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Late Maastrichtian-Late Palaeocene planktic foraminiferal biostratigraphy of the matrix of the Bornova Flysch Zone around Bornova (İzmir, Western Anatolia, Turkey)

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Abstract: The Bornova Flysch Zone (BFZ), located between the Menderes Massif and the İzmir-Ankara Suture in westernmost Anatolia (Turkey), forms the westernmost part of the Anatolide-Taurides. The BFZ comprises intensely sheared Upper Cretaceous-Palaeocene matrix and blocks of various origins. The matrix of the BFZ is mainly made up of unfossiliferous flysch-type sediments (alternations of sandstones and shales). In Bornova (İzmir, western Turkey) and its surroundings, these clastics locally include planktic foraminifera-bearing pelagic micritic limestone and calcareous shale lenses and interbeds (Beytitepe Limestone). As a result of studies focusing on the planktic foraminifera-bearing pelagic interlayers in three areas (Gökdere, Işıklar and Kocaçay areas) around Bornova, a detailed planktic foraminiferal biostratigraphy of the rocks is documented for the first time. The thickness of the laminated micritic limestones attains 360 m in the Gökdere area. Occurrences of late Maastrichtian species such as Abathomphalus mayaroensis (Bolli), Contusotruncana contusa (Cushman), Globotruncanita conica (White) and Racemiguembelina fructicosa (Egger) within planktic foraminifera assemblages obtained from the laminated micritic limestones and red calcareous shales in the three areas suggest a late Maastrichtian age for these rocks. The occurrence of various species of Globanomalina, Morozovella, Igorina and Parasubbotina within the calcareous shales in the Işıklar area suggests a late Palaeocene age. The Kocaçay area has well-preserved outcrops showing the stratigraphy of the matrix, despite the more complex geology. The upper Maastrichtian laminated micritic limestones are gradationally overlain by upper Maastrichtian calcareous shales. The calcareous shales are represented by rich planktic foraminiferal assemblages and include blocks derived from laminated micritic limestones. The upper Maastrichtian calcareous shales are overlain by Palaeocene red calcareous shales. Poor assemblages including Parasubbotina varianta (Subbotina), Subbotina triangularis (White), Subbotina cf. velascoensis (Cushman), Globanomalina compressa (Plummer) and Globanomalina planoconica (Subbotina) indicate a late Palaeocene age for the lower part and a latest Palaeocene age for the upper part of the calcareous shale sequence. Therefore, the age of conglomerates and flysch overlying the calcareous shales should be latest Palaeocene or younger in the Kocaçay area.

Key Words: Planktic foraminifer; biostratigraphy; late Maastrichtian - late Palaeocene; Bornova Flysch Zone; Western Anatolia

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1. Introduction
The Bornova Flysch Zone (BFZ) forms a 50 to 90 km wide and approximately 230 km long tectonic zone between the Menderes Massif and the İzmir-Ankara Suture (Okay & Altuner 2007) in westernmost Turkey (Figure 1). It corresponds to the western part of the İzmir-Ankara Zone of Brinkmann (1966). The rocks of this zone cropping out in İzmir and its surroundings were named the Bornova mélange by Erdoğan (1990b). According to Okay et al. (2012) the Upper Cretaceous rocks of the BFZ were deposited in a narrow basin on the northern margin of the Anatolide-Tauride Block located between the Neo-Tethyan Ocean to the west and a strike-slip tear fault to the east. As the tear fault separated the basin fill and the continental subduction zone to the east, the BFZ escaped Tertiary metamorphism while the coeval rocks of the Menderes Massif underwent HP/LT metamorphism.

The BFZ comprises intensely sheared matrix and blocks of Mesozoic limestone, mafic volcanic rocks, radiolarites and serpentinites ( Erdog an 1990b; Okay & Siyako 1993). The limestone blocks derived from the platform range up to 20 km across and their ages range from Triassic to Late Cretaceous (Özer & İrtem 1982; Öz ğer 1989; Erdoğan 1990a, 1990b; Erdoğan et al. 1990; Okay & Siyako 1993; İşı ntek et al. 2000; İşı ntek et al. 2006; Okay & Altuner 2007; Senowbari-Daryan & İşı ntek 2008; İşı ntek et al. 2009a, 2009b). The matrix of the BFZ in the İzmir area comprises mainly unfossiliferous flysch-type sediments (alterations of sandstones and shales), which locally include calcareous shales and micritic limestone lenses and interbeds with planktic foraminifera suggesting a Campanian-early Palaeocene (Danian) age according to previous studies (Konuk 1977; Yaşmurlu 1980; Özer & İrtem 1982; Erdoğan 1990b).
Figure 1. (a) Main tectonic units of western Anatolia and eastern Greece (after Görür & Tüysüz 2001). Study area is situated in the Bornova Flysch Zone, which corresponds to the westernmost part of the Tauride-Anatolides. (b) Simplified geological map of İzmir and surroundings, showing locations of the study areas (simplified after Erentöz 1964).
Well-preserved outcrops of calcareous shales and micritic limestones occur around Bornova (İzmir) and its surrounding area (Figure 1). These calcareous pelagic interlayers, named the Beytitepe Limestone by Yaşmurlu (1980), are an unique palaeontological data resource within the matrix of the BFZ as they yielded rich planktic foraminifera assemblages. Hence, they possess important data relating to the opening and closing ages and the sedimentological and tectonostratigraphic evolution of the basin. However, few studies have dealt with the palaeontological aspects of these rocks (Konuk 1977; Yaşmurlu 1980; Özer & İrtem 1982; Erdoğan 1990b). The planktic foraminiferal content of the pelagic interlayers has not been documented in detail until today despite its importance in dating the matrix of the BFZ.

A planktic foraminifera based biostratigraphic study of the calcareous shales and micritic limestones of the Beytitepe Limestone is documented here in order to help chronostratigraphic determinations (Figure 2).

