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# Stratigraphy and Larger Foraminifera of the Middle Eocene to Lower Oligocene Shallow-Marine Units in the Northern and Eastern Parts of the Thrace Basin, NW Turkey

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**Abstract:** The shallow-marine Eocene Soğucak Limestone and Oligocene Ceylan Formation were studied in the northern and eastern parts of the Thrace Basin with detailed biometric analysis of the full spectrum of larger benthic foraminifera (mainly nummulitids and orthophragmines). This allows us to establish a high-resolution biostratigraphy in the context of the shallow benthic zonation (with SBZ zones) of the Tethyan Palaeogene since larger foraminiferal assemblages show a very strong Western Tethyan affinity. Only two species (*Heterostegina armenica* and *Orbitoclypeus haynesi*) are unknown so far to the west of the Thrace Basin. The age of particular larger foraminiferal sites is determined based on (i) the occurrence and developmental stage of different species of *Heterostegina* (*H. armenica hacimasliensis* n. ssp. is introduced here), (ii) the presence/absence of giant *Nummulites*, (iii) the presence/absence of *Spiroclypeus*, (iv) the developmental stage of reticulate *Nummulites*, (v) the occurrence and developmental stage of orthophragmines, (vi) the occurrence of particular *Operculina* and radiate *Nummulites*. Six larger foraminiferal horizons could be established. They correspond to (i) the vicinity of the early/late Bartonian boundary (SBZ 17/18), (ii) the middle late Bartonian (SBZ 18B), (iii) the latest Bartonian (SBZ 18C), (iv) the early Priabonian (SBZ 19), (v) the late Priabonian (SBZ 20) and (vi) the early Rupelian (SBZ 21). Three main shallow-water depositional environments could be recognized in both the late Bartonian and Priabonian: two of them took place in the middle shelf; one with low and another with high water-energy (back-bank and *Nummulites*-bank facies) whereas the third one refers to the outer shelf (fore-bank facies). Biostratigraphical and palaeoenvironmental observations allow us to reconstruct three subregions in the northern and eastern parts of the Thrace Basin with different depositional histories: (i) The eastern part of the territory, with an İstanbul Zone basement was flooded at the beginning of the middle late Bartonian (SBZ 18B), but the carbonate platform was drowned in the latest Bartonian (SBZ 18C). (ii) The Çatalca block, lying on the Istranca Massif, formed a palaeohigh in whose peripheries a similar depositional history to for the former sub-region can be reconstructed, although the central part was transgressed only in the late Priabonian and was not drowned at all. (iii) The northern margin of the recent Thrace Basin (also lying on the Istranca Massif) was flooded only in the latest Bartonian (SBZ 18C) or in the early Priabonian (SBZ 19) and the Priabonian carbonate platform had only partly and shallowly been drowned. This subregion very probably formed the real northern margin of the whole Thrace Basin in the Palaeogene.

**Key Words:** Northern and Eastern Thrace, larger benthic foraminifera, biometry, taxonomy, biostratigraphy, Palaeogene, depositional history

## Trakya Havzasının Kuzey ve Doğusundaki (KB Türkiye) Orta Eosen–Alt Oligosen Sığ-Denizel birimlerinin Stratigrafisi ve İri Bentik Foraminiferleri

**Özet:** Trakya Havzasının (KB Türkiye) doğusu ve kuzeyindeki sığ-denizel Eosen Soğucak Formasyon' una ait bazı kesitler ve Oligosen yaşlı Ceylan Formasyon'una ait bir stratigrafik kesit iri bentik foraminiferlerin (başlıca nummulitidler ve orthophragminidler) biyometrik özelliklerini irdeleyerek ayrıntılı olarak çalışılmıştır. Çalışılan foraminifer gruplarının Batı Tetis faunasına benzemesinden dolayı elde edilen veriler Sığ Bentik Zonasyonu (SBZ) kapsamında yüksek çözünürlü biyostratigrafik bir sistemin oluşturulmasına imkan vermiştir. Sadece iki tür, *Heterostegina armenica* ve *Orbitoclypeus haynesi* Trakya Havzası'nın daha batısındaki bölgede Avrupa'da bilinmemektedir. Her bir foraminifer topluluğunun yaşı (i) *Heterostegina* grubunun varlığı ve farklı türlerinin gelişim aşaması (*H. armenica hacimasliensis* n. ssp. ilk kez tanımlanmıştır), (ii) İri *Nummulites*'lerin varlığı/yokluğu, (iii) *Spiroclypeus*'un varlığı/yokluğu, (iv) retikule *Nummulites*'lerin filojenetik gelişim aşaması, (v) orthophragmines grubunun varlığı ve gelişim aşamaları, (vi) bazı *Operculina* ve radyal *Nummulites* gruplarının varlığı ile tayin edilmiştir. Altı iri bentik foraminifer seviyesi tanımlanmış olup bunlar (i) erken/geç Bartoniyen sınırı (SBZ 17/18), (ii) orta geç Bartoniyen (SBZ 18B), (iii) geç Bartoniyen (SBZ 18C), (iv) erken Priaboniyen (SBZ 19), (v) geç Priaboniyen (SBZ 20) ve (vi) erken Rupeliyen'i (SBZ 21) temsil eder. Geç Bartoniyen ve Priaboniyen döneminde üç sığ-denizel çökelim ortamı tanımlanmıştır. İkisi orta şelfin yüksek (set-arkası ve *Nummulites* seti) ve düşük enerjili ortamlarına, üçüncüsü ise dış şelf (set-önü fasiyesi) ortamına karşılık gelir. Biyostratigrafik ve paleo-ortamsal gözlemler Trakya Havzası'nın doğu ve kuzey kısmında üç alt bölge tanımlanmasına imkan vermiştir: (i) Temeli İstanbul Zonu olan doğu kısım orta geç Bartoniyen (SBZ 18B) döneminde transgresyona uğramış olup karbonat platformu geç Bartoniyen'de (SBZ 18C) boğulmuştur. (ii) Istranca Masifi üzerinde bulunanan Çatalca bloğu bir paleo-yükselim oluşturmakla beraber kenar kısımlarında bir önceki alt bölge için tanımlanan benzer tarihçe geçerlidir ve transgresyon bloğun merkezi kısmında sadece geç Priaboniyen döneminde gerçekleşmiştir. Platformun boğulmasıyla ilgili veri yoktur. (iii) Havzanın kuzey kısmında transgresyon geç Bartoniyen'de (SBZ 18C) veya erken Priaboniyen'de (SBZ 19) gerçekleşmiş olup karbonat platform kısmen boğulmuştur. Bu bölge muhtemelen Trakya Havzası'nın Paleojen döneminde kuzey kısmının gerçek kenarını temsil etmektedir.

**Anahtar Sözcükler:** Kuzey ve Doğu Trakya, iri bentik Foraminifer, biyometri, taksonomi, biyostratigrafi, Paleojen, depolanma özellikleri

## Introduction

This study is the second part of the revision of larger benthic foraminifera in the Palaeogene shallow-marine units in the Thrace Basin. In the first part (Özcan *et al*. 2010a) the description of larger foraminifera and their biostratigraphy from the southern part of the basin were given. We here present our new data from the Eocene and lower Oligocene shallow marine units exposed in the northern and eastern parts of the Thrace Basin.

The foraminiferal information on these units is either very poor (for the northern part of the basin) and includes determinations usually at generic level (Keskin 1966, 1971; Varol *et al*. 2009) or obsolete (Daci 1951 for the eastern part), thus not permitting a high-resolution biostratigraphic framework. Among these foraminifera, nummulitids (*Nummulites*, *Heterostegina* and *Spiroclypeus*) and some orthophragminid taxa are particularly important since their recently proposed evolutionary features allow us to subdivide some middle to late Eocene shallow benthic foraminiferal zones (Serra-Kiel *et al*. 1998) into subzones (Özcan *et al*. 2007a; Less *et al*. 2008; Less & Özcan 2008). An updated range-chart for the above and other stratigraphically important benthic taxa that cover the late Lutetian to early Rupelian interval is shown in Figure 1.

Therefore, the main aim of our study was to determine larger benthic foraminifera at the specific (or even subspecific) level (based on detailed biometric analysis) in order to establish a high-resolution biostratigraphic framework for reconstructing the early depositional history of the studied parts of the Thrace Basin in the future. Determination of most of the taxa is based on the study of isolated specimens of the above groups recovered from some argillaceous carbonate levels and from thin-sections.

By concentrating on the palaeontological and biostratigraphic aspects, this work does not contain a detailed facies and regional geological analysis of the Eocene and Oligocene shallow marine units of the studied part of the Thrace Basin. That will be done later for the whole basin by synthesizing not only our data (Özcan *et al*. 2010a and this work) but also those of S. Pálfalvi on coralline red algae, the sedimentological analysis (including microfacies studies) carried out by İ.Ö. Yılmaz and S. Pálfalvi and the structural geological data collected by A.I. Okay and L.I. Fodor. These works have been performed in the frame of a bilateral cooperation project between TÜBİTAK, Turkey and NKTH, Hungary (for details see the 'Acknowledgements').

Nevertheless, our data on larger benthic foraminifera also allow us to draw preliminarily some palaeoecological and regional geological conclusions, which are presented in the description of studied localities at the end of the paper.

Figured specimens prefixed by E. and O. are stored in the Eocene and Oligocene collections of the Geological Institute of Hungary (Budapest), while

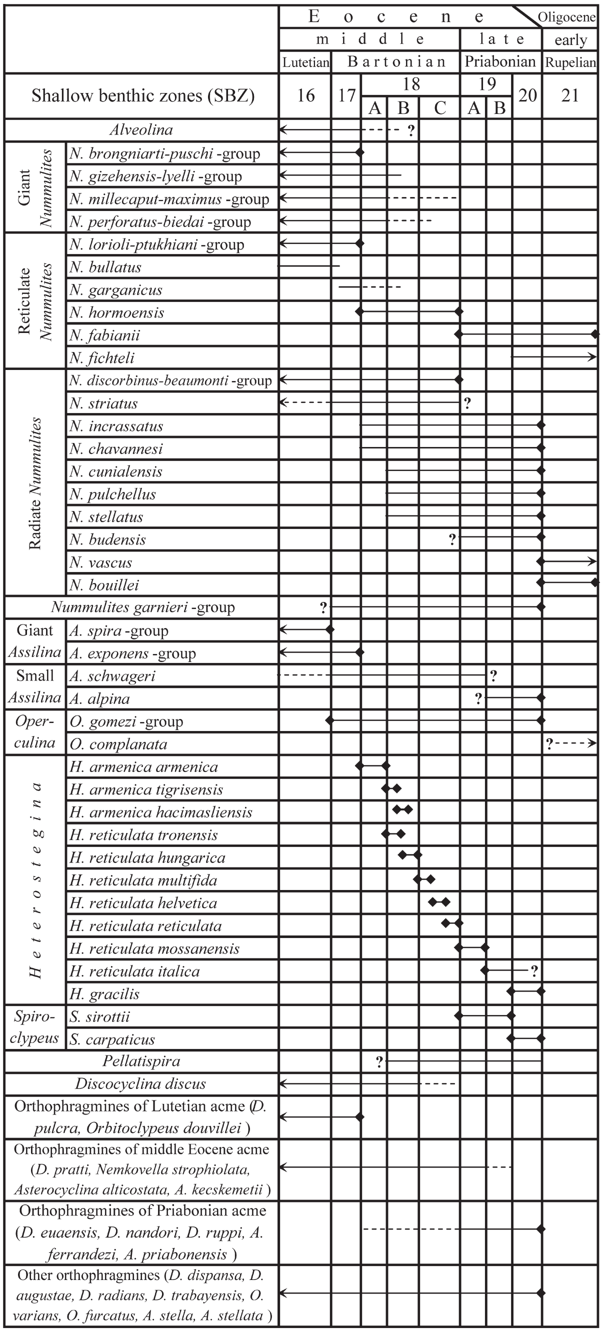



**Figure 1.** Range chart for some late Lutetian to early Rupelian larger benthic foraminiferal taxa of the Western Tethys. The subdivision of the stratigraphic scale is not time-proportional (Less *et al*. 2008, updated).

those marked by 'O/' are in the Özcan collection of Department of Geology, İstanbul Technical University.

Abbreviations for biozones: NP– Palaeogene calcareous nannoplankton zones by Martini (1971); OZ– Orthophragminid zones for the Mediterranean Palaeocene and Eocene (Less 1998a) with correlation to the SBZ zones; P– Palaeogene planktonic foraminiferal zones by Blow (1969), updated by Berggren *et al*. (1995); SBZ– shallow benthic foraminiferal zones for the Tethyan Tertiary (Serra-Kiel *et al*. 1998; Cahuzac & Poignant 1997, with additional sub-zones for SBZ 18 and 19 by Less *et al*. 2008) with correlations to the planktonic and magnetic polarity zones. The correlation of these zonations is shown in Figure 2.

## Stratigraphical and Palaeontological Background

The shallow marine Palaeogene units cover extensive areas in the eastern, northern and southern parts of the Thrace Basin, and their equivalents in the central part of the basin are prospects for oil and gas (Figure 3). Unlike the complex stratigraphic-tectonic evolution of these units in the southern part of the basin (see Okay *et al*. 2010 and Özcan *et al*. 2010a for a review), the stratigraphy of the shallow marine units in the north and east is rather uniform and better known (Figure 4) (Akartuna 1953; Keskin 1966, 1971; Doust & Arıkan 1974; Turgut *et al*. 1991; İslamoğlu & Taner 1995; Turgut & Eseller 2000). In all previous studies these shallow water deposits have been assigned to three units developed during the Eocene and Oligocene.

The lowest Palaeogene unit exposed in the region is the Koyunbaba Formation (also known as İslambeyli Formation in some publications; e.g., Çağlayan & Yurtsever 1998), which consists of continental deposits below the regionally widespread carbonates of the Soğucak Formation. The age of the unit has been considered to range from Lutetian to Priabonian based on ill-documented fauna identified in fossiliferous marine intercalations within the unit (see Yurtsever & Çağlayan 2002; Siyako 2006 for the various ages assigned to the unit by different workers).

The Soğucak Formation (also known as the Kırklareli Limestone in some publications; e.g., Çağlayan & Yurtsever 1998), the most common shallow marine unit in Thrace, consists mainly of limestones deposited in a variety of depositional settings ranging from reef to back-reef and to fore-reef

| Geological time in Ma | 58 | 57 | 56 | 55 | 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stages | THANETIAN | YPRESIAN | | LUTETIAN | BARTONIAN | PRIABONIAN | | | | | | | | | | | | | | | | | | | |
| | | ILERDIAN | CUISIAN | | | | | | | | | | | | | | | | | | | | | | |
| Planktic foraminiferal zones (P) | ← 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | | | | | | | | | | | |
| Calc. nannoplankton zones (NP) | 6 | 7–8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19–20 | 21 | | | | | | | | | | | |
| Shallow benthic zones (SBZ) | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18a | 18b | 18c | 19a | 19b | 20 | | | | |
| Orthophragminid zones (OZ) | 1a | 1b | 2 | 3 | 4 | 5 | 6 | 7 | 8a | 8b | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | | | | | | | |

**Figure 2.** Correlation of orthophragminid biozones with late Palaeocene and Eocene planktonic foraminiferal, calcareous nannoplankton and shallow benthic biozones, based on Özcan *et al.* (2010a). Time scale based on Graciansky *et al.* (1999).

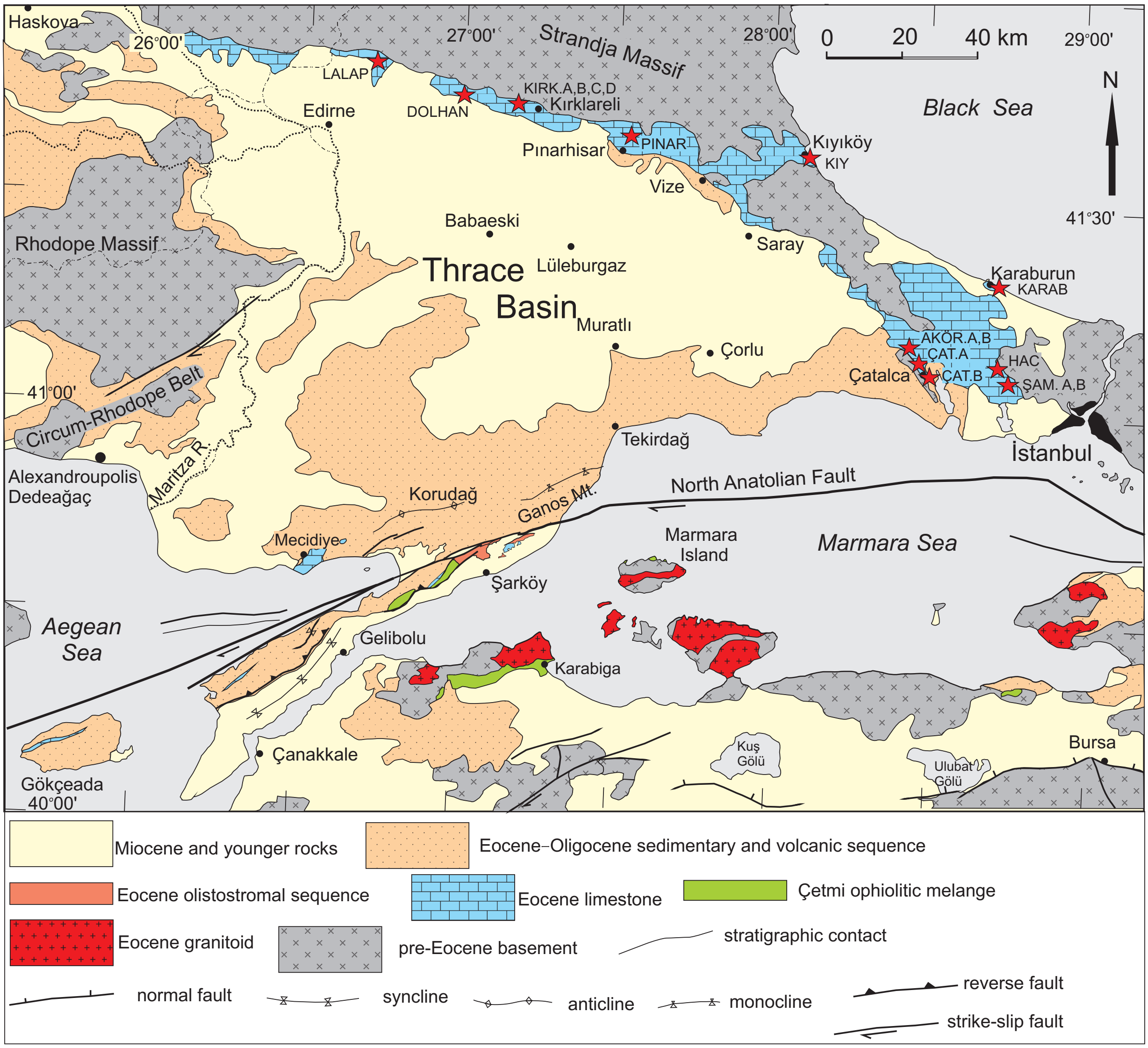



**Figure 3.** Tectonic map of the Thrace and Marmara region (after Okay *et al.* 2010) with the location of stratigraphic sections and samples (red stars).

environments. The unit in most cases directly overlies the basement units (metamorphic rocks and upper Palaeozoic siliciclastics) in the northern and eastern part of Thrace. The age of the Soğucak Formation (see Siyako 2006 for a review) was assigned to the Lutetian, Bartonian or Priabonian, mainly based on the thin-section identification of larger Foraminifera (and partly molluscs) at generic level. The most detailed

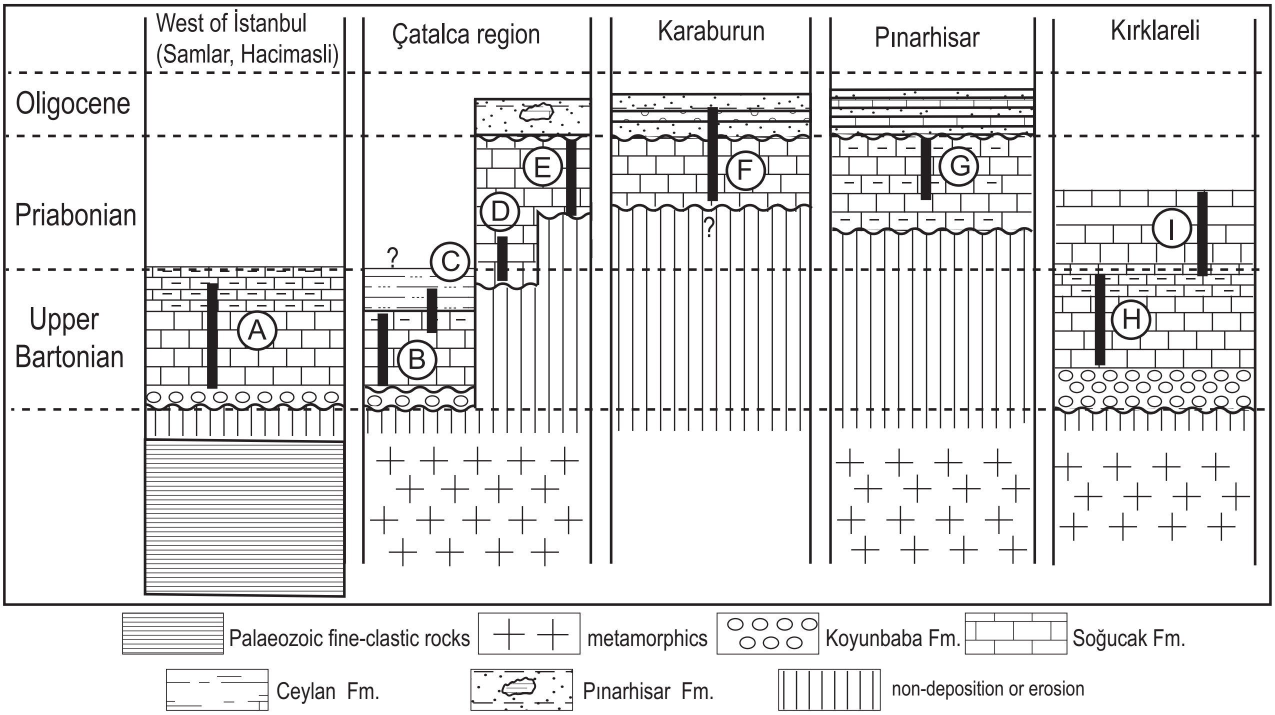



**Figure 4.** Stratigraphic relations of shallow-marine Eocene units in the northern and eastern Thrace Basin based on the present study. Bars indicate the stratigraphic intervals of the studied sections/samples; **A**– Şamlar (ŞAM) A and Hacımaşlı (HAC), **B**– Akören (AKÖR) A, **C**– Akören (AKÖR) B, **D**– Çatalca (ÇAT) A, **E**– Çatalca (ÇAT) B, **F**– Karaburun (KARAB), **G**– Pınarhisar (PINAR), **H**– Kırklareli (KIRK) A and B, **I**– Kırklareli (KIRK) C and D.

study by Daci (1951) on foraminifera, carried out just west of İstanbul (including the Şamlar region in this study), is obsolete and needs revision. Meantime, the age of the unit given in the recent regional scale study by Varol *et al.* (2009) is based on thin-section studies, and in some cases there are strong age differences between their age data and our present data. The faunal composition of the Soğucak Formation given in many unpublished reports of TPAO (Turkish Petroleum Corporation) is also not detailed and in some cases is misleading.

The Soğucak Formation is either overlain by continental beds of the Pınarhisar Formation or by deep marine (partly shallow marine as in Karaburun) beds of the Ceylan Formation, which is widely distributed in the southern part of Thrace. The Pınarhisar Formation comprises continental sandstones/conglomerates and *Congeria*-rich limestones considered to be Oligocene in age based on fish remains, ostracods and molluscs (e.g., İslamoğlu *et al.* 2010) in most previous works (see Yurtsever & Çağlayan 2002 for a review). In southern Thrace, the Ceylan Formation consists of monotonous deep marine siltstones and marls with local debris flows and turbiditic intercalations and several levels of tuffs. Tests of resedimented larger foraminifera occur occasionally in resedimented levels (Özcan *et al.* 2010a). Since its development is connected with the drowning of the carbonate platform, the age of the unit in southern Thrace is diachronous, starting from the Bartonian (Özcan *et al.* 2010a). In the northern and eastern parts of Thrace, the most widespread outcrops of the Ceylan Formation are seen around Karaburun where the basal part of this unit is represented by pelagic siltstones and marls that grade into rather shallow marine conglomerates containing Oligocene *Nummulites*. However, according to our present study, the development of this unit is much earlier near Akören (Çatalca region). This part of the succession passes into pelagic marls and siltstones with very scarce macrofauna. We also present here the faunal and floral composition (larger foraminifera, planktonic foraminifera and calcareous nannoplankton) from the lower part of the Ceylan Formation.

## Description of the Eocene and Oligocene Carbonate Units and Their Palaeontological Content

We studied thirteen stratigraphic sections and ten spot samples from ten localities covering the whole northern and eastern part of the Thrace Basin, as shown in Figure 3.

Their description is organized in four parts. In the first part location data and the geological situation are outlined. In the second part a brief summary of the lithology and of the fossil content are presented and also summarized in most cases graphically. In the third part the age of section/samples is discussed in the frame of the shallow benthic zonation containing SBZ zones. In addition, where available, age data based on orthophragmines (OZ zones), calcareous nannoplankton (NP zones) and planktonic foraminifera (P zones) are also given.

Finally, the palaeoenvironmental interpretation of larger foraminiferal assemblage(s) is presented. There are several recent depositional models for the facial distribution of Eocene larger foraminifera, which are best summarized in Jorry *et al*. (2006). Although ramp models (Bassi 1998, 2005; Ćosović *et al*. 2004; Barattolo *et al*. 2007; Höntzsch *et al*. 2011) became more popular in recent years, we prefer the classical Arni (1965) model followed with some modifications by Kulka (1985), Anketell & Mriheel (2000) and Nebelsick *et al*. (2005), since coral reefs and *Nummulites*-banks are widespread in the studied area. Thus, three main larger foraminiferal palaeoenvironments are distinguished: (i) *Nummulites*-banks corresponding to the high water-energy part of the middle shelf; (ii) the back-bank environment lying in the low water-energy part of the middle shelf, in the background of positive build-ups such as *Nummulites*-banks and coral reefs, and (iii) the fore-bank setting in the foreground of positive build-ups representing open marine outer shelf conditions.

### *Şamlar Region*

Outcrops of the Soğucak Formation, the basal transgressive part of which is clearly exposed, are widespread near Şamlar to the west of İstanbul (Figure 3). Basal conglomerates of the Koyunbaba Formation are not observed in this region. Two sections, ŞAM.A (UTM coordinates: 0646246, 4554732; 0646050, 4554697) and ŞAM.B (UTM coordinates: 0646073, 4555184; 0646260, 4555216) were sampled near Şamlar (Figures 5) where the Soğucak Formation unconformably overlies Carboniferous sandstones and shales. In addition, two spot samples (ŞAMLAR 1 and ŞAMLAR 2; see Figure 5 for their location) representing the upper levels of the Soğucak Formation and considered to be the continuation of section ŞAM.A, have been sampled.

*Section ŞAM (Şamlar) A (With Spot Samples ŞAMLAR 1 and 2)*– In the ŞAM.A section (Figure 6), the lower and middle part of the unit, which is about 22 metres thick, is represented by carbonate-rich sandstone-siltstone or sandy limestone beds containing mainly larger benthic foraminifera accompanied by bivalves, echinoids and locally gastropods. Corals are subordinate in amount. This is followed by an 8-m-thick succession of massive reef limestones poor in *Nummulites* and orthophragmines but containing coralline red algae, corals and foraminifera dominated mainly by *Silvestriella*. Up section, an olistostrome (Figure 7) can be observed, in the marly matrix of which (in samples ŞAMLAR 1 and 2) orthophragmines and megalospheric *Nummulites maximus* dominate. Olistoliths are represented by reef debris, in which corals and coralline red algae can be observed. The composition of fossils is shown in Figure 8.

*Section ŞAM (Şamlar) B*– This section sampled just near to the north of section ŞAM.A (Figure 5) has lithological aspects similar to the lower part of section ŞAM.A. The first 9 metres of the shallow marine sequence of the Soğucak Formation comprise sandstone-siltstone beds resting upon the Carboniferous shales and siltstones. The rare foraminiferal assemblage (shown in Figure 9) is mainly represented by miliolids. This part is succeeded by a 9-m-thick unit composed of calcareous sands or sandy limestones with mainly nummulitids and rare corals.

Based on the co-occurrence of *Heterostegina reticulata* and giant *Nummulites* (*N. aturicus* and *N. maximus*) the major part of both sections belongs to the late Bartonian SBZ 18 Zone. These forms are

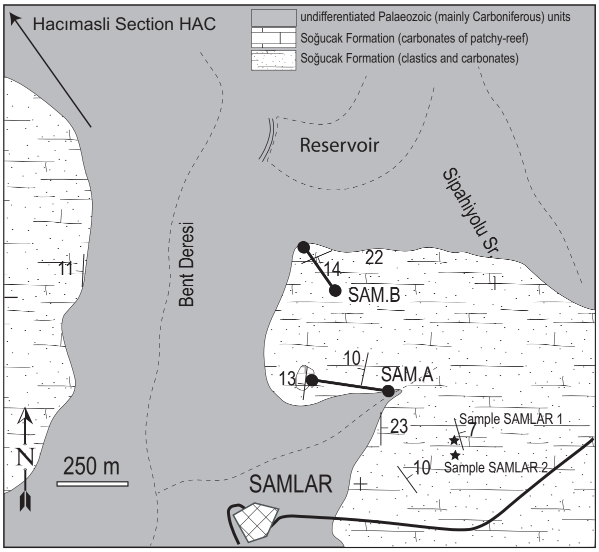



**Figure 5.** Geological map of the Şamlar region with location of stratigraphic sections and samples.

**Figure 6.** View of section Şamlar (ŞAM) A (upper Bartonian) with patch reef on the top.

**Figure 7.** Close-up view of the olistostrome with reef olistoliths, from the matrix of which sample ŞAMLAR 1 was taken.

only missing in the basal part, near samples ŞAM A 4 and ŞAM B 5 where, however, *N. hormoensis* indicates the same age. Less developed reticulate forms (*N. garganicus* and transitional *N. garganicus-hormoensis*), however, could be found up section (in samples ŞAM.A 14, 18 and 22) but already with *H. reticulata*, the first appearance of which indicates the middle late Bartonian SBZ 18B Subzone (see also at *N. garganicus* in the systematic part). Therefore, the basal part of the ŞAM.A section and the whole ŞAM.B section belong to the SBZ 18A–B Subzones, whereas most of the ŞAM.A section belongs to the SBZ 18B Subzone, which is confirmed by the presence of *H. reticulata hungarica*. The evolution of this lineage can nicely be followed up section, since in sample ŞAMLAR 1 *H. r.* ex. interc. *multifida-hungarica*, transitional between SBZ 18B and 18C could be determined, while in the uppermost sample ŞAMLAR 2 the lineage is represented by *H. r. helvetica*, characteristic for the latest Bartonian SBZ 18C Subzone. *Nummulites maximus* only occasionally occurs in this sample possibly caused by the extinction of the *N. millecaput* group (for details see Less *et al.* 2008). In the orthophragmines, the presence of *Discocyclina discus* excludes any age younger than Bartonian, while *D. trabayensis elazigensis*, *D. radians labatlanensis* and *Asterocyclina alticostata danubica* first appear in the late Bartonian to earliest Priabonian OZ 14 Zone. Thus, this assemblage also marks the late Bartonian, although the representatives of the *D. dispansa* lineage are less developed than expected.

