Geologica Acta, Vol.16, Nº 2, June 2018, 163-187, I
DOI: 10.1344/GeologicaActa2018.16.2.4

geologica acta

Middle-Late Eocene marine record of the Biga Peninsula, NW Anatolia, Turkey

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ABSTRACT

The Eocene shallow marine deposits marking the first marine incursion in the Biga Peninsula (NW Turkey) after the collision of the Sakarya and Anatolide-Tauride plates were investigated based on paleontological, litho- and chrono-stratigraphic data. Larger Benthic Foraminifera (LBF) from patchily distributed outcrops were studied in order to i) revise the stratigraphy of Eocene shallow marine units, and ii) establish a modern biostratigraphic setting and a correlation scheme. The Şevketiye Formation (Fm.) is herein defined as a predominantly shallow marine clastic deposit with subordinate carbonates overlying the Çamlıca metamorphic rocks, and passing laterally to the Soğucak Fm., a carbonate unit that is widely represented in the Thrace Basin. The record of alveolinids, primitive developmental stages of heterosteginids, and orthophragminids in the Şevketiye Fm. suggests that this formation is part of the Shallow Benthic Zones (SBZ) 16?/17 (Late Lutetian?/Early Bartonian), SBZ17?/18 and SBZ19A (Early Bartonian/earliest Priabonian). The Soğucak Fm., which overlies the Eocene volcanics, on the other hand, yielded advanced developmental stages of heterosteginids, *Spiroclypeus* sp. and *Nummulites fabianii* lineages, implying a younger marine incursion during the Late Eocene (earliest Priabonian; SBZ19A). A drastic shift in the depositional regime is marked amid Priabonian by the deposition of deep-marine clastics and volcanoclastics of the Ceylan Fm. In conclusion, the Eocene Sea transgressed first Gökçeada (in the Aegean Sea) during the Late Lutetian, then reached the Biga and Gelibolu peninsulas in the Bartonian, and finally led to the widespread deposition of carbonate and siliciclastic rocks in the Biga Peninsula and the Thrace Basin during the Late Bartonian and Priabonian.

KEYWORDS | **Larger Benthic Foraminifera (LBF). Stratigraphy. Biostratigraphy. Biga Peninsula. Eocene.**

INTRODUCTION

The Late Cretaceous-Cenozoic sedimentary succession of Central and West Anatolia provides an archive of the collision of the Sakarya Continent with the Anatolide-Tauride Platform and the Kırşehir Continent with the Anatolide-Tauride Platform (Fig. 1A). The drastic change in the geological record is evidenced by i) the widespread development of the Late to Middle Eocene (Ypresian-Lutetian) post-collisional volcanic rocks, locally intercalated with marine (Middle) Eocene beds in Armutlu Peninsula (Genç and Yılmaz, 1997; Özcan *et al*., 2012; Gülmez *et al*., 2013), ii) the transition from marine to continental deposition in Early- to

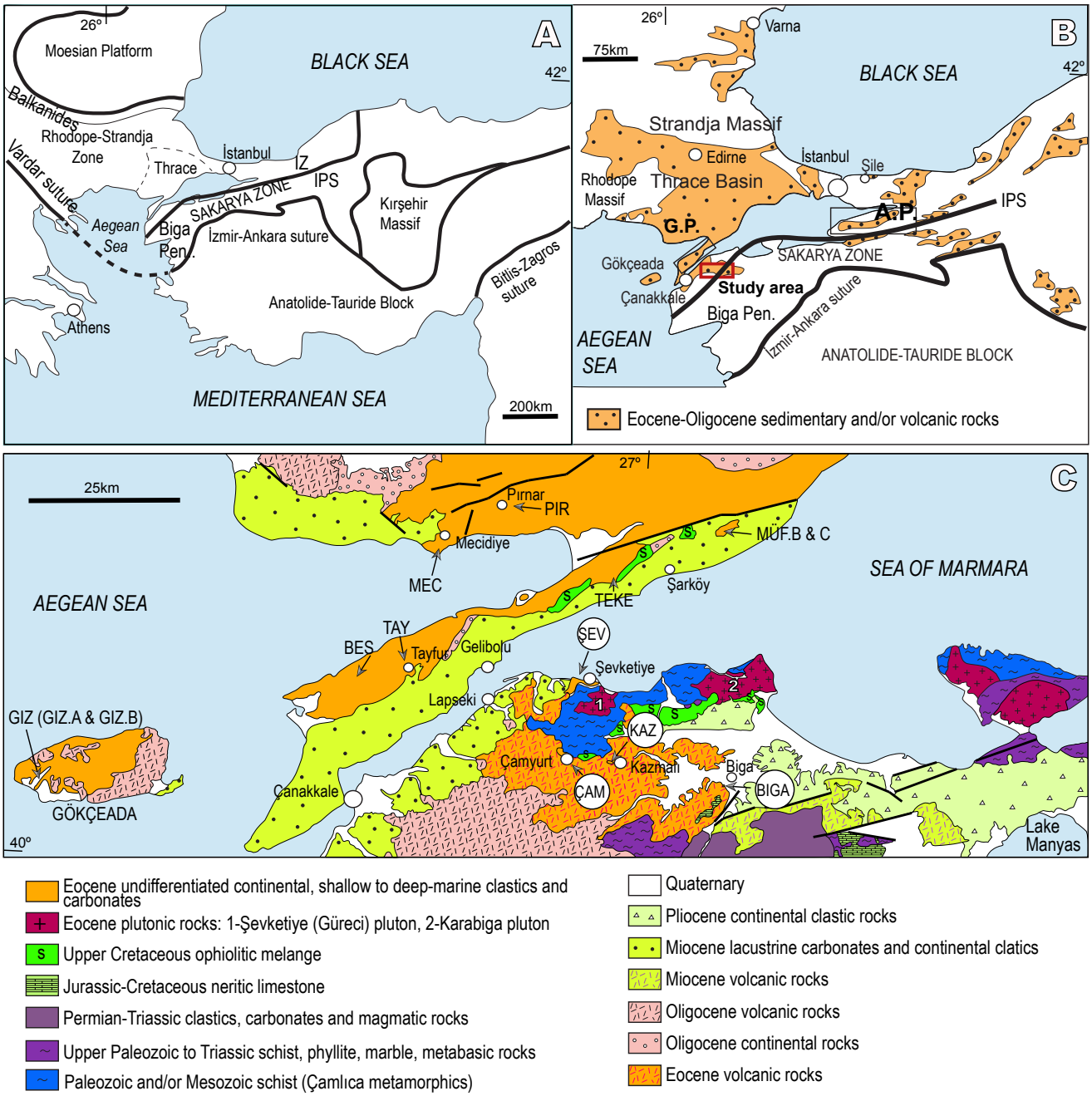

FIGURE 1. A) Tectonic map of the northeastern Mediterranean region showing the major sutures and continental blocks (simplified from Okay and Tüysüz, 1999). IZ in this map refers to Istanbul Zone. B) Simplified map of the Black Sea-North Aegean region showing the distribution of Eocene-Oligocene sedimentary and/or volcanic rocks and the main tectonic sutures (modified from Okay *et al.*, 2017). Study area framed. The positions of the Gelibolu Peninsula (G.P.) and Armutlu Peninsula (A.P.), and Intra-Pontide Suture (IPS) are marked. C) Geological map of the northern segment of the Biga Peninsula and locations of the studied sections: Şevketiye (ŞEV), Çamyurt (ÇAM), Kazmalı (KAZ) and Biga (BIGA) (slightly modified from Akbaş *et al.*, 2011 and Duru *et al.*, 2012). Localities of the sections of the Soğucak Fm., previously studied from the southern Thrace Basin (Özcan *et al.*, 2010) and adopted here for the regional correlation (Fig. 18): GIZ.A and B (Gizliliman, Gökçeada), BEŞ(Beşyol), TAY (Tayfur), MEC (Mecidiye), PIR (Pırnar), TEKE (Teke), MÜF.B and C (Mürefte).

Middle-Eocene in Central Anatolia (Sirel, 1998; Okay *et al.*, 2001; Özcan *et al.*, 2007) and iii) the development of widespread Middle to Late Eocene post-collisional volcanic complexes as well as the lack of marine post-Eocene deposits in the Biga Peninsula (Siyako *et al.*, 1989; Altunkaynak and Genç, 2008; Ilgar *et al.*, 2012; Ersoy and Palmer, 2013).

In the Biga Peninsula, extensive Eocene magmatic rocks (North Anatolian Eocene Magmatic (NAEM) rocks

of Ersoy and Palmer, 2013) post-date the collision of the Anatolide-Tauride Platform and the Sakarya Continent (Figs. 1 and 2) (Siyako *et al.*, 1989; Ilgar *et al.*, 2012). Magmatic activity occurred almost continuously from Middle Eocene to Late Miocene (Altunkaynak and Genç, 2008). The NAEM volcanic rocks were deposited in continental and, partly, marine settings (Genç *et al.*, 2012), and are stratigraphically associated with continental and shallow to deep marine sedimentary units, namely Fıçıtepe, Soğucak and Ceylan formations (fms.), respectively. The Şevketiye Fm., a lithostratigraphic unit established in this study, and the Soğucak Fm., previously reported as the only Eocene marine unit in the Biga Peninsula, crop out between Lapseki and Biga (Fig. 1B; C). The Cenozoic evolution of the Thrace Basin in the North of the Biga Peninsula, on the other hand, strongly contrasts with that of adjacent basins in the East and South. In the Thrace Basin, the Middle Eocene volcanics are missing and Early Eocene deposits (Hamitabat Fm.) belong to the deep marine settings (Siyako and Huvaz, 2007). The Middle to Late Eocene (Bartonian-Priabonian) shallow marine carbonates of the Soğucak Fm. are widely exposed in northern and southern segments of the basin (Saner, 1985; Önal, 1986; Sümengen and Terlemez, 1991; Siyako and Huvaz, 2007; Okay *et al.*, 2010; Özcan *et al.*, 2010; Less *et al.*, 2011) (Fig. 1A; B). Moreover, thick deep marine Early Oligocene marls and shales are also recorded at the East of the basin (Okay *et al.*, 2017). The Soğucak Fm., typified by foraminiferal carbonates and patchy red algal/coral reefs at its type-locality and other outcrops in Thrace, exhibits a wide range of facies characterizing inner, middle- to outer-shelf settings (Özcan *et al.*, 2010; Less *et al.*, 2011 and references therein). The geographic extension of the Soğucak Fm., westwards to Gökçeada and southwards to the Biga Peninsula, was previously reported by Temel and Çiftci (2002), Özcan *et al.* (2010) and Ilgar *et al.* (2012). The chronostratigraphic development of the Soğucak Fm. in the Biga Peninsula is, however, poorly known due to absence of detailed biostratigraphic studies. Therefore, it is not well understood whether the various ages (ranging from Lutetian to Priabonian) previously assigned to the 'Soğucak' Fm. correspond or not to different marine incursion events. Furthermore, the unit was reported either as a 'reefal limestone' or as a 'nummulitic limestone' in the Biga Peninsula (Siyako *et al.*, 1989; Ilgar *et al.*, 2012), which is rather a lithological feature of the Soğucak carbonates in the neighbouring Thrace Basin. On the other hand, the predominantly clastic shallow marine deposits (Şevketiye Fm.) overlying the Çamlıca metamorphics were previously not described.