2. Material and methods
This study is based on detailed geological mapping and systematic sampling through the measured stratigraphic sections. Four hundred seventy nine samples were collected from the pelagic micritic limestones and calcareous shales of the Beytitepe Limestone in order to study the planktic foraminiferal content. A standard washed-sample method did not work as the limestones and calcareous shales are mostly indurated and cut by numerous pressure solution seams as a result of intense shearing. Therefore, thin sections were prepared from 390 samples, from which axially oriented forms were picked to identify most taxa with a high degree of confidence, as most of the diagnostic criteria can be recognized in such axial and/or subaxial sections. This method is widely used in planktic foraminifera studies, especially in the Cretaceous (Wonders 1979; Fleury 1980; Sliter 1989; Premoli Silva & Sliter 1994; Sliter 1999; Robaszynski et al. 2000; Premoli Silva & Verga 2004). Papers specific to Turkey include Farinacci & Yeniyay (1986), Özkann & Köylüoğlu (1988), Özkann Altuner & Özcann (1999), Sarı (1999), Sarı & Özer (2002), Sarı (2006a, 2006b, 2009) and Okay & Altuner (2007), which are based on planktic foraminifera identified in thin section. However, there have been few attempts to study Palaeocene planktic foraminifera from thin section. The resolution of thin-section zonation is nearly as precise as zonal schemes based on isolated specimens for the Cretaceous (Sliter 1989). In addition to these contributions, Robaszynski et al. (1984) is also frequently cited for late Maastrichtian planktic foraminiferal species identification. The Latest Cretaceous planktic foraminiferal zonation of Premoli Silva & Sliter (1994), Premoli Silva & Sliter (1999) and Premoli Silva & Verga (2004) is followed in this study (Figure 3). Palaeocene planktic foraminifera identification is based on Berggren et al. (1995), Olsson et al. (1999) and Olsson...
et al. (2011). Biozonation of Berggren et al. (1995), Olsson et al. (1999), Berggren & Pearson (2005) and Olsson et al. (2011) is followed here (Figure 3). Because it is not easy to separate some Palaeocene species from two dimensional axial views in thin section, these species are grouped as Morozovella angulata (White) - Morozovella aequa (Cushman & Renz) group and Morozovella conicotruncana (Subbotina) - Morozovella velascoensis (Cushman) group.

3. Geological setting and previous studies

The BFZ consists of chaotically deformed Campanian-Lower Palaeocene flysch-type matrix and blocks of various sizes and origins (Erdoğan 1990b; Okay & Siyako 1993). Many of the blocks comprise shallow water limestones, some of which can be as large as 20 km in diameter. These limestone blocks were the subject of several studies, that showed that their ages range from Triassic to Late Cretaceous (Özer & İrtem 1982; Özer 1989; Erdoğan 1990a, 1990b; Erdoğan et al. 1990; Okay & Siyako 1993; İşintek et al. 2000; İşintek et al. 2006, 2007; Okay & Altiner 2007; Senowbari Daryan & İşintek 2008; İşintek et al. 2009a, 2009b). They were stratigraphically and palaeontologically correlated with the Karaburun Mesozoic successions (Erdoğan 1990a, 1990b). Some of the neritic blocks include pelagic interlayers in their stratigraphically upper parts. A Tithonian-Turonian pelagic level in a block from south of Bigadiç (NE of the Zone) was documented by Okay & Altiner (2007), who correlated the stratigraphy of the block with similar successions from the Lycian nappes to the south. Turonian-Maastrichtian, Campanian-Middle Maastrichtian and Santonian-Campanian ages were also recorded from the pelagic parts of the blocks (Erdoğan 1990b). Blocks of radiolarian cherts also yielded palaeontological data. Recently, Mid to Late Triassic (late Ladinian to middle Carnian), Middle Jurassic (late Bathonian to early Callovian) and Middle Jurassic to Late Cretaceous (latest Bajocian to late Cenomanian) ages were documented based on the radiolaria in various chert blocks by Tekin & Göncüoğlu (2007), Tekin & Göncüoğlu (2009) and Tekin et al. (2010) respectively. Some palaeontological studies have data about planktic foraminifera, which give information on the fossiliferous pelagic interlayers within the flysch-type rocks of the matrix. A Turonian-Early Campanian age was documented for the flysch in the Seferhisar area by Akartuna (1962). A late Campanian-Maastrichtian age was obtained from Manisa and its surroundings by Oğuz (1966). According to Marengwa (1968), the age of the flysch in the Işıklar area is Turonian-Campanian. Konuk (1977) described some planktic foraminifera assemblages from the Kocaçay area (north of Bornova, Izmir), where the pelagic calcareous rocks are late Campanian - late Maastrichtian and are overlain by Palaeocene or younger conglomerates and flysch respectively. The calcareous pelagic interlayers were named the Beytitepe Limestone by Yağmurlu (1980), who used the stratigraphical positions for three different flysch formations south of Bornova to establish their Campanian, Maastrichtian-Early Palaeocene and Middle-

![Figure 3](image-url)
of the BFZ in the area between Karaburun, Seferihisar and Manisa. He obtained a Campanian-Maastrichtian age from the Gökdere area, a Middle Maastrichtian-Danian age from the Kocaçay area, an upper Campanian-lower Maastrichtian age from the Pınarbaşı section (SE of Bornova), and a Campanian and middle-late Maastrichtian age from Spil Mountain (Manisa). İşîntek et al. (2007) examined limestone blocks from the Kocaçay Conglomerate, which overlies the Palaecene calcareous shales in the Kocaçay area. They obtained Late Cretaceous-Palaeocene, Palaeocene, middle-late Palaeocene ages from the neritic limestone blocks and suggested that the age of the conglomerates should be middle-late Palaeocene or younger.

The base of the palaeo limestones and overlying flysch-type rocks were observed at two localities. The first locality is from the Karaburun peninsula, where a Mesozoic (Aptian-Albian) neritic sequence is unconformably overlain by Lower Campanian to Middle Maastrichtian pelagic limestones and flysch-type rocks of the Balıkkiova Formation (Brinkmann et al. 1977; Tansel 1990; Erdoğan 1990b; Erdoğan et al. 1990). At the second locality, in the Kemalpaşa area (east of İzmir), Poisson & Şahinci (1988) documented the stratigraphy of a Mesozoic block and suggested that the Mesozoic neritic sequence was overlain by Maastrichtian pelagic rocks, middle Palaeocene or younger conglomerates and flysch respectively.