The composition of larger foraminifera in the section reflects very well changes in the environment as well. The basal part (around sample ŞAM.A 4 and the ŞAM.B section) and around samples ŞAM.A 18 to 22 with predominate reticulate *Nummulites* and occasionally with *N. aturicus* and *N. striatus*, but with no orthophragmines and the genus *Heterostegina* might belong to the (somewhat restricted, low-energy) middle shelf (back-bank facies). The horizons of samples ŞAM.A 13–16 and ŞAM.A 24, in which reticulate *Nummulites* are rare or absent, with no giant *Nummulites* and *N. striatus*,

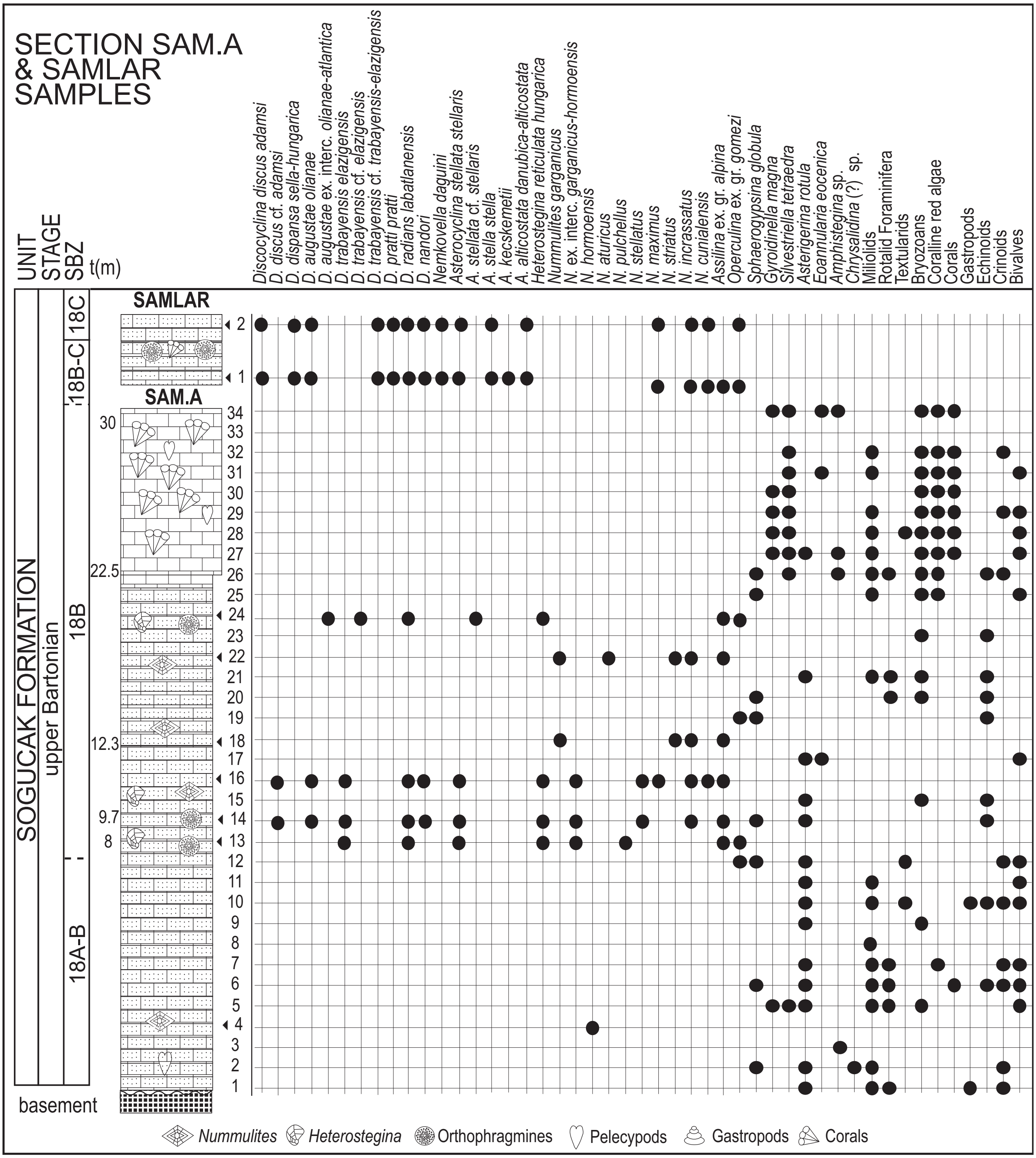



**Figure 8.** Distribution of benthic foraminifera and other fossil groups in section Şamlar (ŞAM) A, and in samples ŞAMLAR 1 and 2.

although with *Heterostegina* and with moderately diverse orthophragmines, might belong to a more open environment very probably near protecting patch reefs, and this is proved by the reef body of samples ŞAM.A 27 to 34. Finally, the upper part of the section, with a diverse orthophragminid fauna and with *Nummulites maximus* in samples ŞAMLAR 1 and 2, indicates the deeper part of the

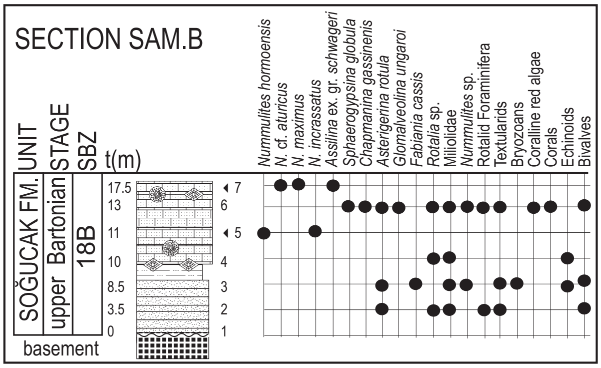



**Figure 9.** Distribution of benthic foraminifera and other fossil groups in section Şamlar (ŞAM) B.

photic zone, the outer shelf in the foreground of coral reefs, the debris of which can abundantly be found in these sediments (Figure 7). The circulation or the chemistry of the water in the case of sample ŞAMLAR 1 could be, however, slightly disturbed, since B-forms of *N. maximus* are almost absent and *Operculina gomezi* strongly predominates over *Heterostegina reticulata*. Altogether the Şamlar sequence reflects a general deepening trend, although with significant fluctuations. In such sequences (e.g., Ajka, Dudar, Úrhida and Bajót in Hungary, see Less 1987 and Less *et al*. 2000; Doluca Tepe in S Thrace, see Okay *et al*. 2010; Puig Aguilera in NE Spain, see Romero *et al*. 2002) the orthophragminid facies (present in samples SAMLAR 1 and 2) is usually covered by pelagic marls; thus it forecasts the drowning of the carbonate platform in most of the eastern part of the Thrace Basin (see also Hacımaşlı and Akören) at the very end of the Bartonian.

*Hacımaşlı Region*

A 31-m-thick succession of the Soğucak Formation north-west of the Şamlar (ŞAM) sections (UTM coordinates: 0644369, 4557461; 0644117, 4557305), unconformably overlies a volcanic series of uncertain age. The lower 10-m-thick part consists of sandstones, siltstones and calcareous sandstones containing pelecypods, gastropods and occasionally nummulitids (samples HAC 1 to 3). It is overlain by a 15-m-thick succession of calcareous sandstones rich in thick *Nummulites* and *Heterostegina* and also contains calcareous red algae (samples HAC 4 to 7). The upper, 6-m-thick part of the section (samples HAC 8 and 9), with common orthophragmines and flat *Nummulites* (*N. maximus*), represents the same olistostrome (with sandy limestone matrix and coral-bearing olistoliths) as in the vicinity of samples ŞAMLAR 1 and 2 in the continuation of the ŞAM A section (see above). The distribution of fossils is shown in Figure 10.

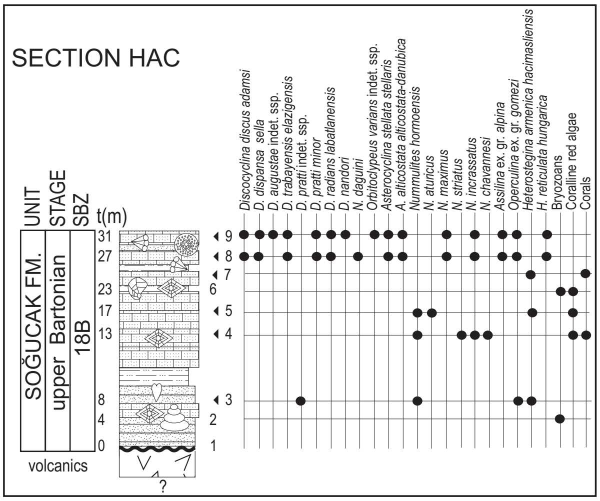



**Figure 10.** Distribution of benthic foraminifera and other fossil groups in section Hacımaşlı (HAC).

Both *Heterostegina armenica hacimasliensis* (see details in the systematic part) found in samples HAC 3, 5 and 7 and *H. reticulata hungarica* in samples HAC 8 and 9 mark the middle part of the late Bartonian, the SBZ 18B Subzone. This age (considered for the whole, not too thick profile) is also supported by the presence of giant *Nummulites* (*N. aturicus* and *N. maximus*), *Discocyclina discus*, (not crossing the Bartonian/Priabonian boundary), *N. hormoensis* (exclusive to the late Bartonian SBZ 18 Zone) and some orthophragmines (*D. trabayensis elazigensis*, *D. pratti minor* and *D. radians labatlanensis*), first appearing in the late Bartonian to earliest Priabonian OZ 14 Zone (only the representatives of the *D. dispansa* lineage are less advanced than expected). The Hacımaşlı section is also important because the superposition of *H. reticulata* with smaller embryon and more nepionic chambers above *H. armenica* with larger embryon and much fewer nepionic chambers can directly be observed.

Three facies types can be recognized in the section. The lower and middle parts containing the reticulate *Nummulites hormoensis*, large and thick *N. aturicus*, *N. striatus* and *Heterostegina armenica* might belong to the middle shelf. The common *N. striatus* in sample HAC 4 indicates, however, low-energy conditions (back-bank), whereas common *N. aturicus* in sample HAC 5 mark the high-energy conditions of the *Nummulites*-bank facies. Up section, in samples HAC 8 and 9, both the large, flat *Nummulites maximus*, and the diverse assemblage of orthophragmines, *Assilina* ex. gr. *alpina*, *Operculina* ex. gr. *gomezi* and *Heterostegina reticulata* indicate the deeper part of the photic zone, the outer shelf in the foreground of coral reefs, the debris of which can abundantly be found in these sediments as in the upper part of the Şamlar section. The drowning of the carbonate platform near Hacımaşlı might have happened somewhat earlier than in the Şamlar region since the uppermost, orthophragmine-bearing beds are slightly older (SBZ 18B versus SBZ 18C) and the section is also considerably thinner than at Şamlar.

*Akören Region*

The Çatalca-Akören region west of İstanbul is characterized by the widespread exposures of the Soğucak Formation, due to the Çatalca High (Figures 3 & 11). The Akören (AKÖR.A and B) sections represent the northern slope of this palaeohigh. In this locality, 7 km NW of Çatalca, two sections (Akören A and B with UTM coordinates 0615401, 4560272; 0615097, 4560484 and 0614701, 4560269, respectively) and one spot sample (Akören 1, see Figure 11 for its position with respect to AKÖR.A and B) have been studied. Based on their facies and age, they can be arranged on top of each other as section Akören A represents the lower and Akören B the upper part of the succession, and the spot sample Akören 1 comes between them.

*Section AKÖR (Akören) A*– The development of the 61-m-thick Soğucak Formation over the basal conglomerates of the Koyunbaba Formation is well seen around Akören village along section AKÖR.A (Figure 12). The relationship of the Koyunbaba Formation to the underlying basement units is not observed, although it is most probable that the basement consists of metamorphic units of the

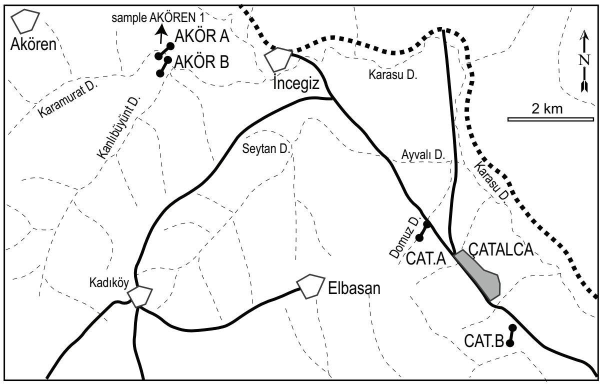



**Figure 11.** Location of stratigraphic sections in the vicinity of Çatalca and Akören.

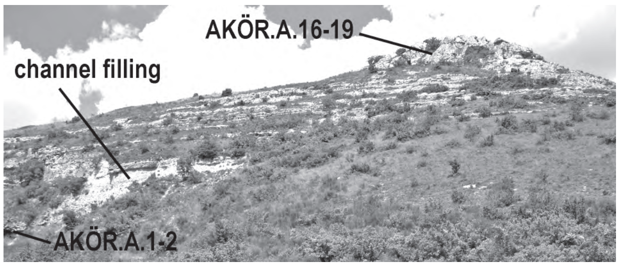



**Figure 12.** View of section Akören (AKÖR) A (upper Bartonian) with nummulitic limestone (containing giant *Nummulites lyelli* and *N. biedai* and also *Heterostegina armenica tigrisensis*) on the top.

Istranca Massif, as these rocks are widespread in the Çatalca region. The lower unit of the Eocene succession, assigned to the Hamitabat Formation by Turgut & Eseller (2000), and considered to be a part of the Koyunbaba Formation here, contains a 8-m-thick, gently dipping, partly calcareous sandstone with nummulitid foraminifera in its lowermost part. The overlying, 9-m-thick, almost horizontal conglomerates mostly contain quartz pebbles of fist-size and some metamorphic pebbles, and are thought to represent a channel-fill deposit. They are devoid of fossils and directly overlain by the carbonate succession of the Soğucak Formation rich in larger foraminifera only in its upper part. The limestones of the Soğucak Formation are represented by a monotonous sequence partly rich in miliolids and coralline red algae indicating a very shallow marine inner platform setting, considered to be Priabonian in age by Turgut & Eseller (2000). Nummulitids, represented mainly by large tests of *Nummulites* and *Heterostegina*, appear in the upper part of the Soğucak

Formation. The distribution of nummulitids and rare orthophragmines, only dominating the lower and upper part of the Soğucak Formation section and other fossils is shown in Figure 13.

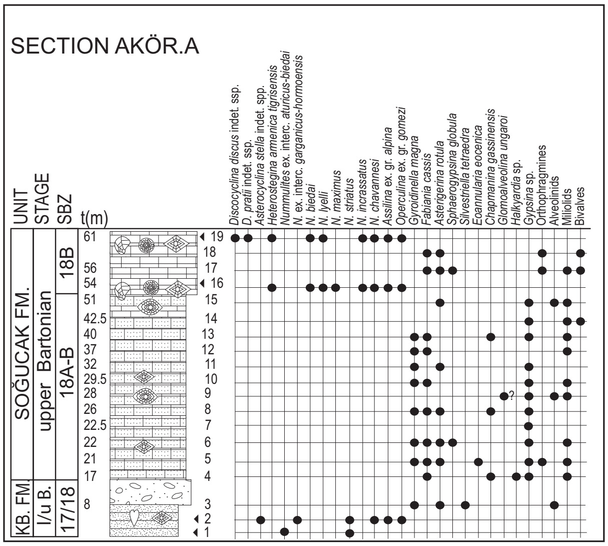



**Figure 13.** Distribution of benthic foraminifera and other fossil groups in section Akören (AKÖR) A.

Based on the presence of *Nummulites* ex. interc. *garganicus-hormoensis*, *N. striatus*, *N.* ex. interc. *aturicus-biedai*, *Operculina* ex. gr. *gomezi* and on the absence of genus *Heterostegina* the age of the basal part of the Akören A section (samples AKÖR.A 1 and 2) can be estimated as close to the boundary between the early and late Bartonian (SBZ 17/18). *Heterostegina* may be absent because of somewhat restricted, low-energy shallow-water (back-bank) conditions indicated by the common occurrence of *N. striatus*. The presence of *H. armenica tigrisensis* in the upper part of the section (samples AKÖR.A 16 and 19) marks the middle late Bartonian SBZ 18B Subzone. Abundant *Nummulites lyelli* and *N. biedai* form a *Nummulites* bank indicating high-energy middle shelf conditions.

*Spot Sample Akören 1*– Based on the mass occurrence of *Heterostegina reticulata hungarica* the marly limestone of sample Akören 1 is of middle late Bartonian (SBZ 18B) age. Openmarine, somewhat low-energy shallow-water conditions can be deduced.

*Section AKÖR (Akören) B*– Both the Soğucak Formation and the overlying pelagic siltstones and marls representing the Ceylan Formation crop out very near section AKÖR.A east of Akören village. This is the only locality in the Çatalca region where the relationship of the Soğucak Formation with the overlying deep marine deposits (Ceylan Formation) can be observed in outcrop. Marly limestones of the Soğucak Formation (about 30 m thick) are represented mainly by debris-flow deposits containing resedimented shallow-marine elements. Coralline red algae, corals and nummulitid foraminifera are locally rich (see Figure 14 for the distribution of fossils). The upper part of the unit contains more clastic material that grades into marls with planktonic foraminifera. A conglomerate level (sample AKÖR.B 19) containing resedimented tests of larger foraminifera occurs in pelagic marls.

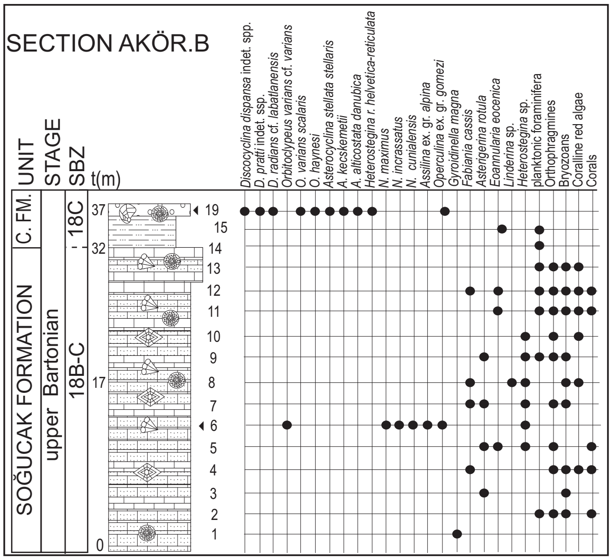



**Figure 14.** Distribution of benthic foraminifera and other fossil groups in section Akören (AKÖR) B. C. FM.- Ceylan Formation.

The presence of planktonic foraminifera and bryozoans in the lower and middle part of the Akören B section represented by the Soğucak Limestone indicates the drowning of the carbonate platform, while coralline debris marks the closeness of reefs. Isolated larger foraminifera were studied from sample AKÖR.B 6 where megalospheric *Nummulites maximus*, characteristic of the open marine fore-bank environment, predominates over rare orthophragmines. This fauna itself only indicates the Bartonian. Based on the stratigraphic position, however, it can be assigned to the middle–late part of the late Bartonian (SBZ 18B–C).

The Soğucak Limestone is covered by pelagic marls. Planktonic forms were identified from sample AKÖR.B 14. The list of calcareous nannoplankton (determined by M. Báldi-Beke) is as follows: *Discolithina plana* (Bramlette & Sullivan), *Pontosphaera latoculata* (Bukry & Percival), ?*Blackites tenuis* (Bramlette & Sullivan), *Cyclicargolithus floridanus* (Roth & Hay), *Reticulofenestra bisecta* (Roth & Hay), *Chiasmolithus solitus* (Bramlette & Sullivan), *C. consuetus* (Bramlette & Sullivan), *C.* sp. ind., *Coccolithus pelagicus* (Wallich), *C. eopelagicus* (Bramlette & Riedel), *Cyclococcolithus formosus* Kamptner, *Zygrhablithus bijugatus* (Deflandre), *Braarudosphaera bigelowi* (Gran & Braarud), ?*Pemma* sp., *Micrantholithus vesper* Deflandre and ?*Sphenolithus predistentus* Bramlette & Wilcoxon. The nannoflora forms a coccolith ooze with abundant *Cyclicargolithus floridanus.* The assemblage belongs to the Middle Eocene. Different *Chiasmolithus* refer the deeper, but *Reticulofenestra bisecta* to the higher part of it.

The list of smaller Foraminifera (determined by K. Kollányi) is as follows: *Spiroplectammina carinata* (D'Orbigny), *Dentalina* sp., *Lenticulina depauperata* (Reuss), *Marginulina behmi* (Reuss), *Uvigerina* sp., *Asterigerina rotula* (Kaufmann), *Pararotalia inermis* (Terquem), *Globorotalia cerroazulensis cerroazulensis* (Cole), *Globigerina corpulenta* Subbotina, *G. cryptomphala* Glaessner, *G. eocaena* Gümbel, *G. praebulloides occlusa* Blow & Banner, *G. venezuelana* Hedberg, *G.* sp., *Planulina* sp. *Gyroidina soldanii* (d'Orbigny). The assemblage of planktonic Foraminifera is very rich, with *Globigerina praebulloides occlusa* especially abundant. The age can be determined as the late part of the middle Eocene, in the P 14 (*Truncorotaloides rohri*) Zone, since *G. corpulenta* only occurs towards the end of the middle Eocene, while *Globorotalia cerroazulensis cerroazulensis* first appears in the P 14 Zone.

A lens with resedimented larger foraminifera has been found in the upper part of the pelagic marls in sample AKÖR.B 19 (for their list see Figure 14). The orthophragmine-dominated assemblage indicates a source in the deeper part of the photic zone in the outer shelf. The presence of *Heterostegina reticulata* ex. interc. *Helvetica-reticulata* with the absence of giant *Nummulites* (especially of *N. maximus*) suggests the end of the Bartonian (SBZ 18C), although the unusually great variability of the *H. reticulata* population also indicates some kind of mixing caused by the redeposition. The orthophragminid assemblage belongs to the late Bartonian part of the OZ 14 Zone, based on the presence of *Asterocyclina alticostata danubica* first appearing in this zone and of rare *Orbitoclypeus haynesi,* reported so far only from the Bartonian (this is the first record of the species from the upper Bartonian).

Based on both planktonic and larger foraminiferal data, shallow marine conditions in the vicinity of Akören ended in the late(st) Bartonian.

*Çatalca Region*

Two sections representing the Soğucak Formation have been studied near Çatalca, on the Çatalca palaeo-high (Figure 11). These sections, ÇAT.A (UTM coordinates: 0517151, 4505041) and ÇAT.B (UTM coordinates: 0623483, 4553953; 0623562, 4554003), 3 km apart, directly overlie the Istranca metamorphic rocks and unlike in section AKÖR.A, they are represented by coralline red algae and coral-dominated limestone facies. The Soğucak Formation is overlain by Pınarhisar sandstones that contain *Congeria*-type bivalves, occasionally in rock-forming abundance.

*Section ÇAT (Çatalca) A*– The basal 6-m-thick siliciclastic part of the Soğucak Formation unconformably overlies the metamorphic units, with shearing along the unconformity. This part, consisting of calcareous sandstones and/or sandy limestones, is rich in larger foraminifera, particularly orthophragmines. The rest of the unit, about 50 m thick, is mainly characterized by limestones with red algae and corals accompanied by foraminiferous levels. Friable limestones in the uppermost part of the unit contain nummulitids. The carbonates are overlain by Oligocene sandstones consisting of *Congeria* in some levels. This unit is completely devoid of foraminifera. The distribution of fossils is shown in Figure 15.

Both *Nummulites* ex. interc. *hormoensis-fabianii* and *Heterostegina reticulata* ex. interc. *reticulata-*

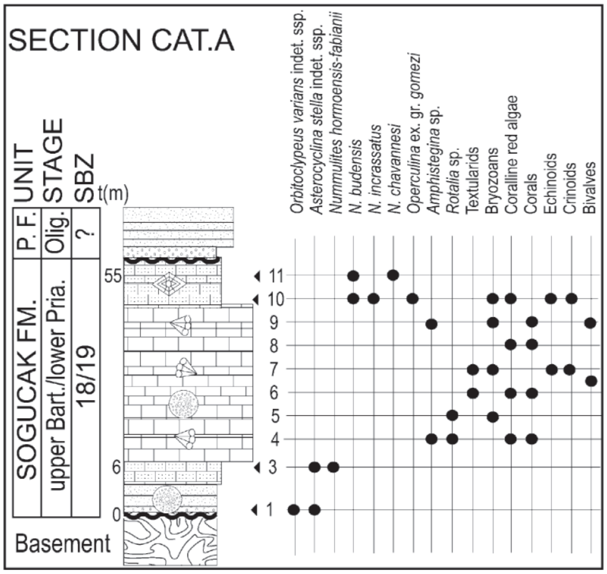



**Figure 15.** Distribution of benthic foraminifera and other fossil groups in section Çatalca (ÇAT) A. P.F.– Pınarhisar Formation.

*mossanensis* in sample ÇAT A 3 indicate an age close to the Bartonian/Priabonian (SBZ 18/19) boundary. The lack of *Spiroclypeus* in all samples suggests rather a Bartonian age (but this can also be caused by unsuitable palaeoenvironmental factors), although *Nummulites budensis* in samples ÇAT.A 10 and 11 is more indicative of the Priabonian. The low diversity larger foraminiferal assemblage may indicate middle shelf conditions that upwards became somewhat restricted (with low water-energy) as marked by the presence of *N. budensis*.

*Section ÇAT (Çatalca) B*– This section represents a carbonate succession of the Soğucak Formation, about 59 metres thick, deposited on the metamorphics of the Istranca Massif. The development of Neptunian dykes in the upper part of the metamorphics is well observed at this locality (Figure 16). The lower part of the Soğucak Formation is characterized by abundant current-oriented tests of orthophragmines, which are absent in the middle and upper part of the succession. Resedimented tests of corals are locally abundant in the middle part of the carbonates. Red algae, bryozoans and corals are dominant in this part; foraminifera are scarce. The distribution of fossils is shown in Figure 17.

The Soğucak Formation is unconformably overlain by the sandstones of the Pınarhisar Formation (Figure 18), which contains pebbles of the

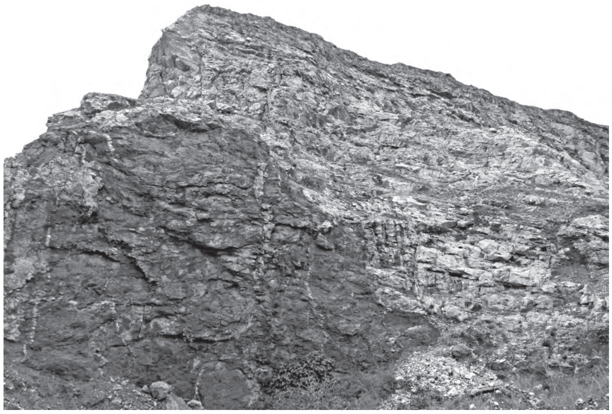


**Figure 16.** View of the Çatalca (ÇAT) B section (right) and Neptunian dykes of the Soğucak Limestone in the metamorphic basement (left).

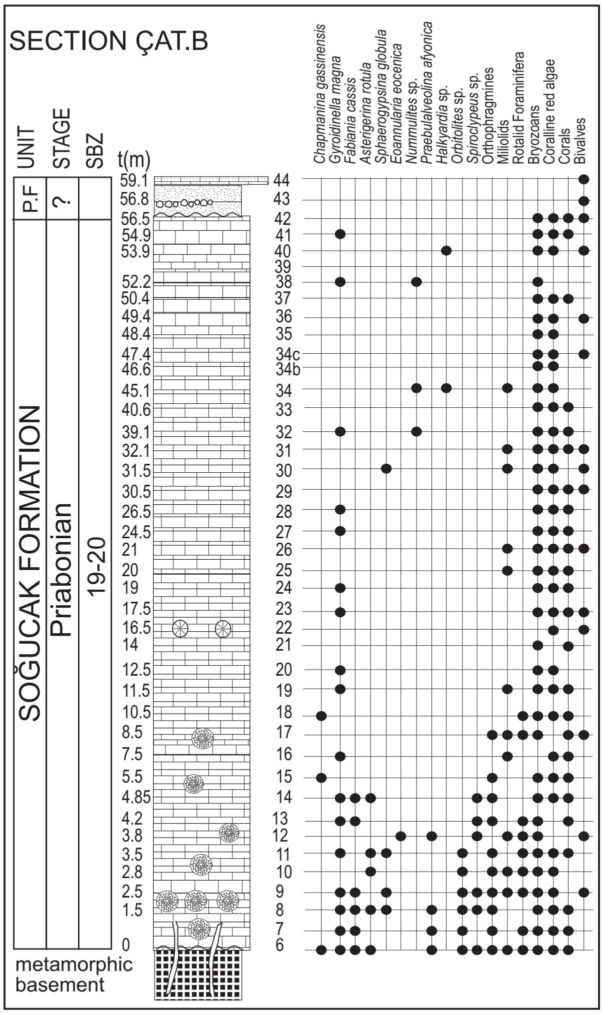



**Figure 17.** Distribution of benthic foraminifera and other fossil groups in section Çatalca (ÇAT) B. P.F.– Pınarhisar Formation.