In order to resolve these pending points, the outcrops of Şevketiye and Soğucak fms. were studied in four localities: Şevketiye, Çamyurt, Kazmalı and Biga. The latter was excluded from biostratigraphic analyses due to the poor stratigraphic development and limited fauna of the Soğucak Fm. there. The data from this locality are used in evaluating the geographic extension of the Eocene Sea in the Biga Peninsula. To sum up, the aim of this study is to i) revise the stratigraphy of post-collisional shallow marine units in the Biga Peninsula, ii) document the Larger Benthic Foraminifera (LBF) assemblages from these deposits by studying both isolated specimens and specimens from rock thin-sections, iii) establish a high-

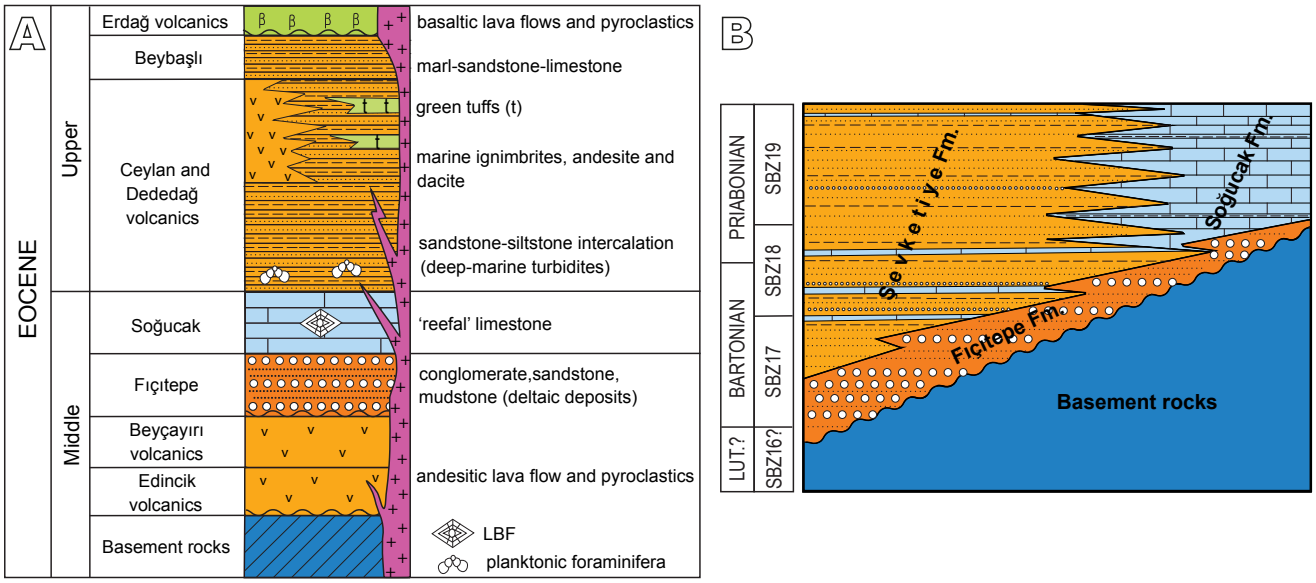

FIGURE 2. A) Eocene chronostratigraphy of the Biga Peninsula (modified from Ilgar *et al.*, 2012), B) stratigraphic lateral-vertical relationships of the Eocene shallow marine units proposed in this study.

resolution biostratigraphy, and iv) provide a correlation scheme between the Thrace Basin and the Biga Peninsula during the Eocene in order to delineate the southward extension of post-collisional marine incursion(s) in the Sakarya Zone.

GEOLOGICAL SETTING, EOCENE STRATIGRAPHY AND BIOSTRATIGRAPHY

The Biga Peninsula lies at the North of the İzmir-Ankara Suture Zone, which separates the Sakarya Zone (in the North) from the Anatolide-Tauride Block (in the South) (Fig. 1B). The basement rocks between Lapseki and Biga Area are constituted by Çamlıca micaschist, built up of quartz micaschist and minor calc-schist, metaquartzite, marble and eclogite (Okay *et al.*, 1991). The metamorphism dates from Late Cretaceous–Early Paleocene (70–64Ma) (Okay and Satır, 2000; Aygül *et al.*, 2012). The cover rocks consist of widespread Eocene to Oligocene-Miocene volcano-plutonic complexes, continental and, shallow to deep marine Eocene deposits (Fig. 1C) (Siyako *et al.*, 1989; Dönmez *et al.*, 2005; Altunkaynak and Genç, 2008; Genç *et al.*, 2012; Ilgar *et al.*, 2012; Ersoy *et al.*, 2017). The volcanic activity started in the Lutetian and lasted until the Miocene producing volcanic suites ranging from basalt to dacite (Altunkaynak and Genç, 2008; Ersoy *et al.*, 2017). With regard to the sedimentary record, previous studies have differentiated continental clastics of the Fıçıtepe Fm., and a main 'reefal' or 'nummulitic' limestone unit, the Soğucak Fm., occurring between the andesitic and basaltic volcanics and deep marine turbidites, ignimbrites, tuffs and andesites (Siyako *et al.*, 1989; Ilgar *et al.*, 2012) (Fig. 2). The Fıçıtepe Fm. is a thick continental unit built up of conglomerate, sandstone, siltstone and mudstone, and is interpreted as a deltaic depositional system (Ilgar *et al.*, 2012). In the Lapseki-Biga Area, this formation was considered Middle Eocene in age by Ilgar *et al.* (2012), and Early Eocene by Siyako *et al.* (1989) based on its position below the Middle Eocene (Lutetian) Soğucak Fm. The latter age designation was adopted by Şengün *et al.* (2011) to explain the exhumation history of the Çamlıca metamorphics. The Fıçıtepe Fm. is overlain either by predominantly clastic deposits of the Şevketiye Fm., comprising fossiliferous sandstone, siltstone, shale, limestone and some conglomerate beds, or by the Soğucak Fm., built up of fossiliferous limestone, sandy/clayey limestone with rare thin sandstone and mudstone beds. LBF occur abundantly in limestone beds, whereas the clastic levels are mostly barren in foraminifera, but rich in mollusks and other invertebrates.

The Middle Eocene-Priabonian shallow marine deposits in Tethys chiefly contain LBF, such as nummulitids, orthophragminids, alveolinids and rotaliids, widely used in biostratigraphy (Serra-Kiel *et al.*, 1998; Less and Özcan, 2012; Hottinger, 2014 and references therein). Common Middle Eocene foraminiferal taxa belong to large *Nummulites* (Giant *Nummulites*), various species of *Assilina, Operculina*, alveolinids and orthophragminids (Fig. 3) (Serra-Kiel *et al.*, 1998; Less and Özcan, 2012). The first appearance of *Heterostegina, Spiroclypeus, Nummulites fabianii* group, *Pellatispira, Chapmanina, Silvestriella,* together with the disappearance of alveolinids and large *Nummulites* in the Bartonian and across the Bartonian/Priabonian boundary, corresponds to significant bioevents in western Tethys, and their superposition allows the definition of some sub-zones in the Bartonian-Priabonian interval

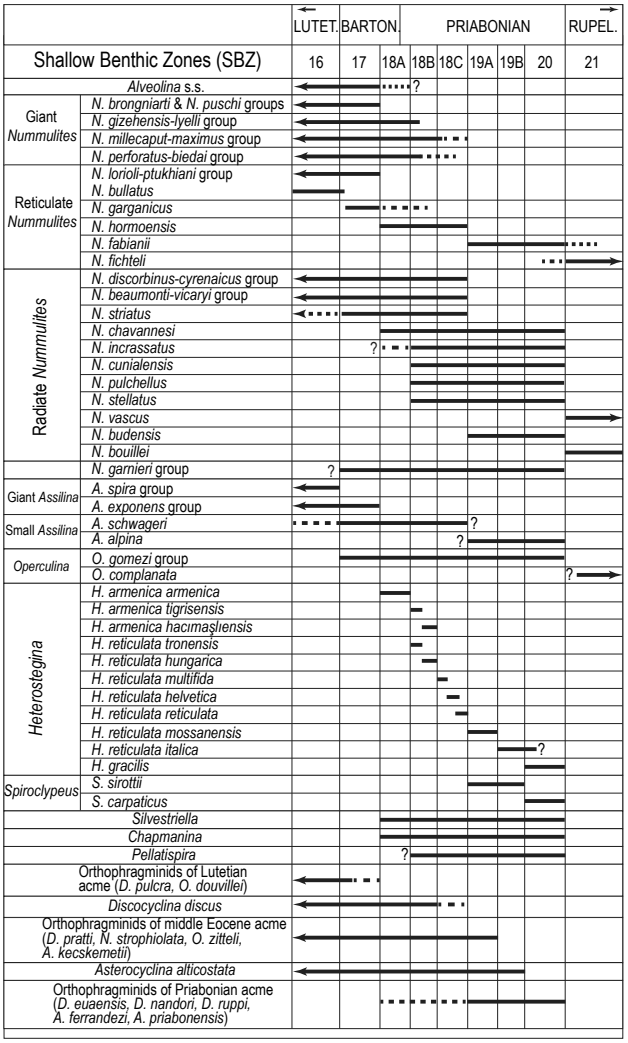

FIGURE 3. Stratigraphic ranges of Late Lutetian-Rupelian Larger Benthic Foraminifera (LBF) of the Western Tethys and proposed biostratigraphic scheme by Less and Özcan (2012). The relationship of the Bartonian/Priabonian boundary with respect to the Shallow Benthic Zonation (SBZ) is after Costa *et al.* (2013) and Papazzoni *et al.* (2017).

(Less and Özcan, 2012). The *Operculina gomezi* group appears to be the most important LBF group in the delineation of the Lutetian/Bartonian boundary, as key foraminiferal events for this boundary are not yet well defined (Less and Özcan, 2012). The *Assilina schwageri-Assilina alpina* group is also abundant in Bartonian-Priabonian Tethyan deposits, although the distinction of the two species is difficult in the lack of morphometric data. In the present study, the species of this group were determined as *A. schwageri-alpina*. The first appearance of *Heterostegina* is perhaps the most significant event across the Bartonian/Priabonian boundary. *Heterostegina armenica* and *H. reticulata*'s lineages display a very rapid evolution and, hence, are used as a valuable proxy to date LBF events and biostratigraphic evaluations (Less *et al.*, 2008). The most important evolutionary trend recorded in these lineages is the reduction in the number of operculinid chambers over time, which is used in the morphometric discrimination of their subspecies. Similarly, reticulate *Nummulites* (*N. fabianii*'s lineage) display a progressive increase of the size of the proloculus, which helps in the discrimination of the successive species (Özcan *et al.*, 2009, 2010). Genus *Spiroclypeus*, a key Priabonian taxon, also displays reduction in the number of operculinid chambers and is, therefore, subdivided into different species with the help of morphometry (Less and Özcan, 2008, 2012). The first presence of *Silvestriella, Pellatispira* and *Chapmanina* close to the Bartonian/Priabonian boundary represents another foraminiferal event and is very useful in the delimitation of Middle/Late Eocene boundary in Tethys (Özcan *et al.*, 2010). Orthophragminids include various species of *Discocyclina, Nemkovella, Orbitoclypeus* and *Asterocyclina* (Less, 1987; Özcan *et al.*, 2006; Less *et al.*, 2011). The extinctions of taxa such as *Discocyclina pulcra* and *Orbitoclypeus douvillei* during the Bartonian, and *Discocyclina pratti, Asterocyclina kecskemetii* and *A. alticostata* in the Priabonian, before the Priabonian/Rupelian boundary, are key events. An integrated biostratigraphy of nummulitids, orthophragminids and alveolinids was established first by Serra-Kiel *et al.* (1998) in the frame of the Shallow Benthic Zonation (SBZ) of the Tethys. This zonation was subsequently updated by Less and Özcan (2012) for the Bartonian-Priabonian, subdividing biozones SBZ18 and SBZ19 in a number of subzones (SBZ18A, 18B, 18C, 19A and 19B). The Bartonian/Priabonian boundary, coincident with the SBZ18/19 boundary in Serra-Kiel *et al.* (1998), was lowered by Costa *et al.* (2013) and Papazzoni *et al.* (2017) (Fig. 3). In this study, the definition of the SBZ18 and 19 subzones proposed by Less and Özcan (2012) is followed. The taxonomy and morphometry of the studied LBF taxa from the Biga Peninsula are not provided here, since they were introduced in former studies focused on the Thrace Basin (Özcan *et al.*, 2010; Less *et al.*, 2011).

MATERIALS AND METHODS

The studied material was sampled in four localities in the northwestern part of the Biga Peninsula, from West to East: Şevketiye, Çamyurt, Kazmalı and Biga (Fig. 1C). The axial and equatorial sections of isolated LBF specimens were prepared for the taxonomic identifications. The taxonomy is based on the morphometry at species and subspecies ranks following the studies of Özcan *et al.* (2006), Less and Özcan (2008, 2012), and Less *et al.* (2008), for genera *Heterostegina, Spiroclypeus, Discocyclina, Orbitoclypeus, Asterocyclina* and reticulate *Nummulites* (*N. fabianii* group). The associated fauna and flora were identified in rock thin-sections. The list of the foraminiferal taxa identified from the Şevketiye and Soğucak fms. is given in the Appendix I.

RESULTS

A new lithostratigraphic unit: Şevketiye Formation

Shallow marine deposits in Şevketiye and Çamyurt sections are characterized predominantly by shale-siltstone-sandstone and conglomerate beds, with minor limestone rich in Bartonian-Priabonian LBF, in contrast to the Soğucak Fm., which is a carbonate unit. Şevketiye Fm. is established here to differentiate the Bartonian-Priabonian (predominantly) clastic marine sequence from the coeval Soğucak carbonates, common in the Thrace Basin. A formal description of the Şevketiye Fm., cropping out near Şevketiye and Çamyurt (Figs. 4 and 5) is given below:

Lithology, lateral and vertical variation: The unit comprises dominantly gray to dark green, thick-bedded to massive shale/marl, siltstone-sandstone, conglomerate and cream to gray limestone and argillaceous nodular limestone interbeds (Figs. 4 and 5). A breccia level is also recognized in the Çamyurt Section. Facies and fossil assemblages indicate a restricted (inner to middle) shelf environment at its base, and middle/outer shelf at its upper part.

Thickness: The measured thickness ranges from ~50m (in the Çamyurt Section) to >132m (in the Şevketiye Section).