The flysch deposits and the blocks of the BFZ are unconformably overlain by undeformed upper Lower Eocene (late Cuisian) neritic limestones north of Akhisar (Akdeniz 1980; Önoğlu 2000). Therefore deformation affecting the BFZ must have predated the late Early Eocene. The rocks of the BFZ are unconformably overlain by the conglomerates, claystones and clayey limestones of the Miocene Sabuncubeli Formation in Bornova and its surroundings (Erdoğan 1990b).

4. Stratigraphy and planktic foraminiferal biostratigraphy of the Beytitepe Limestone

The matrix of the BFZ dominantly comprises intensely sheared flysch-type deposits (alternations of sandstones and shales), which include conglomerates, micritic limestones and calcareous shales as lenses or conformable interbeds (Figure 2). This study focuses on the micritic limestones and calcareous shales, known as the Beytitepe Limestone, as they include rich planktic foraminiferal assemblages (Figure 2). The stratigraphy and planktic foraminiferal biostratigraphy of the micritic limestones and calcareous shales of the Beytitepe Limestone were studied in detail in the Gökdere, İşîklar and Kocaçay areas around Bornova (Figure 1).

4.1. The Gökdere area

The Gökdere area, covering approximately 12 km², is located 10 km southeast of Bornova (Figures 1, 4). The Beytitepe Limestone occurs as a thick interlayer within flysch-type rocks and shows significant fluctuations in thickness over short distances (Figure 4). Numerous levels of variable thickness and size were also observed within the flysch. Two stratigraphic sections, the Beytitepe and the Gökdere sections, were measured from the Gökdere area. Details of the stratigraphic and palaeontological data obtained from these measured stratigraphic sections are presented below.

The Beytitepe stratigraphic section

The Beytitepe Limestone is bounded both below and above by sandstone-shale alternations (Figures 4, 5, 6). The sandstone beds overlying the limestones show partial Bouma sequences. The Beytitepe Limestone consists of grey laminated micritic limestones (Figure 7a). Pinkish grey and pale greenish-grey interlayers were also observed. Lamina thickness is millimetric to centimetric. Fifty nine samples were collected through the section. The carbonate content of the sandstone-shale alternation increases towards the flysch-limestone contact and flysch gradually passes into the laminated limestones at the bottom of the sequence (Figure 6). Neritic blocks and sand-size clasts were observed at the base of the micritic limestones. In addition, reworked orbitoid benthic foraminifera were also observed throughout this level. The limestones have a planktic foraminiferal mudstone/wackestone depositional texture (Figures 7c, d). The abundance of planktic foraminifera varies from sample to sample (Figure 6). Some levels were severely affected by intense shearing. As a result, rock and the planktic foraminifera were cut by pressure solution seams (Figure 7d). However, some levels escaped the effect of shearing, and many complete specimens of planktic foraminifera were observed (Figure 7c). An echinoid fragment was observed 149 m above the section base (Figures 6,7b). The specimen belongs to the holasterid group and probably is a species of the genus Echinocyrtus (Andy Gale, Pers. comm. 2010). The laminated micritic limestones of the Beytitepe stratigraphic section mostly have a moderate to poor planktic foraminifera content. But, some rich planktic foraminifera-bearing levels were also observed (Figure 6).

The following planktic foraminifera were observed in the Beytitepe stratigraphic section: Abathomphalus mayaroensis (Bolli), Contusotruncana contusa (Cushman), C. fornicata (Plummer), C. patelliformis (Gandolfi), Contusotruncana wafischensis (Todd), Gansserina cf. gansseri (Bolli), Globotruncanina arca (Cushman), G. arca-orientalis, G. dubueicie Caron et al., G. eschenensis Nakkady, G. falsostuarti Sigal, G. linneiana (d’Orbigny), G. mariie Banner & Blow, G. orientalis El Naggar, G. ventricosa White, Globotruncanina havanensis (Voorwijk), Globotruncanita angulata (Tiley), G. conica (White), G. pettersi (Gandolfi), G. stuarti de Lapparent), G. stuartiformis (Dalbize), Racemiguedelina fructicosa (Egger), Rugoglobigerina rugosa (Plummer), Praegublerina acuta (de Klaz) and Praegublerina robusta (de Klaz) (Figure 6; Plate 1). The occurrence of A. mayaroensis throughout the succession indicates that age of the laminated micritic limestones in the Beytitepe stratigraphic section is late Maastrichtian (Figures 3, 6). The late Maastrichtian Abathomphalus mayaroensis is the index species of the homonym biozone (Figure 3) (Bolli, 1957; Robaszynski et al. 1984; Caron 1985; Premoli Silva
The coexistence of the two species suggests the presence of the C. contusa-R. fructicosa zone (Premoli Silva & Bolli 1973; Premoli Silva & Sliter 1994; Premoli Silva & Sliter 1999; Premoli Silva & Verga 2004), which corresponds to the lowermost part of the late Maastrichtian (Figure 3).

In addition, G. conica, another late Maastrichtian species, is also recorded throughout the section (Figure 6). These data update the previous age assignment for these levels (Campanian-Maastrichtian) by Erdoğan (1990b).

**The Gökdere stratigraphic section** A very thick pile of laminated micritic limestones crops out just north of the Gökdere Village. This increased thickness was caused by an overturned syncline. Partial Bouma sequences were observed in the sandstone-shale alternations to the SE and
NW of the micritic limestones. The position of the Bouma sequences indicates that the SE flank of the fold is normal and the NW flank is overturned (Figures 4, 8). The whole limestone package was measured from SE to NW in order to correlate the limestones with the Beytitepe stratigraphic section. A 720 m thick limestone sequence was measured through the section line. Hence, the thickness of the laminated micritic limestones increases southwestwards from 220 m to 360 m within 1 km (Figure 4). The body of the laminated micritic limestones shows thickness reduction from the Beytitepe measured section to the NE and grades laterally into flysch-type rocks. Similarly, a single body of the micritic limestones is separated into several large and small lenses north of Beyti Tepe. They

**Figure 5.** Lithology and fossil explanations for stratigraphic sections.
interfinger with the flysch-type rocks and pinch out NE of the study area (Figure 4).