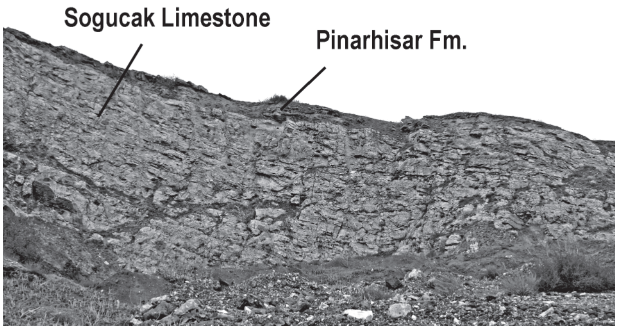



**Figure 18.** The Pınarhisar Formation (Oligocene) unconformably overlying the Soğucak Limestone in the quarry of section Çatalca (ÇAT) B.

Soğucak Formation in its basal part. In the studied portion of the Pınarhisar Formation some bivalves occur, but no foraminifera have been identified.

Although no isolated forms could be investigated because of the hard limestones of the whole sequence of Soğucak Formation, the presence of *Heterostegina gracilis*, *Spiroclypeus* sp. and *Praebullalveolina afyonica* (Figure 19) in the lowermost (ÇAT B 6) sample (determined in thin section) certainly indicates a late Priabonian age (SBZ 20, based on *H. gracilis*) for the lower part of the profile. The upper part of the Soğucak Formation cannot be dated confidently, but the regional correlations and facies development also suggest a late Priabonian age. In terms of environmental considerations, *Heterostegina*, *Spiroclypeus* and orthophragmines in the lower part of the section suggest open, outer shelf conditions whereas corals and red algae in the middle and upper part indicate a shallower, high-energy middle shelf palaeoenvironment.

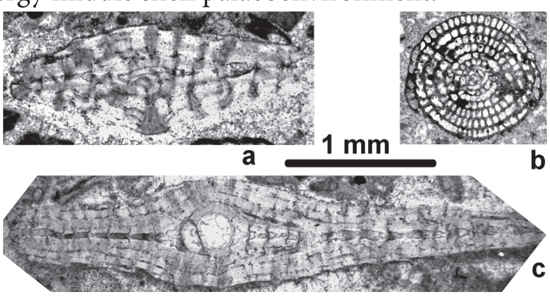



**Figure 19.** Nearly axial sections of larger foraminifera (×20) from the Çatalca (ÇAT) B section. **(a)** *Spiroclypeus* sp., ÇAT B-14, **(b)** *Praebullalveolina afyonica* Sirel & Acar, ÇAT B-12, **(c)** *Heterostegina gracilis* Herb, ÇAT B-6.

*Kırklareli and Dolhan Regions*

Exposures of the Soğucak and Koyunbaba formations are widespread near Kırklareli, along the banks of Tekke river, where their relationship to the metamorphic units of the basement can also be observed. The upper part of the Soğucak carbonates is also exposed in a limited area along a small creek north of Dolhan village, southwest of Kırklareli. Four stratigraphic sections (KIRK.A, B, C and D) and two spot samples (KIRK 12 and KIRK 19) along the valley of the Tekke river and one spot sample (DOLHAN 1) from the upper part of the Soğucak Formation near Dolhan have been studied (Figures 3 & 20). The UTM coordinates of the sections and spot samples are as follows: KIRK.A– 0510322, 4621686; KIRK.B– 0510571, 4621928; KIRK.C– 0510337, 4621900; KIRK.D– 0517151, 4505041; KIRK 12– 0509478, 4621915; KIRK 19– 0510446, 4621574 and DOLHAN 1– 0502349, 4623924.

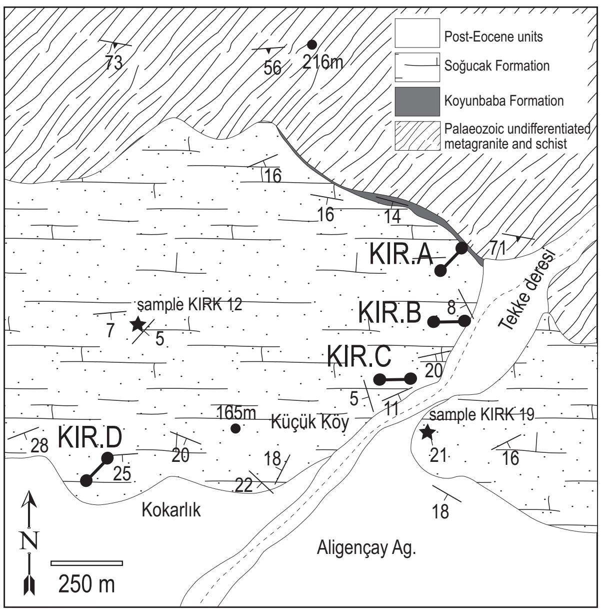



**Figure 20.** Geological map of the Tekke river region (near Kırklareli) with locations of stratigraphic sections and samples.

*Sections KIRK (Kırklareli) A, B, C and D and Spot Samples KIRK 12 and 19*– The sedimentary sequence developed near Kırklareli is a typical transgressive succession involving continental conglomerates assigned to the Koyunbaba Formation and the overlying Soğucak Formation consisting of very shallow marine calcareous sandstones and limestones that pass into a reef limestone body (in sections KIRK.A, see Figures 21 & 22 and KIRK.B – Figure 23 – corresponding to the middle and upper parts of section KIRK.A). The Koyunbaba Formation, unconformably overlying the metamorphic rocks of the Istranca Massif, is about 18 m thick and represented by sandstones and conglomerates devoid of foraminifera. Some bones of unidentified mammalians have been discovered in its lower part in the Tekke valley. The Soğucak Formation starts with a 17-m-thick series of shallow marine calcareous sandstones and limestones, very rich in bivalves, gastropods and echinoids. Foraminifera are only represented by (mainly reticulate) *Nummulites*. At these levels foraminiferal groups such as *Silvestriella* and *Chapmanina* are dominant. The overlying reef body, about 4 m × thick, is mainly represented by in-situ development of corals that may reach up to 1 m in size.

**Figure 21.** View of the Kırklareli (KIRK) A section with metamorphic rocks below and the coral reef body above.

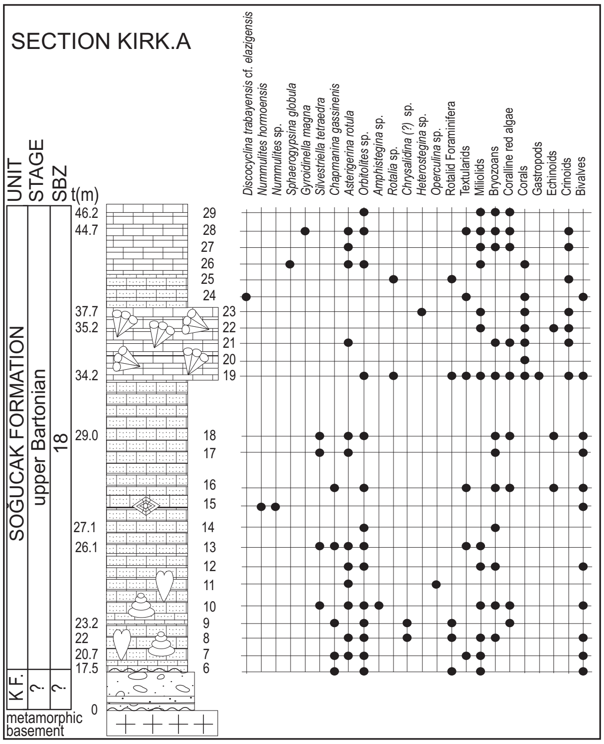



**Figure 22.** Distribution of benthic foraminifera and other fossil groups in section Kırklareli (KIRK) A. K.F.– Koyunbaba Formation.

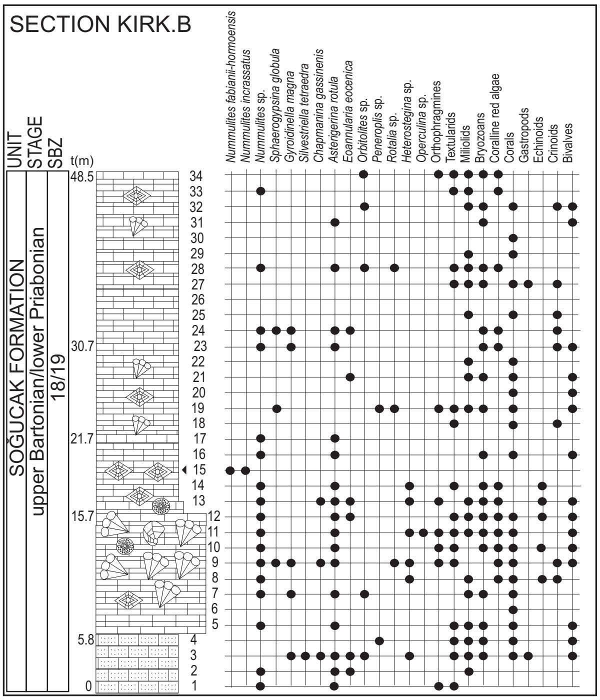



**Figure 23.** Distribution of benthic foraminifera and other fossil groups in section Kırklareli (KIRK) B.

The carbonate succession overlying the reef body is at least 40–45 metres thick, as deduced from the measured sections of KIRK.C and D. The reef level of sections KIRK.A and B is overlain by shallow marine limestones poor in fossils (section KIRK.C) that grade into foraminifera-rich levels and finally reef carbonates containing a reasonable amount of land-derived siliciclastic material (section KIRK.D). The fossil composition of the sections is shown in Figures 24 and 25.

Spot samples KIRK 12 and 19 (see Figure 24 for the faunal and floral composition of the latter) tentatively correspond to limestones in the middle and upper part of the Soğucak Formation. The former contains exclusively nummulitids whereas the latter consists of a diverse assemblage of nummulitids and orthophragmines.

*Dolhan (Spot Sample DOLHAN 1)*– This sample is from a limestone horizon of the Soğucak Formation north of Dolhan, where we have identified common *Nummulites fabianii* and rare *Assilina* ex. gr. *alpina* indicating a Priabonian age. Just above the limestones the overlying siliciclastics of the Pınarhisar Formation have also been interpreted to represent the Soğucak Formation by İslamoğlu *et al.* (2010), based on the occurrence of probable *N. fichteli* mentioned in Sirel

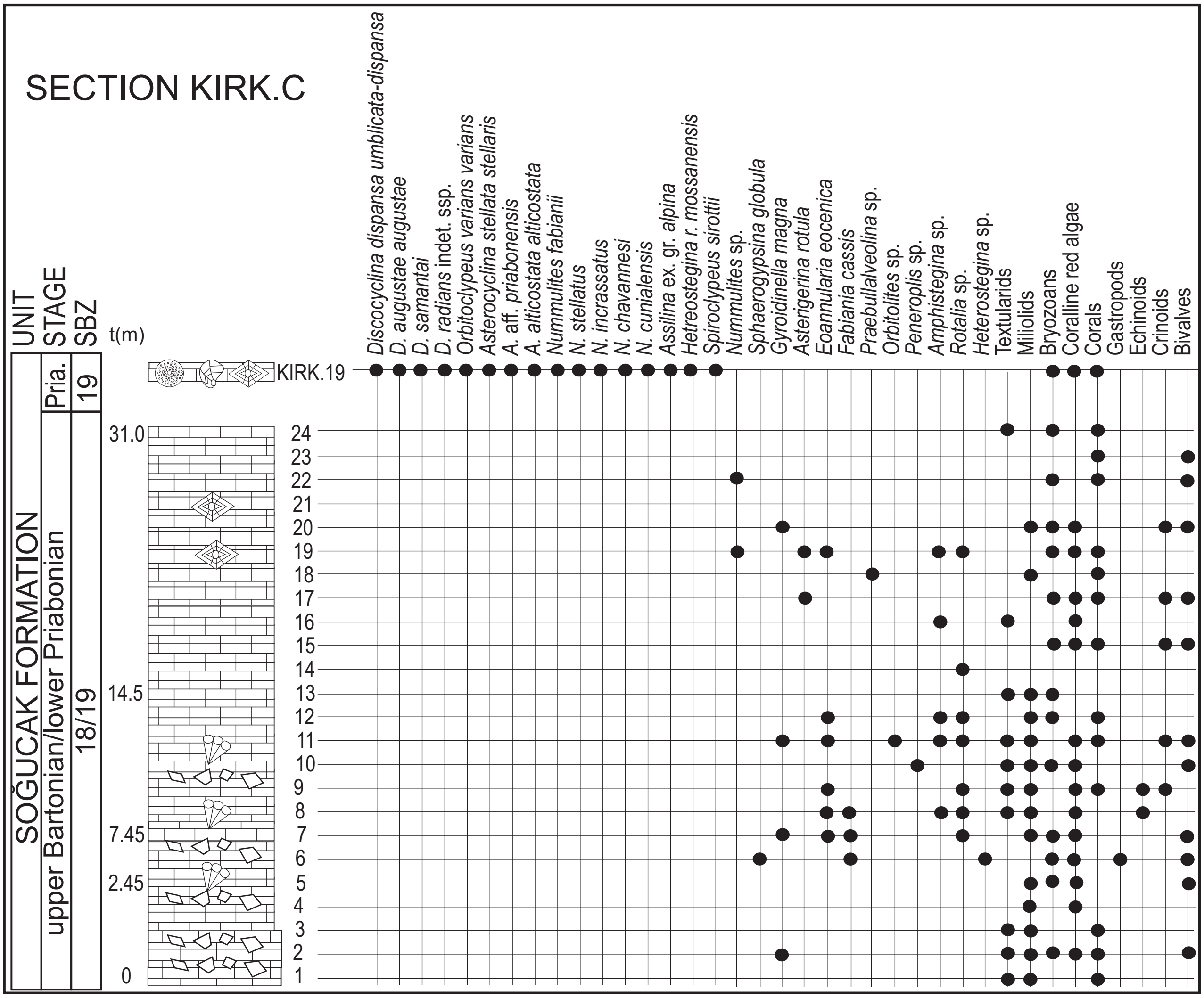



**Figure 24.** Distribution of benthic foraminifera and other fossil groups in section Kırklareli (KIRK) C.

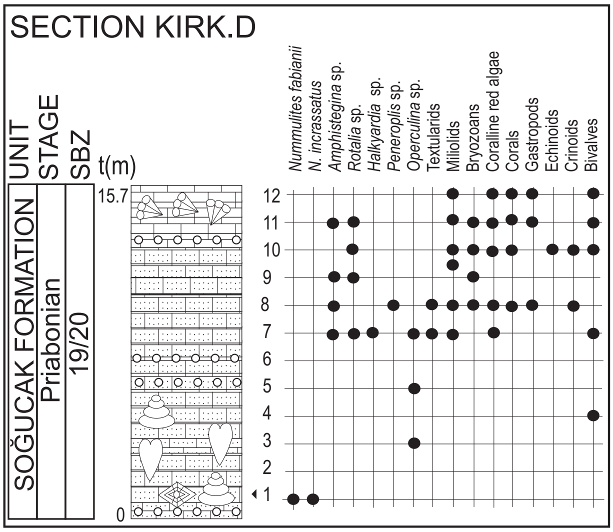



**Figure 25.** Distribution of benthic foraminifera and other fossil groups in section Kırklareli (KIRK) D.

& Gündüz (1976). We could not recognize this taxon in the sandstones, which in our view should represent the lower part of the Pınarhisar Formation.

The evolution of the *Nummulites fabianii* lineage can nicely be followed in the different localities near Kırklareli (KIRK sections), giving a sound basis for age determination. Thus, less developed forms (*N. hormoensis*) could be recognized close to the base of the Kırklareli sequence, in sample KIRK.A 15, indicating a late Bartonian (SBZ 18) age. Somewhat more developed populations, determined as *N.* ex. interc. *fabianii-hormoensis,* could be recorded in samples KIRK.B 15 and KIRK 12 from the middle part of the sequence. This developmental stage suggests an age close to the Bartonian–Priabonian (SBZ 18/19) boundary. Finally, the most advanced populations (of typical *N. fabianii*) could be found in samples KIRK 19 and KIRK.D 1 from the top of the Kırklareli sequence and also in sample DOLHAN 1, show they already belong to the Priabonian. The age of sample KIRK 19 can be more precisely determined as earliest Priabonian (SBZ 19A), based on the presence of *Heterostegina reticulata mossanensis* and *Spiroclypeus sirottii*. The orthophragminid assemblage in this sample (detailed in Figure 24) suggests an age close to the boundary of the OZ 14 and 15 Zones, within the early Priabonian, based on the co-occurrence of *Discocyclina dispansa* ex. interc. *umbilicata–dispansa*, *D. augustae augustae*, *Orbitoclypeus varians varians*, *Asterocyclina stellata stellaris* and *A. alticostata alticostata*. The first three forms are mostly characteristic for the Priabonian, while the latest occurrence of the *A. alticostata* lineage is known so far from the early Priabonian. Since the developmental stage of *N. fabianii* in samples KIRK.D 1 and DOLHAN 1 is very similar to that in sample KIRK 19, the age of these samples can also be very close to each other.

The basal part of the Soğucak Limestone contains molluscs and represents inner shelf conditions passing up into a back-bank environment in the vicinity of sample KIRK.A 15, with the first larger foraminifera still below the reef body. Reticulate *Nummulites* predominate in almost all larger foraminifera-bearing samples above the reef body and indicate high-energy middle shelf conditions of *Nummulites*-banks close to coral reefs. These were most suitable for them in the case of sample KIRK.D 1, bearing a considerable amount of microspheric forms. Deeper, open marine outer shelf (fore-bank) conditions can be deduced for sample KIRK 19, based on the very diverse larger foraminiferal assemblage, including a rich orthophragminid fauna.

### *Kıyıköy Region*

The outcrops of the Soğucak Formation are exposed near Kıyıköy village (Black Sea coast) west of the Şamlar and Karaburun region to the west of İstanbul. The basement metamorphic rocks are not exposed near Kıyıköy but can be seen south of the village. At this locality three samples (KIY 1, 2, 3) were studied from the unit. Sample KIY 1 (UTM coordinates: 0585749, 4610336) represents a friable limestone level on the Vize-Kıyıköy road about 6 km from Kıyıköy. Samples KIY 2 and 3 were collected in Kıyıköy village near the harbour (Figure 26). The lithology of sample KIY 2 is similar to that of sample KIY 1, while sample KIY 3 represents the limestone facies with a rich bryozoan assemblage.

Two facies types could be recognized at this site. *Nummulites fabianii* predominate in the lower part of the section (samples KIY 1 and 2), representing shallow water, high-energy middle shelf conditions, similar to *Nummulites* banks. In the uppermost part (sample KIY 3) abundant bryozoans, *N. budensis* and

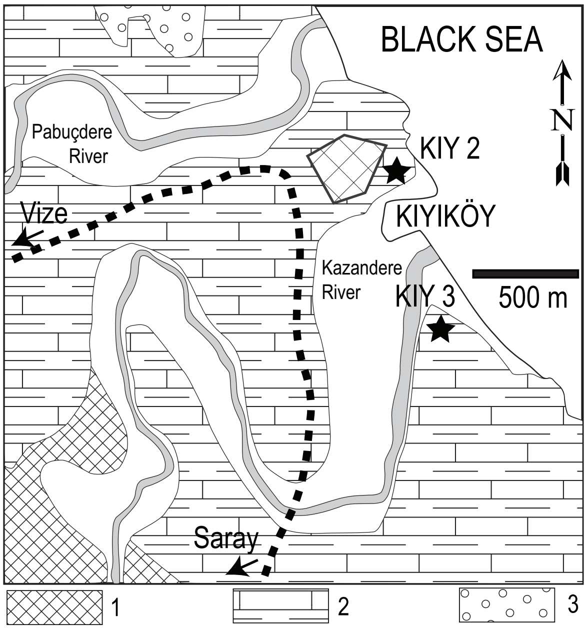



**Figure 26.** Geological map of the Kıyıköy region (after Çağlayan & Yurtsever 1998 with small modifications) with sample locations. 1– Palaeozoic–Mesozoic basement (Mahya schist and Sivriler metagranodiorite), 2– Soğucak Formation, 3- Trakya Formation (Upper Miocene–Pliocene continental clastics).

the absence of orthophragmines may indicate the back-bank facies of the deeper part of the middle shelf with low water energy. The above two *Nummulites* are characteristic for the entire Priabonian (SBZ 19–20). The developmental stage of *N. fabianii* in samples KIY 1 and 2 suggests, however, rather an early Priabonian (SBZ 19) age for them.

*Pınarhisar Region*

Exposures of both the Soğucak and the overlying Pınarhisar formations were observed in the Vize and Pınarhisar regions east of Kırklareli (Figure 3). The relation of the Soğucak Formation to the underlying metamorphic units was not directly observed near the studied section. However, about 5 km further west, the Soğucak Limestone directly overlies the metamorphic basement. Information about the molluscs of the two units from this locality is given in İslamoğlu & Taner (1995). The Soğucak limestone and the overlying Pınarhisar Formation have been assigned to the Priabonian and Stampian by these authors. A microfacies study of the Soğucak Formation and the geology of the Pınarhisar region were also presented by Keskin (1966, 1971). Six samples (the first five from along the local road between Pınarhisar and Akören, see Figure 27), PINAR.A 1 (0550300, 4610586), PINAR 1 (0546379, 4616888), PINAR 6 (0546393, 4616599), PINAR 9 (0546382, 4616474), PINAR 20 (0544755, 4611650) and PINAR 22 (0543997, 4609855) that contain free specimens of larger foraminifera have been studied. No orthophragmines have been identified in any of these samples, and the larger foraminifera exclusively belong to *Nummulites*.

Based on the predominance of *Nummulites budensis* and on the absence of orthophragmines both the age (Priabonian, SBZ 19–20) and the facies (back-bank, representing the deeper part of the middle shelf with low water energy) of the stratigraphically lowermost sample (PINAR A 1) are very similar to those in sample KIY 3 (Kıyıköy). The only difference between the two samples is in the quantity of bryozoans, which is much lower in sample PINAR.A 1.

Abundant *Nummulites fabianii* predominates in samples PINAR 1, 6 and 9. They form *Nummulites* banks corresponding to shallow water middle shelf conditions, and, based on their developmental stage, of rather late Priabonian (SBZ 20) age. Coral

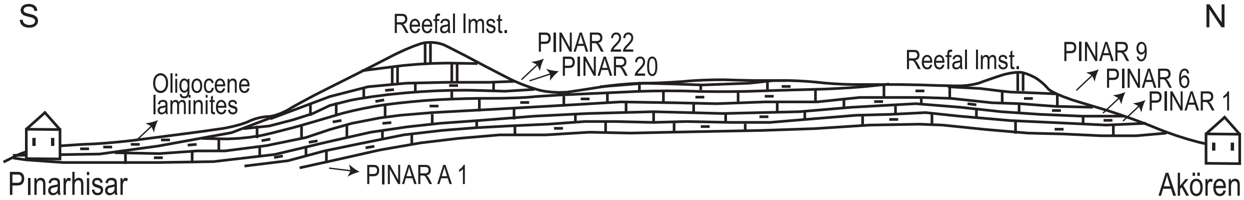



**Figure 27.** Geological sketch between Pınarhisar and Akören with sample locations (not to scale).

patch reefs directly above these deposits (Figure 28) already mark a very shallow, high water energy palaeoenvironment.

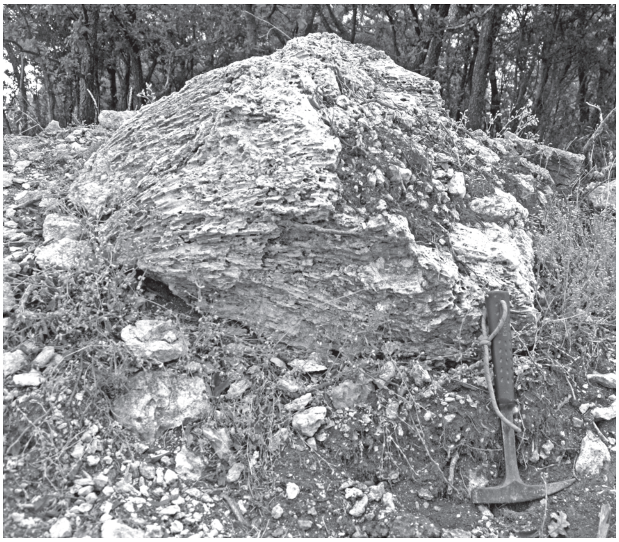


**Figure 28.** Close-up view of the coral patch reef in the Pınarhisar section just S of sample PINAR 9.

The poor larger foraminiferal assemblage at the top of the Eocene sequence, in samples PINAR 20 and 22, dominated by *N. incrassatus* and less by N. *budensis*, and lacking reticulate *Nummulites*, is characteristic for low energy middle shelf conditions of the back-bank facies. This part of the section is rich in coralline red algae. Based on their stratigraphic position just below the lower Oligocene laminite-bearing carbonates of the Pınarhisar Formation (Figure 29), they most probably belong to the upper Priabonian (SBZ 20).

**Figure 29.** Close-up view of laminite of the Oligocene Pınarhisar Formation covering the Eocene part of the Pınarhisar section.

*Lalapaşa Region*

Limestones of the Soğucak Formation north-east of Edirne and south of Lalapaşa have been studied near Sinanköy village (Figure 3). Two spot samples, LALAP 5 (UTM coordinates: 0475369, 4629871) and LALAP 12 (UTM coordinates: 0474383, 4628532, near the cement factory) yielded a fairly rich assemblage of larger foraminifera represented by *Nummulites*.

The poor larger foraminiferal fauna allows determination of the age of these deposits as Priabonian (SBZ 19–20). Monospecific *Nummulites incrassatus* in sample LALAP 5 may indicate low energy middle shelf (back-bank) conditions, meanwhile the slightly richer assemblage in sample LALAP 12 with the predominance of *N. budensis* and *N. chavannesi* (associated with rich coralline red algae) may be characteristic for a somewhat deeper part of the same back-bank environment with very low water energy.

*Karaburun Region*

This is the only region along the Black sea coast (Figure 3) in the Thrace Basin where the relationship of the Soğucak Limestone to the unconformably overlying Ceylan Formation and the stratigraphic sequence of the latter can be observed. The relationship of the Soğucak Limestone to the underlying units, however, is not seen since the lower part of the carbonates is submerged in the Black Sea. The section KARAB (UTM coordinates; 0640859, 4578963) covers both the Soğucak and the lowermost part of the Ceylan formations. The Soğucak Formation, most of which is thick-bedded to massive, is an approximately 61-m-thick limestone unit mainly represented by coral levels with in-situ coral developments. Larger Foraminifera occur sporadically in the lower and middle part (characterized by rich coralline red algae) but become abundant (sample KARAB 20) in the uppermost part just below a hardground along an unconformity surface separating the limestones from the fine siltstones/marls of the Ceylan Formation. These fine clastics containing planktonic foraminifera and calcareous nannoplankton (sample KARAB 22) pass upwards into coarse sands and conglomerates containing specimens of *Nummulites* (samples KARAB 23 and 24), previously studied by Sakınç

(1994) who assigned all nummulitids to *N. vascus*. The fauna and flora identified in the whole section are shown in Figure 30.

Based on the joint occurrence of in-situ corals, coral debris and orthophragmines the visible part of the Soğucak Limestone may represent a very short, mobile transition between the fore-reef and the outer shelf. A precise age can only be given for the upper part where (in sample KARAB 20) both *Heterostegina gracilis* and *Asterocyclina stellata* cf. *buekkensis* indicate a late Priabonian (SBZ 20) age.

The age of the Ceylan Formation can be determined using larger foraminifera in sample KARAB 24. The assemblage of *Nummulites vascus*, *N. bouillei* and *Operculina complanata* marks the early Rupelian SBZ 21 Zone and also indicates a moderately shallow-water, low-energy middle ramp environment (coral reefs are unknown from the Oligocene of this region) also taking into account the absence of reticulate *Nummulites* (of the *N. fabianii* group). Planktonic forms were investigated from sample KARAB 22. The nannofloral assemblage (studied by M. Báldi-Beke) with the dominant *Cyclicargolithus floridanus* refers

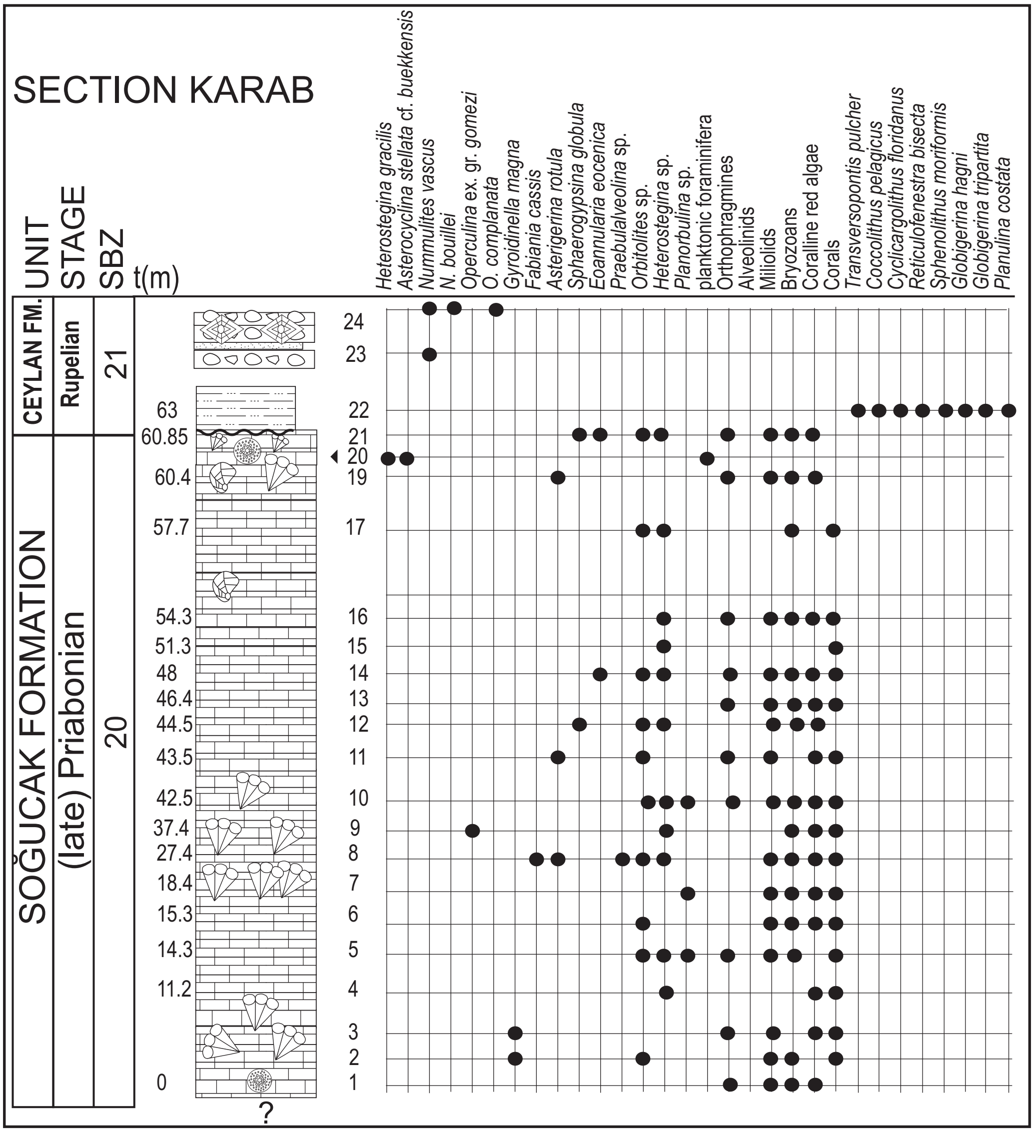



**Figure 30.** Distribution of benthic foraminifera and other fossil groups in section Karaburun (KARAB).

to extreme ecological conditions. The typically large *Reticulofenestra bisecta* occurs from the Bartonian to the Oligocene. Smaller Foraminifera (investigated by K. Kollányi) are recrystallized, poorly preserved, with no zonal marker planktonic forms.

