Burdur-2 section and at three intermediate levels in the Burdur-1 section (Fig. 2). These sediments, within beach and longshore bars, are considered to be the result of reworking of fan-delta deposits by wave action (Crowell & Link 1982). The process is considered to be associated with a sea level rise. Coal seams are considered to have accumulated in protected parts.

Shallow shelf carbonate deposits
The shallow shelf marine carbonates are composed of fossiliferous, parallel-bedded limestones and laminated claystones. They are located at the highest levels of the Hayrettin Formation (Fig. 2). Wright & Burchette (1996) found that similar facies developed in the ramp-type carbonate platform. Aigner (1985) also noted such deposits in carbonate benches or shallow marine environments. The mud banks are considered to have accumulated in local depositional lows (Basan 1973; Turnel & Swensen 1976). Increased carbonate production produced skeletal benches, that later developed into shell islands and beaches.

Oligocene Basin development
According to the facies and facies assemblages obtained from the sequence of Oligocene in the Burdur region, the

Çardak Formation is formed in alluvial fan /fluvial, fan-delta environments and the Hayrettin Formation occurs in beach and shallow shelf carbonate environments (Fig. 3). The basin fill is controlled by the Burdur Normal Fault which formed the southern edge of the basin. The fan controlled by this fault spread to the south (Fig. 3). The clastics material were then deposited along the beaches, bringing with the effect of waves. In the absence of clastic yield, carbonate precipitation has occurred and many organisms have found shelter.

SYSTEMATIC PALAEONTOLOGY

Order FORAMINIFERIDA Eichwald, 1830
Suborder ROTALIINA Delage & Herouard, 1896
Superfamily ROTALIICEA Ehrenberg, 1839
Family NUMMULITIDAE Blainville, 1825
Genus *Nummulites* Lamarck, 1801

Nummulites fichteli Michelotti, 1841
(Fig. 4A-J; 5C, J)

Nummulites fichteli Michelotti, 1841: 296, figs 7a, b. — Cole 1960: pl. 3, figs 9-18. — Schaub 1981: pl. 50, figs 5-18. — Sirel 2003: pl. II, figs 12-19. — Gedik 2008: pl. 1, figs 1-14, 22.

Nummulites intermedius D'Archiac, Sirel & Gündüz, 1976: pl. I, figs 5-9.

REMARKS
This reticulate species belongs to the *N. fabianii* lineage. This form has inflated lenticular shell with rounded periphery. The diameter of test ranges from 2 to 6.4 mm and the thickness from 0.5 to 1.8 mm. The test surface is covered with a reticulation that has rectangular or subrectangular mesh (Fig. 4A, C-E; Fig. 5C). The large microsphere (diameter 0.3 to 0.4 mm) is followed by the regular coiled whorls.

Genus *Operculina* d'Orbigny, 1826

Operculina complanata (Defrance, 1822)
(Fig. 5A, B)

Lenticulites complanata Defrance, 1822: 453.

Operculina complanata – Souaya 1963: pl. 53, figs 1, 2. — Cherif 1980: pl. I, figs 4, 10; pl. II, figs 1, 5. — Abdelgany 2002: pl. II, figs 2-4. — Sirel 2003: pl. III, figs 1-9. — Gedik 2008: pl. 2, figs 6-10.

REMARKS
The test is thin, bilateral and symmetric. Its diameter ranges from 2.5 to 2.9 mm, and the thickness from 0.4 to 1.8 mm. The test is planispiral and evolute, with numerous narrow chambers in many rapidly expanding whorls, so that the height of the chambers may be five times the width of the chambers (Fig. 5A, B). The proloculus is spherical and small (90 µ diameter).

Family LEPIDOCYCLINIDAE Scheffen, 1932
Genus *Nephrolepidina* Douvillé, 1911

Nephrolepidina praemarginata (Douvillé, 1908)
(Fig. 5D-G)

Lepidocyclina praemarginata Douvillé, 1908: 91-92, figs 1, 2, 4a.

Nephrolepidina praemarginata – Douvillé 1924: 51-123, pl. 6, figs 4, 6. — Gomez Llueca 1929: 1-400, pl. 32, figs 4-10. — Flandrin 1935: 251-272, pl. 15, figs 14-18. — Poignant 1967: 197-211, pl. V, fig. 2. — Gedik 2014: 101, pl. 6, figs 1-14.