Relationship to adjacent stratigraphic units and nature of boundaries: The unit conformably overlies the Fıçıtepe Fm. and is overlain in gradational contact by the Ceylan Fm. Its upper contact, not observed at the Şevketiye Section (ŞEV), crops out in the Çamyurt Area.

Type-section: Type section is situated 2.6km West of Şevketiye (40°23'59.21"N, 26°50'34.35"E; 40°24'1.86"N, 26°50'24.01"E), about 15km northeast of Lapseki (Fig. 4).

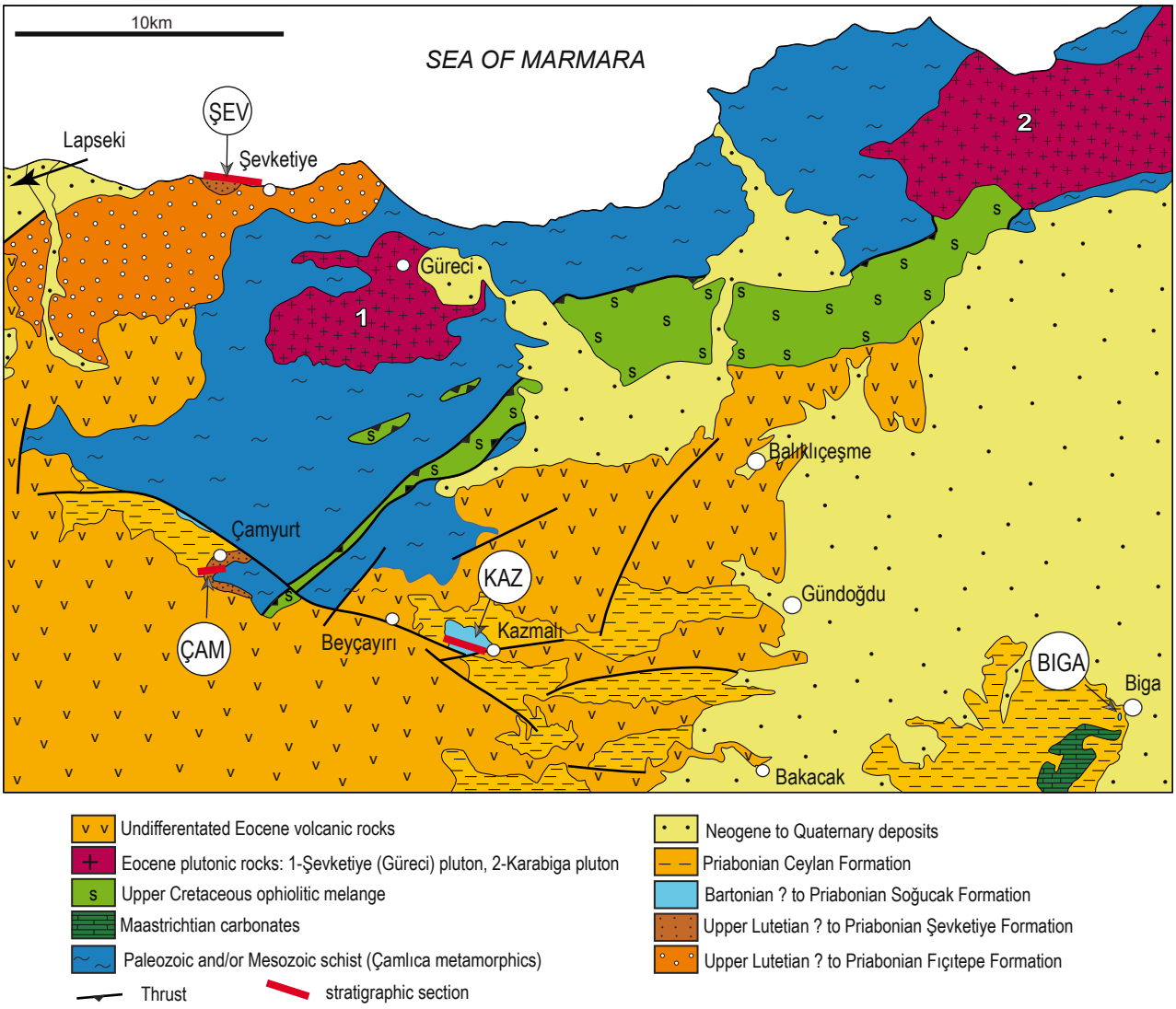

FIGURE 4. Geological map of the region between Lapseki and Biga and location of the studied sections: Şevketiye (ŞEV), Çamyurt (ÇAM), Kazmalı (KAZ) and Biga (BIGA) (map slightly modified after Duru *et al.*, 2012).

Geographic distribution: The unit crops out between Şevketiye and Çamyurt (East of Lapseki).

Fossil composition: Foraminifera consist of *Discocyclina discus discus* (Rütimeyer, 1850), *D. pratti pratti* (Michelin, 1846), *D. radians* (d'Archiac, 1850), *Nemkovella daguini* (Neumann, 1958), *Orbitoclypeus varians varians* (Kaufmann, 1867), *O. varians scalaris* (Schlumberger, 1903), *Asterocyclina stellata stellaris* (Brünner, in Rütimeyer, 1850), *A. stella cf. stella* (Gümbel, 1861), *A. alticostata cf. alticostata* (Nuttall, 1926), *A. kecskemetii* Less, 1987, *Nummulites fabianii* (Prever, in Fabiani, 1905), *Heterostegina armenica armenica* (Grigoryan, 1986), *H. reticulata mossanensis* Less, Özcan, Papazzoni and Stockar, 2008, *Spiroclypeus* sp., *Operculina gomezi* Colom and Bauzá, 1950, *Assilina schwageri* Silvestri, 1928–*A. alpina* (Douvillé, 1916), *Silvestriella tetraedra* (Gümbel, 1868), *Gyroidinella magna* Le Calvez, 1949, *Pellatispira madaraszi* Hantken, 1876. In addition, bivalves, echinoids, gastropods, bryozoans and red algae are common.

Age: Late Lutetian? to Priabonian.

Description of sections

Şevketiye Section

The studied section (ŞEV: 40°23'59.32"N, 26°50'49.93"E; 40°24'1.86"N, 26°50'24.01"E) is located 2.6km West of Şevketiye and is well exposed along the shores of the Marmara Sea (Fig. 1C). It shows the Fıçıtepe Fm., up to several hundred metres-thick, overlain by the 135m-thick Şevketiye Fm. This

formation has a limited geographic extent in the region, cropping out only along the hillside of Çam Tepe (ÇAM) (Fig. 4). The basal conglomerates of the Fıçıtepe Fm., resting nonconformably on the Çamlıca high-grade metamorphics, are made of mudstone, sandstone, siltstone and clast-supported conglomerates, dominated by subangular to subrounded andesite pebbles (Figs. 5 and 6A; B). These continental clastics, barren in fossils, pass upwards into marine sandy limestone, siltstone-sandstone intercalations of the Şevketiye Fm. with locally abundant shells of bryozoans, bivalves, gastropods, echinoids, red and dasycladacean algae, miliolids and *Nummulites* sp. (Figs. 6C; D and 7A; B). The portion of the unit with thin-to-medium bedded limestone intercalations contains coarse pebbles at their base, which grade into sand and silt at their upper parts (samples 1–4). The lower part of the Şevketiye Fm. (55m-thick) lacks age-diagnostic fossils and is assumed to be Late Lutetian? and/or Early Bartonian (SBZ16? and/or 17) based on the occurrence of alveolinids and its location below the *Heterostegina armenica*-bearing beds up in the section. Upwards, the succession comprises thick-bedded siltstone/sandstone with thin-to-medium bedded limestone intercalations (from 55 to 90m; Fig. 8) yielding LBF such as nummulitids (*Nummulites* sp. and *Operculina gomezi*), alveolinids and other fossil groups shown in Figure 8. The alveolinid bed (sample 8) at *ca.* 80 metres from the base consists of abundant globular and axially elongated forms (Fig. 6E). Bryozoans are abundant in the upper part of the siltstone-limestone intercalations. This part is attributed to the Early Bartonian based on the occurrence of *Operculina gomezi* and its position immediately below the beds bearing the first primitive *Heterostegina* (*H. armenica*). The upper part of the Şevketiye Fm. (90–135m-thick) consists of sandstone, calcareous sandstone and siltstone, conglomerate and highly fossiliferous limestone intercalations (Fig. 6F). This is the most fossiliferous part of the section. The occurrence of *Heterostegina armenica armenica, Assilina schwageri-alpina, Operculina gomezi, Discocyclina discus discus, Asterocyclina stellata, A. stella, Orbitoclypeus varians, Silvestriella tetraedra, and Linderina* sp. points out to the SBZ18A, suggesting an age close to the Bartonian/Priabonian boundary. The section cannot be followed further up because the last observable beds dip under the Marmara Sea.

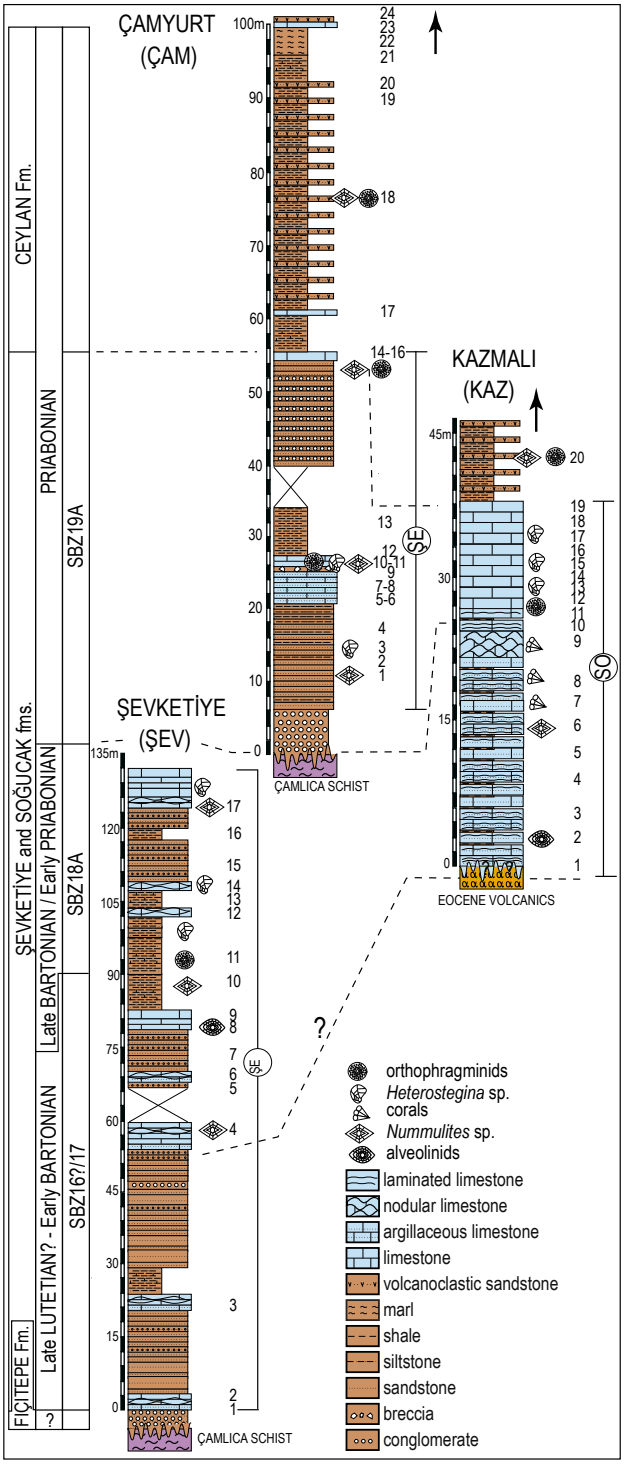

FIGURE 5. Lithostratigraphic columns of the Soğucak and Şevketiye fms. in the studied sections and their correlation. SBZ: Shallow Benthic Zones by Serra-Kiel *et al.* (1998), updated by Less and Özcan (2012). ŞE: Şevketiye Fm., SO: Soğucak Fm.