## Systematic Palaeontology

### Order FORAMINIFERIDA Eichwald 1830

In this section, a selective systematic description of stratigraphically important groups such as orthophragmines and nummulitids is given, since the description of taxa discussed in Özcan *et al.* (2007a, 2010a) is not repeated here. The list of other accompanying benthic foraminifera can be found in the section 'Synthesis of Palaeontological Data'.

*Principles of Taxon Determination*

We follow the morphometric method described in detail by Drooger (1993), i.e. in each sample we group specimens into populations, the members of which are clearly distinguishable from the specimens of the other populations of the same sample. Taxonomic determinations are based on these populations (as a whole) and not on their separate individuals. These taxa are mostly members of a long-lasting and continuous evolutionary chain called a lineage or phylum. In the case of orthophragmines and genus *Heterostegina* lineages correspond to species while for genus *Nummulites* and *Spiroclypeus* they form a series of chronospecies. Many lineages are used for biostratigraphic purposes after being artificially segmented into chronospecies (or chronosubspecies for orthophragmines and *Heterostegina*) separated from each other by arbitrary biometric limits of a characteristic numerical evolutionary parameter.

Sometimes the parameter mean of a population can be very close (closer than 1 s.e. of the mean) to the limit of two neighboring species/subspecies. In this case we need an intermediate notation in the species/subspecies units, and a two-species/subspecies exemplum intercentrale notation (abbreviated as ex. interc.) is used in which the prevalent species/subspecies unit will be ranked first: the closest specific/subspecific unit in the other as the second part of the determination. If the population consists of only a single specimen, no species/subspecies is determined, in the case of only two or three specimens, the species/subspecies is determined as 'cf.'. Samples close to each other and containing practically the same assemblages with similar parameters are evaluated both separately and jointly. However, the specific/subspecific determination is given for the joint samples.

*Orthophragmines*

This name is an informal collective term for three-layered orbitoidal larger foraminifera of the late Palaeocene and Eocene comprising two independent families: Discocyclinidae and Orbitoclypeidae. More details about their architecture (including the discriminative qualitative features for separating the four different Tethyan orthophragminid genera) are given in Less (1987, 1993, 1998a), Ferràndez-Cañadell & Serra-Kiel (1992), Ferràndez-Cañadell (1998), Özcan *et al.* (2007a, b), Less *et al.* (2007) and Less & Ó. Kovács (2009). The most recent description of most orthopragminid species found in our territory, with information on references to more detailed descriptions, geographic and stratigraphic ranges and up-to-date subdivision into subspecies, can be found in Özcan *et al.* (2007a); whereas for *Orbitoclypeus haynesi* and *Asterocyclina* aff. *priabonensis* see Özcan *et al.* (2010a).

In the determination of orthophragmines we adopted the principles used by Less (1987, 1993) as illustrated in Figure 31A, and explained in the header of Tables 1 & 2. Because of the limited space, a complete statistical evaluation with the number of specimens (№), arithmetical mean and standard error (s.e.) is given only for deuteroconchal size (d), the crucial parameter in subspecific determination. Biometric data are summarized in Tables 1 & 2. An updated synopsis of subspecies identification based on the outer cross-diameter of the deuteroconch (parameter d) is given in Zakrevskaya *et al.* (2011). A revised stratigraphy of late Lutetian to Priabonian orthophragmines is presented in Figure 32 where updates (as compared to the range-chart by Özcan *et al.* 2007a) based on the whole Thrace Basin are shown in red.

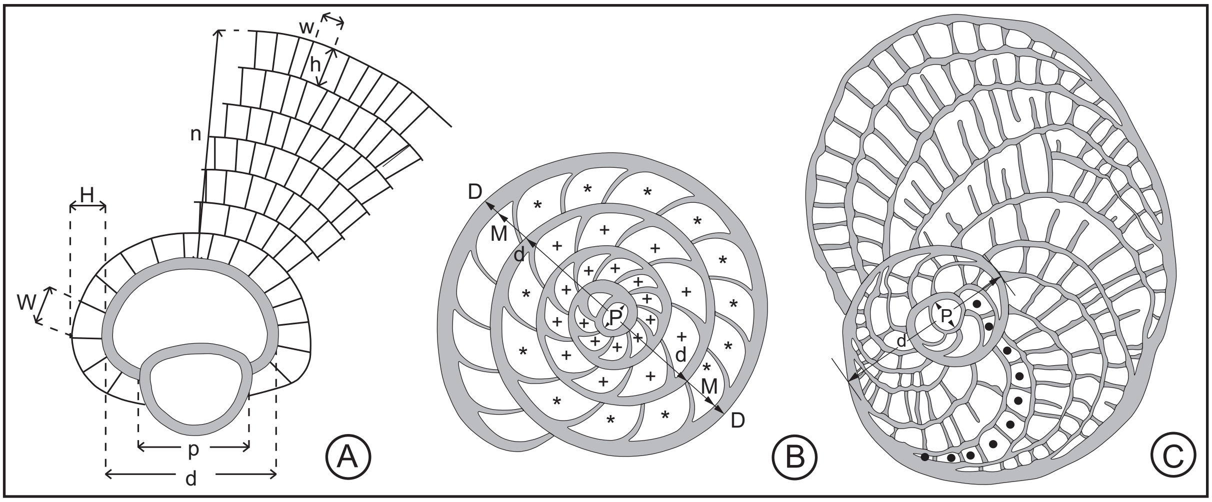



**Figure 31.** Measurement system for megalospheric larger foraminifera (parameters are explained in the headers of Tables 1 to 7) with parameters for the definition of megalospheric orthophragmines **(A)**, *Nummulites* **(B)**, *Heterostegina* and *Spiroclypeus* **(C)**.

### Family DISCOCYCLINIDAE Galloway 1928

### Genus *Discocyclina* Gümbel 1870

All species found in our area except for *Discocyclina* sp. are discussed in Özcan *et al.* (2007a, 2010a) and therefore are not described here. Unribbed taxa, such as *Discocyclina discus* (Rütimeyer 1850), *D. dispansa* (Sowerby 1840), *D. augustae* van der Weijden: 1940, *D. trabayensis* Neumann 1955 and *D. pratti* (Michelin 1846) are illustrated in Figure 33, while the ribbed ones, including *D. samantai* Less 1987, *D. nandori* Less 1987 and *D. radians* (d'Archiac 1850), in Figure 34.

***Discocyclina* sp.**

Figure 33c

Few specimens resembling *Discocyclina discus*, albeit with considerably smaller embryon and adauxiliary chamberlets (compare them in Figure 33) were found in sample Kırklareli (KIRK) 19. The equatorial chamberlets are also somewhat narrower than those of *D. discus*. Such forms with similar biometric parameters as in Kırklareli, also in small quantity, can be found in the *Discocyclina* and *Asterocyclina* beds of the Priabona type section, as recognized by the senior author after studying the Sirotti (1978) and the Setiawan (1983) material in Modena and Utrecht, respectively. We have found one single specimen of these forms in sample Mossano 8 (see Less *et al*. 2008) as well. Sirotti (1978) determined them as *D. discus*, while Setiawan (1983) arranged them into *Discocyclina* II (cf. *D. sella*). We cannot use these last names for the Kırklareli specimens, since they are occupied for other taxa. At the same time, the Kırklareli material is not rich or well-preserved enough to introduce a new name. It is worth noting, however, the very similar stratigraphic position (around the middle of the Priabonian) of the known occurrences of this form.

### Genus *Nemkovella* Less 1987

This genus is very poorly represented in the upper Lutetian–Priabonian sediments of the whole Thrace Basin, since *Nemkovella strophiolata* (widespread in the coeval deposits of other Western Tethyan basins) has not yet been recorded. The only species from this region belonging to this genus is *N. daguini* (Neumann 1958), figured in Figure 34k (for biometrical data see Table 2) and discussed in Özcan *et al.* (2007a).

### Family ORBITOCLYPEIDAE Brönnimann 1946

### Genus *Orbitoclypeus* Silvestri 1907

This genus occurs in the Soğucak Limestone of the northern and eastern parts of the Thrace Basin

**Table 1.** Statistical data of *Discocyclina* populations. №– number of specimens, s.e.– standard error.

| Parameters | | Outer cross-diameter of the embryon | | | | | Adauxiliary chamberlets | | | Equatorial chamberlets | | | Subspecific determination |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | deuteroconch | | | protoconch | | number | width | height | annuli/ 0.5 mm | width | height | |
| | | d (µm) | | | p (µm) | | N | W (µm) | H (µm) | n | w (µm) | h (µm) | |
| Species | Sample | № | range | mean±s.e. | range | mean | range | range | range | range | range | range | |
| *Discocyclina discus* | **AKÖR A 19** | 1 | | 1960 | | 910 | – | – | – | – | – | – | indet. ssp. |
| | **SAM A 14+16** | 2 | 1700 – 2150 | 1925 | 710 – 960 | 835 | – | – | – | – | – | – | cf. *adamsi* |
| | SAM A 14 | 1 | | 1700 | | 710 | – | – | – | – | – | – | |
| | SAM A 16 | 1 | | 2150 | | 960 | – | – | – | – | – | – | |
| | **HAC 8+9** | 9 | 1350 – 2400 | 1745 ± 106 | 490 – 1000 | 758 | 80–100 | 60–90 | 90–150 | 5–6 | 40–45 | 90–160 | *adamsi* |
| | HAC 8 | 3 | 1460 – 2400 | 1842 | 600 – 1000 | 803 | 87–100 | 60–90 | 100–150 | 5–6 | 40–45 | 100–150 | |
| | HAC 9 | 6 | 1350 – 2100 | 1697 ± 103 | 490 – 750 | 731 | 80–100 | 65–85 | 90–150 | 5–6 | 40–45 | 90–160 | |
| | **SAMLAR 1+2** | 5 | 1270 – 2070 | 1692 ± 149 | 520 – 810 | 684 | 90–100 | 65–110 | 120–150 | 4–5 | 40–50 | 110–150 | *adamsi* |
| | SAMLAR 1 | 3 | 1270 – 1800 | 1467 | 520 – 810 | 670 | 90 | 65–80 | 120–150 | 5 | 40 | 110–130 | |
| | SAMLAR 2 | 2 | 1930 – 2070 | 2030 | 680 – 730 | 705 | 100 | 80–11 | 80–110 | 4–4.5 | 45–50 | 130–150 | |
| *D. dispansa* | **HAC 8+9** | 16 | 250 – 505 | 336 ± 18 | 115 – 250 | 183 | 25–37 | 35–45 | 45–65 | 10–13 | 25–30 | 45–60 | *sella* |
| | HAC 8 | 8 | 250 – 505 | 370 ± 30 | 140 – 250 | 194 | 25–35 | 40–45 | 45–55 | 10–13 | 25–30 | 45–60 | |
| | HAC 9 | 8 | 255 – 340 | 302 ± 10 | 115 – 230 | 171 | 30–37 | 35–45 | 50–65 | 11–13 | 25–30 | 45–60 | |
| | **SAMLAR 1+2** | 31 | 240 – 410 | 294 ± 8 | 120 – 205 | 156 | 24–34 | 30–40 | 40–110 | 9–14 | 25–35 | 40–75 | *sella-hungarica* |
| | SAMLAR 1 | 22 | 240 – 390 | 286 ± 8 | 120 – 205 | 154 | 24–33 | 30–40 | 40–65 | 11–14 | 25–30 | 40–60 | |
| | SAMLAR 2 | 9 | 255 – 410 | 316 ± 19 | 130 – 190 | 159 | 25–34 | 35–40 | 50–110 | 9–13 | 25–35 | 40–75 | |
| | **AKÖR B 19** | 1 | | 445 | | 255 | – | – | – | – | – | – | indet. ssp. |
| | **KIRK 19** | 30 | 410 – 795 | 532 ± 17 | 180 – 405 | 227 | 30–49 | 35–50 | 85–120 | 7–10 | 25–35 | 60–110 | *umbilicata-dispansa* |
| *D. augustae* | **SAM A 4** | 1 | | 205 | | 140 | – | – | – | – | – | – | indet. ssp. |
| | **SAM A 14+16** | 25 | 165 – 260 | 199 ± 5 | 90 – 145 | 110 | 15–19 | 25–35 | 30–45 | 12–14 | 25–30 | 40–70 | *olianae* |
| | SAM A 14 | 9 | 165 – 260 | 211 ± 10 | 105 – 145 | 117 | 16–19 | 25–30 | 30–35 | 12–14 | 25 | 40–50 | |
| | SAM A 16 | 16 | 165 – 215 | 192 ± 3 | 90 – 120 | 106 | 15–19 | 30–35 | 35–45 | 12–13 | 25–30 | 45–70 | |
| | **SAM A 24** | 7 | 160 – 200 | 182 ± 6 | 100 – 120 | 104 | 15–18 | 30 | 30–40 | 13–14 | 25–30 | 45–60 | *olianae-atlantica* |
| | **HAC 9** | 1 | | 230 | | 110 | – | – | – | – | – | – | indet. ssp. |
| | **SAMLAR 1+2** | 25 | 170 – 245 | 198 ± 3 | 85 – 155 | 109 | 14–19 | 30 | 40–50 | 14–17 | 25–30 | 40–55 | *olianae* |
| | SAMLAR 1 | 15 | 170 – 245 | 202 ± 5 | 85 – 155 | 118 | 14–18 | 30 | 40 | 15–17 | 25–30 | 50–55 | |
| | SAMLAR 2 | 10 | 180 – 205 | 192 ± 2 | 85 – 105 | 96 | 17–19 | 30 | 45–50 | 14–15 | 25 | 40–50 | |
| | **KIRK 19** | 6 | 210 – 305 | 253 ± 16 | 110 – 170 | 143 | 20–25 | 30–35 | 55–60 | 11–13 | 25–30 | 45–50 | *augustae* |
| *D. trabayensis* | **SAM A 13-16** | 19 | 110 – 160 | 140 ± 3 | 55 – 105 | 79 | 6–11 | 35–50 | 25–40 | 13–17 | 25–30 | 50–80 | *elazigensis* |
| | SAM A 13 | 2 | 130 – 140 | 135 | 80 – 85 | 82 | 6–7 | – | – | – | – | – | |
| | SAM A 14 | 14 | 110 – 160 | 142 ± 4 | 55 – 105 | 80 | 6–10 | 35–50 | 25–40 | 13–17 | 25–30 | 50–80 | |
| | SAM A 16 | 3 | 110 – 150 | 135 | 60 – 100 | 77 | 8–11 | 45–50 | 30–35 | 14–16 | 25–30 | 55–80 | |
| | **SAM A 24** | 3 | 145 – 150 | 148 | 80 – 85 | 82 | 9 | – | – | – | – | – | cf. *elazigensis* |
| | **HAC 8+9** | 11 | 140 – 175 | 151 ± 3 | 80 – 100 | 92 | 7–13 | 30–45 | 25–40 | 11–16 | 25–30 | 50–90 | *elazigensis* |
| | HAC 8 | 8 | 140 – 175 | 152 ± 4 | 85 – 100 | 94 | 9–13 | 30–35 | 35–40 | 11–13 | 25 | 50–60 | |
| | HAC 9 | 3 | 140 – 160 | 148 | 80 – 90 | 85 | 7–9 | 35–45 | 25–35 | 13–16 | 30 | 50–90 | |
| | **SAMLAR 1+2** | 3 | 100 – 155 | 122 | 65 – 95 | 81 | 6–8 | 45–50 | 25–30 | 17 | 30 | 50–60 | cf. *trabayensis* - *elazigensis* |
| | SAMLAR 1 | 1 | | 110 | | 65 | 7 | – | – | – | – | – | |
| | SAMLAR 2 | 2 | 100 – 155 | 128 | 82 – 85 | 88 | 6–8 | 45–50 | 25–30 | 17 | 30 | 50–60 | |
| *D. pratti* | **AKÖR A 19** | 1 | | 860 | | 290 | – | – | – | – | – | – | indet. ssp. |
| | **HAC 3** | 1 | | 610 | | | – | – | – | – | – | – | indet. ssp. |
| | **HAC 8+9** | 23 | 505 – 1320 | 759 ± 45 | 190 – 650 | 335 | 39–75 | 40–70 | 90–130 | 5.5–7 | 30–35 | 85–140 | *minor* |
| | HAC 8 | 9 | 510 – 1320 | 760 ± 84 | 210 – 650 | 332 | 39–65 | 50–70 | 95–130 | 6–7 | 30–35 | 85–140 | |
| | HAC 9 | 14 | 505 – 1185 | 759 ± 52 | 190 – 520 | 336 | 40–75 | 40–60 | 90–130 | 5.5–7 | 30–35 | 100–135 | |
| | **SAMLAR 1+2** | 38 | 445 – 990 | 671 ± 22 | 195 – 530 | 303 | 42–58 | 45–60 | 75–120 | 5.5–7 | 25–30 | 80–100 | *pratti* |
| | SAMLAR 1 | 27 | 445 – 990 | 686 ± 27 | 195 – 530 | 308 | 42–58 | 45–60 | 75–120 | 5.5–6.5 | 25–30 | 80–100 | |
| | SAMLAR 2 | 11 | 510 – 860 | 635 ± 35 | 210 – 480 | 293 | 45–55 | 45–55 | 80–110 | 6–7 | 30 | 80–100 | |
| | **AKÖR B 19** | 1 | | 655 | | 235 | 43 | 50–60 | 95–120 | 6–7 | 25–30 | 90–100 | indet. ssp. |
| *D.* sp. | **KIRK 19** | 4 | 950 – 1410 | 1180 ± 86 | 490 – 655 | 585 | 55–65 | 90–100 | 75–110 | 5–7 | 35–40 | 100–120 | – |
| *D. samantai* | **KIRK 19** | 4 | 665 – 1185 | 900 ± 100 | 310 – 465 | 389 | 60–70 | 50–55 | 80–120 | 5 | 30–35 | 100–130 | – |
| *D. radians* | **SAM A 13-16** | 22 | 310 – 740 | 453 ± 23 | 115 – 305 | 193 | 22–30 | 45–55 | 65–85 | 7–8 | 25–30 | 70–100 | *labatlanensis* |
| | SAM A 13 | 1 | | 350 | | 145 | – | – | – | – | – | – | |
| | SAM A 14 | 11 | 315 – 740 | 467 ± 40 | 115 – 305 | 195 | 25–30 | 45–55 | 65–85 | 7–8 | 25–30 | 80–100 | |
| | SAM A 16 | 10 | 310 – 485 | 448 ± 24 | 155 – 235 | 196 | 22–29 | 45–50 | 70–80 | 7–8 | 25–30 | 70–85 | |
| | **SAM A 24** | 5 | 330 – 600 | 448 ± 43 | 170 – 210 | 191 | 23–28 | 45–55 | 70–85 | 7–8 | 25–30 | 80–100 | *labatlanensis* |
| | **AKÖREN 1** | 1 | | 540 | | 230 | 31 | 70 | 70 | 8 | 25–30 | 100 | indet. ssp. |
| | **HAC 8+9** | 4 | 360 – 470 | 415 ± 20 | 160 – 195 | 184 | 32 | 40–45 | 90 | 7.5 | 25 | 90 | *labatlanensis* |
| | HAC 8 | 2 | 360 – 410 | 385 | 160 – 190 | 175 | – | – | – | – | – | – | |
| | HAC 9 | 2 | 420 – 470 | 445 | 190 – 195 | 192 | 32 | 40–45 | 90 | 7.5 | 25 | 90 | |
| | **SAMLAR 1+2** | 4 | 345 – 610 | 509 ± 50 | 150 – 310 | 235 | 26–34 | 40–50 | 80–90 | 6.5–7 | 25–30 | 80–120 | *labatlanensis* |
| | SAMLAR 1 | 1 | | 610 | | 310 | 33 | 50 | 90 | 6.5 | 30 | 100–120 | |
| | SAMLAR 2 | 3 | 345 – 550 | 475 | 150 – 270 | 210 | 26–34 | 40–50 | 80–90 | 6.5–7 | 25 | 80–100 | |
| | **AKÖR B 19** | 3 | 410 – 440 | 420 | 190 – 250 | 215 | 38 | 30 | 85 | 7.5 | 25–30 | 80–90 | cf. *labatlanensis* |
| | **KIRK 19** | 1 | | 415 | | 180 | 30 | 35–40 | 80–85 | 7.5 | 25–30 | 80 | indet. ssp. |
| *D. nandori* | **SAM A 14+16** | 2 | 205 – 235 | 220 | 105 – 110 | 108 | – | – | – | – | – | – | – |
| | SAM A 14 | 1 | | 205 | | 105 | – | – | – | – | – | – | |
| | SAM A 16 | 1 | | 235 | | 110 | – | – | – | – | – | – | |
| | **HAC 9** | 2 | 155 – 195 | 175 | 90 – 90 | 90 | 15 | 30–35 | 45–50 | 9 | 20–25 | 70–80 | |
| | **SAMLAR 1+2** | 7 | 165 – 260 | 206 ± 11 | 90 – 140 | 113 | 13–17 | 30–40 | 40–65 | 10–11 | 20–25 | 55–80 | |
| | SAMLAR 1 | 3 | 165 – 260 | 212 | 90 – 140 | 118 | 14–17 | 30–40 | 40–65 | 10 | 20–25 | 55–70 | |
| | SAMLAR 2 | 4 | 170 – 225 | 201 ± 11 | 90 – 140 | 108 | 13–16 | 30–35 | 40–50 | 11 | 20–25 | 60–80 | |

**Table 2.** Statistical data of *Nemkovella*, *Orbitoclypeus* and *Asterocyclina* populations. №– number of specimens, s.e.– standard error.

| Parameters | | Outer cross-diameter of the embryon | | | | | Adauxiliary chamberlets | | | Equatorial chamberlets | | | Subspecific determination |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | deuteroconch | | | protoconch | | number | width | height | annuli/ 0.5 mm | width | height | |
| | | d (µm) | | | p (µm) | | N | W (µm) | H (µm) | n | w (µm) | h (µm) | |
| Species | Sample | № | range | mean±s.e. | range | mean | range | range | range | range | range | range | |
| *Nemkovella daguini* | **HAC 8** | **1** | | **95** | | **60** | **1** | **–** | **–** | **–** | **–** | **–** | – |
| | **SAMLAR 1+2** | **5** | **70 – 100** | **82 ± 5** | **60 – 70** | **62** | **1–2** | **25–35** | **20–30** | **20** | **20–25** | **30–65** | |
| | SAMLAR 1 | 4 | 70 – 90 | 78 ± 4 | 60 | 60 | 1–2 | 25–35 | 20–30 | 20 | 20–25 | 30–65 | |
| | SAMLAR 2 | 1 | | 70 | | 70 | – | – | – | – | – | – | |
| *Orbitoclypeus varians* | **HAC 9** | **1** | | **500** | | **295** | **44** | **45–55** | **70–80** | **13** | **35** | **50–60** | indet. ssp. |
| | **AKÖR B 6** | **2** | **405 – 450** | **428** | **210 – 240** | **225** | **–** | **–** | **–** | **–** | **–** | **–** | cf. *varians* |
| | **AKÖR B 19** | **16** | **280 – 465** | **355 ± 12** | **140 – 255** | **211** | **27–36** | **35–50** | **60–80** | **9–13** | **30–35** | **45–65** | *scalaris* |
| | **CAT A 1** | **1** | | **560** | | **305** | **41** | **45–50** | **75–80** | **9** | **35** | **50–60** | indet. ssp. |
| | **KIRK 19** | **23** | **270 – 605** | **432 ± 19** | **140 – 380** | **271** | **28–37** | **40–50** | **50–90** | **9–11** | **30–40** | **45–70** | *varians* |
| *O. haynesi* | **AKÖR B 19** | **2** | **195 – 210** | **202** | **100 – 145** | **122** | **16–19** | **35** | **35–40** | **15–19** | **30–35** | **35–55** | – |
| *O. furcatus* | **SAMLAR 2** | **13** | **295 – 405** | **350 ± 10** | **155 – 235** | **195** | **27–32** | **35–40** | **45–55** | **12–15** | **30–35** | **45–85** | *furcatus* |
| *Asterocyclina stellata* | **SAM A 13-16** | **20** | **160 – 255** | **219 ± 6** | **105 – 160** | **130** | **3–6** | **60–110** | **40–65** | **18–22** | **20–25** | **30–40** | *stellaris* |
| | SAM A 13 | 1 | | 190 | | 115 | – | – | – | – | – | – | |
| | SAM A 14 | 14 | 160 – 255 | 220 ± 7 | 110 – 160 | 132 | 3–6 | 60–110 | 40–65 | 18–21 | 20–25 | 30–40 | |
| | SAM A 16 | 5 | 195 – 255 | 220 ± 11 | 105 – 155 | 127 | 3–5 | 70–100 | 40–60 | 19–22 | 20–25 | 30–40 | |
| | **SAM A 24** | **2** | **210 – 220** | **215** | **130 – 140** | **135** | **–** | **–** | **–** | **–** | **–** | **–** | cf. *stellaris* |
| | **HAC 8+9** | **15** | **155 – 225** | **198 ± 5** | **100 – 155** | **130** | **3–5** | **60–95** | **40–65** | **19–22** | **20–25** | **30–45** | *stellaris* |
| | HAC 8 | 6 | 175 – 210 | 199 ± 5 | 110 – 140 | 133 | 3–4 | 60–80 | 40–60 | 19–22 | 20–25 | 30–40 | |
| | HAC 9 | 9 | 155 – 225 | 197 ± 7 | 100 – 155 | 127 | 3–5 | 65–95 | 45–65 | 20–22 | 25 | 30–45 | |
| | **SAMLAR 1+2** | **37** | **150 – 260** | **210 ± 4** | **105 – 195** | **136** | **3–5** | **70–115** | **35–55** | **19–22** | **25** | **30–40** | *stellaris* |
| | SAMLAR 1 | 28 | 150 – 260 | 210 ± 5 | 105 – 195 | 137 | 3–5 | 70–115 | 35–50 | 19–22 | 25 | 30–40 | |
| | SAMLAR 2 | 9 | 170 – 245 | 209 ± 9 | 105 – 160 | 134 | 3–4 | 80–110 | 40–55 | 20 | 25 | 30–40 | |
| | **AKÖR B 19** | **5** | **185 – 210** | **201 ± 4** | **120 – 150** | **135** | **3–4** | **55–60** | **50–55** | **19–22** | **20–25** | **30–40** | *stellaris* |
| | **KIRK 19** | **17** | **190 – 255** | **226 ± 4** | **130 – 165** | **147** | **3–5** | **65–95** | **40–55** | **20–23** | **20–25** | **35–40** | *stellaris* |
| | **KARAB 20** | **2** | **245 – 405** | **325** | **140 – 180** | **160** | **5–6** | **65–100** | **50–85** | **12–15** | **25–30** | **35–50** | cf. *buekkensis* |
| *A. stella* | **AKÖR A 2** | **1** | | **185** | | **115** | **–** | **–** | **–** | **–** | **–** | **–** | indet. ssp. |
| | **SAMLAR 1+2** | **19** | **140 – 255** | **191 ± 8** | **85 – 165** | **122** | **10–12** | **25–40** | **30–40** | **16–22** | **25** | **25–45** | *stella* |
| | SAMLAR 1 | 8 | 170 – 255 | 218 ± 12 | 120 – 165 | 141 | 11–12 | 25–40 | 30–40 | 19–22 | 25 | 25–35 | |
| | SAMLAR 2 | 11 | 140 – 220 | 177 ± 7 | 85 – 130 | 108 | 10–12 | 30–35 | 30–35 | 16–20 | 25 | 30–45 | |
| | **AKÖREN 1** | **1** | | **205** | | **130** | **14** | **35** | **35** | **21** | **20–25** | **25–30** | indet. ssp. |
| | **CAT A 1+3** | **12** | **210 – 275** | **239 ± 6** | **130 – 180** | **154** | **11–14** | **30–40** | **35–45** | **15–19** | **25** | **30–35** | *stella* |
| | CAT A 1 | 6 | 210 – 275 | 244 ± 9 | 145 – 180 | 158 | 11–14 | 30–40 | 35–45 | 16–19 | 25 | 30–35 | |
| | CAT A 3 | 6 | 210 – 260 | 234 ± 9 | 130 – 180 | 150 | 12–14 | 35–40 | 35–45 | 15–18 | 25 | 30–35 | |
| *A. kecskemetii* | **AKÖR B 19** | **4** | **255 – 350** | **290 ± 19** | **190 – 235** | **208** | **6–9** | **55–75** | **40–50** | **15–18** | **25–30** | **35–55** | – |
| | **SAMLAR 1** | **1** | | **360** | | **180** | **8** | **90** | **55–60** | **14** | **30** | **45–50** | |
| *A.* aff. *priabonensis* | **KIRK 19** | **2** | **250 – 260** | **255** | **145 – 150** | **148** | **14** | **30** | **40** | **17** | **25** | **35** | – |
| *A. alticostata* | **HAC 8+9** | **7** | **350 – 530** | **436 ± 20** | **245 – 395** | **331** | **2–3** | **270–400** | **50–75** | **10–11** | **40–45** | **60–80** | *alticostata–danubica* |
| | HAC 8 | 1 | | 415 | | 395 | – | – | – | – | – | – | |
| | HAC 9 | 6 | 350 – 530 | 440 ± 23 | 245 – 365 | 321 | 2–3 | 270–400 | 50–75 | 10–11 | 40–45 | 60–80 | |
| | **SAMLAR 1+2** | **20** | **310 – 635** | **460 ± 15** | **240 – 530** | **367** | **2–3** | **200–400** | **55–65** | **10–11** | **35–45** | **50–90** | *danubica–alticostata* |
| | SAMLAR 1 | 11 | 310 – 635 | 480 ± 24 | 240 – 530 | 369 | 2–3 | 270–400 | 55–60 | 10–11 | 35–45 | 50–90 | |
| | SAMLAR 2 | 9 | 350 – 490 | 436 ± 14 | 270 – 430 | 365 | 2–3 | 200–350 | 55–65 | 10–11 | 40–45 | 60–90 | |
| | **AKÖR B 19** | **5** | **410 – 515** | **464 ± 15** | **350 – 405** | **374** | **2–4** | **250–300** | **45–60** | **10–12** | **35–45** | **70–90** | *danubica* |
| | **KIRK 19** | **5** | **375 – 450** | **420 ± 13** | **320 – 360** | **340** | **2–4** | **250–300** | **40–55** | **9–10** | **40–45** | **55–65** | *alticostata* |

much less abundantly than in the southern part. It is represented by the unribbed *Orbitoclypeus varians* (Kaufmann 1867) and *O. haynesi* (Samanta & Lahiri 1985) and also by the ribbed *O. furcatus* (Rütimeyer 1850). The last taxon was discussed in Özcan *et al.* (2007a), the second one in Özcan *et al.* (2010a), while the first one in both of them. All three species are figured in Figure 34.