REMARKS
The identification is based only upon axial sections. The small test is inflated, lenticular with a central umbo, so that the shell is thicker towards the center. The diameter of the test ranges from 1.5 to 2.1 mm and the thickness from 0.6 to 0.9 mm. The large, central umbo consists of numerous small pustules (Fig. 5E, G). Lateral chambers are numerous at the surface of test and rosette shaped, and this feature forms a comb-like surface appearance (Fig. 5E). The embryo consists of subspherical small protoconch (diameter 0.25 mm) and reniform deuteroconch (diameter 0.22 mm). Secondary chambers are very small and their sizes are almost equal to each other. The equatorial chambers are subrectangular or rhombic in outline. There are 6-7 orders of lateral chambers in the center of the test.

Genus *Eulepidina* Douvillé, 1911

Eulepidina sp.
(Fig. 5H, I)

REMARKS
The identification is based only upon axial sections. The test is lenticular, its diameter ranges from 8.1 to 11.2 mm and its thickness from 1.1 to 1.7 mm. The equatorial chambers are polygonal in shape.

DISCUSSION ON THE LARGER FORAMINIFERAL RECORD

The study of Oligocene hyaline larger foraminifera, based on the biometric study of the nummulitids and lepidocyclinids, from western Taurids, gives insights on their palaeobiogeography in the Tethys. These groups show that they are closely related with the coeval assemblages known from the European basins. The larger benthic foraminiferal association from the Burdur-2 section correlates with the Shallow Benthic Zone (SB) 22, late Rupelian-early Chattian, based on the time range of *Nummulites fichteli* and *Nephrolepidina praemarginata* (Cahuzac & Poignant 1997). In the upper part of the Burdur-2 section, *N. praemarginata* and *N. fichteli* are associated with *Operculina complanata*, *Eulepidina* sp., *Asterigerina* sp., *Planorbulina* sp., and *Amp-*