Çamyurt Section

Çamyurt Section (ÇAM: 40°16'22.22"N, 26°51'3.35"E; 40°16'16.22"N, 26°50'47.14"E) is situated along a small creek at the vicinity of Çamyurt village, 14.3km to the South of the Şevketiye Section (Fig. 4). The basement consists of the Çamlıca metamorphics, which are overlain by *ca.* 6m-thick basal conglomerates of the Fıçıtepe Fm., comprising metamorphic pebbles from underlying rocks (Figs. 5 and 6G). These coarse clastic materials are devoid of any fossils and their age remains

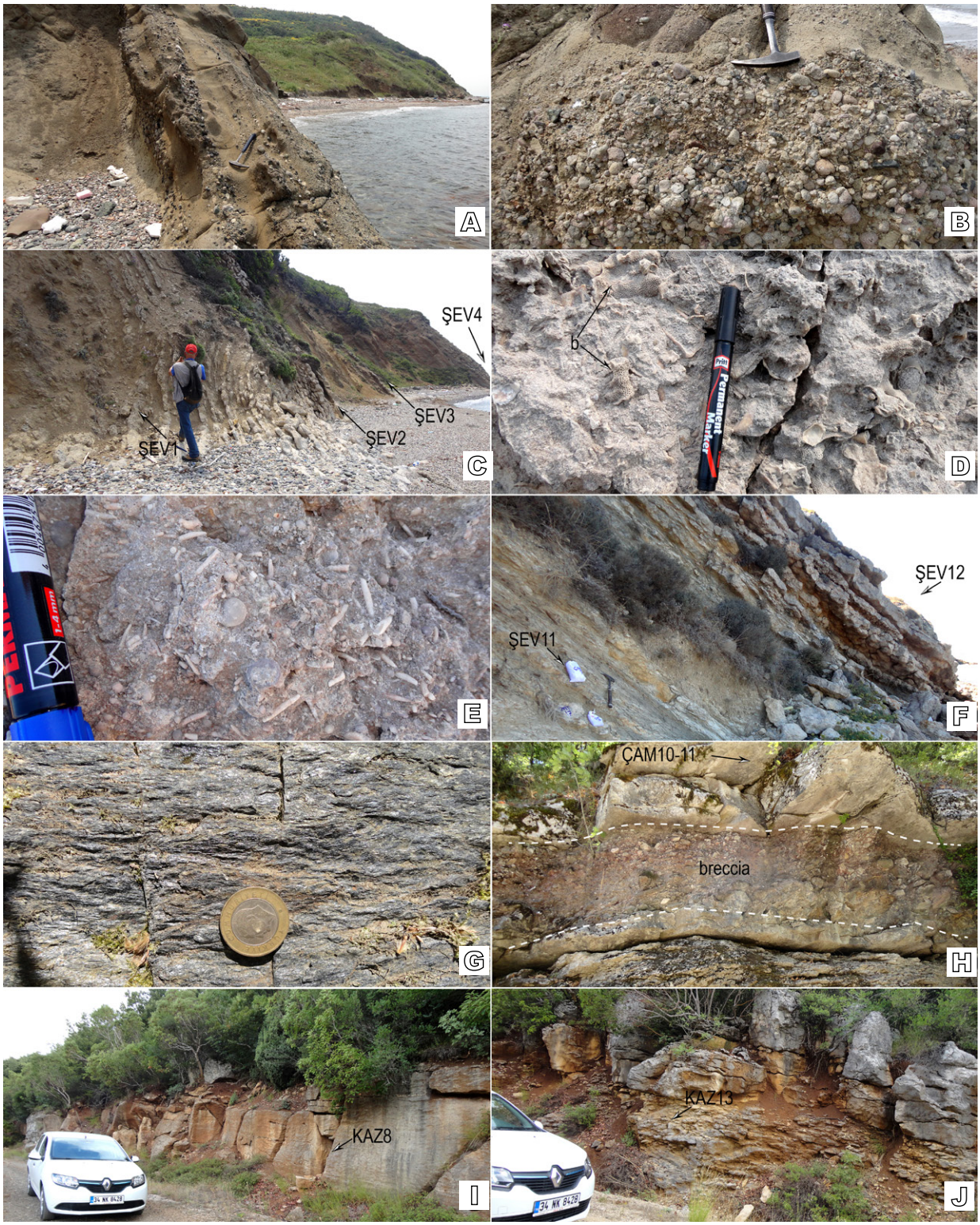

FIGURE 6. Field photographs of Şevketiye (A–H) and Soğucak (I–J) fms. A–F: Şevketiye Section, A, B) conglomerates of the Fıçıtepe Fm. consisting of mainly basaltic pebbles (B); C) limestone beds in the lower part of the Şevketiye Fm. (sampling points are shown); D) very fossiliferous limestone bed in the lower part of the Şevketiye Fm., rich in bryozoans (B) and mollusks (sample ŞEV4); E) alveolinid marker limestone bed in the middle part of the Şevketiye Fm. (sample ŞEV8); F) transition from marine siltstone-sandstone to highly fossiliferous limestone in the middle part of the Şevketiye Fm. (samples ŞEV11-12), where *Heterostegina armenica, Discocyclina discus* and *Operculina gomezi* occur abundantly. G–H: Çamyurt Section, G) basement Çamlıca schist; H) breccia interlayer (thickness of *ca.* 1.5m) in the lower part of the Şevketiye Fm., indicating the transition from marine to continental setting. I–J: Kazmalı Section, I) laminated argillaceous limestone in the lower portion of Soğucak Fm.; J) nodular limestone with corals in the middle part of the Soğucak Fm.

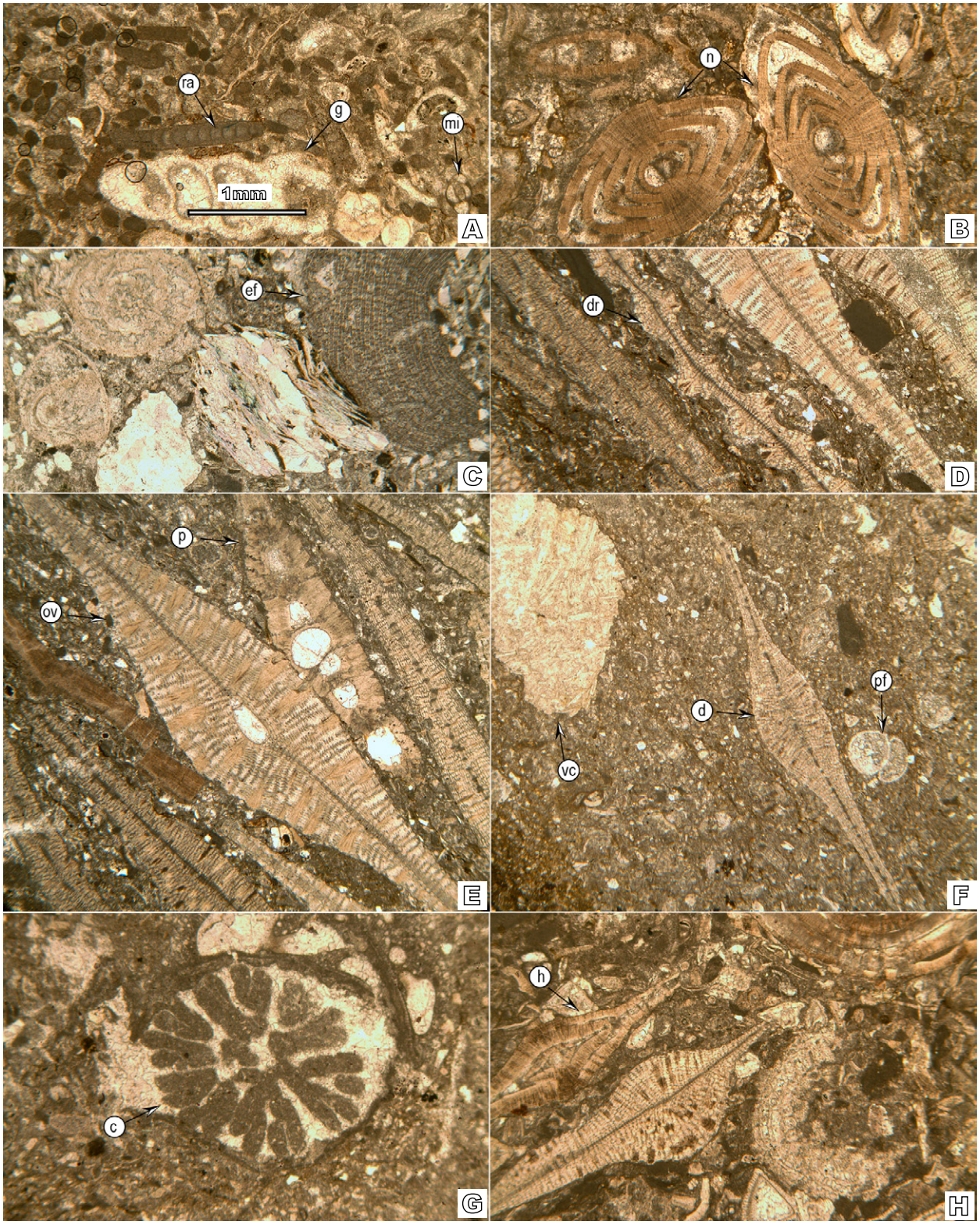

FIGURE 7. Thin-section microphotographs of the fossil associations from the Şevketiye (A–F) and Soğucak (G–H) fms. A) Red algae-gastropod packstone (ŞEV2) and B) nummulitid packstone (ŞEV4) in the lower part of the Şevketiye Section. C) Siltstone/sandstone level with encrusting foraminifera (ÇAM1), and D–E) orthophragminids and *Pellatispira* (ÇAM4) in the lower part of the Soğucak Fm. In the Çamyurt Section. F) Shale/siltstone facies with planktonic foraminifera, orthophragminids and volcanic fragments in the Çamyurt Section (ÇAM13). G) Corals encrusted by red algae in the lower part (KAZ8), and H) foraminiferal packstone (KAZ16) in upper part of the Soğucak Fm. in the Kazmalı Section. Abbreviations: c, corals; d, *Discocyclina* sp.; dr, *Discocyclina radians*; ef, encrusting foraminifera; g, gastropods; h, *Heterostegina*; mi, miliolids; n, *Nummulites*; ov, *Orbitoclypeus varians*; p, *Pellatispira madaraszi*; pf, planktonic foraminifera; ra, red algae; vc, volcanic fragments.

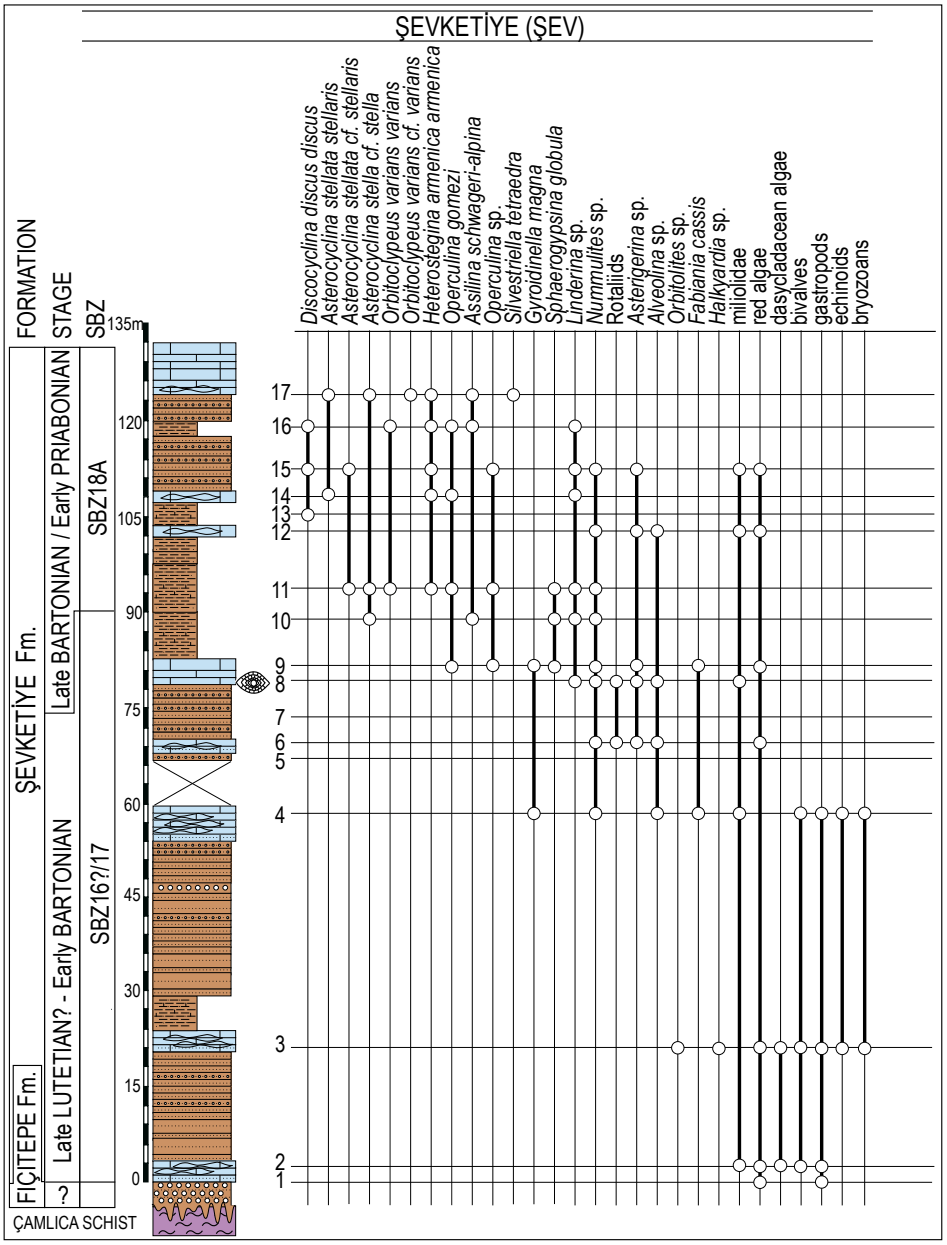

FIGURE 8. Distribution of Larger Benthic Foraminifera (LBF) and associated fossil groups with inferred Shallow Benthic Zones (SBZ) from the Şevketiye Fm. in the Şevketiye Section.