### Genus *Asterocyclina* Gümbel 1870

The specific composition of this genus in the northern and eastern part of the Thrace Basin equates with that in the southern part of the basin (Özcan *et al.* 2010a). *Asterocyclina* aff. *priabonensis* Gümbel 1870 was described in the above paper, while the other species, such as *A. stellata* (d'Archiac 1846), *A. stella* (Gümbel 1861), *A. kecskemetii* Less 1987 and *A. alticostata* (Nuttall 1926) were described in Özcan *et al.* (2007a). Specimens from our territory are illustrated in Figure 35.

### Family NUMMULITIDAE de Blainville 1827

For the generic classification of the family we apply the Hottinger (1977) principles and subdivision,

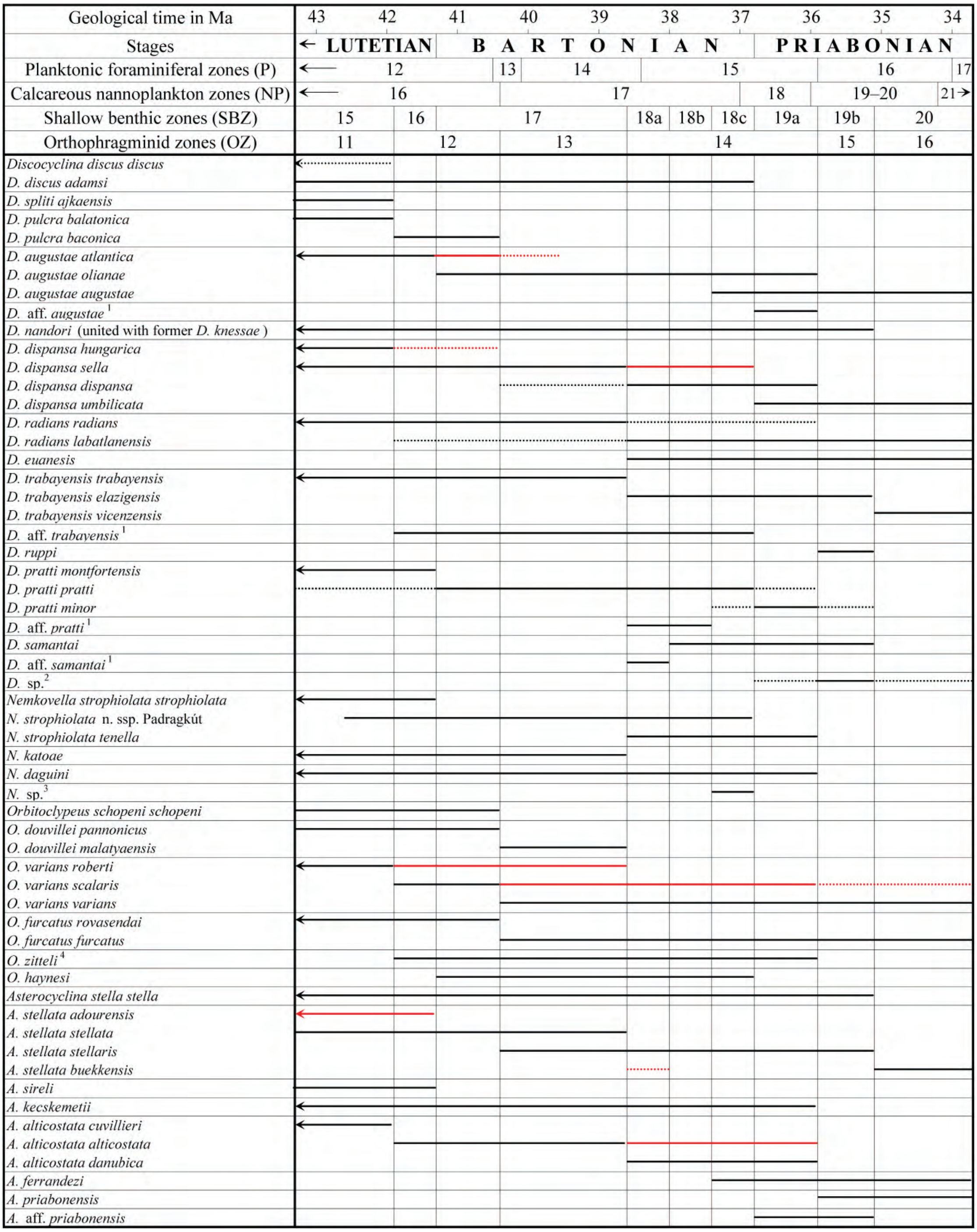



**Figure 32.** Updated orthophragminid range chart and zonation for the late Lutetian to late Priabonian. Updates compared to the range chart by Özcan *et al.* (2007a) are marked by red. Dashed lines indicate uncertain occurrences. The time scale, position of stages and zonal subdivision by planktonic foraminifera, calcareous nannoplankton and shallow benthic foraminifera are based on de Graciansky *et al.* (1999). [1] Described in Özcan *et al.* (2007a), [2] see in this paper, [3] figured in Less & Gyalog (2004) under the name of *N. oezcani* with no description, [4] see in Özcan *et al* (2010a), described as *O.* aff. *varians* in Özcan *et al.* (2007a).

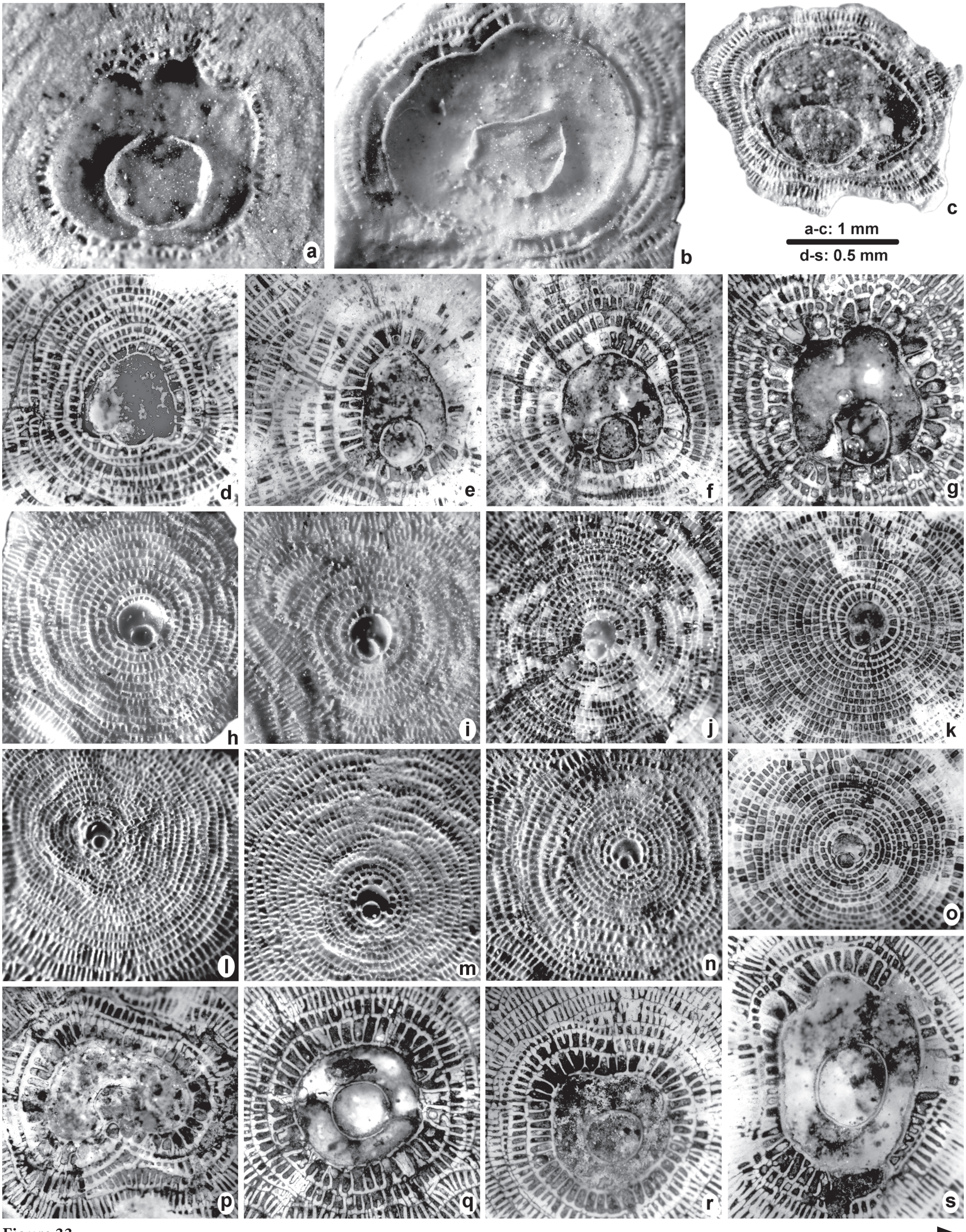



**Figure 33.**

with the addition by Romero *et al.* (1999) on the distinction of *Assilina* and *Operculina*. Five genera are recoded; three of them (*Nummulites*, *Assilina* and *Operculina*) with no secondary chamberlets, and the other two (*Heterostegina* and *Spiroclypeus*) with subdivided chambers.

### Genus *Nummulites* Lamarck 1801

The determination of *Nummulites* is based on both the surface characteristics and the features of the equatorial section. Following Drooger *et al.* (1971), Less (1999) introduced a measurement and parameter system to characterize the equatorial section of A-forms that is slightly modified here (Figure 31B, for explanation see the header of Tables 3 & 4).

Based on their surface characteristics the representatives of genus *Nummulites* in the studied area can be classified into three categories as follows: *N. garganicus*, *N. hormoensis* and *N. fabianii* belong to the reticulate, *N. aturicus*, *N. biedai* and *N. lyelli* to the granulate, while *N. maximus*, *N. striatus*, *N. incrassatus*, *N. vascus*, *N. chavannesi*, *N. cunialensis*, *N. pulchellus*, *N. stellatus*, *N. budensis*, *N. bouillei* and *N.* sp. to the radiate forms. Among these taxa the diameter of microspheric forms of *N. aturicus*, *N. biedai*, *N. lyelli* and *N. maximus* exceeds at least 2 cm; they are called giant *Nummulites*. Their proloculus size is also large, around 1 mm.

*Nummulites garganicus*, *N. hormoensis* and *N. fabianii* belong to the *N. fabianii* lineage. Numerous populations of this phylum from the Western Tethys, spanning from the early Bartonian to the early Chattian, are elaborated and the lineage is revised according to the measurement and parameter system mentioned above. Based on our preliminary communication (Less *et al.* 2006) the lineage is subdivided into species using the criteria shown in Figure 36. Biometric data are summarized in Table 3, whereas illustrations can be found in Figure 37. Since *N. hormoensis* Nuttall & Brighton 1931 and *N. fabianii* (Prever *in* Fabiani 1905) were recently discussed in Özcan *et al.* (2010a), we do not repeat their description here.

Among giant *Nummulites* (illustrated in Figure 38) *N. aturicus* and *N. biedai* belong to the *N. perforatus* group, *N. lyelli* (with characteristic multiplication of the spire in microspheric forms, see Figure 38a) to the *N. gizehensis* group, whereas *N. maximus* to the *N. millecaput* group, within which the size increase of the proloculus with time was well documented by Schaub (1981), Serra-Kiel (1984) and Less (1998b). A biometric calibration for the middle Eocene representatives of the *N. perforatus* group is in progress, the preliminary results are used in this work. Biometric data for the fully analyzed *N. perforatus* and *N. gizehensis* groups are summarized in Table 4, whereas for *N. maximus* only the statistical parameters of the inner cross-diameter of the proloculus (P) is given in Table 5. Since *N. biedai* Schaub 1962 and *N. lyelli* d'Archiac & Haime 1853 were recently discussed in Özcan *et al.* (2010a), we do not repeat their description here.

Based on Herb & Hekel (1975) and Less (1999) radiate *Nummulites* listed above (with the exception of *N. maximus*) belong to different lineages distinguishable by using typological criteria. They are illustrated in Figure 39, with the exception of *N. striatus* figured in Figure 37. Biometric data for the fully analyzed *N. vascus*, *N. pulchellus*, *N. stellatus*, *N. budensis*, *N. bouillei* and *N.* sp. are summarized in Table 4, whereas for *N. striatus*, *N. incrassatus*, *N. chavannesi* and *N. cunialensis* only the statistical parameters of the inner cross-diameter of the proloculus (P) is given in Table 5. Since *N. striatus* (Bruguiére 1792) was recently discussed in Özcan *et al.* (2010a), we do not repeat their description here.

**Figure 33.** **(a, b)** *Discocyclina discus adamsi* Samanta & Lahiri, **(a)** HAC 8, E.09.21., **(b)** Şamlar 2, E.09.22. **(c)** *Discocyclina* sp., KIRK 19, E.09.23. **(d)** *Discocyclina dispansa sella* (d'Archiac), HAC 8, E.09.24. **(e)** *Discocyclina dispansa* ex. interc. *sella* (d'Archiac) et *hungarica* Kecskeméti, Şamlar 2, E.09.25. **(f, g)** *Discocyclina dispansa* ex. interc. *umbilicata* (Deprat) et *dispansa* (Sowerby), KIRK 19. **(f)** E.09.26., **(g)** E.09.27. **(h–k)** *Discocyclina augustae olianae* Almela & Rios, **(h)** ŞAM.A 14, E.09.28., **(i)** ŞAM.A 16, E.09.29., **(j)** Şamlar 1, E.09.30., **(k)** Şamlar 2, E.09. 31. **(l–o)** *Discocyclina trabayensis elazigensis* Özcan & Less, **(l)** ŞAM.A 14, E.09.32., **(m)** ŞAM.A 14, E.09.33., **(n)** ŞAM.A 16, E.09.34., (o) HAC 9, E.09.35. **(p)** *Discocyclina pratti* (Michelin) indet. ssp., AKÖR B 19, E.09.36. **(q, r)** *Discocyclina pratti pratti* (Michelin), (q) Şamlar 1, E.09.37., (r) Şamlar 2, E.09.38. **(s)** *Discocyclina pratti minor* Meffert, HAC 9, E.09.39. All– A-form, equatorial sections. a–c: 20×, all the others: 40×.

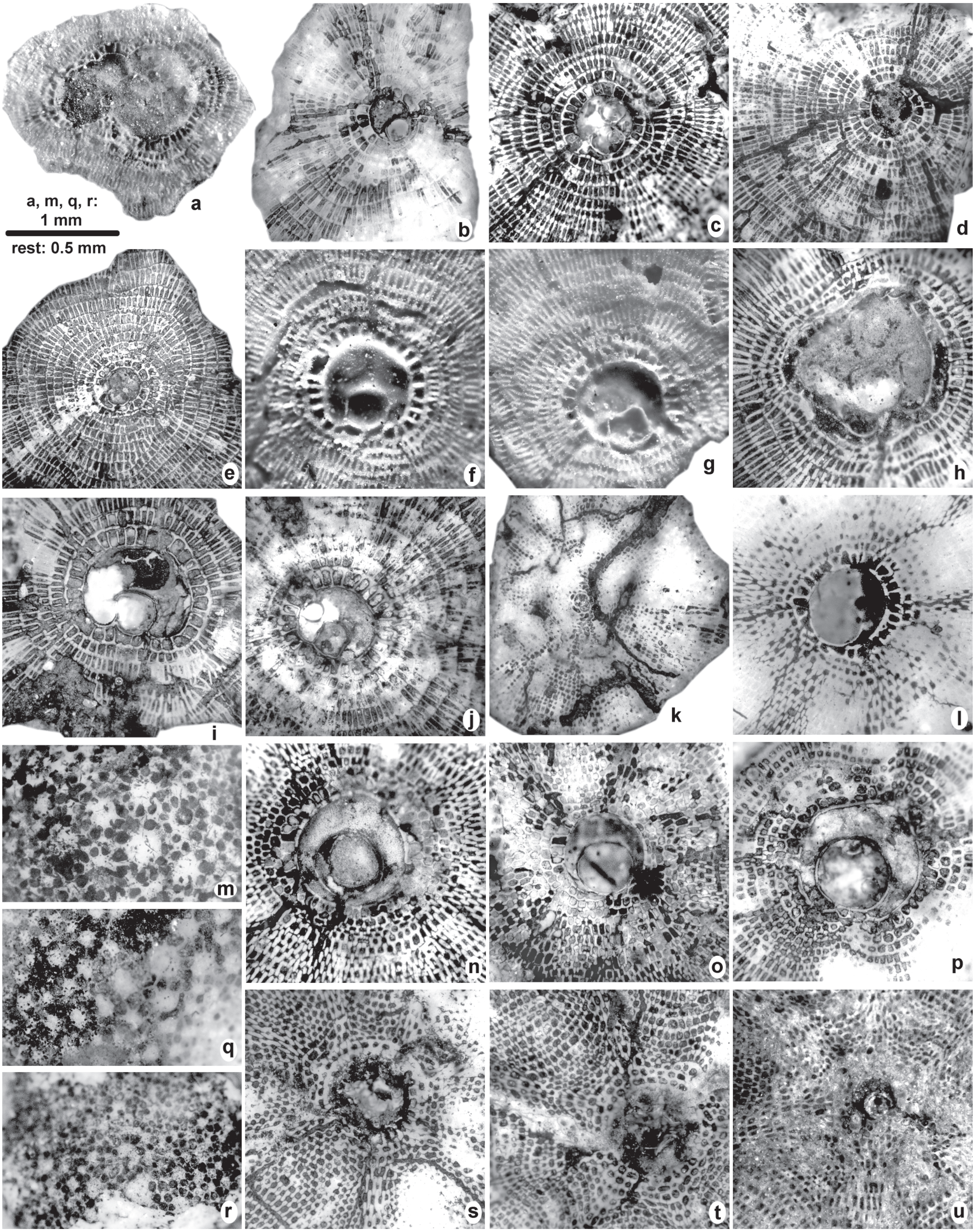



**Figure 34.**

### *Nummulites garganicus* Tellini 1890

Figure 37a–e, g–m

1890 *Nummulites garganica* nov. sp., Tellini, p. 381; plate 12, figure 5, plate 14, figure 4.

1890 *Nummulites subgarganica* nov. sp., Tellini, p. 382; plate 12, figures 10–11, plate 14, figures 1–3.

1971 *Nummulites garganicus* Tellini, Matteucci, p. 209–214; text-figures 7–9, plate 1, figures 1–21. (cum syn.)

2007a *Nummulites garganicus* Tellini, Özcan *et al*., plate 1, figure 4.

Based on our studies on topotypical *Nummulites garganicus*, the mean inner proloculus diameter, $P_{mean±s.e.}$ is 125±5 μm (22 specimens), which fits well to the biometric criterion given in Figure 36. These forms (mostly A-forms) occur abundantly in the middle part of the Şamlar section. Typical representatives occur in samples SAM.A 18 and 22 (Figure 37a–e, i), while intermediate forms towards *N. hormoensis* can be found below these horizons, mainly in sample SAM.A 14 (Figure 37j, k, m). The most striking feature is, however, that in the basal part of the section (in samples SAM.A 4 and SAM.B 5) reticulate *Nummulites* are represented by the more advanced *N. hormoensis*. This phenomenon can only be explained if we consider that these forms belong to one single, arbitrarily segmented lineage, whose large-scale evolution is influenced by local environmental and random factors, which causes slight fluctuations of the size parameters, and hence stratigraphical overlap of these artificial taxa as well. Formerly we believed that *N. garganicus* is characteristic for the early Bartonian SBZ 17 Zone (Less *et al*. 2006), but its presence above the first occurrence of *Heterostegina reticulata hungarica* in sample Şamlar SAM.A 14 indicates that the stratigraphic range of *N. garganicus* should be extended into the SBZ 18B Subzone.

### *Nummulites aturicus* Joly & Leymerie 1848

Figure 38q, r, t, u

1848 *Nummulites Aturica* (nob.) n. sp., Joly & Leymerie, p. 70, plate 2, figures 9, 10.

1981 *Nummulites aturicus* Joly & Leymerie, Schaub, p. 95–97, plate 15, figures 20–26, plate 16, figures 1–30, table 2p. (cum syn.)

According to our calibration of the middle Eocene representatives of the *N. perforatus* group this taxon is defined by mean proloculus diameter ($P_{mean}$) between 600 and 950 μm and mean average chamber length in the third whorl ($L_{mean}$) between 420 and 600 μm. It is characteristic mainly of the early Bartonian SBZ 17 Zone, although it can also be found in the late Lutetian (SBZ 16) and also in somewhat higher levels (SBZ 18A–B). In the eastern part of the Thrace Basin *N. aturicus* coexists or is very close to the primitive representatives of genus *Heterostegina*. Thus, these occurrences belong to the highest ones, up to the early–middle part of the late Bartonian (SBZ 18A–B Subzones).

### *Nummulites maximus* d'Archiac 1850

Figure 38f–k

1850 *Nummulites complanata* var. *maxima* n. var., d'Archiac, p. 12.

1981 *Nummulites maximus* d'Archiac, Schaub, p. 187–188; figures 109, 110c, plate 69, figures 23–32.

1981 *Nummulites* cf. *dufrenoyi* d'Archiac & Haime, Schaub, plate 69, figures 8–12, 14–21.

2007a *Nummulites maximus* d'Archiac, Özcan *et al*., plate 1, figure 3.

This taxon, with mean proloculus diameter ($P_{mean}$) above 900 μm, is probably the youngest and most developed member of the *Nummulites millecaput* group. It could be found in abundance in the higher

**Figure 34.** **(a)** *Discocyclina samantai* Less, KIRK 19, E.09.40. **(b–e)** *Discocyclina nandori* Less, **(b)** HAC 9, E.09.41., **(c)** Şamlar 1, E.09.42., **(d)** Şamlar 2, E.09.43., **(e)** Şamlar 1, E.09.44. **(f, g, i, j)** *Discocyclina radians labatlanensis* Less, **(f)** ŞAM.A 14, E.09.45., **(g)** ŞAM.A 16, E.09.46., **(i)** HAC 9, E.09.47., **(j)** Şamlar 2, E.09.48. **(h)** *Discocyclina radians* (d'Archiac) indet. ssp., Akören 1, E.09.49. **(k)** *Nemkovella daguini* (Neumann), Şamlar 1, E.09.50. **(l, m, o)** *Orbitoclypeus varians scalaris* (Schlumberger), AKÖR.B 19, **(l)** E.09.51., **(m)** E.09.52., **(o)** E.09.53. **(n)** *Orbitoclypeus varians* (Kaufmann) indet. ssp., HAC 9, E.09.54. **(p)** *Orbitoclypeus varians varians* (Kaufmann), KIRK 19, E.09.55. **(q, u)** *Orbitoclypeus haynesi* (Samanta & Lahiri), AKÖR.B 19, **(q)** E.09.56., **(u)** E.09.57. **(r–t)** *Orbitoclypeus furcatus furcatus* (Rütimeyer), Şamlar 2, **(r)** E.09.58., **(s)** E.09.59., **(t)** E.09.60. All A-forms. m, q, r– rosette (surface ornamentation), all the others– equatorial sections a, m, q, r: 20×, all the others: 40×.

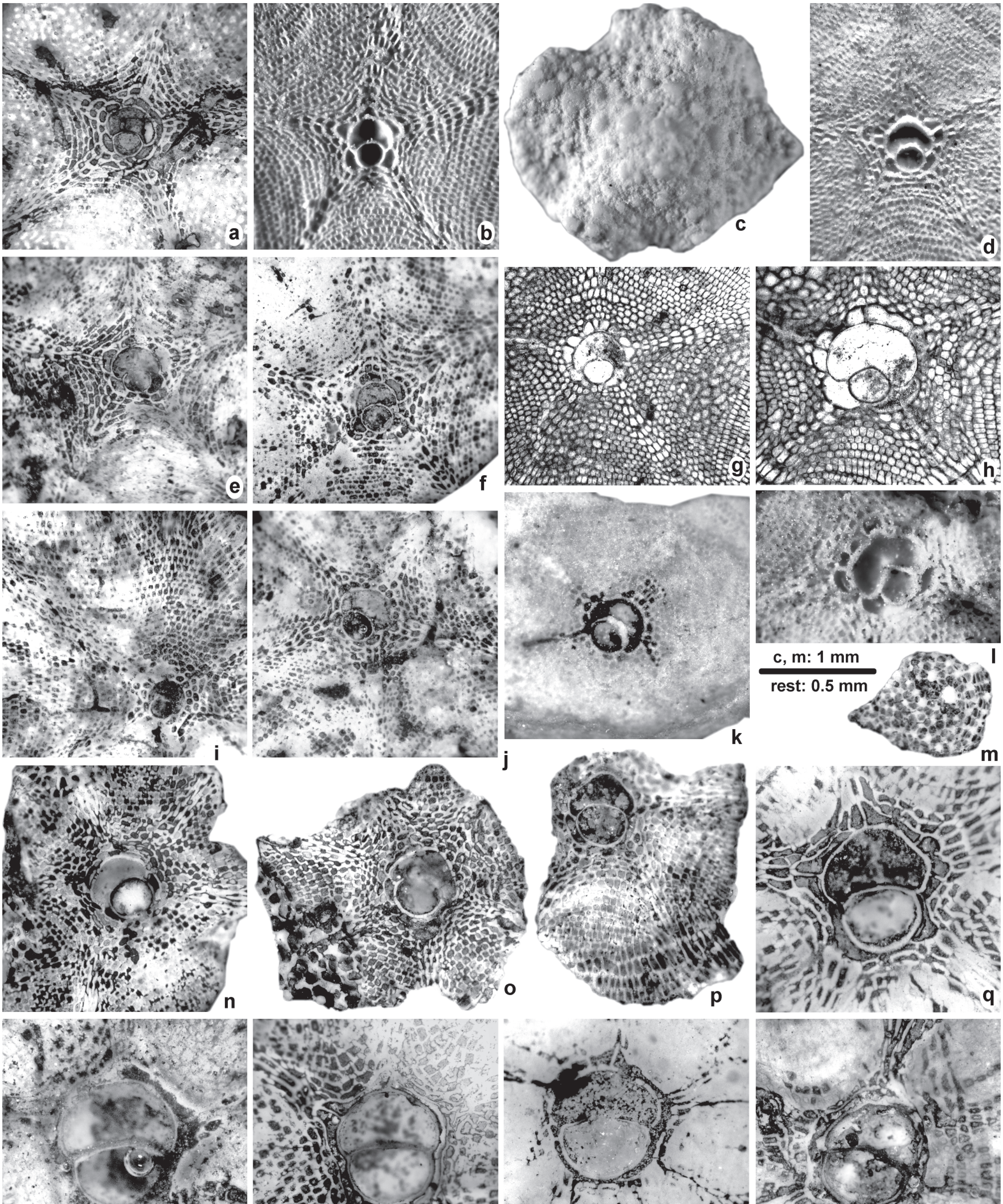



**Figure 35.**

→

| Taxon | $P_{mean}$ (μm) | Surface | Stage | SBZ zone |
|---|---|---|---|---|
| *N. bullatus* | 65–100 | granules, no reticulation | late Lutetian to basal Bartonian | SBZ 16 to early SBZ 17 |
| *N. garganicus* | 100–140 | heavy granules + reticulation | early to middle late Bartonian | late SBZ 17 to SBZ 18B |
| *N. hormoensis* | 140–200 | heavy granules + umbo + reticulation | late Bartonian | SBZ 18 |
| *N. fabianii* | 200–300 | weak granules + umbo + heavy reticulation | Priabonian to early Rupelian | SBZ 19–21 |
| *N. fichteli* | 200–300 | weak reticulation to irregular mesh | late Priabonian to late Rupelian | SBZ 20–22A |
| *N. bormidiensis* | 300–450 | irregular mesh | early Chattian | SBZ 22B |

**Figure 36.** Subdivision of the *Nummulites fabianii*-lineage in the Bartonian to early Chattian time-span (Özcan *et al.* 2010a).

part of the Şamlar and Hacimaşlı sections in the orthophragmine-dominated facies and commonly in sample Akören, AKÖR.B 6 with only subordinate orthophragmines. Microspheric forms appeared only to be abundant in the Hacimaşlı samples. In some other samples (Table 5) this taxon could only sporadically be found. All occurrences belong to the late Bartonian SBZ 18 Zone; in most of them its middle part, the SBZ 18B Subzone also can be recognized. Usually the representatives of the *N. millecaput* group found in the upper Bartonian are called *N.* (cf.) *dufrenoyi*. Our studies, however, from Safranbolu, the type locality of this taxon (Özcan *et al.* 2007b), have shown that the shallow marine succession at this locality close to the town ends at about the Ypresian/Lutetian boundary, and the Lutetian is represented by pelagic marls with no larger Foraminifera. Therefore, we refuse to use the name of *N. dufrenoyi* for the Bartonian representatives of the *N. millecaput* group and (not being better) prefer *N. maximus* for these forms.