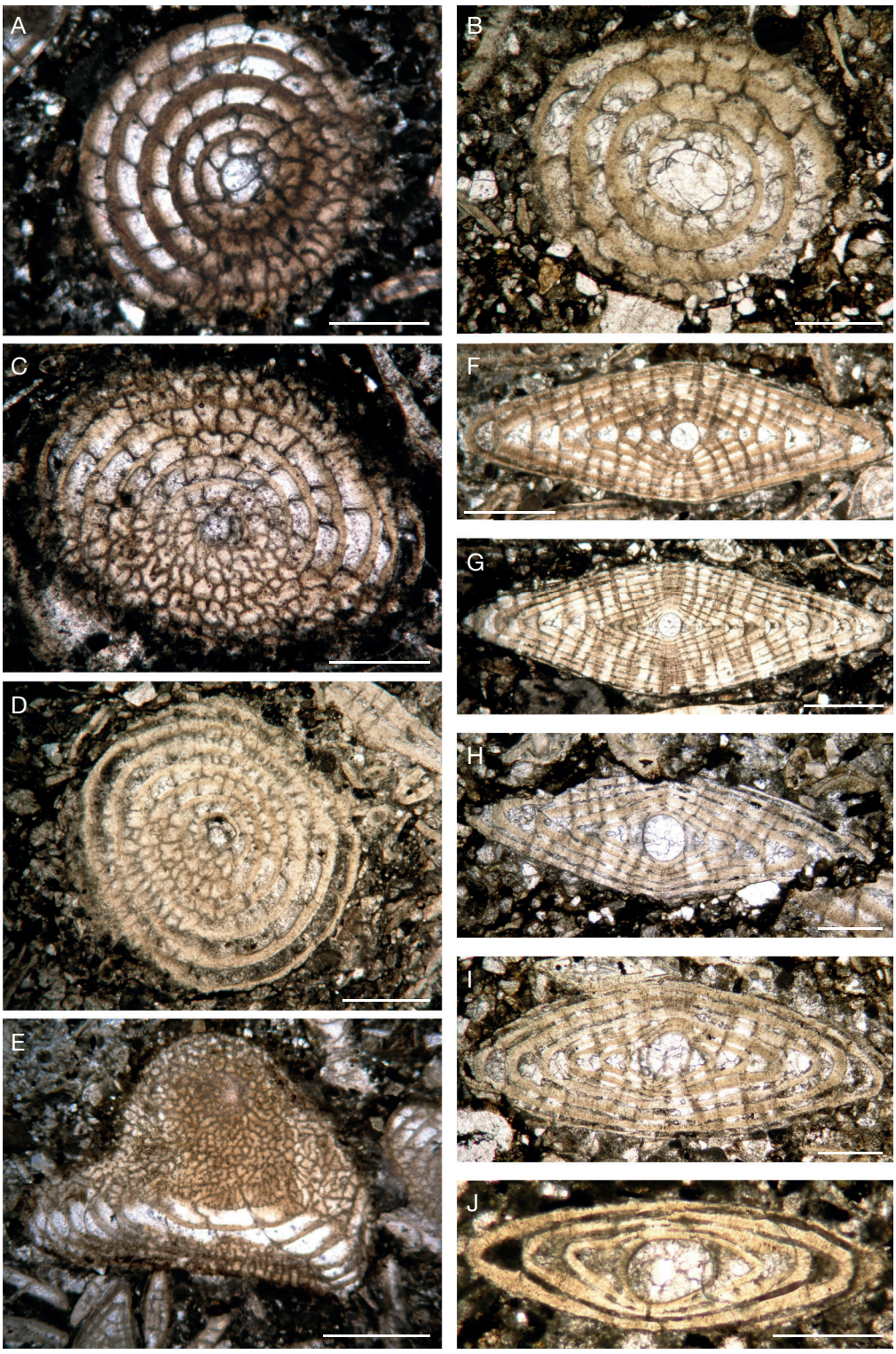

FIG. 4. — **A-J**, *Nummulites fichteli* Michelotti, 1841; **A**, equatorial section and external view, megalospheric form, İl-6B/3; **B**, equatorial section, megalospheric form, İl-6C/1; **C**, oblique equatorial section and external view, microspheric form, İl-7/B; **D**, oblique equatorial section and external view, microspheric form, İl-7/A; **E**, external view, İl-6C/3; **F-J**, axial sections, İl-6B/2, İl-7/A, İl-6C/2, İl-6B/5. Scale bars: A, C, D, F, G, 1 mm; B, H-J, 0.5 mm; E, 2 mm.

histegina sp. (Fig. 6). Some species of this assemblage have a longer stratigraphical range such as *Operculina complanata* which extends from the base of the Oligocene to the Late Miocene (Cahuzac & Poignant 1997). This evidence dates the Hayrettin Formation as late Rupelian-early Chattian (SB 22).

In the Mediterranean realm, the evolutionary lineage of *Nephrolepidina praemarginata-N. morgani-N. tournoueri*