questionable. Overlying thick-bedded intercalations of pebbly siltstone and sandstone (*ca*. 14m-thick) mark well the increasing marine influence and yield reticulate *Nummulites* (*N. fabianii*), *Heterostegina reticulata mossanensis, Pellatispira madaraszi, Gyroidinella magna*, bivalves, and echinoids (Fig. 7C–E). This part of the sequence becomes calcareous upward and grades into sandy limestone/calcareous sandstone beds. The assemblage of *Heterostegina reticulata mossanensis, Nummulites fabianii* and associated foraminifera listed in Figure 9 indicate the SBZ19A, corresponding to the Priabonian. Upwards, a chaotic breccia (*ca*. 1.5m-thick) is built up of large angular metamorphic clasts (up to 50cm across), and is attributed to intermittent inputs of terrestrial materials (Fig. 6H). The breccia bed is overlain by the first prominent limestone bed in the section (samples 10 and 11), rich in *Heterostegina reticulata mossanensis* and *Assilina schwageri-alpina*. This bed is, in turn, overlain by a *ca*. 7m-thick shale-siltstone succession consisting of rare planktonic foraminifera and orthophragminids (sample 13, Fig. 7F), suggesting a deepening in the depositional environment. The higher part of the succession contains shales, siltstone with rare *Nummulites* sp., and conglomerates devoid of fossils,

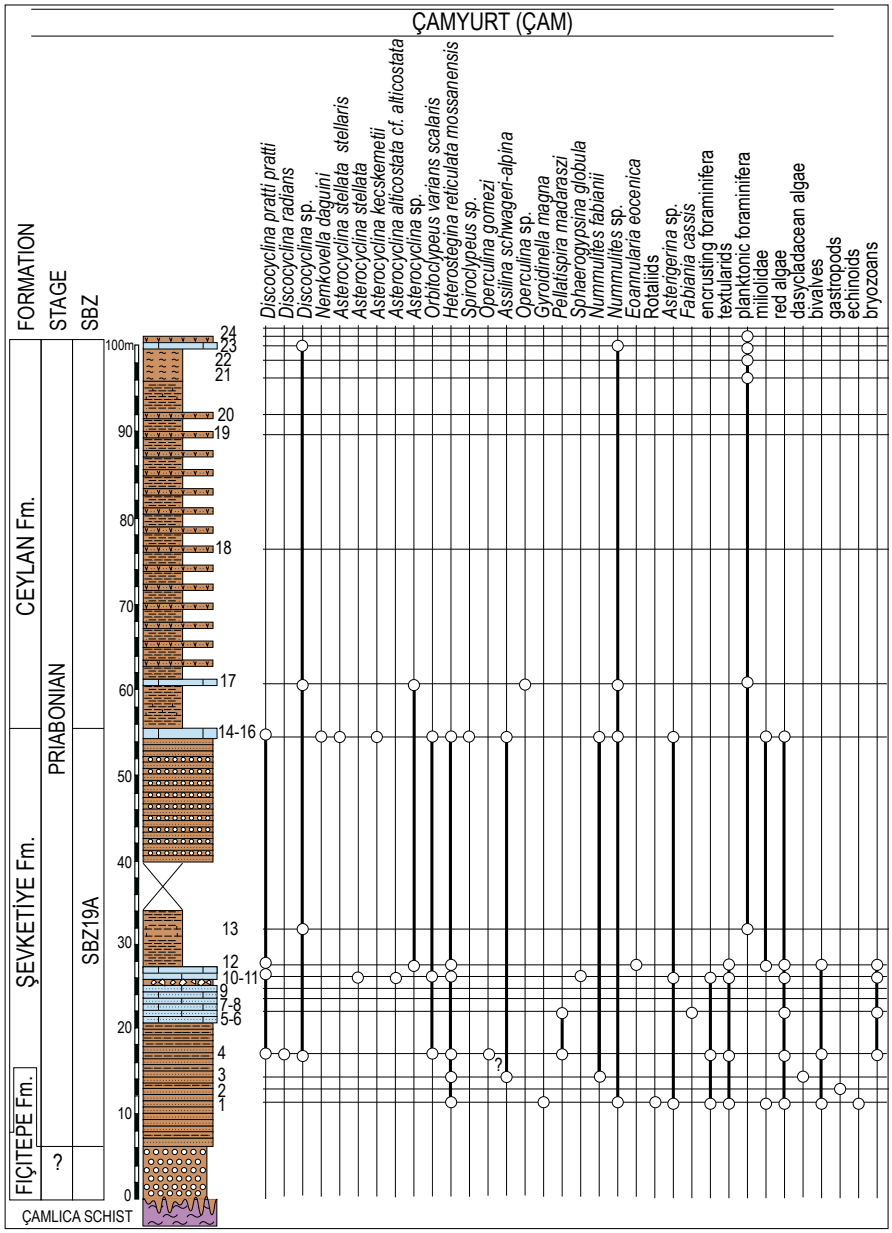

FIGURE 9. Distribution of Larger Benthic Foraminifera (LBF) and associated fossil groups with inferred Shallow Benthic Zones (SBZ) from the Şevketiye Fm. in the Çamyurt Section.

then it passes into a limestone bed with abundant LBF (samples 14–16). The conglomerates consist of pebbles from the Çamlıca metamorphics and may represent a continental influence in the upper part of the section. The limestone bed (samples 14–16) above the siltstone-sandstone part contains biostratigraphically diagnostic LBF, such as *Heterostegina reticulata mossanensis, Assilina schwageri-alpina, Nummulites fabianii, Discocyclina pratti pratti, Orbitoclypeus varians varians*, and *Nemkovella daguini*. The assemblage corresponds to the SBZ19A, suggesting a Priabonian age for the upper part of the unit. The Soğucak Fm. is overlain by volcaniclastic rocks of the Ceylan Fm., containing sporadic planktonic foraminifera and re-sedimented LBF, such as *Discocyclina* sp., and *Nummulites* sp. in sample 23.

Kazmalı Section

Kazmalı Section (KAZ: 40°14’56.89”N, 26°57’14.19”E; 40°14’48.29”N, 26°58’8.12”E) is located at the vicinity of Kazmalı village, 10km southeast of the Çamyurt Section (ÇAM). The Soğucak Fm. is best exposed along the road from Kazmalı to

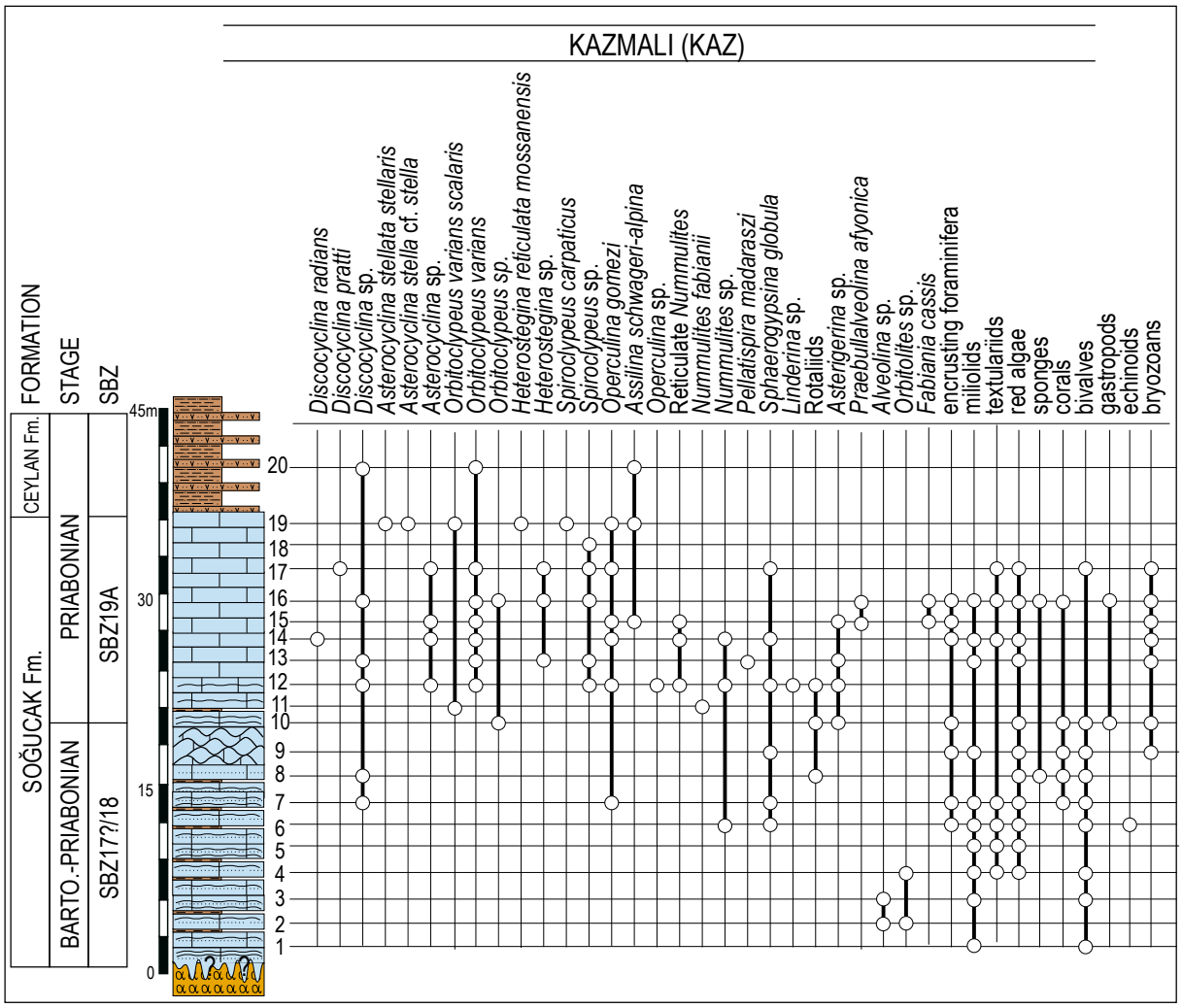

FIGURE 10. Distribution of Larger Benthic Foraminifera (LBF) and associated fossil groups with inferred Shallow Benthic Zones (SBZ) from the Soğucak Fm., in the Kazmalı Section.

Beyçayır, where the unit unconformably rests on the Early (?) Eocene volcanic rocks (Fig. 4). The lower part of the Soğucak Fm. (*ca*. 0–25m-thick) is built up of thick-bedded, laminated, argillaceous limestone with thin marl/shale intercalations and nodular limestone (Fig. 6I; J). Corals constitute a significant part of the fossil assemblage found in nodular limestones. The LBF include sporadic axially elongated alveolinids, *Nummulites* sp. and *Orbitolites* sp. Nodular limestones grade upward into medium to thick-bedded limestones with *Heterostegina reticulata mossanensis, Spiroclypeus carpaticus, Assilina schwageri-alpina, Operculina gomezi, Nummulites fabianii, Pellatispira madaraszi, Orbitoclypeus varians scalaris,* and associated fauna and flora (Fig. 10). This assemblage would belong to SBZ19A (Priabonian) based on the presence of *Heterostegina reticulata mossanensis*, although the occurrence of *Spiroclypeus carpaticus*, which is a key species of SBZ20, suggests a younger age. The Soğucak Fm. is overlain by the volcaniclastic rocks of the Ceylan Fm., which contain sporadic planktonic foraminifera and re-sedimented LBF. *Orbitoclypeus varians, Discocyclina* sp., *Assilina schwageri-alpina* and *Nummulites* sp. occur in volcanogenic clasts (sample 20) and show an affinity to the Bartonian-Priabonian fauna of Şevketiye and Soğucak fms.

Biga Section

Biga Section (40°13’18.59”N, 27°14’3.67”E) is located near Biga town, along the hillside of Balıklıtepe, just next to the Biga nursing home (Figs. 1C and 4). The outcrop is poorly developed, with conglomerate or coarse sand and upper argillaceous limestone, *ca*. 1.5–2m-thick. LBF are represented by scarce *Nummulites* sp. and *Assilina schwageri-alpina*. The unit could not

be assigned to any SBZ, but the common occurrence of latter species suggests that it might have been deposited during the Bartonian-Priabonian time interval.