The lithological, sedimentological and palaeontological aspects of the micritic limestones of the Gökdere stratigraphic section are similar to the limestones in the Beytitepe stratigraphic section (Figure 8). One hundred and fifty two limestone samples were collected for thin section examination. The planktic foraminiferal assemblages in the Gökdere stratigraphic section include all the species observed in the Beytitepe stratigraphic section, with, in addition, *C. fornicata-patelliformis*, *C. plicata* (White), *G. bulloides* Vogler, *G. hilli* Pessagno, *G. insignis* (Gandolfi), *G. petaloidea* (Gandolfi), *G. elevata* (Brotzen), *Radotruncana subspinosa* (Pessagno), *Rugoglobigerina milamensis* Smith & Pessagno, *Rugoglobigerina pennyi* Brönnimann and biserial and multiserial heterohelicids (See Plate 1 for the images). The occurrence of *A. mayaroensis* indicates that the age of the

**Figure 7.** Field and photomicrographs of the laminated micritic limestones observed in the Gökdere area; (a) Close-up view of the micritic limestones, which are mainly characterized by distinct lamination (Coordinate: 0520815/4248786). (b) Field photograph of a Holasterid echinoid (probably *Echinocorys*) from the 149th metre of the Beytitepe stratigraphic section. (c) Photomicrograph of laminated micritic limestones, which escaped the effect of shearing. Planktic foraminifera are observed as complete specimens within the wackestone/mudstone microfacies (Sample no: N-3). (d) Photomicrograph of laminated micritic limestones, which contain numerous pressure solution seams cutting planktic foraminifera embedded within the wackestone/mudstone microfacies (Sample no: N-28).

**Figure 8.** Gökdere stratigraphic section. The section comprises laminated micritic limestones within the flysch-type deposits, which formed an overturned syncline. This section presents the thickest package of laminated micritic limestones, which are 360-m-thick (See Figure 4 for location of the section).
micritic limestones in the Gökdere stratigraphic section is late Maastrichtian, as in the Beytitepe stratigraphic section. *Abathomphalus mayaroensis* existed for 3.66 my from 68.66 my to 65.0 my (Robaszynski 1998) (Figure 3). During this time interval, a sequence at least 360 m thick, made up of laminated micritic limestones, was deposited. Therefore, the sedimentation rate of the laminated micritic limestones was approximately 9.84 cm/ky. Because flysch-type sediments were observed at the base and top of the limestones, the sedimentation rate obviously exceeded 9.84 cm/ky in this part of the basin.

4.2. The Işıklar area
Matrix and blocks of the BFZ were observed in the Işıklar area (Figure 9). The contact between the matrix and the blocks trends SW-NE and is mostly faulted. The matrix consists mainly of sheared flysch, including laminated micritic limestone and calcareous shale lenses in variable thickness. These lenses occur mostly along or near the block-matrix contact (Figure 9). The contacts between the lenses and adjacent flysch deposits are generally sharp. While original stratigraphic contact relations are generally preserved, some micritic limestones have sheared contacts.

Figure 9. Geological map of the Işıklar area. Many lenses and blocks of the Beytitepe Limestone seen at or close to matrix-block contact. (See Figure 1b for location of the area).
with the flysch. 16 lenses and lensoid laminated micritic limestone and calcareous shale blocks were sampled and mapped. Although some lenses are a few metres thick, they were indicated on the geological map exaggeratedly as they contain important palaeontological data. 64 samples were collected from the Işıklar area. Laminated micritic limestones are mostly light grey and similar to the micritic limestones, somewhat as in the Gökdere area with respect to lithological aspects, depositional texture and planktic foraminiferal content. Some lenses have rather poor planktic foraminifer content without any diagnostic species. Therefore, four relevant sections are presented here to save space;

**Section 1** This section comprises several laminated micritic limestone interlayers, which are intercalated with flysch and separated by numerous faults (Figure 10). Sample N-268 yielded a rich planktic foraminiferal assemblage. The occurrence of A. cf. *mayaroensis* in the assemblage seemingly indicates that the age of the laminated micritic limestone is late Maastrichtian. Other late Maastrichtian species such as *G. conica* and *R. fructicosa* were also observed in this sample (Figure 10; Plate 2). Samples N-271 and N-273 include rare Maastrichtian planktic foraminifera. The lenses from which samples N-269, N-270 and N-272 were collected are similar to the other lenses lithologically, but include late Palaeocene planktic foraminifera such as *Globanomalina chapmani* (Part), *Globanomalina ehrenbergi* (Bolli), *Globanomalina ehrenbergi-pseudomenardii*, *Globanomalina planoconica* (Subbotina), *Igorina albeari* (Cushman & Bermúdez), *Morozovella acuta* (Toumin), gr. *Morozovella angulata* (White) - *Morozovella aequa* (Cushman & Renz), *Parasubbotina cf. variospira* (Belford) and *Subbotina velascoensis* (Cushman) (Figure 10; Plate 2). This section illustrates the magnitude of deformation that affected the BFZ matrix, as lenses from various stratigraphic intervals are in contact with each other (Figure 10).

**Section 2** This section comprises a 2-m-thick laminated micritic limestone interlayered within the flysch sediments. The occurrence of *G. conica* and *R. fructicosa* suggests a late Maastrichtian age (Figure 11; Plate 2).

**Section 3** This section includes three laminated micritic limestone levels. The lower two levels include sand to block-size neritic and pelagic lithoclasts and reworked benthic foraminifera, which are embedded within a planktic foraminifera-bearing micrite matrix. Sample N-264 was collected from the topmost level, and its late Maastrichtian age is documented by the presence of *G. conica* and *R. fructicosa* (Figure 12).