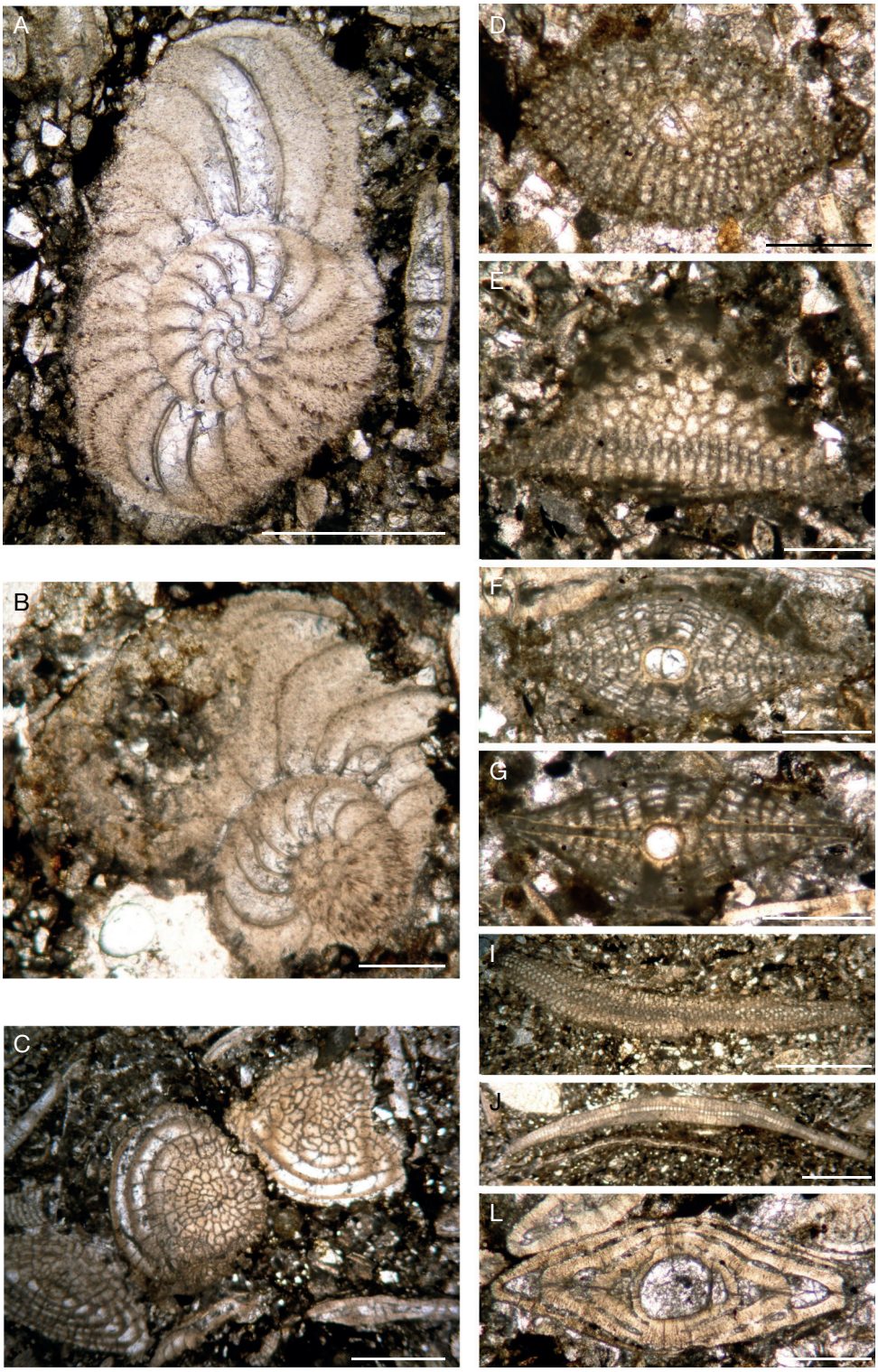

FIG. 5. — **A**, **B**, *Operculina complanata* (Defrance, 1822); **A**, equatorial section, İl-6C/2; **B**, incomplete equatorial section, İl-6B/2; **C**, **J**, *Nummulites fichteli* Michelotti, 1841; **C**, external view, İl-6C/3; **J**, axial section, megalospheric form, İl-6A; **D-G**, *Nephrolepidina praemarginata* (Douvillé, 1908); **D**, axial section, İl-6A; **E**, external view, İl-6B/4; **F**, axial section, megalospheric form, İl-6C/1; **G**, axial section, İl-6B/2. **H**, **I**, Eulepidina sp., subaxial sections, İl-6A, İl-6B/5. Scale bars: A, 1 mm; B, D-G, L, 0.5 mm; C, I, J, 2 mm.

is used as key criteria in Oligo-Miocene biostratigraphy. Although Douvillé (1908, 1925) reported *N. praemarginata* from the early Oligocene of Italy and from the Oligocene-Miocene transition in France, Cahuzac & Poignant (1997) demonstrated that this form is limited to the biozone SB 22.

This taxon is poorly documented in Turkey. Some specimens of this species have been described in eastern Turkey