LBF and associated fossils from the Şevketiye and Soğucak formations

The Şevketiye and Soğucak fms. preserve a diverse assemblage of LBF dominated by nummulitids, and orthophragminids, whereas rotaliids occur sporadically. Alveolinids are represented by *Alveolina* in the lower-middle part of the Şevketiye Fm. near Şevketiye (sample 8) and in the lowermost part of the Soğucak Fm. in the Kazmalı Section, and by *Praebullalveolina* in the upper part of Soğucak Fm. in Kazmalı Section. In general, the LBF from the Biga Peninsula are similar to those from Gökçeada and the Thrace Basin. However, orthophragminids appear to be less diverse in the Biga Peninsula in comparison with those from the Soğucak Fm. in the Thrace Basin (see Özcan *et al.*, 2010; Less *et al.*,

FIGURE 11. *Heterostegina*, *Operculina* and *Assilina* from the Şevketiye Fm. in the Şevketiye Section (SBZ17 and 18A). A–G: *Heterostegina armenica* armenica. A) Sample ŞEV11-3, B) sample ŞEV17-13, C) sample ŞEV17-35, D) sample ŞEV17-34, E) sample ŞEV17-4, F) sample ŞEV17-5, G) sample ŞEV17-2. H-I: *Operculina gomezi*. H) Sample ŞEV14-3, I) sample ŞEV16-4. J–L: *Assilina schwageri-alpina*. J) Sample ŞEV10-5, K) sample ŞEV16-21, L) sample ŞEV17-25.

FIGURE 12. *Heterostegina*, *Spiroclypeus* and *Assilina* from the Şevketiye (A–D, G–H, M–O, respectively) and Soğucak (E-F, I-L, P, respectively) fms. in the Çamyurt and Kazmalı sections (SBZ19A, 19A/20, respectively). A–H: *Heterostegina reticulata mossanensis*. A) Sample ÇAM10-15, B) sample ÇAM14-14, C) sample ÇAM14-32, D) sample ÇAM14-17, E) sample KAZ19-5, F) sample KAZ19-4, G) sample ÇAM12-4, H) sample ÇAM10-19. I–M: *Spiroclypeus carpaticus*. I) Sample KAZ19-15, J) sample KAZ19-20, K) sample KAZ19-9, L) sample KAZ17-4, M) sample ÇAM17-2. N–P: *Assilina schwageri-alpina*. N) Sample ÇAM14-22, O) sample ÇAM10-6, P) sample KAZ15-1.

2011). The benthic foraminifera listed in the Appendix are identified and illustrated here for the first time in the studied area (Figs. 11–17). In addition, encrusting foraminifera, *Fabiania cassis*, red and dasycladacean algae, bivalves, gastropods, bryozoans, echinoids and corals are recorded in some levels.

Heterostegina specimens belong to the most primitive subspecies of *Heterostegina armenica*'s lineage, *H. armenica armenica*, in the Şevketiye Fm. (Figs. 8 and 11A–G), and an advanced developmental stage of *Heterostegina reticulata*'s lineage, *H. reticulata mossanensis*, in Çamyurt and Kazmalı sections (Figs. 9, 10 and 12A–H). *Operculina* is characterised by *Operculina gomezi*, while *Assilina* is represented by the *Assilina schwageri-alpina* group in the Şevketiye and Çamyurt sections (Figs. 8 and 11H; I) and in the Kazmalı Section (Figs. 9, 10 and 12N–P). *Spiroclypeus*, identified only in Çamyurt and Kazmalı sections, belongs to *S. carpaticus*, which is an advanced developmental stage of this genus (Figs. 9, 10 and 12I–M). This genus could not be identified at the species level in the upper part of the Kazmalı Section, below sample 19. The co-occurrence of *H. reticulata mossanensis* and *S. carpaticus* is somewhat in contradiction, as both taxa are the key species of SBZ19 and 20, respectively. Due to the prevalent occurrence of *Heterostegina* in the studied samples, the assignment of SBZ was based on this taxon. The reticulate *Nummulites* (*N. fabianii* group) have only been recognized in Çamyurt and Kazmalı sections, and are assigned to *N. fabianii* (Fig. 13A–F). Orthophragminids are dominant in the upper parts of the Şevketiye Section and belong to *Discocyclina discus* (Fig. 15H; I), *Asterocyclina stellata* (Fig. 15A–D), *A. stella* (Fig. 15E; F) and *Orbitoclypeus varians* (Fig. 14D). A more diverse orthophragminid assemblage occurs in the upper part of Kazmalı and Çamyurt sections, mostly dominated by *O. varians* (Fig. 14E–G) and *A. stellata* (Fig. 14I). The associated orthophragminids are *Discocyclina pratti* (Fig. 14A–C), *D. radians* (Fig. 7D), rare *Nemkovella daguini* (Fig. 14H), *A. stellata, A. stella, A. kecskemetii* and *A. alticostata* (Fig. 15G). The other biostratigraphically significant taxa associated with nummulitids and orthophragminids in the Şevketiye and Soğucak fms. are *Linderina* sp. (Fig. 16A–G), *Sphaerogypsina globula* (Fig. 16H; I), *Pellatispira madaraszi* (Fig. 16J; K), *Silvestriella tetraedra* (Fig. 16L), *Orbitolites* sp. (Fig. 16O), *Praebullalveolina afyonica* (Fig. 16P), *Gyroidinella*

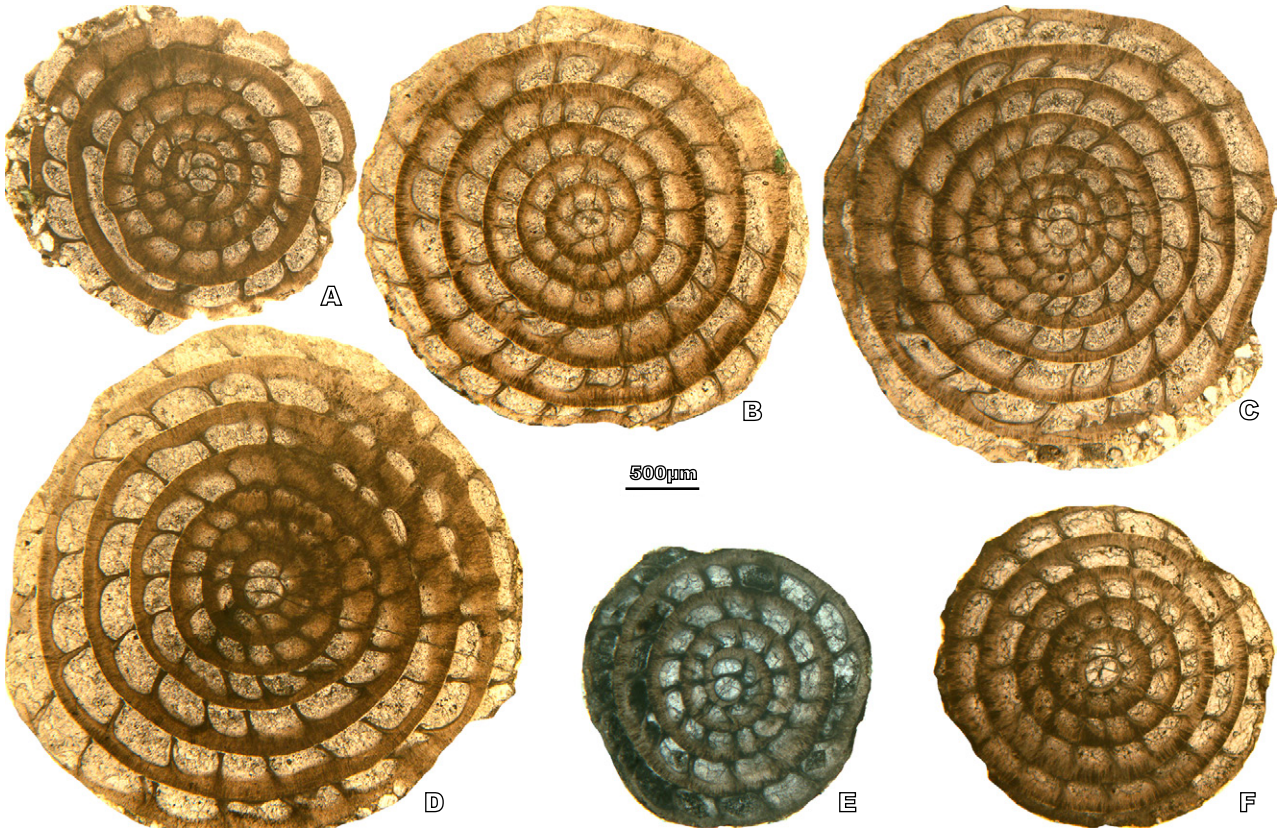

FIGURE 13. Reticulate *Nummulites* from the Şevketiye (A–E) and Soğucak (F) fms. in Çamyurt and Kazmalı sections (SBZ19A, 19A/20, respectively). A–F: *Nummulites fabianii*. A) Sample ÇAM3-2, B) sample ÇAM3-3, C) sample ÇAM3-4, D) sample ÇAM3-8, E) sample ÇAM14-21, F) sample KAZ11-9.

FIGURE 14. Orthophragminids from the Şevketiye (A–C, E–I), and Soğucak (D) fms. in Çamyurt and Kazmalı sections (SBZ19). A–C) *Discocyclina pratti pratti*. A) sample ÇAM14-37, B) sample ÇAM14-12, C) sample ÇAM17-1; D) *Orbitoclypeus varians scalaris*, sample KAZ11-29; E–G) *O. varians varians*. E) sample ÇAM14-28, F) sample ÇAM14-2, G) sample ÇAM14-26; H) *Nemkovella daguini*, sample ÇAM14-25; I) *Asterocyclina stellata*, sample ÇAM10-3.

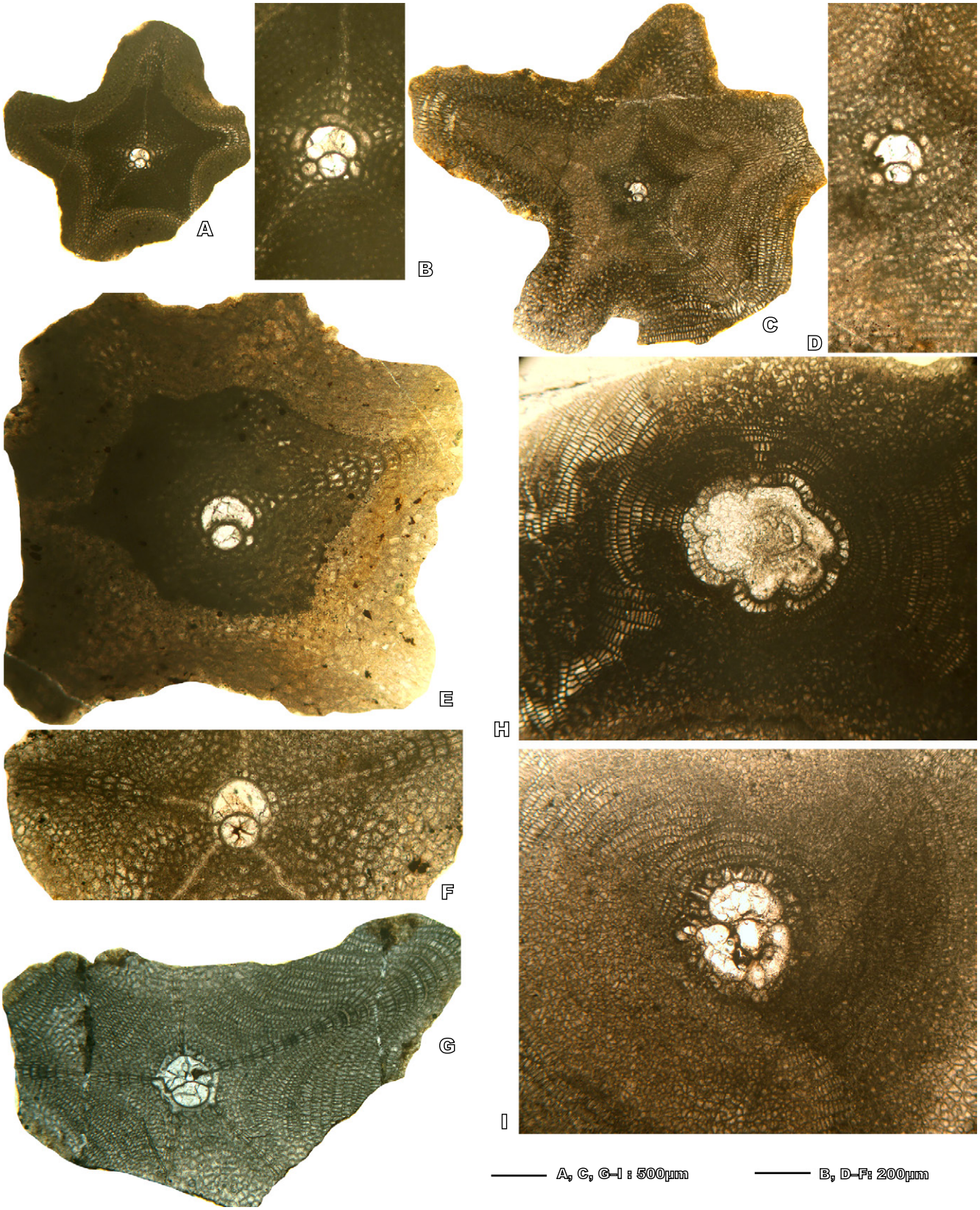

FIGURE 15. Orthophragminids from the Şevketiye Fm. in the Şevketiye (SBZ17) and Çamyurt sections (SBZ19). A–D) *Asterocyclina stellata stellaris*. A–B) Sample ŞEV11-24, C-D) sample ŞEV11-14. E–F) *A. stella cf. stella*. E) Sample ŞEV7-5, F) sample ŞEV7-13. G) *A. alticostata cf. alticostata*. Sample ÇAM14-24. H–I) *Discocyclina discus discus*. H) Sample ŞEV10-14, I) sample ŞEV10-17.