**Section 4** This section comprises a beigish-grey to pinkish-grey calcareous shale lens, which appears at the matrix-block contact (Figure 9). The calcareous shales gradationally overlie the flysch and include silt to fine sand-size clasts at the base. Carbonate content increases upwards. 12 samples were collected from the calcareous shales (Figure 13), which mainly consist of planktic foraminifera-bearing mudstones/wackestones throughout (Figure 14). Planktic foraminifera assemblages including *Acarinina cf. strabocella* (Loeblich & Tappan), *G. chapmani*, *G. compressa-ehrenbergi*, *G. ehrenbergi* (Bolli), *G. cf. pseudomenardii* (Bolli), *I. albeari*, *I. pusilla* (Bolli), gr. *M. angulata - M. aequa*, *Morozovella occlusa* (Loeblich & Tappan), *Morozovella praecangulata-angulata*, *P. variospira*, *S. triangularis* (White) and *S. velascoensis* are dominated by keeled Palaeocene forms, which became dominant during the late Palaeocene (Olsson et al. 2011). The occurrences of keeled *Morozovella* species such as gr. *M. angulata - M. aequa, M. occlusa* and the other species in the planktic foraminiferal assemblages, such as A. cf.
strabocella, G. chapmani, G. cf. pseudomenardii, I. albeari, P. variaspira and S. velascoensis (Figure 13; Plate 2) suggest a late Palaeocene age (Berggren et al. 1995; Olsson et al. 1999; Berggren & Pearson 2005; Olsson et al. 2011). This assemblage is documented for the first time from the Işıklar area and provides important information about the age of the matrix of the Bornova Flysch Zone. The only palaeontologic data from that area were previously recorded by Özer & İtem (1982), who identified a nannoplankton assemblage and ‘Globoratalia sp’, suggesting a Danian age.

4.3. The Kocaçay area
The geology of the Kocaçay area is rather complicated (Figure 15) due to the presence of a large number of units in such a small area, the blocky nature of the units and syn-and post-depositional deformation. Also, contacts of the units are generally concealed either because they have soft lithologies, or by young cover and vegetation. Despite the complexity of the geology and difficulties mentioned above, the Kocaçay area displays important information about the stratigraphy and the planktic foraminiferal biostratigraphy of the matrix of the BFZ. The data summarized below were based on detailed geological mapping and measured stratigraphic sections. The matrix and blocks of the BFZ were observed in the Kocaçay area. Rudist-bearing neritic limestone blocks and planktic foraminifera-bearing micritic limestone blocks were observed within the pelagic laminated micritic limestones. The original contact relations of the two lithologies were also observed in this area. In many localities, rudist fragments and benthic foraminifera-bearing neritic facies is intercalated with the planktic foraminifera-bearing pelagic facies. Field and thin section studies at these levels revealed the allodapic nature of these deposits. Occurrences of Dicarinella asymetrica (Sigal), Dicarinella concavata (Brotzen) and Marginotruncana coronata (Bolli) in pelagic facies indicate that the allodapic deposition occurred during the middle-late Santonian. Blocks with only pelagic or neritic facies were also identified. Small and large (up to 250 m) laminated micritic limestone blocks are also present within the calcareous shales and the Kocaçay Conglomerate (Figure 15).

The matrix of the BFZ in the Kocaçay area comprises the Beytitepe Limestone, Kocaçay Conglomerate and sheared flysch (Figures 2, 15). The Beytitepe Limestone comprises two lithologies: laminated micritic limestones and calcareous shales. Laminated micritic limestones lie at the base of the matrix sequence in the Kocaçay area. They include pelagic and neritic limestone blocks of middle-late Santonian age in various sizes and shapes (Figure 15). They are mostly grey or pale grey and include pinkish grey, reddish grey and dark grey layers. Laminated micritic limestones are mostly massive in appearance.
and bituminous. In thin section, they contain planktic foraminifera-bearing mudstones/wackestones. Rarely, reworked orbitoid benthic foraminifera fragments were also observed within the micritic matrix. Planktic foraminifera such as *A. mayaroensis* suggest a late Maastrichtian age. Laminated micritic limestones are gradationally overlain by calcareous shales, which are mainly red and reddish to pinkish grey. The colour may change to pale greenish-grey. Sand to block-sized laminated micritic limestone clasts were observed within the calcareous shales, which mainly consist of abundant planktic foraminifera-bearing wackestones to mudstones with a rare depositional texture of planktic foraminifera. Planktic foraminifera associations indicate a late Maastrichtian–late Palaeocene age. Conglomerates cropping out in the Kocaçay area were called the Kocaçay Conglomerate by Erdoğan (1990b). The Kocaçay Conglomerate contains various pebble to block-sized clasts from the underlying lithologies and overlies the various stratigraphic levels of the laminated micritic limestones and calcareous shales of the Beytitepe Limestone. They also include laminated micritic limestone blocks from pebble-size to 250 m across (Figure 15). Sheared flysch cropping out in the westernmost part of the study area overlies the conglomerates and consists of a highly deformed sandstone-shale alternation. The sheared flysch is the youngest level of the matrix of the BFZ in the Kocaçay area.

One hundred and three samples were collected from the laminated micritic limestones and the calcareous shales of the Beytitepe Limestone and from several blocks in order to understand the geology of the Kocaçay area, the stratigraphy of the matrix and the planktic foraminiferal biostratigraphy of the Beytitepe Limestone. Details of the four selected stratigraphic sections are presented below (Figures 16-19).