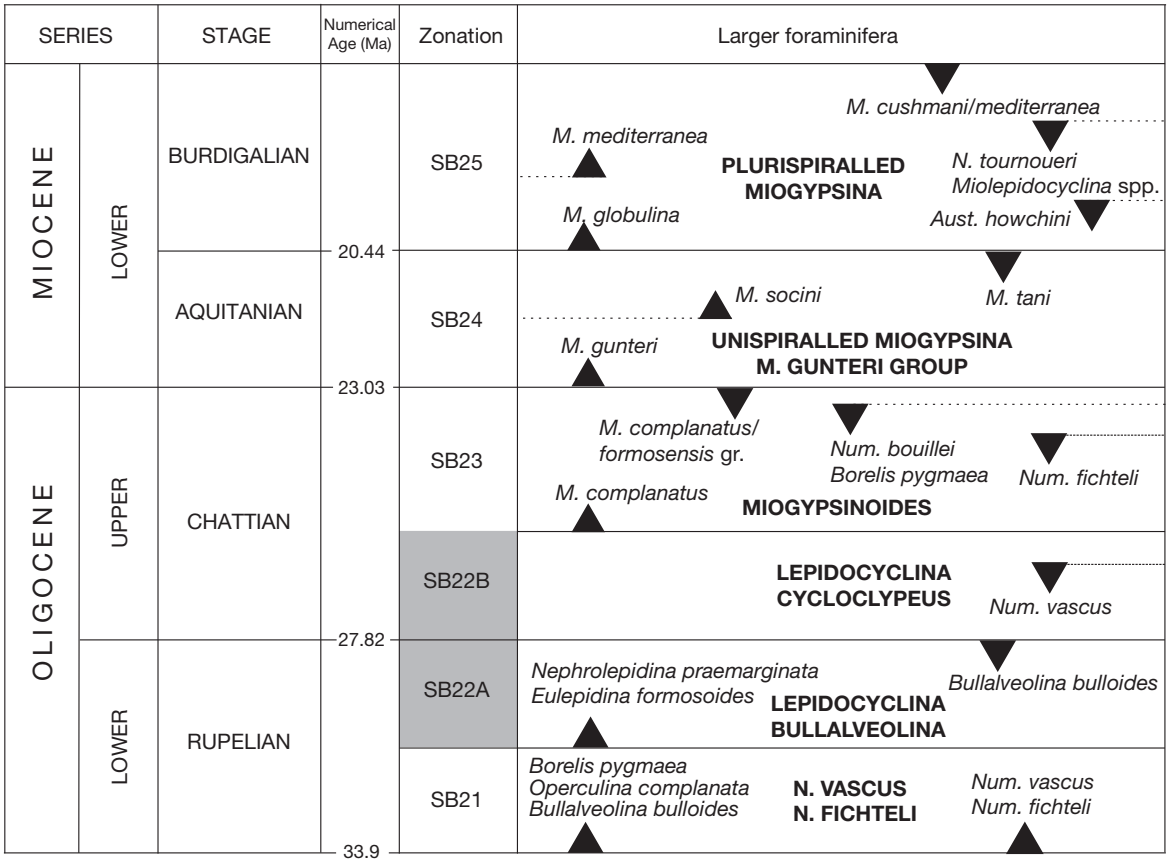

FIG. 6. — The chart of Oligocene-Lower Miocene larger foraminiferal biozones (Cahuzac & Poignant 1997).

as *Nephrolepidina partita* based on the presence of coarse granules in the umbonal part of the test (Sirel 2003; Gedik 2014, 2015). According to Sirel (2003), *N. praemarginata* is associated in the Sarıbuğday section (Elazığ region, eastern Turkey) with *Nummulites fichteli*, *N. vascus*, *N.* cf. *germanicus*, *Borelis pygmaea*, *B. inflata*, *B. merici*, *Operculina complanata*, *Neorotalia lithothamnica*, *N. pinarensis*, *N.* cf. *tectoria*, *N. viennoti*, *Austrotrillina asmariensis*, *Eulepidina* sp., *Thalmannita* sp. and other smaller benthic foraminifera. This foraminiferal association corresponds with the biozones SB 21 and SB 22 of Cahuzac & Poignant (1997). It is present at the Rupelian/Chattian boundary (*G. opima opima* zone; P 21) in the Kelereşdere section (Muş region, eastern Turkey) which yielded *N. partita*, *B. merici*, *B.* cf. *inflata*, *A. striata*, *Eulepidina* sp. corresponding to the biozone SB 22.

According to Özcan *et al.* (2009), in the Korkuteli area (namely Kabaktepe, Yuvaköy, Hacıbekar sections) and in the Tavas-Burdur Basin (Kızılcaağaç section), *N. praemarginata* is associated with *Eulepidina dilatata*, *Operculina complanata*, *Nummulites kecskemetii*, *Heterostegina assilinoides*. This foraminiferal association corresponds to SB 22B (early Chattian).

As inferred by Gedik (2014, 2015), *N. praemarginata* is associated in the Develi section (W of Malatya, eastern Turkey) with *Archaias kirkukensis*, *Austrotrillina asmariensis*, *A. brunni*, *Peneroplis* cf. *laevigatus*, *Nephrolepidina* sp. This foraminiferal association corresponds with biozones SB 21, 22 of Cahuzac & Poignant (1997). It occurs at the Rupelian/Chattian boundary in the Edilme section (W Malatya, eastern Turkey) together with *Heterostegina assilinoides*, *Nummulites* cf. *vascus*, *Eulepidina* cf. *formosoides*, *Risananeiza crassaparies*, and *Neorotalia lithothamnica* corresponding to the biozone SB 22.