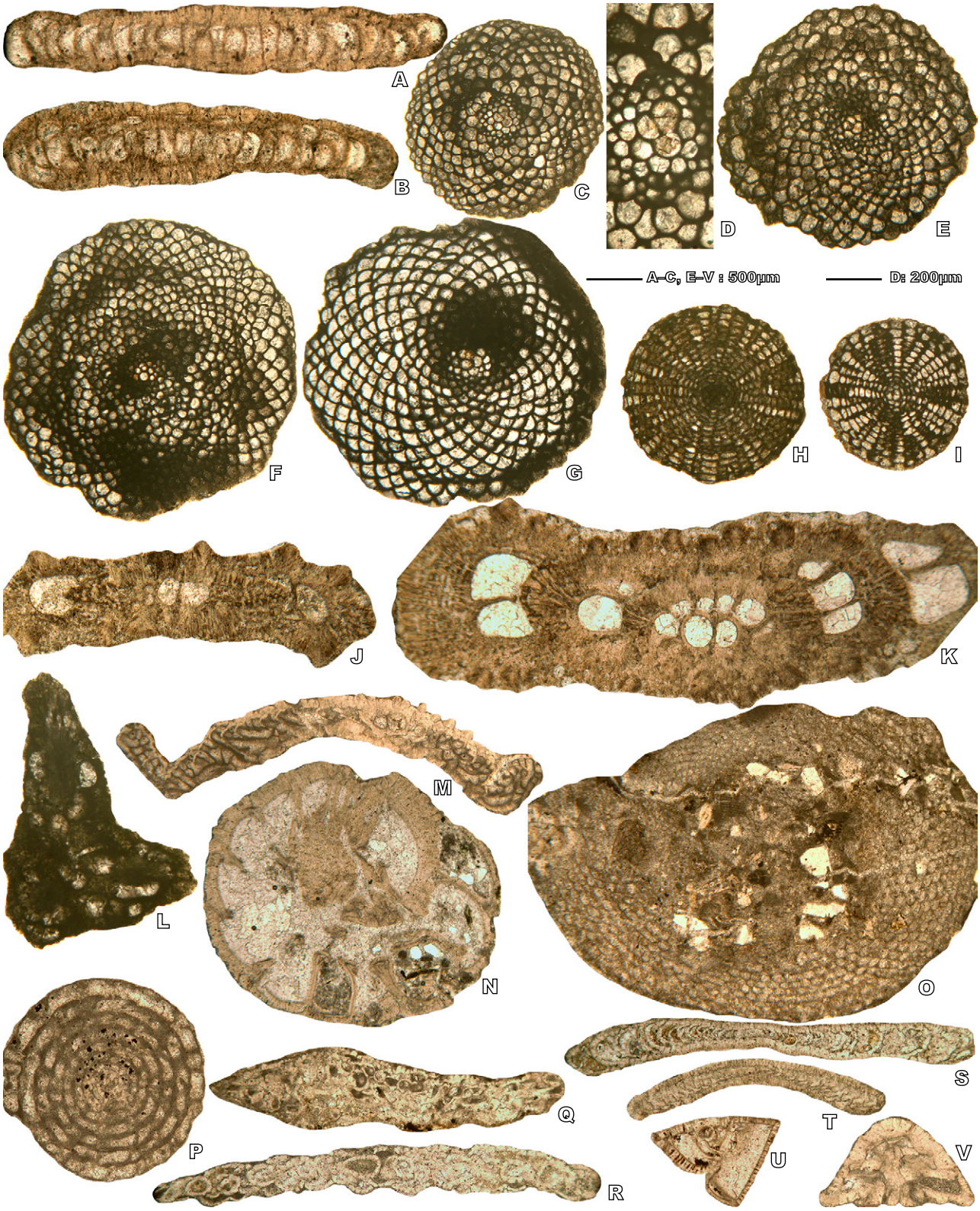

FIGURE 16. Foraminifera and other fossils groups in the Şevketiye (A–L, N–P, S–T), and Soğucak (M, Q–R, U–V) fms. A–G) *Linderina* sp. A–B) Sample ŞEV10, C–G) sample ŞEV11. H–I) *Sphaerogypsina globula*. H) Sample ŞEV11, I) sample ŞEV10. J–K) *Pellatispira madarazsi*. J) Sample ÇAM4, K) sample ÇAM6. L) *Silvestriella tetraedra*. Sample ŞEV17. M) *Fabiania cassis*. Sample KAZ15. N) *Gyroidinella magna*. Sample ÇAM1. O) *Orbitolites* sp. Sample ŞEV3. P) *Praebullalveolina afyonica*. Sample KAZ16. Q–R) encrusting foraminifera. Q) Sample KAZ14, R) sample ÇAM16. S–T) *Eoannularia eocenica*. S) Sample ÇAM8, T) sample ÇAM16. U–V) Rotalids. Sample KAZ12.

magna (Fig. 16N), *Eoannularia eocenica* (Fig. 16S; T) and rotaliids (Fig. 16U; V). Encrusting foraminifera, *Fabiania cassis* (Fig. 16M) and others (Fig. 16Q; R), are common in both units. Corals, a major component of the patchy reefs in the Thrace Basin, are recognized only in the lower part of the Şevketiye Fm., near Kazmalı.

Biostratigraphy

The record of *Heterostegina, Spiroclypeus*, reticulate *Nummulites, Assilina, Operculina*, orthophragminids and other taxa that first appear across the Bartonian/Priabonian boundary (*e.g. Pellatispira, Silvestriella*), provide a sound basis in the establishment of SBZ (Less and Özcan, 2008, 2012; Less *et al.*, 2008; Özcan *et al.*, 2010; Papazzoni *et al.*, 2017). Shallow marine clastics and carbonates in the lower to middle part (0–90m) of the Şevketiye Fm. are referred to the SBZ16?-17 based on the first record of *Operculina gomezi* in sample 9 (at 82m) and the stratigraphic position of these beds below the first record of *Heterostegina armenica* at 94m in the section, a marker species of the SBZ18A and 18B in western Tethys. The lowermost part of the unit might extend down into late Lutetian considering the relatively thick sequence below the *H. armenica* beds and the absence of any typical Bartonian species. Based on the occurrence of *Opeculina gomezi*, the part of the Şevketiye section between 82–90 meters is confidently referred to SBZ17, hence, Early Bartonian in age. The LBF assemblage, represented by *Heterostegina armenica armenica*, a subspecies characteristic of the SBZ18A, *Operculina gomezi, Assilina schwageri-alpina, Discocyclina discus discus, Silvestriella tetraedra* and other associated LBF in the upper part of the section (Fig. 8), points to a younger stratigraphic position, referable to SBZ18A across the Bartonian-Priabonian boundary according to Papazzoni *et al.* (2017). The occurrence of axially elongated *Alveolina* specimens in the lowermost part of the Kazmalı section, below the Priabonian strata suggests that these beds are Bartonian in age. Contrary to the LBF assemblages in the Şevketiye Section, the foraminiferal fauna of both Şevketiye and Soğucak fms. in Çamyurt and Kazmalı sections are characterized exclusively by phylogenetically advanced stages of *Heterostegina reticulata*'s lineage, which are associated with the typically Priabonian genus *Spiroclypeus* and the advanced developmental stages of the *Nummulites fabianii* group. In the Çamyurt Section, the lowest marine beds of the Şevketiye Fm. (just about the conglomerates of the Fıçıtepe Fm.) contain *Nummulites fabianii, Heterostegina reticulata mossanensis, Pellatispira madaraszi* and *Orbitoclypeus varians scalaris*, and are assigned to the SBZ19A. The highest limestone bed of the unit contains a similar assemblage as well as *Spiroclypeus*, suggesting the same zone. The lower beds of the Soğucak Fm. in Kazmalı Section (0–12m) cannot be confidently assigned to any biozone in the absence of key taxa. These beds may be referred to the SBZ17?/18 on the basis of the first occurrence of *Operculina gomezi* in sample 7 and their position below the *Spiroclypeus-N. fabianii* beds (samples 11–19). The diverse assemblages represented by *Spiroclypeus* sp., *N. fabianii, Discocyclina pratti, Orbitoclypeus varians scalaris, Heterostegina reticulata mossanensis* and *Pellatispira* in the upper part of the section (12–37m) are confidently assigned to the SBZ19A (Priabonian).

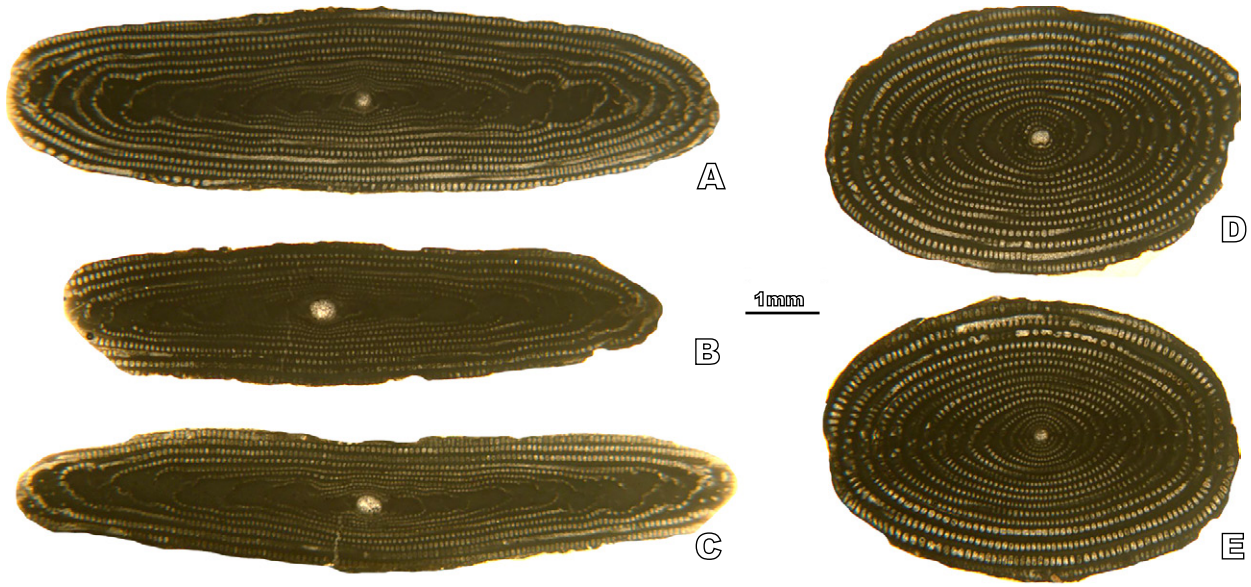

FIGURE 17. Alveolinids from the Şevketiye Fm. in the Şevketiye Section (sample ŞEV8).