**Section 5** Two lithologies of the Beytitepe Limestone are overlain by Kocaçay Conglomerate in this section (Figure 16). Grey, locally pale reddish-grey laminated (massive in appearance) bituminous micritic limestones lie at the base of the sequence (Figure 20a). They are represented by abundant planktic foraminifera, calcisphere and thin shell fragments-bearing wackestones (Figure 20b). The occurrence of *A. mayaroensis* in sample K-103 suggests a late Maastrichtian age. In addition, occurrences of *G. conica*, *C. contusa* and *R. fructicosa* from the samples above the horizon with *A. mayaroensis* confirm this age assignment (Figure 16; Plates 3, 4). Pinkish grey, distinctly laminated calcareous shales overlie the laminated micritic limestones along an uneven undulatated surface (Figures 16, 20a). Calcareous shales fill the gaps in the laminated micritic limestones through this uneven surface, which is here interpreted as a block contact (Figure 20a). The calcareous shales are represented by rich planktic foraminiferal wackestones. Many pressure solution seams were observed in thin sections. These surfaces cut many planktic foraminifera, reducing the number of identifiable species (Figure 20d). Occurrences of *C. contusa* and *R. fructicosa* in the basal beds of the calcareous shales (samples K-31, K-32) indicate a late Maastrichtian age (Figure 16; Plates 3, 4). Towards the top is a thin calcareous shale layer with rare planktic foraminiferal content, consisting of mudstone with rare planktic foraminifera. The planktic foraminifera are globular chambered small forms, which are unidentifiable because they are cut by dissolution surfaces. Cretaceous forms were not observed in this level, and the small planktic foraminifera with globular chambers could be Palaeocene species. Conglomerates

**Figure 14.** Photomicrograph of the calcareous shales, represented by the planktic foraminifera-bearing mudstone/wackestone microfacies (Sample no: N-233).

**Figure 15.** Geological map of the Kocaçay area. Four stratigraphic sections were measured from the Beytitepe Limestone (See Figure 1b for location of the area).
Figure 16. Section 5; (a) Sketch map, (b) Cross section showing contact relations between the laminated micritic limestones and calcareous shales of the Beytitepe Limestone and Kocaçay Conglomerate (See Figure 5 for explanation and Figure 15 for location of the section).
overlie the calcareous shales at the top of the succession (Figure 16).

Section 6 A 35-m-thick sequence of calcareous shales and overlying conglomerates was observed in this section (Figure 17). The 1-m-thick basal part of the calcareous shales is red and consists of abundant planktic foraminiferal wackestones (Figure 20c, d), resembling the calcareous shales observed in Section 5. Occurrences of C. contusa and R. fructicosa in two samples (K-65, K-66) suggest a late Maastrichtian age (Plates 3, 4). The overlying calcareous shales are mainly red, but some thin beige-grey, grey and pale greenish-grey layers were also observed. Sand to block-size light grey bioclastic limestone clasts were observed at some levels in the calcareous shales (Figures 17, 20e). The first Palaeocene species appear in sample K-67. The Palaeocene calcareous shales are represented by a rare planktic foraminifer-bearing mudstone depositional texture (Figure 20f). As many of the species are cut by numerous pressure solution seams, it is almost impossible to identify these species (Figure 20f). Another difficulty in identifying the Palaeocene planktic foraminifera in thin section is the frequent similarity of axial sections of species of Subbotina, Parasubbotina and Praemurica. For this reason, such species are grouped as ‘unidentified Palaeocene species’. However, it is possible to identify some species such as P. varianta (Subbotina), S. triangularis, S. cf. velascoensis, G. compressa (Plummer) and G. planoconica (Figure 17; Plates 3, 4). The occurrence of S. cf. velascoensis in sample K-70 suggests that this level and the overlying 30 m thick calcareous shales were deposited during the late Palaeocene (Olsson et al. 2011). Moreover, the occurrence of G. planoconica in sample K-77 indicates that the age of the 15 m thick uppermost part of the calcareous shale sequence is latest Palaeocene (planktic foraminiferal zones P4c to P5) according to Olsson et al. 2011 (Figure 3). Conglomerates overlie the calcareous shales along a sharp contact in this section (Figure 17).

Section 7 In the northern part of the section, grey bituminous micritic limestones containing thin shell fragments lie at the base of the succession (Figure 18). In the thin sections from samples K-20 and K-87 there are very rare planktic foraminifera, reworked orbitoid benthic foraminifera fragments, and an abundant microfacies of wackestone containing recrystallized shell fragments. A one metre thick, slightly recrystallized, indurated laminated micritic limestone (massive in appearance) layer overlies the micritic limestones. In thin sections of samples K-88, K-21 and K-89, a wackestone microfacies containing abundant planktic foraminifera, rare calcisphere and shell fragments was observed, as in the laminated micritic limestones in Section 5. Laminated micritic limestones are overlain by 4-m-thick red calcareous shales (Figure 18). In thin sections of samples K-90, K-22, K-91 and K-92, a rich planktic foraminifera-bearing depositional texture in wackestone was observed, as in the red calcareous shales of the Sections 5 and 6. The planktic foraminifera are diverse, large, thick-walled and represented by morphologically complex morphotypes (K-selection). Occurrences of A.
Abathomphalus mayaroensis, C. contusa, G. conica and R. fructicosa at these levels (Figure 18; Plates 3, 4) suggest a late Maastrichtian age. Another upper Maastrichtian calcareous shale level, which is overlain by conglomerates, was observed in the southern part of the section (Figure 18). The colour of the one meter thick uppermost layer of the calcareous shales is pale greenish grey. Three lithologies seem to be conformable, as a discontinuity surface was not observed at the contacts. The presence of reworked orbitoid benthic foraminifera, abundant shell fragments and the scarceness of planktic foraminifera in the bituminous micritic limestones indicate the proximity of the shallow sea environment. Occurrences of planktic foraminifera, together with calcispheres in laminated micritic limestones, suggest a deeper depositional environment than in the underlying orbitoid benthic foraminifera-bearing micritic limestones. The abundance of the K-selected specialists within the planktic foraminiferal assemblages in the red calcareous shales means a deeper distal depositional environment, as they dominate in open oceans, mainly during the onset of highstands of sea level (Robaszynski & Caron 1995). In summary, a deepening trend is clearly seen from the micritic limestones to the calcareous shales in the northern part of Section 7. Red calcareous shales with very scarce planktic foraminifera occurring in mid-section are similar to the Palaeocene calcareous shales in Section 6.