### *Nummulites incrassatus* de la Harpe 1883

Figure 39a–r

1883 *Nummulites Boucheri* var. *incrassata* n. var., de la Harpe, plate 8, figure 53a.

1967 *Nummulites incrassatus* de la Harpe, Nemkov, p. 220–224, plate 29, figures 8–18, plate 30, figures 1–5. (cum syn.)

1975 *Nummulites incrassatus ramondiformis* de la Harpe, Herb & Hekel, p. 120–121, plate 1, figures 1–4, text-figures 6–8.

1999 *Nummulites incrassatus ramondiformis* de la Harpe, Less, p. 352, plate 1, figures 17, 18, table 3.

Under this name we probably joined some closely related radiate taxa, with moderately small embryon, evenly coiled spiral and slightly arched, more or less isometric chambers. The great variability and the differences between forms united under this name from different localities can well be seen in Figure 39. Since all these forms are described by different authors as *Nummulites incrassatus*, sometimes with different subspecific names (see the synonym list), we followed their practice. Serra-Kiel *et al.* (1998) indicated a late Bartonian to Priabonian age (SBZ 18–20) for the stratigraphic range of *N. incrassatus*, which is approved in this study.

### *Nummulites vascus* Joly & Leymerie 1848

Figure 39s–u, w

1848 *Nummulites Vasca* nobis, Joly & Leymerie, p. 38, 67, plate 1, figures 15–17, plate 2, figure 7.

1981 *Nummulites vascus* Joly & Leymerie, Schaub, p. 123–124, plate 53, figures 1–6, table 15e (cum syn.)

**Figure 35.** **(a-f)** *Asterocyclina stellata stellaris* (Brunner in Rütimeyer), (a) Hac 9, E.09.61., (b, c) Şam A 14, E.09.62., (d) Şam A 14, E.09.63., (e) Şamlar 1, E.09.64., (f) Şamlar 1, E.09. 65. **(g, h)** *Asterocyclina stellata* cf. *buekkensis* Less, Karab 20, (g) O/Karab-4, (h) O/Karab-3. **(i, j)** *Asterocyclina stella stella* (Gümbel), Şamlar 1, (i) E.09.66., (j) E.09.67. **(k)** *Asterocyclina* aff. *priabonensis* Gümbel, Kırk 19, E.09.68. **(l-p)** *Asterocyclina kecskemetii* Less, (l) Şamlar 1, E.09.69., (m, p) Akör B 19, E.09.70., (n) Akör B 19, E.09.71., (o) Akör B 19, E.09.72. **(q)** *Asterocyclina alticostata* ex. interc. *alticostata* (Nuttall) et *danubica* Less, Hac 9, E.09.73. **(r, s)** *Asterocyclina alticostata* ex. interc. *danubica* Less et *alticostata* (Nuttall), (r) Şamlar 1, E.09.74., (s) Şamlar 2, E.09.75. **(t)** *Asterocyclina alticostata danubica* Less, Akör B 19, E.09.76. **(u)** *Asterocyclina alticostata alticostata* (Nuttall), Kırk 19, E.09.77. All A-forms. c– external view, m– rosette (surface ornamentation), all the others– equatorial sections. c, m: 20×, all the others: 40×.

**Table 3.** Statistical data of reticulate *Nummulites* populations. №– number of specimens, s.e.– standard error.

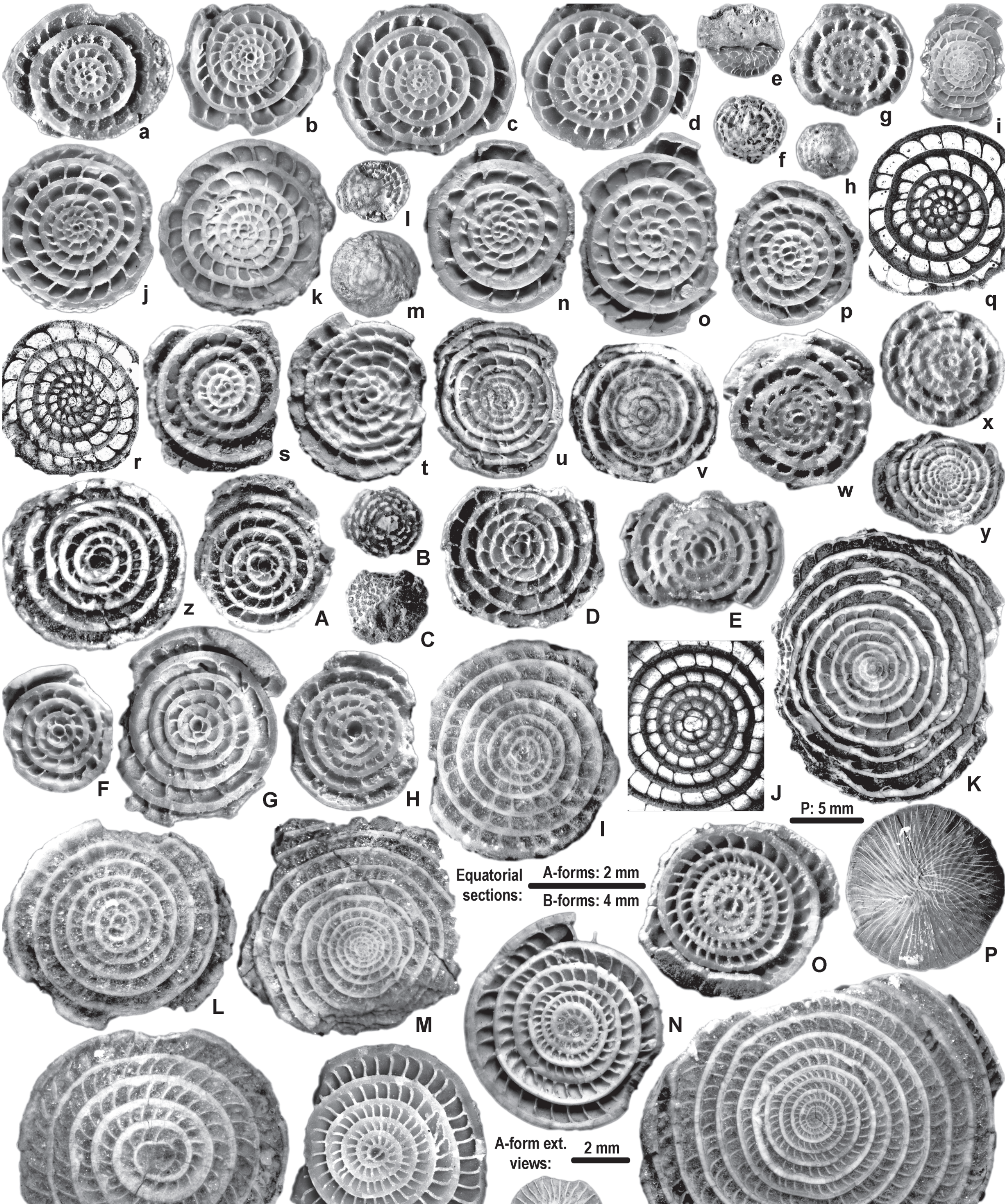
| Parameters | | Inner cross-diameter of the proloculus P (μm) | | | Outer diameter of the first two whorls d (μm) | | | Number of post-embryonic chambers in the first two whorls E | | | Index of spiral opening 3. whorl vs. first 3 whorls K=100×(D–d)/(D–P) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Taxon | Sample | № | range | mean ± s.e. | № | range | mean ± s.e. | № | range | mean ± s.e. | № | range | mean ± s.e. |
| *Nummulites garganicus* | **SAM A 18+22** | **42** | **85 – 185** | **124.6 ± 3.7** | **42** | **745 – 1170** | **949 ± 15** | **42** | **17 – 24** | **20.31 ± 0.22** | **42** | **33.3 – 46.0** | **38.00 ± 0.40** |
| | SAM A 18 | 16 | 90 – 180 | 126.9 ± 5.4 | 16 | 815 – 1110 | 938 ± 19 | 16 | 17 – 24 | 20.56 ± 0.43 | 16 | 34.3 – 41.3 | 38.47 ± 0.44 |
| | SAM A 22 | 26 | 85 – 185 | 123.3 ± 4.9 | 26 | 745 – 1170 | 956 ± 20 | 26 | 18 – 22 | 20.15 ± 0.22 | 26 | 33.3 – 46.0 | 37.72 ± 0.58 |
| *N.* ex. interc. *garganicus-hormoensis* | **AKÖR A 2** | **9** | **80 – 165** | **137.2 ± 8.4** | **9** | **915 – 1210** | **1034 ± 29** | **9** | **20 – 23** | **21.22 ± 0.41** | **8** | **33.8 – 39.3** | **36.81 ± 0.69** |
| | **SAM A 13-16** | **23** | **90 – 195** | **138.5 ± 6.4** | **23** | **760 – 1190** | **998 ± 25** | **23** | **19 – 23** | **20.91 ± 0.26** | **23** | **31.8 – 43.8** | **36.48 ± 0.53** |
| | SAM A 13 | 1 | | 110.0 | 1 | | 910 | 1 | | 19.00 | 1 | | 34.43 |
| | SAM A 14 | 21 | 90 – 195 | 138.1 ± 6.6 | 21 | 760 – 1165 | 993 ± 26 | 21 | 19 – 23 | 21.00 ± 0.27 | 21 | 31.8 – 43.8 | 36.70 ± 0.56 |
| | SAM A 16 | 1 | | 175.0 | 1 | | 1190 | 1 | | 21.00 | 1 | | 33.88 |
| *N. hormoensis* | **SAM A4+B5** | **47** | **100 – 195** | **146.1 ± 3.4** | **47** | **720 – 1345** | **1059 ± 18** | **47** | **17 – 23** | **20.57 ± 0.21** | **47** | **27.6 – 43.7** | **36.82 ± 0.46** |
| | SAM A 4 | 30 | 100 – 195 | 144.3 ± 4.6 | 30 | 720 – 1260 | 1042 ± 22 | 30 | 17 – 23 | 20.37 ± 0.27 | 30 | 34.0 – 43.7 | 38.27 ± 0.38 |
| | SAM B 5 | 17 | 110 – 190 | 149.1 ± 4.7 | 17 | 890 – 1345 | 1090 ± 28 | 17 | 19 – 23 | 20.94 ± 0.29 | 17 | 27.6 – 39.4 | 34.27 ± 0.75 |
| | **HAC 3** | **9** | **140 – 200** | **171.7 ± 5.7** | **9** | **980 – 1250** | **1151 ± 28** | **9** | **20 – 24** | **21.56 ± 0.47** | **7** | **29.9 – 38.9** | **35.62 ± 1.18** |
| | **HAC 4** | **16** | **120 – 175** | **145.3 ± 3.8** | **15** | **925 – 1305** | **1106 ± 29** | **15** | **18 – 23** | **20.47 ± 0.32** | **14** | **34.5 – 43.0** | **38.59 ± 0.65** |
| | **HAC 5** | **6** | **105 – 200** | **150.0 ± 12.8** | **6** | **1015 – 1180** | **1102 ± 24** | **6** | **19 – 22** | **20.50 ± 0.39** | **4** | **36.2 – 37.8** | **36.80 ± 0.30** |
| *N. hormoensis-fabianii* | **KIRK A 15** | **16** | **120 – 210** | **169.7 ± 6.6** | **16** | **910 – 1170** | **1009 ± 22** | **16** | **18 – 24** | **21.06 ± 0.35** | **16** | **28.6 – 41.8** | **35.76 ± 0.95** |
| | **CAT A 3** | **13** | **155 – 240** | **198.5 ± 6.8** | **13** | **1045 – 1440** | **1214 ± 28** | **13** | **18 – 23** | **20.38 ± 0.56** | **12** | **29.5 – 41.7** | **34.95 ± 0.97** |
| *N. fabianii-hormoensis* | **KIRK B 15** | **20** | **165 – 255** | **200.8 ± 5.4** | **20** | **910 – 1460** | **1185 ± 30** | **20** | **18 – 24** | **20.95 ± 0.37** | **20** | **29.3 – 43.1** | **33.45 ± 0.72** |
| | **KIRK 12** | **16** | **145 – 305** | **203.8 ± 9.9** | **16** | **855 – 1380** | **1140 ± 28** | **16** | **17 – 26** | **20.81 ± 0.52** | **16** | **29.8 – 39.1** | **34.06 ± 0.58** |
| *N. fabianii* | **KIRK 19** | **20** | **160 – 290** | **228.5 ± 7.9** | **19** | **910 – 1460** | **1225 ± 28** | **19** | **19 – 25** | **21.26 ± 0.40** | **19** | **29.5 – 36.4** | **33.80 ± 0.42** |
| | **KIRK D 1** | **20** | **165 – 310** | **238.8 ± 9.1** | **20** | **960 – 1545** | **1237 ± 34** | **20** | **16 – 20** | **17.85 ± 0.30** | **20** | **27.8 – 36.3** | **32.11 ± 0.54** |
| | **DOLHAN 1** | **22** | **160 – 305** | **235.9 ± 9.4** | **22** | **990 – 1460** | **1190 ± 28** | **22** | **14 – 20** | **17.27 ± 0.32** | **22** | **22.7 – 42.3** | **33.07 ± 0.85** |
| | **KIY 1** | **10** | **205 – 335** | **250.5 ± 10.5** | **10** | **1060 – 1340** | **1232 ± 25** | **10** | **17 – 22** | **19.70 ± 0.57** | **10** | **30.2 – 36.7** | **33.87 ± 0.62** |
| | **KIY 2** | **18** | **160 – 300** | **225.3 ± 9.3** | **18** | **1020 – 1600** | **1293 ± 37** | **18** | **16 – 21** | **18.50 ± 0.35** | **17** | **29.7 – 38.4** | **34.88 ± 0.63** |
| | **PINAR 1** | **19** | **210 – 460** | **283.2 ± 11.8** | **19** | **985 – 1615** | **1208 ± 35** | **19** | **16 – 23** | **19.74 ± 0.53** | **19** | **29.4 – 38.8** | **33.62 ± 0.51** |
| | **PINAR 6+9** | **49** | **200 – 395** | **287.6 ± 6.1** | **49** | **1010 – 1650** | **1257 ± 18** | **48** | **16 – 23** | **19.21 ± 0.24** | **49** | **29.3 – 45.6** | **34.07 ± 0.40** |
| | PINAR 6 | 22 | 205 – 305 | 267.0 ± 6.3 | 22 | 1035 – 1445 | 1213 ± 24 | 22 | 16 – 23 | 19.09 ± 0.42 | 22 | 29.3 – 36.1 | 33.33 ± 0.41 |
| | PINAR 9 | 27 | 200 – 395 | 304.3 ± 8.5 | 27 | 1010 – 1650 | 1293 ± 25 | 26 | 17 – 21 | 19.31 ± 0.27 | 27 | 29.6 – 45.6 | 34.67 ± 0.62 |

| Parameters | | T h i r d w h o r l | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | average length of chambers L=d×π/N (μm) | | | average shape of chambers F=100×(D–d)/(D–d+2d×π/N) | | | relative width of the spiral cord m=100×(D–M)/(D–d) | | |
| Taxon | Sample | № | range | mean ± s.e. | № | range | mean ± s.e. | № | range | mean ± s.e. |
| *Nummulites garganicus* | **SAM A 18+22** | **42** | **145 – 237** | **192.8 ± 3.0** | **42** | **52.0 – 64.1** | **56.67 ± 0.47** | **42** | **28.3 – 50.0** | **38.07 ± 0.74** |
| | SAM A 18 | 16 | 145 – 213 | 190.7 ± 4.2 | 16 | 54.0 – 61.9 | 57.05 ± 0.57 | 16 | 28.3 – 40.0 | 36.32 ± 0.83 |
| | SAM A 22 | 26 | 150 – 237 | 194.0 ± 4.0 | 26 | 52.0 – 64.1 | 56.44 ± 0.66 | 26 | 28.8 – 50.0 | 39.14 ± 1.03 |
| *N.* ex. interc. *garganicus-hormoensis* | **AKÖR A 2** | **9** | **151 – 236** | **199.0 ± 9.0** | **8** | **51.9 – 63.0** | **56.37 ± 1.19** | **8** | **26.3 – 42.9** | **36.01 ± 1.72** |
| | **SAM A 13-16** | **23** | **157 – 261** | **195.1 ± 5.5** | **23** | **49.9 – 65.3** | **55.85 ± 0.68** | **23** | **26.7 – 47.6** | **38.33 ± 1.12** |
| | SAM A 13 | 1 | | 166.2 | 1 | | 55.82 | 1 | | 47.62 |
| | SAM A 14 | 21 | 157 – 245 | 193.3 ± 5.0 | 21 | 52.1 – 65.3 | 56.13 ± 0.68 | 21 | 26.7 – 46.7 | 37.79 ± 1.13 |
| | SAM A 16 | 1 | | 261.4 | 1 | | 49.86 | 1 | | 40.38 |
| *N. hormoensis* | **SAM A4+B5** | **47** | **141 – 283** | **209.8 ± 3.5** | **47** | **45.4 – 64.5** | **55.83 ± 0.50** | **47** | **15.7 – 60.4** | **37.84 ± 1.07** |
| | SAM A 4 | 30 | 141 – 283 | 208.9 ± 4.8 | 30 | 51.1 – 64.5 | 57.09 ± 0.51 | 30 | 15.7 – 48.0 | 35.78 ± 1.20 |
| | SAM B 5 | 17 | 175 – 253 | 211.3 ± 5.0 | 17 | 45.4 – 59.5 | 53.61 ± 0.82 | 17 | 28.6 – 60.4 | 41.49 ± 1.72 |
| | **HAC 4** | **14** | **191 – 277** | **231.9 ± 6.5** | **14** | **52.5 – 59.2** | **56.27 ± 0.54** | **14** | **32.6 – 49.1** | **38.89 ± 1.28** |
| | **HAC 5** | **5** | **199 – 247** | **218.1 ± 8.1** | **4** | **52.9 – 58.4** | **56.18 ± 1.10** | **4** | **27.9 – 43.8** | **36.73 ± 2.83** |
| | **HAC 3** | **9** | **205 – 277** | **235.4 ± 7.4** | **7** | **47.9 – 57.5** | **53.81 ± 1.08** | **7** | **27.7 – 43.8** | **35.34 ± 2.22** |
| *N. hormoensis-fabianii* | **KIRK A 15** | **16** | **181 – 282** | **212.6 ± 7.9** | **16** | **47.2 – 60.1** | **52.39 ± 1.11** | **16** | **26.1 – 50.7** | **36.48 ± 2.07** |
| | **CAT A 3** | **13** | **197 – 285** | **240.8 ± 6.9** | **12** | **45.2 – 57.8** | **52.72 ± 1.13** | **12** | **28.0 – 53.5** | **39.77 ± 2.08** |
| *N. fabianii-hormoensis* | **KIRK B 15** | **20** | **168 – 287** | **235.2 ± 7.3** | **20** | **44.0 – 62.1** | **51.23 ± 0.87** | **20** | **21.8 – 56.9** | **43.24 ± 2.09** |
| | **KIRK 12** | **16** | **181 – 319** | **224.2 ± 7.8** | **16** | **45.9 – 57.5** | **51.89 ± 0.66** | **16** | **30.6 – 51.9** | **39.64 ± 1.24** |
| *N. fabianii* | **KIRK 19** | **19** | **188 – 276** | **236.7 ± 4.9** | **19** | **47.2 – 55.8** | **51.82 ± 0.61** | **19** | **29.1 – 50.0** | **40.30 ± 1.06** |
| | **KIRK D 1** | **20** | **197 – 373** | **264.6 ± 8.2** | **20** | **42.6 – 53.9** | **47.14 ± 0.66** | **20** | **24.4 – 50.6** | **38.33 ± 1.50** |
| | **DOLHAN 1** | **22** | **198 – 330** | **260.6 ± 8.0** | **22** | **41.4 – 57.4** | **47.50 ± 0.85** | **22** | **24.4 – 48.6** | **37.14 ± 1.26** |
| | **KIY 1** | **10** | **201 – 260** | **236.0 ± 6.2** | **10** | **47.5 – 56.1** | **51.56 ± 0.91** | **10** | **18.1 – 43.1** | **32.62 ± 2.43** |
| | **KIY 2** | **18** | **238 – 336** | **275.3 ± 6.7** | **17** | **43.6 – 58.4** | **50.64 ± 0.90** | **17** | **32.7 – 43.3** | **37.84 ± 0.76** |
| | **PINAR 1** | **19** | **175 – 322** | **233.9 ± 9.1** | **19** | **43.2 – 56.8** | **50.15 ± 0.75** | **19** | **20.6 – 40.8** | **28.89 ± 1.18** |
| | **PINAR 6+9** | **49** | **177 – 314** | **242.2 ± 4.1** | **49** | **41.8 – 60.4** | **50.82 ± 0.48** | **49** | **18.3 – 94.5** | **29.87 ± 1.53** |
| | PINAR 6 | 22 | 177 – 310 | 234.6 ± 6.7 | 22 | 41.8 – 56.1 | 50.28 ± 0.72 | 22 | 18.3 – 36.0 | 28.63 ± 1.04 |
| | PINAR 9 | 27 | 198 – 314 | 248.4 ± 4.8 | 27 | 46.9 – 60.4 | 51.26 ± 0.63 | 27 | 19.5 – 94.5 | 30.88 ± 2.62 |

**Table 4.** Statistical data of fully analyzed non-reticulate *Nummulites* populations. №– number of specimens, s.e.– standard error.

| Parameters | | Inner cross-diameter of the proloculus P (μm) | | | Outer diameter of the first two whorls d (μm) | | | Number of post-embryonic chambers in the first two whorls E | | | Index of spiral opening 3. whorl vs. first 3 whorls K=100×(D–d)/(D–P) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Taxon | Sample | № | range | mean ± s.e. | № | range | mean ± s.e. | № | range | mean ± s.e. | № | range | mean ± s.e. |
| *Nummulites lyelli* | AKÖR A 16+19 | 25 | 865 – 1820 | 1171.0 ± 48.5 | 25 | 2660 – 4780 | 3668 ± 108 | 25 | 19 – 31 | 23.84 ± 0.68 | 22 | 19.0 – 50.4 | 29.98 ± 1.31 |
| | AKÖR A 16 | 24 | 865 – 1820 | 1155.2 ± 47.9 | 24 | 2660 – 4780 | 3643 ± 109 | 24 | 19 – 31 | 24.00 ± 0.69 | 21 | 19.0 – 50.4 | 30.26 ± 1.34 |
| | AKÖR A 19 | 1 | | 1550.0 | 1 | | 4280 | 1 | | 20.00 | 1 | | 24.17 |
| *N. aturicus* | HAC 5 | 17 | 610 – 1250 | 888.5 ± 36.8 | 14 | 2350 – 3390 | 2969 ± 79 | 14 | 18 – 27 | 21.50 ± 0.59 | 14 | 26.1 – 39.0 | 32.42 ± 0.86 |
| | SAM A 22 | 7 | 760 – 1145 | 915.0 ± 47.0 | 6 | 2530 – 3680 | 3059 ± 146 | 6 | 20 – 26 | 22.50 ± 0.74 | 6 | 23.1 – 39.4 | 32.36 ± 2.00 |
| *N.* cf. *aturicus* | SAM B 7 | 4 | 760 – 1100 | 930.0 ± 65.0 | 1 | | 2860 | 1 | | 21.00 | 1 | | 33.12 |
| *N.* ex. interc. *aturicus-biedai* | AKÖR A 1 | 10 | 820 – 1200 | 944.5 ± 34.9 | 7 | 2710 – 3650 | 3139 ± 102 | 6 | 21 – 27 | 23.67 ± 0.93 | 6 | 28.4 – 32.7 | 31.52 ± 0.61 |
| | AKÖR A 16+19 | 38 | 710 – 1375 | 1005.8 ± 26.3 | 38 | 2370 – 4370 | 3181 ± 71 | 38 | 17 – 27 | 21.71 ± 0.38 | 36 | 26.0 – 36.2 | 30.93 ± 0.50 |
| *N. biedai* | AKÖR A 16 | 11 | 770 – 1210 | 1030.9 ± 43.7 | 11 | 2730 – 3900 | 3244 ± 115 | 11 | 17 – 26 | 20.45 ± 0.72 | 11 | 26.7 – 36.2 | 31.15 ± 0.83 |
| | AKÖR A 19 | 27 | 710 – 1375 | 995.6 ± 32.3 | 27 | 2370 – 4370 | 3155 ± 88 | 27 | 19 – 27 | 22.22 ± 0.41 | 25 | 26.0 – 36.0 | 30.83 ± 0.61 |
| *N. pulchellus* | SAM A 13 | 6 | 95 – 145 | 121.7 ± 8.4 | 5 | 645 – 960 | 767 ± 49 | 5 | 26 – 30 | 28.40 ± 0.61 | 5 | 37.5 – 62.5 | 46.64 ± 3.92 |
| *N. stellatus* | SAM A 14+16 | 14 | 35 – 90 | 53.2 ± 3.7 | 14 | 450 – 740 | 583 ± 24 | 14 | 14 – 22 | 17.79 ± 0.64 | 14 | 40.0 – 57.1 | 45.71 ± 1.19 |
| | SAM A 14 | 10 | 35 – 90 | 50.5 ± 4.7 | 10 | 450 – 720 | 558 ± 25 | 10 | 14 – 22 | 17.50 ± 0.83 | 10 | 41.1 – 57.1 | 46.29 ± 1.47 |
| | SAM A 16 | 4 | 55 – 70 | 60.0 ± 3.1 | 4 | 570 – 740 | 645 ± 38 | 4 | 17 – 21 | 18.50 ± 0.75 | 4 | 40.0 – 49.5 | 44.24 ± 1.76 |
| | KIRK 19 | 10 | 45 – 105 | 78.5 ± 5.3 | 10 | 580 – 910 | 756 ± 35 | 10 | 16 – 21 | 18.90 ± 0.46 | 10 | 35.5 – 48.9 | 40.70 ± 1.41 |
| | PINAR 20 | 1 | | 70.0 | 1 | – | 990 | 1 | | 19.00 | 1 | | 39.87 |
| *N. budensis* | CAT A 10+11 | 9 | 60 – 85 | 70.0 ± 3.1 | 9 | 700 – 1470 | 1104 ± 79 | 9 | 18 – 24 | 20.78 ± 0.52 | 3 | 39.4 – 55.3 | 46.70 |
| | CAT A 10 | 5 | 60 – 85 | 69.0 ± 4.3 | 5 | 700 – 1310 | 986 ± 100 | 5 | 18 – 22 | 20.40 ± 0.61 | 2 | 45.4 – 55.3 | 50.37 |
| | CAT A 11 | 4 | 60 – 80 | 71.3 ± 4.5 | 4 | 1020 – 1470 | 1253 ± 80 | 4 | 20 – 24 | 21.25 ± 0.82 | 1 | | 39.35 |
| | LALAP 12 | 12 | 50 – 95 | 70.0 ± 4.9 | 10 | 850 – 2050 | 1277 ± 133 | 10 | 18 – 22 | 19.60 ± 0.35 | 5 | 50.3 – 53.7 | 51.86 ± 0.61 |
| | KIY 3 | 33 | 40 – 135 | 72.6 ± 4.0 | 29 | 690 – 2200 | 1241 ± 63 | 29 | 16 – 25 | 20.90 ± 0.34 | 10 | 48.3 – 61.1 | 53.94 ± 1.43 |
| | PINAR A 1 | 18 | 50 – 100 | 71.7 ± 3.3 | 18 | 790 – 2400 | 1284 ± 91 | 18 | 18 – 22 | 20.39 ± 0.27 | 9 | 47.8 – 58.7 | 55.25 ± 1.10 |
| | PINAR 6 | 2 | 55 – 85 | 70.0 | 2 | 1390 – 1550 | 1470 | 2 | 17 – 18 | 17.50 | | | |
| | PINAR 20 | 3 | 55 – 100 | 83.3 | 3 | 1270 – 1350 | 1323 | 3 | 19 – 20 | 19.67 | 1 | | 39.23 |
| *N. vascus* | KARAB 24 | 14 | 145 – 360 | 236.1 ± 13.2 | 14 | 850 – 1460 | 1231 ± 47 | 14 | 20 – 26 | 22.29 ± 0.50 | 13 | 32.5 – 39.9 | 35.89 ± 0.56 |
| *N. bouillei* | KARAB 24 | 9 | 110 – 215 | 135.6 ± 10.2 | 8 | 900 – 1530 | 1165 ± 59 | 8 | 20 – 28 | 23.00 ± 0.90 | 8 | 40.8 – 46.6 | 43.50 ± 0.76 |
| *N.* sp. | KIRK A 15 | 5 | 55 – 90 | 74.0 ± 6.5 | 5 | 560 – 700 | 608 ± 26 | 5 | 24 – 27 | 25.20 ± 0.52 | 5 | 37.8 – 44.4 | 41.16 ± 1.03 |