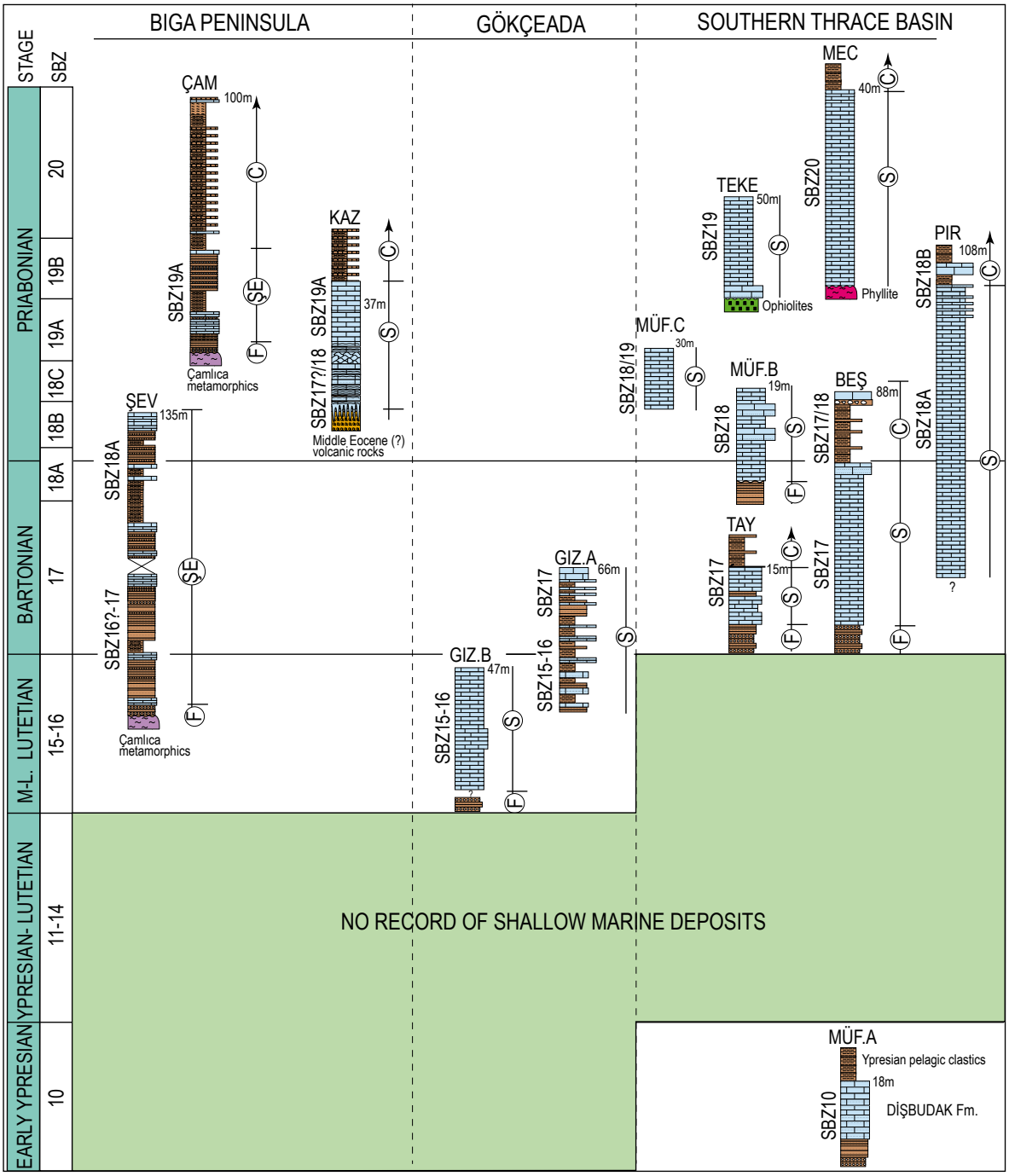

FIGURE 18. Biostratigraphic correlation scheme of the Şevketiye and Soğucak fms. in NW Anatolia. The sections of the unit from northern Thrace Basin are not included. The sections from Gökçeada and Thrace Basin are from Özcan *et al.* (2010). Abbreviations: ŞE: Şevketiye Fm., S: Soğucak Fm.

DISCUSSION

Extension and correlation of Şevketiye and Soğucak formations in NW Turkey

Soğucak Fm., a common carbonate unit in the Thrace Basin, and its clastic equivalent, the Şevketiye Fm., were deposited in the northwestern part of the Biga Peninsula, between Lapseki and Biga towns. The southern extension of the Eocene Sea is tentatively delimited by the Kazmalı and Çamyurt localities, where both units dip beneath a thick sequence of the Late Eocene Ceylan Fm. and post-Eocene volcanic units, making it impossible to trace both formations further to the South. The limited vertical extent of the Soğucak Fm. in the Biga locality and the absence of any coeval units

FIGURE 19. Cartoons depicting the marine transgression in NW Anatolia during the Late Lutetian-Priabonian interval. Middle to Late Eocene reefal and nummulitic deposits in the Strandja Massif in Bulgaria, as well as in Greece, are not considered due to the lack of precise biostratigraphic data (*e.g.* Caracciolo *et al.*, 2012). Data from the northern part of the Thrace Basin are from Less *et al.* (2011). Abbreviations: B.P.: Biga Peninsula, S.C.: Sakarya Continent.

further to the East of the study area suggest that the sea transgressed eastward to reach this region. The shallow-marine deposits display a diachronic development in the area, as it has been shown in the Thrace Basin and Gökçeada (Figs. 18 and 19). The oldest record to date the transgression was found in Gökçeada and belongs to the SBZ15/16 (Middle to Late Lutetian), whereas all the other sections studied in the Gelibolu Peninsula (southern Thrace) and northern Thrace yielded a range of zones, varying from SBZ17 to 20 (Bartonian to Priabonian). At a regional scale, the results point out at a polarity from West (Gökçeada) to northeast (northern Thrace; see Less *et al.*, 2011). The SBZ17 was only recorded from Gökçeada and Gelibolu Peninsula (*e.g.* TEKE and BEŞ sections in southern Thrace) and from Şevketiye Section in the Biga Peninsula, whereas this zone was never recorded in northern Thrace. Diachronic marine onlap of the Eocene Sea at a single locality is best recorded in Çatalca high where topographic lows were flooded in the SBZ18A and highs in the SBZ19 and 20 (Okay *et al.*, 2010, 2017; Less *et al.*, 2011). The latter age of the marine incursion is recorded widely in the Thrace Basin. The metamorphic basement near Mecidiye (MEC Section) and the ophiolites near Teke (TEKE Section) in southern Thrace are directly overlain by the Soğucak Fm. The metamorphic rocks of the Strandja Massif(?) near Karaburun (KARA Section) in northern Thrace are covered by the Soğucak Fm. that yielded LBF from the SBZ19 and/or 20. Thick carbonates of the same unit cover the Strandja Massif

in sections TEKE and Hacımaşlı, which belong to the SBZ18 (A, B, C) at its lower parts (Less *et al.*, 2011).

To sum up, the Biga Peninsula and the Thrace Basin display a similar Bartonian-Priabonian evolution. The oldest marine record in Şevketiye (SBZ16?/17) suggests a minor age difference with that of the Section GIZ.B in Gökçeada and shows a great similarity to sections BEŞ and TEKE from the Gelibolu Peninsula. A shallow marine realm developed in Gökçeada, Gelibolu and Biga peninsulas during the Bartonian (SBZ17), which did not reach the northern part of Thrace. During the Priabonian, the shallow-marine realm increased and is recorded from both southern and northern Thrace and the Biga Peninsula. A marine connection was established with the Black Sea in the Priabonian, as evidenced by the deposition of the Soğucak Fm. upon the Strandja Massif, which formed an emerged landmass until the Bartonian/Priabonian transition (SBZ18: Less *et al.*, 2011; Okay *et al.*, 2017) (Fig. 19). A continuous shallow marine section, including both SBZ18 and 19, has never been documented, although the superpositon of other zones was recorded. This suggests that the SBZ19 may correspond to a separate, major marine incursion at a basinal scale.

Inferences for regional geology

In the Biga Peninsula, the Şevketiye and Soğucak fms. correspond to the first marine incursions of the post-collisional Eocene sequence. The oldest volcanics beneath the Soğucak/Şevketiye transgression, Edincik volcanics, were previously dated as 42.3Ma (Lutetian), and the overlying Beyçayır volcanics as 37.3Ma (Altunkaynak and Genç, 2008; Genç *et al.*, 2012). This age is close to the Bartonian/Priabonian boundary according to Gradstein *et al.* (2012). The results presented here are in strong agreement with these geochronological data, suggesting that the Lutetian was a period of extensive volcanism, followed by a marine realm during the Bartonian and Priabonian. Nevertheless, the marine transgression appears to have developed diachronically as shown from the Şevketiye and Çamyurt sections. The age of the Soğucak Fm. was previously commonly reported to be 'Middle Eocene-Lutetian' (*e.g.* Siyako *et al.*, 1989). The 'Lutetian' was widely adopted to constrain the age of oceanic suturing (İzmir-Ankara suture) and the onset of the exhumation history of the metamorphic basement rocks (Şengör and Yılmaz, 1981; Okay *et al.*, 1991, 2001; Şengün *et al.*, 2011). Siyako *et al.* (1989) considered the Soğucak Fm. of 'Lutetian' age and the underlying continental clasts of the Fıçıtepe Fm. of Early Eocene age based only on stratigraphic superposition. This flawed age was, then, widely used to interpret the tectonic evolution of the region and exhumation of the Çamlıca metamorphics (*e.g.* Bonev and Beccaletto, 2007; Şengün *et al.*, 2011). However, the continental clasts of the Fıçıtepe Fm. cannot be older than 'Middle Eocene' based on the marine record in the studied sections and the geochronological data obtained from the volcanics covering the basement rocks. The Early Eocene (Late Ypresian) shallow marine deposits in Bozcaada, attributed to the Soğucak Fm. by Varol *et al.* (2007), are the product of a much earlier transgression, which is also recorded in the Thrace Basin (Fig. 18). The results presented here suggest that suturing occurred before the Lutetian/Bartonian boundary, as the lower part of the Şevketiye Fm. is younger than the SBZ16. This is in accordance with the records from sections along the same suture zone in Central Anatolia, where the youngest pre-collisonal marine deposits range up to the Middle Lutetian (Okay *et al.*, 2001).

CONCLUSIONS

The Eocene shallow marine deposits in the Biga Peninsula are characterized by two partly coeval lithostratigraphic units, Şevketiye and Soğucak fms. The Şevketiye Fm., formally described in the present study, consists of dominantly a clastic sequence with subordinate carbonates deposited during the Late Lutetian (?)/Bartonian–Priabonian. The Soğucak Fm., on the other hand, is characterized by dominantly limestone and subordinate shale/marl laminae, deposited during the Bartonian (?)–Priabonian. Unstable depositional conditions are inferred by the non-marine breccia or conglomerate intercalations, and by temporary deepening of the shelf, evidenced by beds rich in planktonic foraminifera in the lower part of the Şevketiye Fm. (Çamyurt Section). The oldest marine incursion is dated as Late Lutetian?-Bartonian in Şevketiye, while the youngest one is Priabonian in the Çamyurt and Kazmalı sections. This is consistent with the geochronological ages obtained in previous studies from the volcanic units underlying the Soğucak Fm. The oldest volcanic materials, allegedly recording a post-collisional event, constrain further the collision as pre- Middle Lutetian. The correlation of the sections with those from southern Thrace and previous data from northern Thrace, clearly point out to a transgression polarity from Gökçeada towards the Biga Peninsula and the southern Thrace Basin that ended with a regional marine transgression in the Priabonian. The marine connection with the Black Sea was established in the Priabonian, as evidenced by the deposition of the Soğucak Fm. on the Strandja Massif and İstanbul Zone via the Çatalca gap and further northwest in the Vize-Kıyıköy Region.

ACKNOWLEDGMENTS

We are grateful to D. Bassi (Ferrara), an anonymous reviewer and associate editor C. Martín-Closas for helpful suggestions in the review of the manuscript. We thank C. Ferràndez-Cañadell (Barcelona) for his comments on genus *Linderina*. This study was supported by İstanbul Technical University BAP project No. 34768.

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Manuscript received October 2017;
revision accepted February 2018;
published Online May 2018.

APPENDIX I

LIST OF THE FOSSIL TAXA

Discocyclina discus discus (Rütimeyer, 1850)
D. pratti pratti (Michelin, 1846)
D. radians (d'Archiac, 1850)
Nemkovella daguini (Neumann, 1958)
Orbitoclypeus varians varians (Kaufmann, 1867)
O. varians (Kaufmann, 1867) *scalaris* (Schlumberger, 1903)
Asterocyclina stellata (d'Archiac, 1846) *stellaris* (Brünner, in Rütimeyer, 1850)
A. stella cf. stella (Gümbel, 1861)
A. alticostata cf. alticostata (Nuttall, 1926)
A. kecskemetii Less, 1987
Nummulites fabianii (Prever, in Fabiani, 1905)
Heterostegina armenica armenica (Grigoryan, 1986)
H. reticulata (Rütimeyer) *mossanensis* Less, Özcan, Papazzoni and Stockar, 2008
Spiroclypeus carpaticus Uhlig, 1886
Operculina gomezi Colom and Bauzá, 1950
Assilina schwageri Silvestri 1928-*alpina* (Douvillé, 1916)
Silvestriella tetraedra (Gümbel, 1868)
Sphaerogypsina globula (Reuss, 1848)
Gyroidinella magna Le Calvez, 1949
Pellatispira madaraszi Hantken, 1876
Praebullalveolina afyonica Sirel and Acar, 1982
Fabiania cassis (Oppenheim, 1896)
Eoannularia eocenica Cole and Bermudez, 1944
Linderina sp.
Orbitolites sp.
Alveolina sp.
Nummulites sp.
Operculina sp.