Section 8 Calcareous shales, a laminated micritic limestone block within the calcareous shales and overlying conglomerates were observed in this section (Figure 19). The laminated micritic limestone block is embedded within the calcareous shale matrix and is very similar to the laminated micritic limestones observed in Section 5. In thin section, they show a depositional texture featuring planktic foraminifera, calcisphere and thin shell fragments-bearing wackestone. Another small laminated micritic limestone clast, 20 cm in diameter (sample K-59), was observed within the calcareous shales (Figure 19). Calcareous shales were observed beneath and above the laminated micritic limestone clast, 20 cm in diameter (sample K-59), was observed within the calcareous shales (Figure 19). Calcareous shales were observed beneath and above the laminated micritic limestones and the contact between the two lithologies is very similar to the contact in Section 5. Calcareous shales fill the hollows in the laminated micritic limestones with its uneven, undulating surface (Figure 19). Calcareous shales also resemble calcareous shales observed in Sections 5, 6 and 7. Occurrences of rich late Maastrichtian assemblages in both laminated micritic limestones and calcareous shales indicates that laminated micritic limestones were deposited, lithified, and then subsequently fragmented and transported to the deeper part of the basin during the late Maastrichtian.
Figure 19. Section 8; (a) Sketch map, (b) Cross-section showing a late Maastrichtian laminated micritic limestone block within late Maastrichtian calcareous shales (See Figure 5 for explanation and Figure 15 for location of the section).
Figure 20. Field photographs and photomicrographs of the various lithologies of the Beytitepe Limestone in the Kocaçay area. (a) Contact between the laminated micritic limestones and the calcareous shales. Numbers stand for sample numbers, which are indicated in Section 5. (b) Photomicrograph of the laminated micritic limestones, represented by wackestones (Sample no: K-32 in Section 5). (c) Close-up view of the upper Maastrichtian calcareous shales from Section 6 (Numbers stand for sample numbers, which are indicated in Section 6). (d) Upper Maastrichtian calcareous shales are represented by abundant planktic foraminifera-bearing wackestones. The rock and the planktic foraminifera are mostly cut by numerous pressure solution seams (Sample no: K-65 in Section-6). (e) Close-up view of the upper Palaeocene calcareous shales (26.5m of Section 6, where sample K-82 was collected). (f) Palaeocene calcareous shales, mainly represented by rare planktic foraminifera-bearing wackestones and mudstones. Pressure solution seams commonly cut planktic foraminifera (Sample no: K-80 in Section-6).
Figure 21. Detailed stratigraphic column of the matrix of the Bornova Flysch Zone around Bornova. The column is based on data derived from all three areas. The age of the Beytitepe Limestone and accompanying flysch-type rocks is late Maastrichtian in the Gökdere area and late Maastrichtian and late Palaeocene in the Işıklar area. The age of the Beytitepe Limestone is late Maastrichtian-latest Palaeocene in the Kocaçay area. The age of the Kocaçay Conglomerate and flysch, which overlie the calcareous shales must be latest Palaeocene or younger.
5. Discussion and conclusions

Detailed studies based on the planktic foraminiferal biostratigraphy of the Beytitepe Limestone in the matrix of the BFZ around Bornova (İzmir) have revealed new data about the stratigraphy and age of the matrix (Figure 21). The age of the laminated micritic limestones in the Gökdere area, indicated by the occurrence of zonal maker *A. mayaroensis* together with other late Maastrichtian species such as *C. contusa*, *G. conica* and *R. fructicosa*, is late Maastrichtian. The layer thickness attains 360 m, indicating a sedimentation rate of at least 9.84 cm/ky. A previous Campanian-Maastrichtian age assigned for this level by Erdoğan (1990b) is revised in this study.

The Işıklar area has thin lenses of laminated micritic limestones and calcareous shales within the flysch-type deposits. A late Maastrichtian age was indicated for the laminated micritic limestones by the presence of *A. mayaroensis*, *C. contusa*, *G. conica* and *R. fructicosa*. A late Palaeocene age was also documented from the calcareous shales (Figure 21) which contain a rich late Palaeocene calcareous shales, which are overlain by Palaeocene calcareous shales (Figure 21). The Late Maastrichtian and Palaeocene calcareous shales are similar in appearance but the Palaeocene calcareous shales have a scarce planktic foraminifera content. Poor assemblages, including *P. varianta*, *S. triangularis*, *S. cf. velascoensis*, *G. compressa* and *G. planoconica*, indicate a late Palaeocene age for the lower part and a latest Palaeocene age for the upper part of the calcareous shale sequence. In this study, index species such as *A. mayaroensis*, *G. conica*, *R. fructicosa* and many other Maastrichtian species have been documented from this area for the first time. It appears that the age of the calcareous shales extends to the latest Palaeocene, which is also new information about this area (Figure 21). The Kocaçay Conglomerate overlies various stratigraphic levels of the calcareous shales and laminated micritic limestones (Figure 21). Flysch-type sediments are the younger lithologies in the Kocaçay area and overlie the Kocaçay Conglomerate (Figure 21).

Based on the palaeontological data from the planktic foraminifera from all three areas, it can be concluded that the age of the Beytitepe Limestone and accompanying flysch-type sediments is late Maastrichtian in the Gökdere area, late Maastrichtian and late Palaeocene in the Işıklar area and late Maastrichtian - latest Palaeocene in the Kocaçay area. The age of the Kocaçay Conglomerate and overlying flysch-type deposits in the Kocaçay area must be latest Palaeocene or younger (Figure 21).

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Plate 1

Planktic foraminifera observed in the Gökdere area.