| Parameters | | Third whorl: average length of chambers L=d×π/N (μm) | | | Third whorl: average shape of chambers F=100×(D–d)/(D–d+2d×π/N) | | | Third whorl: relative width of the spiral cord m=100×(D–M)/(D–d) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Taxon | Sample | № | range | mean ± s.e. | № | range | mean ± s.e. | № | range | mean ± s.e. |
| *Nummulites lyelli* | AKÖR A 16+19 | 24 | 400 – 648 | 507.0 ± 12.1 | 22 | 42.0 – 67.5 | 50.76 ± 1.16 | 22 | 14.0 – 45.7 | 28.63 ± 1.70 |
| | AKÖR A 16 | 23 | 400 – 648 | 505.7 ± 12.5 | 21 | 42.0 – 67.5 | 51.05 ± 1.18 | 21 | 14.0 – 45.7 | 28.74 ± 1.78 |
| | AKÖR A 19 | 1 | | 537.8 | 1 | | 44.71 | 1 | | 26.44 |
| *N. aturicus* | HAC 5 | 14 | 462 – 625 | 533.6 ± 15.2 | 14 | 41.3 – 54.1 | 48.29 ± 1.02 | 14 | 12.8 – 24.8 | 18.39 ± 0.86 |
| | SAM A 22 | 6 | 474 – 590 | 536.9 ± 16.7 | 6 | 39.9 – 55.4 | 48.62 ± 2.08 | 6 | 25.4 – 41.4 | 31.71 ± 2.02 |
| *N.* cf. *aturicus* | SAM B 7 | 1 | | 493.7 | 1 | | 51.30 | 1 | | 21.15 |
| *N.* ex. interc. *aturicus-biedai* | AKÖR A 1 | 6 | 448 – 638 | 539.0 ± 28.8 | 6 | 42.7 – 52.4 | 47.79 ± 1.30 | 6 | 19.8 – 25.5 | 23.63 ± 0.77 |
| | AKÖR A 16+19 | 37 | 338 – 743 | 519.8 ± 14.7 | 36 | 41.4 – 55.7 | 48.24 ± 0.59 | 36 | 17.4 – 35.8 | 26.00 ± 0.72 |
| *N. biedai* | AKÖR A 16 | 11 | 438 – 743 | 564.6 ± 29.4 | 11 | 42.2 – 52.4 | 47.08 ± 0.88 | 11 | 20.4 – 34.0 | 26.51 ± 1.28 |
| | AKÖR A 19 | 26 | 338 – 646 | 500.9 ± 15.4 | 25 | 41.4 – 55.7 | 48.75 ± 0.73 | 25 | 17.4 – 35.8 | 25.77 ± 0.87 |
| *N. pulchellus* | SAM A 13 | 5 | 79 – 129 | 110.6 ± 7.8 | 5 | 64.3 – 85.2 | 70.95 ± 3.44 | 5 | 12.0 – 26.7 | 18.63 ± 2.16 |
| *N. stellatus* | SAM A 14+16 | 14 | 101 – 197 | 138.8 ± 7.1 | 14 | 54.3 – 74.0 | 61.63 ± 1.28 | 14 | 19.4 – 39.7 | 28.24 ± 1.47 |
| | SAM A 14 | 10 | 101 – 178 | 130.6 ± 7.4 | 10 | 55.6 – 74.0 | 62.58 ± 1.55 | 10 | 19.4 – 39.7 | 28.79 ± 1.83 |
| | SAM A 16 | 4 | 140 – 197 | 159.3 ± 11.3 | 4 | 54.3 – 64.3 | 59.25 ± 1.79 | 4 | 21.8 – 33.8 | 26.87 ± 2.20 |
| | KIRK 19 | 10 | 139 – 203 | 163.9 ± 5.8 | 10 | 54.7 – 64.7 | 58.42 ± 0.90 | 10 | 17.6 – 48.7 | 30.21 ± 2.86 |
| | PINAR 20 | 1 | | 200.7 | 1 | | 60.32 | 1 | | 14.75 |
| *N. budensis* | CAT A 10+11 | 6 | 122 – 201 | 167.3 ± 12.0 | 3 | 63.1 – 76.2 | 69.71 | 3 | 15.1 – 19.7 | 18.10 |
| | CAT A 10 | 4 | 122 – 196 | 156.1 ± 14.7 | 2 | 69.8 – 76.2 | 73.00 | 2 | 15.1 – 19.5 | 17.31 |
| | CAT A 11 | 2 | 178 – 201 | 189.5 | 1 | | 63.14 | 1 | | 19.67 |
| | LALAP 12 | 5 | 160 – 188 | 174.0 ± 4.9 | 5 | 69.8 – 75.3 | 73.29 ± 0.93 | 5 | 14.3 – 18.8 | 16.57 ± 0.64 |
| | KIY 3 | 14 | 128 – 254 | 173.1 ± 10.0 | 10 | 70.5 – 83.0 | 77.13 ± 1.17 | 10 | 7.9 – 23.0 | 11.93 ± 1.36 |
| | PINAR A 1 | 15 | 131 – 260 | 183.9 ± 10.4 | 9 | 71.4 – 82.5 | 78.47 ± 0.95 | 9 | 7.0 – 17.4 | 12.28 ± 0.92 |
| | PINAR 6 | | | | | | | | | |
| | PINAR 20 | 2 | 210 – 249 | 229.7 | 1 | | 61.88 | 1 | | 14.81 |
| *N. vascus* | KARAB 24 | 13 | 167 – 287 | 221.7 ± 8.8 | 13 | 51.1 – 60.2 | 55.85 ± 0.81 | 13 | 18.1 – 34.7 | 25.85 ± 1.40 |
| *N. bouillei* | KARAB 24 | 8 | 149 – 226 | 198.4 ± 8.3 | 8 | 63.2 – 68.6 | 66.54 ± 0.57 | 8 | 15.6 – 29.5 | 20.89 ± 1.70 |
| *N.* sp. | KIRK A 15 | 5 | 84 – 129 | 102.0 ± 7.0 | 5 | 59.5 – 69.1 | 64.70 ± 1.38 | 5 | 31.4 – 41.0 | 35.46 ± 1.69 |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P: 5 mm
Equatorial sections:
A-forms: 2 mm
B-forms: 4 mm
A-form ext. views:
2 mm

**Figure 37.**

This taxon is only recorded from sample KARAB 24 in the lower Rupelian (SBZ 21) deposits of the Karaburun section, where it coexists with *N. bouillei* and scarcer *Operculina complanata*. It is recognized by the medium-sized embryon, evenly coiled spiral and definitely arched isometric chambers. The senior author also compared the Karaburun specimens with topotypical *N. vascus* from Biarritz, rocher de la Vierge (SW France) of early Rupelian (SBZ 21) age, and found them quite similar both typologically and biometrically. The Karaburun specimens (Figure 39s, w) are also very similar to some Priabonian forms from samples KIRK 19, KIY 3 and PINAR 20+22 (Figure 39p, q, r) determined here as *N. incrassatus*, although the embryon is considerably larger. Therefore, we suppose there was phylogenetic relationship between these forms. A Rupelian to early Chattian (SBZ 21 to 22B) age was deduced by Cahuzac & Poignant (1997) for the stratigraphic range of *N. vascus*. In Turkey, however, we failed to find it in the upper Rupelian (SBZ 22A) and lower Chattian (SBZ 22B) assemblages of the western Taurides (Özcan *et al.* 2009a) and of the Kelereşdere section near Muş (Özcan *et al.* 2010b).

### *Nummulites chavannesi* de la Harpe 1878

Figure 39v, x–z, A, B

1878 *Nummulites chavannesi* n. sp., de la Harpe, p. 232. (nomen nudum)

1883 *Nummulites chavannesi* de la Harpe, de la Harpe, plate 6, figures 22–41.

1975 *Nummulites chavannesi* de la Harpe, Herb & Hekel, p. 123–125, plate 2, figures 1–3, text-figures 14–21. (cum syn.)

1999 *Nummulites chavannesi* de la Harpe, Less, p. 352, 354, plate 1, figures 15, 16, table 3.

1999 *Nummulites chavannesi* de la Harpe, Rasser *et al.*, p. 687, plate 3, figures 1–3, 5–7.

This radiate taxon with a distinct umbo is characterized by a moderately small embryon, moderately opening spiral and moderately arched, relatively high chambers. Although some variation can be observed between assemblages from different localities, these are much smaller than in the case of *Nummulites incrassatus* (see above). Serra-Kiel *et al.* (1998) deduced a late Bartonian to Priabonian age (SBZ 18–20) for the stratigraphic range of *N. chavannesi*, in agreement with our data presented here.

### *Nummulites cunialensis* Herb & Hekel 1975

Figure 39C–I

1975 *Nummulites cunialensis* n. sp., Herb & Hekel, p. 122–123, plate 1, figures 5–8, text-figures 9–13.

1999 *Nummulites cunialensis* Herb et Hekel, Rasser *et al.*, p. 687, plate 3, figures 4, 8, 12, 16.

This taxon bears almost the same characteristics as *Nummulites chavannesi*, but its proloculus is considerably smaller (compare them in Figure 39 and in Table 5). According to Serra-Kiel *et al.* (1998) the stratigraphic range of this taxon is restricted to the early Priabonian (SBZ 19), which, based on our new data, has to be extended (as in the case of *N. pulchellus* and *N. stellatus*, see below) at least to the middle and late part of the late Bartonian (SBZ 18B–C). Its persistence up to the end of the Priabonian (SBZ 20) cannot be excluded either.

**Figure 37.** **(a–e, i)** *Nummulites garganicus* Tellini, **(a)** ŞAM.A 18, E.09.78., **(b)** ŞAM.A 22, E.09.79., **(c)** ŞAM.A 22, E.09.80., **(d, e)** ŞAM.A 22, E.09.81., **(i)** ŞAM.A 22, E.09.82. **(f, l, n-u)** *Nummulites hormoensis* Nuttall & Brighton, **(f, p)** ŞAM.B 5, E.09.83., **(l)** ŞAM.A 4, E.09.91., **(n, o)** ŞAM.A 4, E.09.84., **(q)** HAC 4, Ö.HAC2-1, **(r)** HAC 3, Ö.HAC-7-22, **(s)** HAC 5, E.09.85., **(t)** KIRK.A 15, E.09.86., **(u)** KIRK.A 15, E.09.87. **(g, h, j, k, m)** *Nummulites* ex. interc. *garganicus* Tellini et *hormoensis* Nuttall et Brighton, **(g, h)** AKÖR.A 2, E.09.88., **(j)** ŞAM.A 14, E.09.89., **(k, m)** ŞAM.A 14, E.09.90. **(v)** *Nummulites* ex. interc. *hormoensis* Nuttall et Brighton et *fabianii* (Prever in Fabiani), ÇAT.A 3, E.09.92. **(w, y)** *Nummulites* ex. interc. *fabianii* (Prever in Fabiani) et *hormoensis* Nuttall et Brighton, **(w)** KIRK.B 15, E.09.93., **(x)** KIRK.12, E.09.94., **(y)** KIRK.B 15, E.09.95. **(z–M)** *Nummulites fabianii* (Prever in Fabiani), **(z)** KIRK 19, E.09.96., **(A, B)** KIRK 19, E.09.97., **(C)** KIRK.D 1, E.09.98., **(D)** KIRK.D 1, E.09.99., **(E)** Dolhan 1, E.10.1., **(F)** KIY 2, E.09.100., **(G)** KIY 2, E.09.101., **(H)** KIY 1, E.09.102., **(I)** Pinar 1, E.09.103., **(J)** Pınar 9, Ö.Pın-8-12, **(K)** KIRK.D 1, E.09.104., **(L)** Pınar 6, E.09.105., **(M)** Pınar 6, E.09.106. **(N–T)** *Nummulites striatus* Bruguière, **(N, S)** AKÖR.A 2, E.09.107., **(O)** HAC 4, E.09.108., **(P)** AKÖR.A 2, E.09.109., **(Q)** AKÖR.A 1, E.09.110., **(R)** ŞAM.A 22, E.09.111., **(T)** AKÖR.A 2, E.09.112. i, u, y, K, M, P, T– B-forms, all the others– A-forms. e, f, h, l, m, B, C, P, S– external views, all the others– equatorial sections. P: 2.5×, e, f, h, i, l, m, u, y, B, C, K, M, S, T: 5×, all the others: 10×.

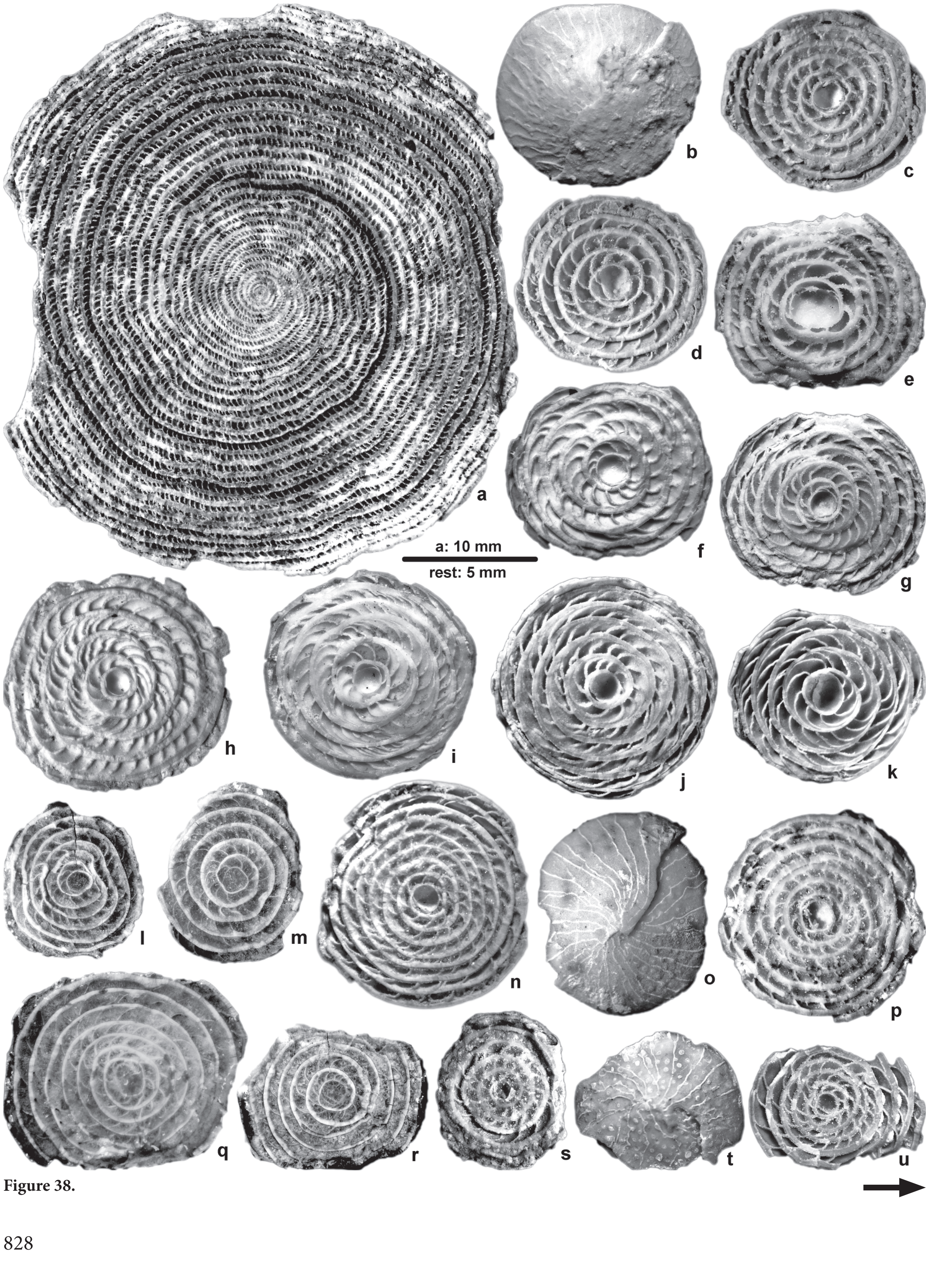


**Figure 38.**

### *Nummulites pulchellus* Hantken in de la Harpe 1883

Figure 39J

1883 *Nummulites pulchella* Hantken, de la Harpe, p. 160, plate 5, figures 15–21.

1975 *Nummulites pulchellus* Hantken in de la Harpe, Herb & Hekel, p. 126–127, plate 2, figures 4–13, text-figures 26–32. (cum syn.)

1999 *Nummulites pulchellus* Hantken in de la Harpe, Less, p. 354, plate 1, figure 19, table 3.

This *Nummulites* can easily be distinguished from the other upper Bartonian and Priabonian radiate forms by its densely spaced, narrow and high, almost straight chambers. It only occurs, although abundantly, in sample Şamlar, SAM.A 13, together with *Heterostegina reticulata hungarica*. This is in the middle part of the upper Bartonian (SBZ 18B) well below the horizons with giant *Nummulites* (*N*. ex. interc. *aturicus-biedai* in sample SAM.A 22 and *N. maximus* in samples SAMLAR 1 and 2). This means that the stratigraphic range of *N. pulchellus*, given by Serra-Kiel *et al*. (1998) as restricted to the Priabonian (SBZ 19–20), has to be extended to at least the middle late Bartonian.

### *Nummulites stellatus* Roveda 1961

Figure 39U–X

1961 *Nummulites stellatus* n. sp., Roveda, p. 181, plate 15, figures 1–14, plate 17, figures 7, 11, text-figures 12–13.

1975 *Nummulites stellatus* Roveda, Herb & Hekel, pp. 127–128, plate 1, figures 12–16, text-figures 33–37.

1999 *Nummulites stellatus* Roveda, Less, p. 354, plate 1, figure 20, plate 2, figures 1, 2, table 3.

This radiate *Nummulites* can easily be identified by its very small embryon, moderately open spiral, and principally by its more or less isometric chambers bordered by strongly inclined and arched septa. It has been found not only in Priabonian samples such as Kırklareli KIRK 19 and Pınarhisar PINAR 20 but also in the middle part of the Şamlar section, in samples SAM.A 14 and 16, together with *Heterostegina reticulata hungarica* and well below the horizons with giant *Nummulites* listed above at *N. pulchellus*. As in the case of this latter taxon, the stratigraphic range (SBZ 19–20, given by Serra-Kiel *et al*. 1998) has to be extended to at least the middle late Bartonian (SBZ 18B).

### *Nummulites budensis* Hantken 1875

Figure 39K–Q

This radiate *Nummulites* (for synonym list see Özcan *et al*. 2010a) can easily be identified based on its very small embryon, loose spiral, narrow and high chambers, straight near the base, then strongly arched. It can be found abundantly, predominating over other taxa, in samples Çatalca, ÇAT.A 10 and 11, Kıyıköy, KIY 3 and Pınarhisar, PINAR.A 1, whereas in other samples (see Table 4) it is accessorial. As discussed in Less (1999), *Nummulites budensis* is a characteristic taxon of the middle to late Priabonian (SBZ 19B–20). Its occurrence in the Çatalca samples, however, allows us to extend the above stratigraphic range down to the Bartonian/Priabonian boundary.

### *Nummulites bouillei* de la Harpe 1879

Figure 39R, S

1879 *Nummulites Bouillei* n. sp., de la Harpe, p. 142–143, plate 1, figures 1–3.

1999 *Nummulites bouillei* de la Harpe, Less, plate 2, figures 11–13.

**Figure 38.** (**a**–**e**) *Nummulites lyelli* d'Archiac & Haime, (**a**) AKÖR.A 16, E.09.113., (**b**) AKÖR.A 16, E.09.114., (**c**) AKÖR.A 16, E.10.2., (**d**) AKÖR.A 16, E.10.3., (**e**) AKÖR.A 19, E.09.115. (**f**–**k**) *Nummulites maximus* d'Archiac, (**f**) HAC 8, E.09.118., (**g**) Hac 9, E.09.117., (**h**) AKÖR.B 6, E.09.119., (**i**) AKÖR.B 6, E.09.120., (**j**) Şamlar 1, E.09.121., (**k**) Şamlar 1, E.09.122. (**l, m**) *Nummulites* ex. interc. *aturicus* Joly & Leymerie et *biedai* Schaub, AKÖR.A 1, (**l**) E.09.123., (**m**) E.09.124. (**n**–**p**) *Nummulites biedai* Schaub, (**n**) AKÖR.A 16, E.10.4., (**o**) AKÖR.A 19, E.09.125., (**p**) AKÖR.A 19, E.09.126. (**q, r ,t ,u**) *Nummulites aturicus* Joly & Leymerie, (**q**) HAC 5, E.09.128., (**r**) HAC 5, E.09.129., (**t, u**) ŞAM.A 22, E.09.131. (**s**) *Nummulites* cf. *aturicus* Joly & Leymerie, ŞAM.B 7, E.09.130. a– B-form, all the others– A–forms. b, n, t– external views, all the others– equatorial sections. a: 2.5×, all the others: 5×.


a
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A-form equatorial sections:
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2 mm
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**Figure 39.**

This taxon is only recorded from sample KARAB 24 in the lower Rupelian (SBZ 21) deposits of the Karaburun section, where it coexists with the dominant *Nummulites vascus* and rare *Operculina complanata*. *N. bouillei* is determined by its moderately small embryon, moderately loose spiral and definitely arched, moderately high chambers. The senior author also compared the Karaburun specimens with topotypical *N. bouillei* from Biarritz, rocher de la Vierge (SW France) of early Rupelian (SBZ 21) age (see in Less 1999), and found them similar both typologically and biometrically. Based on Cahuzac & Poignant (1997) *N. bouillei* spans from the Priabonian up to the end of the Chattian. Less (1999) showed, however, that in this interpretation three, biometrically distinguishable taxa are united under this name. The Priabonian forms belong to *N. budensis* (see above), whereas the Chattian forms belong to *N. kecskemetii*, and only the (early) Rupelian representatives correspond to the true *N. bouillei*.

**_Nummulites_ sp.**

Figure 39T

A few radiate forms with very small embryon, moderately loose spiral and almost straight septa bordering small chambers that are only slightly higher than wide could be found sporadically, coexisting with *Nummulites hormoensis* in the basal beds of the Kırklareli series of sections in sample KIRK.A 15. The internal image of these forms closely resembles that of the *N. garnieri* group, with which, however, they could not be grouped because of the lack of granulation.

**Genus _Assilina_ d'Orbigny 1839**

**_Assilina_ ex. gr. _alpina_ (Douvillé 1916)**

Figure 40a–i

Based on Romero *et al.* (1999) the evolute forms, formerly named *Operculina alpina*, *O. schwageri*, etc. belong to the genus *Assilina*, since their septa are not folded and not intersected by stolons. According to Hottinger (1977), this group forms a single evolutionary lineage. As this needs, however, a serious revision since biometric limits between chronotaxa are not yet established, they are described jointly under the name of *A.* ex. gr. *alpina*. Based on data in Table 6 a considerable size increase of the mean of the inner cross-diameter of the proloculus (P) with time can be observed, starting from about 60–70 µm in sample Akören AKÖR.A 2 of middle Bartonian (SBZ 17/18) age, and ending with 130–150 µm in sample Kırklareli KIRK 19 of early Priabonian (SBZ 19) age.

**Genus _Operculina_ d'Orbigny 1826**

This genus (illustrated in Figure 40) with folded septa intersected by stolons is represented in the Eocene by the involute *O.* ex. gr. *gomezi* Colom & Bauzá 1950 with very dense and high chambers, but in the Oligocene by the evolute *O. complanata* (Defrance 1822). Since recently the former was briefly discussed by Özcan *et al.* (2010a), while the latter by Özcan *et al.* (2009a, b) and Özcan & Less (2009), here we do not give their description. Statistical data of the inner diameter of the proloculus (P) are tabulated in Table 6.

**Figure 39.** **(a–r)** *Nummulites incrassatus* de la Harpe, **(a)** AKÖR.B 6, E.09.132., **(b)** Akören 1, E.09.133., **(c, d)** AKÖR.B 6, E.09.134., **(e)** AKÖR.B 19, E.09.135., **(f, l)** AKÖR.B 19, E.09.136., **(g)** ŞAM.A 14, E.09.137., **(h)** ŞAM.A 14, E.09.138., **(i)** ŞAM.A 22, E.09.139., **(j)** Şamlar 1 E.09.140., **(k)** Şamlar 1, E.09.141., **(m)** ÇAT.A 10, E.09.143., **(n)** KIRK.B 15, E.09.144., **(o)** KIRK.D 1, E.09.145., **(p)** KIY 3, E.09.146., **(q)** KIRK 19, E.09.147., **(r)** Pınar 20, E.09.148. **(s–u, w)** *Nummulites vascus* Joly & Leymerie, Karab 24, **(s)** O.09.1., **(t, u)** O.09.2., **(w)** O.09.3. **(v, x–z, A, B)** *Nummulites chavannesi* de la Harpe,. **(v)** AKÖR.A 2, E.09.149., **(x, z)** Lalap 12, E.09.150., **(y)** AKÖR.A 16, E.09.151., **(A)** HAC 4, E.09.152., **(B)** Lalap 12, E.09.153. **(C–I)** *Nummulites cunialensis* Herb & Hekel, **(C)** AKÖR.B 6, E.09.160., **(D)** KIRK 19, E.09.155., **(E)** KIY 2, E.09.156., **(F)** Şamlar 2, E.09.157., **(G)** Akören 1, E.09.158., **(H)** ŞAM.A 16, E.09.159., **(I)** Pınar.A 1, E.09.154. **(J)** *Nummulites pulchellus* Hantken in de la Harpe, ŞAM.A 13, E.09.161. **(K–Q)** *Nummulites budensis* Hantken, (K) KIY 3, E.09.162., **(L)** Lalap 12, E.09.163., **(M)** KIY 3, E.09.164., **(N, P)** Pınar.A 1, E.09.165., **(O)** Pınar 20, E.09.166., **(Q)** Pınar.A 1, E.09.167. **(R, S)** *Nummulites bouillei* de la Harpe, KARAB 24, **(R)** O.09.4., **(S)** O.09.5. **(T)** *Nummulites* sp. KIRK A 15, E.09.168. **(U–X)** *Nummulites stellatus* Roveda, **(U)** Pınar 20, E.09.169., **(V)** ŞAM.A 14, E.09.170., **(W)** ŞAM.A 16, E.09.171., **(X)** KIRK 19, E.09.172. c, d, k, u, v, y, z–B-forms, all the others– A-forms. c, l, m, u, y, P– external views, all the others– equatorial sections. c, d, k, l, m, u, v, y, z, P: 5×, all the others: 10×.

**Table 5.** Statistical data of the inner cross-diameter of the proloculus of not fully analyzed, non-reticulate *Nummulites* populations (in µm). №– number of specimens, s.e.– standard error.

| Taxon | Sample | № | range | mean ± s.e. |
|---|---|---|---|---|
| *Nummulites maximus* | **AKÖR A 16** | **3** | **1020 – 1215** | **1095** |
| | **SAM B 7** | **2** | **1010 – 1050** | **1030** |
| | **SAM A 16** | **1** | | **840** |
| | **HAC 8+9** | **35** | **855 – 1500** | **1085 ± 22** |
| | HAC 8 | 17 | 900 – 1500 | 1115 ± 34 |
| | HAC 9 | 18 | 855 – 1270 | 1057 ± 26 |
| | **SAMLAR 1+2** | **20** | **740 – 1550** | **1114 ± 46** |
| | SAMLAR 1 | 18 | 740 – 1550 | 1097 ± 50 |
| | SAMLAR 2 | 2 | 1250 – 1270 | 1260 |
| | **AKÖR B 6** | **10** | **790 – 1185** | **950 ± 37** |
| *N. striatus* | **AKÖR A 1+2** | **26** | **200 – 440** | **306 ± 13** |
| | AKÖR A 1 | 8 | 285 – 440 | 349 ± 20 |
| | AKÖR A 2 | 18 | 200 – 400 | 286 ± 14 |
| | **HAC 4** | **19** | **195 – 470** | **273 ± 13** |
| | **SAM A 18+22** | **17** | **200 – 345** | **269 ± 10** |
| | SAM A 18 | 6 | 200 – 295 | 248 ± 15 |
| | SAM A 22 | 11 | 230 – 345 | 281 ± 11 |
| *N. incrassatus* | **AKÖR A 16+19** | **7** | **160 – 230** | **190 ± 10** |
| | AKÖR A 16 | 5 | 160 – 230 | 186 ± 13 |
| | AKÖR A 19 | 2 | 190 – 210 | 200 |
| | **AKÖREN 1** | **7** | **145 – 240** | **185 ± 11** |
| | **AKÖR B 6** | **6** | **130 – 240** | **191 ± 17** |
| | **AKÖR B 19** | **7** | **170 – 245** | **197 ± 9** |
| | **SAM B 5** | **1** | | **160** |
| | **HAC 4** | **2** | **140 – 210** | **175** |
| | **SAM A 14+16** | **17** | **105 – 195** | **154 ± 6** |
| | SAM A 14 | 13 | 105 – 195 | 155 ± 8 |
| | SAM A 16 | 4 | 145 – 165 | 150 ± 4 |
| | **SAM A 18+22** | **9** | **110 – 190** | **152 ± 8** |
| | SAM A 18 | 3 | 135 – 155 | 145 |
| | SAM A 22 | 6 | 110 – 190 | 156 ± 11 |
| | **HAC 8+9** | **18** | **110 – 225** | **164 ± 6** |
| | HAC 8 | 9 | 130 – 225 | 163 ± 8 |
| | HAC 9 | 9 | 110 – 200 | 166 ± 10 |
| | **SAMLAR 1+2** | **13** | **115 – 190** | **150 ± 5** |
| | SAMLAR 1 | 12 | 115 – 190 | 150 ± 6 |
| | SAMLAR 2 | 1 | | 155 |
| | **CAT A 10** | **2** | **155 – 280** | **218** |
| | **KIRK B 15** | **15** | **155 – 330** | **252 ± 14** |
| | **KIRK 12** | **2** | **190 – 200** | **195** |
| | **KIRK D 1** | **7** | **145 – 240** | **176 ± 12** |
| | **KIRK 19** | **13** | **145 – 240** | **197 ± 8** |
| | **KIY 2** | **1** | | **160** |
| | **KIY 3** | **8** | **120 – 215** | **152 ± 9** |
| | **LALAP 5** | **6** | **195 – 250** | **222 ± 8** |
| | **PINAR 6** | **1** | | **160** |
| | **PINAR 20+22** | **7** | **170 – 200** | **184 ± 4** |
| *N. chavannesi* | **AKÖR A 2** | **2** | **155 – 205** | **180** |
| | **AKÖR A 16+19** | **6** | **135 – 255** | **189 ± 16** |
| | AKÖR A 16 | 5 | 135 – 255 | 186 ± 18 |
| | AKÖR A 19 | 1 | | 205 |
| | **HAC 4** | **3** | **150 – 190** | **168** |
| | **SAMLAR 2** | **1** | | **155** |
| | **CAT A 11** | **2** | **140 – 150** | **145** |
| | **KIRK 19** | **1** | | **200** |
| | **LALAP 12** | **8** | **200 – 260** | **229 ± 8** |
| *N. cunialensis* | **AKÖREN 1** | **3** | **55 – 80** | **68** |
| | **AKÖR B 6** | **3** | **85 – 100** | **92** |
| | **SAM A 16** | **4** | **50 – 100** | **78 ± 9** |
| | **SAMLAR 1+2** | **15** | **55 – 110** | **84 ± 5** |
| | SAMLAR 1 | 9 | 55 – 105 | 81 ± 6 |
| | SAMLAR 2 | 6 | 60 – 110 | 89 ± 6 |
| | **KIRK 19** | **5** | **110 – 140** | **127 ± 5** |
| | **KIY 2** | **1** | | **100** |
| | **LALAP 12** | **2** | **80 – 90** | **85** |
| | **PINAR A 1** | **3** | **105 – 150** | **130** |