An early Rupelian to early Chattian (SB 21-22B) age is known for *Nummulites fichteli* in Europe and Mediterranean area (Cahuzac & Poignant 1997; Sirel 2003; Gedik 2008). This species is known from the lower Oligocene shallow marine deposits in central and southern Iran (SB 21-22A) (Ehrenberg *et al.* 2007; Van Buchem *et al.* 2010; Yazdi-Moghadam 2011). In the Denizli Basin, which is located adjacent to the study area, *Nummulites fichteli* is associated with *Nummulites vascus* and *Operculina complanata*, indicating a Rupelian-early Chattian age (SB 21-22; Gedik 2008). *Nummulites vascus* is a key species for the Oligocene but we did not find it in the examined strata.

CONCLUDING REMARKS

Southwestern Anatolia has been under the influence of an extension regime since the Oligocene (Seyitoğlu *et al.* 2004;

Karadenizli *et al*. 2009, 2017), with thick sequences deposited in graben basins opened by normal faults. An example of this system is seen in the Burdur region where a 840 m thick fan sequence developed in a graben basin (Fig. 3). A simple stratigraphic succession developed in the Burdur Fan during the Oligocene, which consists of the Çardak and Hayrettin formations. The ten lithofacies have been grouped into four facies associations (Fig. 2) based on their lateral and vertical relations (Fig. 3). Sedimentary environments of these facies associations show that the Burdur region was invaded by a shallow sea from the west, and that the sea penetrated into Anatolia.

The basin fill is controlled by the Burdur Normal Fault which formed the southern edge of the basin. Along this margin, alluvial-fluvial fan and fan-delta facies associations developed, while in the northern part sedimentation was limited to fan-delta successions (Fig. 3). These facies mainly consist of coarse-grained sediments derived from the Taurus tectonic unit. There is no evidence for sediment derivation from the metamorphics of the Menderes Massif. A beach facies is present towards the center of the basin (Fig. 3). Ramp-type carbonate platforms also developed depending on the shelf topography in the intervals when clastic input was minimal (Fig. 3).

A moderately diverse and well-preserved assemblage of hyaline and porcellaneous larger foraminifera was found in the late Rupelian-early Chattian shallow marine deposits of the Hayrettin Formation in the Burdur Basin, SW Anatolia. The foraminiferal association includes 7 genera. Larger foraminifera from the Hayrettin Formation, classified under the genera *Nummulites*, *Operculina*, *Nephrolepidina*, *Eulepidina*, *Planorbulina*, *Amphistegina* and *Asterigerina* show close similarity to the coeval assemblages already known from the European and circum-Mediterranean marine sedimentary sequences. Their western Tethyan affinity allowed us to apply the standard biozonation scheme (SB zonation) for our study area in SW Turkey. The late Rupelian-early Chattian age, i.e., SB 22 Zone of Cahuzac & Poignant (1997) for the Burdur-2 section is documented by the presence of *Nephrolepidina praemarginata*, together with *Nummulites fichteli*. This evidence dates the Hayrettin Formation as late Rupelian-early Chattian (SB 22).

Acknowledgements
This study was financially supported by General Directorate of Mineral Research and Exploration (MTA, Ankara). The authors would like to thank to European Synthesys Program for giving opportunity to Fatma Gedik to attend this programme for comparison of the studied material with those from the collections of the Natural History Museum of London. Also the first author is grateful to Dr S. Stukins (Senior Curator of Micropalaeontology, Natural History Museum, London) who allowed her to study two major collections (the former British Petroleum micropalaeontology collection and the former Iraq Petroleum Company collection) under his care that she used for comparison of samples from Turkey. We are grateful to Şevket Şen (MNHN, Paris) for his advice and constructive comments which greatly improved the manuscript. Special thanks to Dr G. W. Hughes (Applied Microfacies Limited, UK) for his comments on this paper, and to an anonymous reviewer for his/her critical comments. Special thanks are due to Emmanuel Côtez (copy editor) for times and efforts.

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Submitted on 16 October 2019;
accepted on 27 February 2020;
published on 28 June 2021.