1. Abathomphalus mayaroensis (Bolli), Sample no: N-44,
2. Abathomphalus mayaroensis (Bolli), Sample no: N-90,
3. Abathomphalus mayaroensis (Bolli), Sample no: N-16
4. Contusotruncana contusa (Cushman), Sample no: N-17
5. Contusotruncana fornicata (Plummer), Sample no: N-130
6. Contusotruncana fornicata-patelliformis, Sample no: N-116
7. Contusotruncana patelliformis (Gandolfi), Sample no: N-102
8. Contusotruncana walfischensis (Todd), Sample no: N-92
9. Gansserina cf. gansseri (Bolli), Sample no: N-53
10. Globotruncana arca (Cushman), Sample no: N-38
11. Globotruncana arca-orientalis, Sample no: N-97
12. Globotruncana bulloides Vogler, Sample no: N-206
13. Globotruncana stuarti (de Lapparent), Sample no: N-110
14. Globotruncana esnehensis Nakkady, Sample no: N-81
15. Globotruncana cf. falsostuarti Sigal, Sample no: N-193
16. Globotruncana hilli Pessagno, Sample no: N-211
17. Globotruncana linneiana (d'Orbigny), Sample no: N-101
18. Globotruncana ventricosa White, Sample no: N-42
19. Globotruncanella havanensis (Voorwijk), Sample no: N-102
20. Globotruncanita conica (White), Sample no: N-20
21. Globotruncanita elevata (Brotzen), Sample no: N-99
22. Globotruncanita pettersi (Gandolfi), Sample no: N-193
23. Racemiguembelina fructicosa (Egger), Sample no: N-17
24. Rugoglobigerina milamensis Smith & Pessagno, Sample no: N-116
25. Rugoglobigerina pennyi Brönnimann, Sample no: N-52
26. Rugoglobigerina rugosa (Plummer), Sample no: N-212
27. Praegublerina acuta (de Klasz), Sample no: N-227
28. Multiserial heterohelicids, Sample no: N-101
29. Praegublerina robusta (de Klasz), Sample no: N-111
Plate 2

Planktic foraminifera observed in the Işıklar area.

1. *Acarinina* cf. *strabocella* (Loeblich & Tappan), Sample no: N-234,
2. *Globanomalina chapmani* (Parr), Sample no: N-245,
3. *Globanomalina chapmani* (Parr), Sample no: N-232,
4. *Globanomalina ehrenbergi* (Bolli), Sample no: N-232,
5. *Igorina albeari* (Cushman & Bermúdez), Sample no: N-232,
6. *Morozovella angulata* (White) - *Morozovella aequa* (Cushman & Renz), Sample no: N-232,
7. *Morozovella acutispira* (Bolli & Cita), Sample no: N-275,
8. *Morozovella angulata* (White) - *Morozovella aequa* (Cushman & Renz), Sample no: N-233,
9. *Globanomalina* cf. *pseudoemenardii* (Bolli), Sample no: N-236,
10. *Globanomalina planoconica* (Subbotina), Sample no: N-269,
11. *Igorina albeari* (Cushman & Bermúdez), Sample no: N-245,
12. *Acarinina* cf. *strabocella* (Loeblich & Tappan), Sample no: N-231,
13. *Morozovella conicotrunca* (Subbotina) - *Morozovella velascoensis* (Cushman), Sample no: N-245,
14. *Subbotina triangularis* (White), Sample no: N-234,
15. *Parasubbotina variospira* (Belford), Sample no: N-231,
16. *Subbotina velascoensis* (Cushman), Sample no: N-245,
17. *Contusotruncana plicata* (White), Sample no: N-268,
18. *Contusotruncana walfischensis* (Todd), Sample no: N-268,
19. *Globotruncana arca* (Cushman), Sample no: N-268,
20. *Globotruncana dupeublei* (Caron et al.), Sample no: N-252,
21. *Globotruncana linneiana* (d'Orbigny), Sample no: N-249,
22. *Globotruncana mariei* Banner & Blow, Sample no: N-251,
23. *Globotruncana orientalis* El Naggar, Sample no: N-268,
24. *Globotruncanella havanensis* (Voorwijk), Sample no: N-268,
25. *Globotrunchanita stuarti* (de Lapparent), Sample no: N-251,
26. *Globotrunchanita pettersi* (Gandolfi), Sample no: N-268,
27. *Rugoglobigerina hexacamerata* Brönnimann, Sample no: N-246,
28. *Rugoglobigerina milamensis* Smith & Pessagno, Sample no: N-268,
29. *Racemiguembelina fructicosa* (Egger), Sample no: N-268,
30. Multiserial heterohelicids, Sample no: N-251,
Plate 3

Planktic foraminifera observed in the Kocaçay area.

1. *Eoglobigerina* cf. *spiralis* (Bolli), Sample no: K-27
2. *Globoanomalina compressa* (Plummer), Sample no: K-74,
3. *Globoanomalina planoconica* (Subbotina), Sample no: K-77,
4. *Igorina* cf. *pusilla* (Bolli), Sample no: K-27
5. *Parasubbotina varianta* (Subbotina), Sample No: K-85
6. *Abathomphalus mayaroensis* (Bolli), Sample no: K-22,
7. *Abathomphalus mayaroensis* (Bolli), Sample no: K-92,
8. *Abathomphalus mayaroensis* (Bolli), Sample no: K-59,
9. *Abathomphalus mayaroensis* (Bolli), Sample no: K-88,
10. *Contusotruncana contusa* (Cushman), Sample no: K-88,
11. *Contusotruncana contusa* (Cushman), Sample no: K-59,
12. *Contusotruncana contusa* (Cushman), Sample no: K-21,
13. *Contusotruncana fornicata* (Plummer), Sample no: K-32,
14. *Contusotruncana patelliformis* (Gandolfi), Sample no: K-36,
Plate 4

Planktic foraminifera observed in the Kocaçay area.

1. *Globotruncana eoceneensis* Nakkady, Sample no: K-88,
2. *Globotruncana hilli* Pessagno, Sample no: K-32,
3. *Globotruncana conica* (White), Sample no: K-90,
4. *Globotruncana pettersi* (Gandolfi), Sample no: K-59,
5. *Globotruncana stuarti* (de Lapparent), Sample no: K-32,
6. *Rugoglobigerina pennyi* Brönnimann, Sample no: K-49,
7. *Racemiguembelina fructicosa* (Egger), Sample no: K-88,
8. Multiserial heterohelicids, Sample no: K-21,
9. Multiserial heterohelicids, Sample no: K-22,
10. Biserial heterohelicids, Sample no: K-32,
11. *Dicarinella asimetrica* (Sigal), Sample no: K-6,
12. *Dicarinella concavata* (Brotzen), Sample no: K-6,