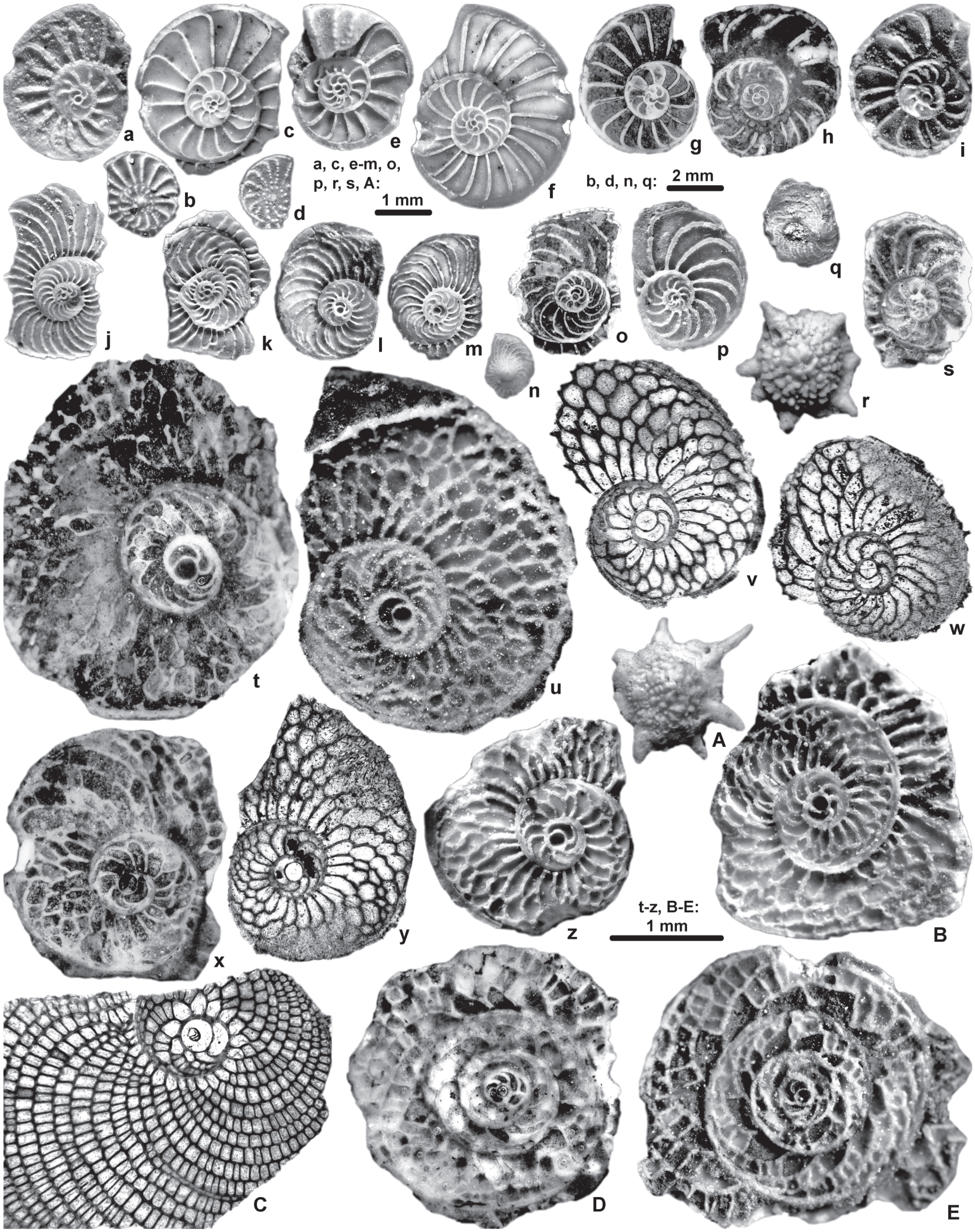
## Genus *Heterostegina* d'Orbigny 1826

Based on a rather widespread Mediterranean material, the Eocene representatives of this genus from the Western Tethys have recently been revised by Less *et al*. (2008), who arranged them into three species. These are *Heterostegina armenica*, *H. reticulata* and *H. gracilis*; all of them occurring in our material, too. Their numerical description is based on the system introduced by Drooger & Roelofsen (1982) for *Cycloclypeus*. The explanation of measurements and counts made in the equatorial section of each megalospheric specimen (Figure 31C) are given in the header of Table 7, where biometrical data are also presented. Here we do not repeat the descriptions by Less *et al*. (2008), only the results are applied. However, in *H. armenica* we could observe its more developed evolutionary stage known so far, which allowed us to introduce a new subspecies called *H. a. hacimasliensis*. With this, the diagnosis of both the species and *H. a. tigrisensis* had to be emended. Since genus *Heterostegina* is quite widespread in the Thrace Basin, in Figure 41 we have plotted the mean values of P and X (see Figure 31C and the header of Table 7) of their populations at the 95% confidence level in order to show the rapid evolution within the *H. armenica* and *H. reticulata* lineages. Beside our material we have also used data from the southern margin of the Thrace Basin presented in Özcan *et al*. (2007a, 2010a). The Hacimaşlı section is of great importance for the stratigraphy of Eocene *Heterostegina*, since here the superposition of *H. reticulata* above *H. armenica* could directly be observed.

### *Heterostegina armenica* (Grigoryan 1986)

Figure 40t–z, B

*Emended Diagnosis*– Involute, flat biconvex test with oval contour, central pile and slightly sigmoid septal sutures passing into an irregular sutural network in the edges. The proloculus is relatively large, the chamberlets (often with incomplete secondary septa) are rather irregularly arranged and characteristically polygonal. The number of undivided chambers (X) is subjected to nepionic acceleration. Based on this, the species is subdivided into three chronosubspecies as follows:


a
b
c
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a, c, e-m, o,
p, r, s, A:
1 mm
f
g
h
i
b, d, n, q: 2 mm
j
k
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p
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t
u
v
w
A
x
y
z
t-z, B-E:
1 mm
B
C
D
E

**Figure 40.**

**Table 6.** Statistical data of the of the inner cross-diameter of the proloculus of *Assilina* and *Operculina* populations (in μm). №– number of specimens, s.e.– standard error.

| Taxon | Sample | № | range | mean ± s.e. |
|---|---|---|---|---|
| *Assilina* ex. gr. *alpina* | **AKÖR A 2** | **3** | **55 – 85** | **67** |
| | **AKÖR A 16+19** | **10** | **90 – 120** | **102 ± 3** |
| | AKÖR A 16 | 9 | 90 – 110 | 100 ± 2 |
| | AKÖR A 19 | 1 | | 120 |
| | **SAM B 7** | **3** | **70 – 145** | **107** |
| | **SAM A 4** | **12** | **60 – 135** | **98 ± 5** |
| | **SAM A 13-16** | **23** | **65 – 125** | **94 ± 3** |
| | SAM A 13 | 1 | | 80 |
| | SAM A 14 | 10 | 75 – 125 | 92 ± 4 |
| | SAM A 16 | 12 | 65 – 120 | 97 ± 4 |
| | **SAM A 18+22** | **19** | **75 – 180** | **111 ± 6** |
| | SAM A 18 | 7 | 90 – 140 | 109 ± 7 |
| | SAM A 22 | 12 | 75 – 180 | 112 ± 9 |
| | **SAM A 24** | **4** | **80 – 100** | **90 ± 4** |
| | **HAC 8+9** | **18** | **60 – 120** | **89 ± 4** |
| | HAC 8 | 10 | 75 – 120 | 92 ± 4 |
| | HAC 9 | 8 | 60 – 100 | 85 ± 4 |
| | **SAMLAR 1** | **7** | **85 – 115** | **94 ± 3** |
| | **AKÖR B 6** | **3** | **60 – 105** | **87** |
| | **KIRK 19** | **17** | **90 – 195** | **141 ± 6** |
| *Operculina* ex. gr. *gomezi* | **AKÖR A 2** | **9** | **80 – 150** | **113 ± 8** |
| | **AKÖR A 16+19** | **6** | **80 – 140** | **112 ± 9** |
| | AKÖR A 16 | 3 | 80 – 105 | 92 |
| | AKÖR A 19 | 3 | 125 – 140 | 133 |
| | **HAC 3** | **3** | **90 – 110** | **102** |
| | **HAC 8+9** | **20** | **55 – 115** | **91 ± 3** |
| | HAC 8 | 12 | 55 – 100 | 86 ± 4 |
| | HAC 9 | 8 | 90 – 115 | 98 ± 3 |
| | **SAM A 24** | **3** | **80 – 115** | **92** |
| | **SAMLAR 1+2** | **25** | **55 – 155** | **110 ± 4** |
| | SAMLAR 1 | 24 | 55 – 155 | 109 ± 4 |
| | SAMLAR 2 | 1 | | 140 |
| | **AKÖR B 6** | **4** | **65 – 140** | **105 ± 13** |
| | **AKÖR B 19** | **4** | **60 – 150** | **92 ± 17** |
| | **CAT A 10** | **1** | | **90** |
| | **LALAP 12** | **16** | **60 – 175** | **116 ± 7** |
| *O. complanata* | **KARAB 24** | **3** | **80 – 140** | **118** |

| | | |
|---|---|---|
| *H. armenica armenica* | $X_{mean} > 8$ | SBZ 18A |
| *H. armenica tigrisensis* | $X_{mean} = 5–8$ | SBZ 18B |
| *H. armenica hacimasliensis* n. ssp. | $X_{mean} < 5$ | SBZ 18B |

The species is only recorded from the upper Bartonian beds of the eastern part of the Thrace Basin and represented by the two more evolved subspecies.

### *Heterostegina armenica tigrisensis* Less, Özcan, Papazzoni & Stockar 2008

Figure 40t, u, x

2008 *Heterostegina armenica tigrisensis* n. ssp., Less *et al*., p. 334, figures 11G–I, M.

2010a *Heterostegina armenica tigrisensis* Less *et al*., Özcan *et al*., p. 71, figure 31o.

*Emended Diagnosis*– *Heterostegina armenica* populations with $X_{mean}$ ranging from 5 to 8.

### *Heterostegina armenica hacimasliensis* n. ssp.

Figure 40v, w, y, z, B

*Etymology*– Named after Hacımaşlı village, close to the type locality of the taxon near Arnavutköy (İstanbul province, Turkey).

*Holotype*– Specimen E.09.194. (Figure 40B).

*Paratypes*– Specimens Ö.Hac 7-2 (Figure 40y) and E.09.193. (Figure 40z).

*Depository*– Eocene collection of the Geological Institute of Hungary (Budapest).

*Type Locality*– Sample HAC 3, close to Hacımaşlı village (İstanbul province, Turkey).

**Figure 40.** (**a**–**i**) *Assilina* ex. gr. *alpina* (Douvillé), (**a**) AKÖR.A 19, E.09.173., (**b, c**) ŞAM.A 4, E.09.174., (**d**) ŞAM.A 4, E.09.175., (**e**) ŞAM.A 14, E.09.176., (**f**) ŞAM.A 22, E.09.177., (**g**) HAC 9, E.09.178., (**h**) Şamlar 1, E.09.179., (**i**) KIRK 19, E.09.180. (**j**–**q**) *Operculina* ex. gr. *gomezi* Colom & Bauzá, (**j**) AKÖR.A2, E.09.181., (**k**) AKÖR.A 2, E.09.182., (**l**) HAC 3, E.09.183., (**M, N**) Şamlar 1, E.09.184., (**o**) ÇAT.A 10, E.09.185., (**p**) Lalap 12, E.09.186., (**Q**) PINAR.A 1, E.09.187. (**r, A**) *Calcarina* sp., AKÖR.A 2, (**r**) E.09.188., (**A**) E.09.189. (**s**) *Operculina complanata* Defrance, Karab 24, O.09.6. (**t, u, x**) *Heterostegina armenica tigrisensis* Less *et al*., AKÖR.A 19, (**t**) E.09.190., (**u**) E.09.191., (**x**) E.09.192. (**v, w, y, z, B**) *Heterostegina armenica hacimasliensis* n. ssp., (**v**) HAC 5, Ö.Hac 4-4, (**w**) HAC 5, Ö.Hac4-5, (**y**) HAC 3, Ö.Hac 7-2, (**z**) HAC 3, E.09.193., (**B**) HAC 3, E.09.194., holotype., (**C**) *Heterostegina gracilis* Herb, Karab 20, O/Karab 1-1., (**D, E**) *Spiroclypeus sirottii* Less & Özcan, KIRK 19, (**D**) E.09.195., (**E**) E.09.196. q– B-form, all the others– A–forms. b, d, n, q, r, A– external views, all the others– equatorial sections. b, d, n, q: 5×, a, c, e-m, o, p, r, s, A: 10×, t-z, B-E: 20×.

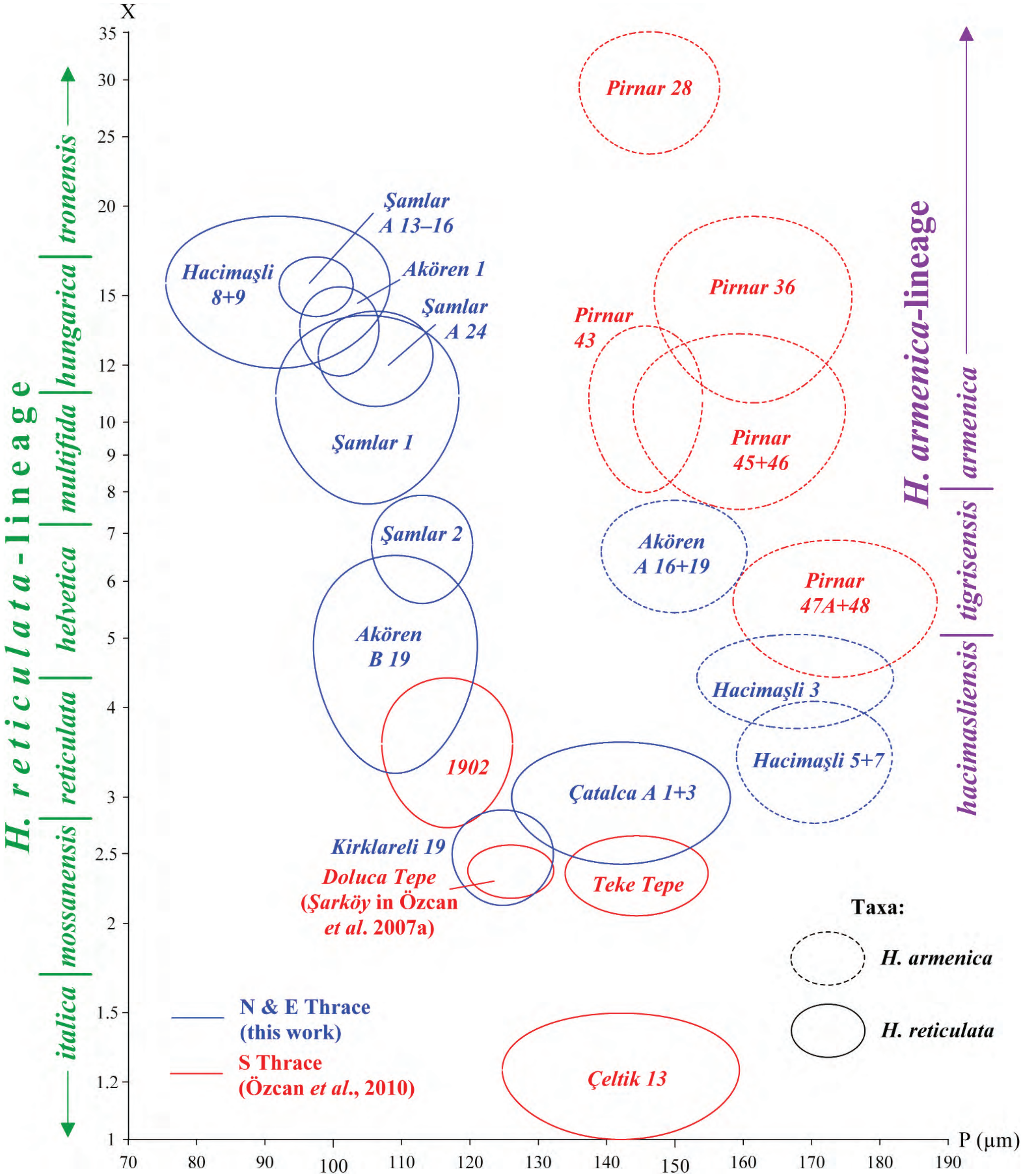



**Figure 41.** Distribution of heterosteginid populations from the Thrace Basin (mean values at the 95% confidence level corresponding to 2 s.e.) on the P–X (proloculus diameter versus number of undivided post-embryonic chambers) bivariate plot (X is on logarithmic scale) with the subspecific subdivision of *Heterostegina reticulata* and *H. armenica*.

**Table 7.** Statistical data of *Heterostegina* and *Spiroclypeus* populations. №– number of specimens, s.e.– standard error.

| Parameters | | Inner cross-diameter of the proloculus P (μm) | | | Outer diameter of the first whorl d (μm) | | | Number of post-embryonic pre-heterosteginid chambers X | | | Number of chamberlets in the fourteenth chamber S | | | Subspecific determination |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Taxon | Sample | № | range | mean ± s.e. | № | range | mean ± s.e. | № | range | mean ± s.e. | № | range | mean ± s.e. | |
| *Heterostegina armenica* | **AKÖR A 16+19** | **38** | **95 – 245** | **149.9 ± 5.3** | **37** | **590 – 1195** | **864 ± 25** | **38** | **2 – 21** | **6.61 ± 0.59** | **37** | **1 – 6** | **2.78 ± 0.18** | *tigrisensis* |
| | AKÖR A 16 | 19 | 105 – 245 | 156.3 ± 7.9 | 19 | 630 – 1195 | 870 ± 37 | 19 | 2 – 21 | 7.11 ± 0.99 | 19 | 1 – 6 | 2.84 ± 0.29 | |
| | AKÖR A 19 | 19 | 95 – 200 | 143.4 ± 6.9 | 18 | 590 – 1110 | 859 ± 32 | 19 | 3 – 12 | 6.11 ± 0.62 | 18 | 1 – 4 | 2.72 ± 0.20 | |
| | **HAC 3** | **21** | **110 – 250** | **167.6 ± 7.2** | **21** | **790 – 1400** | **1010 ± 37** | **20** | **2 – 8** | **4.40 ± 0.33** | **18** | **2 – 4** | **3.17 ± 0.16** | *hacimasliensis* |
| | **HAC 5+7** | **13** | **130 – 210** | **170.4 ± 5.7** | **6** | **950 – 1130** | **1042 ± 27** | **12** | **2 – 6** | **3.42 ± 0.33** | **7** | **2 – 5** | **3.71 ± 0.33** | *hacimasliensis* |
| | HAC 5 | 6 | 165 – 200 | 180.0 ± 5.1 | 6 | 950 – 1130 | 1042 ± 27 | 6 | 2 – 4 | 3.17 ± 0.28 | 4 | 4 – 5 | 4.25 ± 0.22 | |
| | HAC 7 | 7 | 130 – 210 | 162.1 ± 8.4 | | | | 6 | 2 – 6 | 3.67 ± 0.56 | 3 | 2 – 4 | 3.00 | |
| *H. reticulata* | **SAM A 13-16** | **46** | **60 – 145** | **97.5 ± 2.7** | **46** | **410 – 960** | **631 ± 17** | **46** | **5 – 29** | **15.52 ± 0.74** | **46** | **1 – 3** | **1.22 ± 0.08** | *hungarica* |
| | SAM A 13 | 2 | 95 – 125 | 110.0 | 2 | 605 – 640 | 622 | 2 | 18 – 23 | 20.50 | 2 | 1 | 1.00 | |
| | SAM A 14 | 24 | 60 – 145 | 96.7 ± 4.4 | 24 | 410 – 920 | 622 ± 24 | 24 | 5 – 29 | 15.83 ± 1.04 | 24 | 1 – 3 | 1.21 ± 0.12 | |
| | SAM A 16 | 20 | 65 – 115 | 97.2 ± 2.9 | 20 | 490 – 960 | 642 ± 26 | 20 | 7 – 23 | 14.65 ± 1.05 | 20 | 1 – 3 | 1.25 ± 0.12 | |
| | **SAM A 24** | **27** | **70 – 130** | **100.9 ± 2.9** | **20** | **450 – 1000** | **662 ± 30** | **27** | **4 – 24** | **13.52 ± 0.96** | **27** | **1 – 3** | **1.41 ± 0.13** | *hungarica* |
| | **HAC 8+9** | **8** | **55 – 140** | **91.9 ± 8.2** | **8** | **440 – 770** | **576 ± 33** | **8** | **9 – 22** | **15.63 ± 1.87** | **8** | **1 – 2** | **1.50 ± 0.18** | *hungarica* |
| | HAC 8 | 5 | 55 – 140 | 92.0 ± 13.0 | 5 | 440 – 770 | 574 ± 50 | 5 | 9 – 22 | 14.80 ± 2.47 | 5 | 1 – 2 | 1.60 ± 0.22 | |
| | HAC 9 | 3 | 85 – 100 | 91.7 | 3 | 510 – 620 | 580 | 3 | 11 – 22 | 17.00 | 3 | 1 – 2 | 1.33 | |
| | **AKÖREN 1** | **30** | **55 – 145** | **106.2 ± 4.2** | **30** | **380 – 800** | **620 ± 21** | **30** | **4 – 22** | **12.40 ± 0.94** | **30** | **1 – 3** | **1.50 ± 0.11** | *hungarica* |
| | **SAMLAR 1** | **9** | **55 – 130** | **105.0 ± 6.7** | **4** | **570 – 880** | **712 ± 16** | **9** | **5 – 22** | **10.89 ± 1.60** | **6** | **1 – 3** | **2.00 ± 0.22** | *multifida-hungarica* |
| | **SAMLAR 2** | **20** | **85 – 145** | **113.0 ± 3.7** | **20** | **480 – 1120** | **773 ± 37** | **20** | **3 – 14** | **6.75 ± 0.58** | **20** | **1 – 5** | **2.70 ± 0.21** | *helvetica* |
| | **AKÖR B 19** | **17** | **80 – 180** | **109.1 ± 6.0** | **17** | **460 – 1150** | **668 ± 39** | **17** | **1 – 13** | **4.88 ± 0.82** | **16** | **1 – 7** | **3.50 ± 0.36** | *helvetica-reticulata* |
| | **CAT A 1+3** | **12** | **105 – 195** | **142.1 ± 8.0** | **12** | **630 – 1160** | **844 ± 51** | **12** | **2 – 5** | **3.00 ± 0.29** | **11** | **3 – 9** | **4.73 ± 0.50** | *reticulata-mossanensis* |
| | CAT A 1 | 3 | 105 – 140 | 125.0 | 3 | 665 – 800 | 742 | 3 | 3 – 5 | 4.00 | 3 | 3 – 5 | 4.33 | |
| | CAT A 3 | 9 | 105 – 190 | 147.8 ± 9.5 | 9 | 630 – 1160 | 878 ± 63 | 9 | 2 – 4 | 2.67 ± 0.27 | 8 | 3 – 9 | 4.88 ± 0.65 | |
| | **KIRK B 15** | **1** | | **100.0** | **1** | | **680** | **1** | | **3.00** | **1** | | **4.00** | indet. ssp. |
| | **KIRK 19** | **24** | **100 – 165** | **124.8 ± 3.7** | **24** | **590 – 1020** | **746 ± 23** | **24** | **1 – 5** | **2.50 ± 0.19** | **24** | **3 – 6** | **4.17 ± 0.20** | *mossanensis* |
| *H. gracilis* | **KARAB 20** | **2** | **255 – 285** | **270.0** | **2** | **1910 – 2215** | **2062** | **1** | | **1.00** | **2** | **16 – 24** | **20.00** | – |
| *S. sirottii* | **KIRK 19** | **23** | **75 – 130** | **100.4 ± 3.2** | **23** | **440 – 660** | **579 ± 13** | **23** | **2 – 5** | **3.57 ± 0.18** | **23** | **2 – 6** | **3.22 ± 0.18** | – |

*Type Level*– Middle late Bartonian, SBZ 18B Subzone.

*Diagnosis*– *Heterostegina armenica* populations with $X_{mean}$ less than 5.

*Description*– External characters are identical with *H. armenica* (see above). In the equatorial section of A-forms the chamberlets are of somewhat irregularly polygonal shape. The secondary septa are mostly complete, undivided chambers only reappear very rarely in the neanic stage of the growth. The proloculus is quite large (P= 110–250 μm, $P_{mean}$= 150–185 μm), as well as the diameter of the first whorl (d= 800–1400 μm, $d_{mean}$= 930–1100 μm). The number of post-embryonic undivided chambers is low (X= 2–8, $X_{mean}$= 2.5–5), meanwhile the number of chamberlets in the fourteenth chamber is high (S=2–5, $S_{mean}$=2.8–4.4). Microspheric generation have not yet been found.

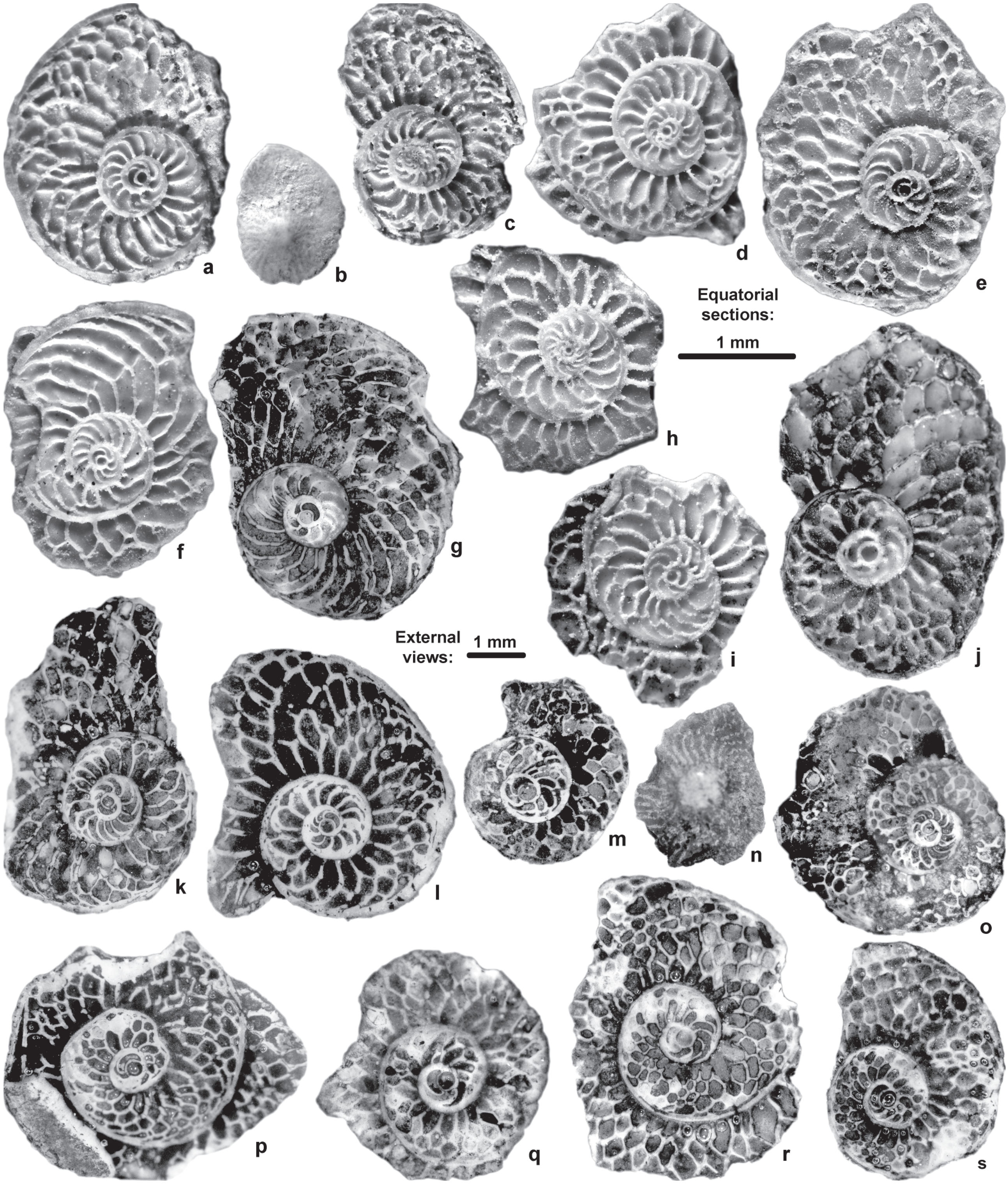
*Remarks*– This most advanced developmental stage of *Heterostegina armenica* has been found together with the giant *Nummulites aturicus* (of the *N. perforatus* group) and with the reticulate *N. hormoensis* in samples Hacimaşlı, HAC 3, 5 and 7. Above these levels still giant *N. maximus* (of the *N. millecaput* group) can be found but associated with *H. reticulata hungarica* indicating (according to Less *et al*. 2008) the middle part of the late Bartonian (SBZ 18B). Since *H. armenica tigrisensis*, the ancestor of *H. a. hacimasliensis*, also marks this zone (see above), the stratigraphic range of the new subspecies can also be determined as SBZ 18B.

### *Heterostegina reticulata* Rütimeyer 1850

Figure 42a–s

Based on the reduction of undivided post-embryonic chambers (parameter X), Less *et al.* (2008) subdivided the species into seven chronosubspecies as follows:

| | | |
|---|---|---|
| *H. reticulata tronensis* | $X_{mean}$ > 17 | SBZ 18B |
| *H. reticulata hungarica* | $X_{mean}$ = 11–17 | SBZ 18B |
| *H. reticulata multifida* | $X_{mean}$ = 7.2–11 | SBZ 18C |
| *H. reticulata helvetica* | $X_{mean}$ = 4.4–7.2 | SBZ 18C |


a
b
c
d
e
Equatorial
sections:
1 mm
f
g
h
i
j
External
views:
1 mm
k
l
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s

**Figure 42.**

| | | |
|---|---|---|
| *H. reticulata reticulata* | $X_{mean}$ = 2.8–4.4 | SBZ 18C |
| *H. reticulata mossanensis* | $X_{mean}$ = 1.7–2.8 | SBZ 19A |
| *H. reticulata italica* | $X_{mean}$ < 1.7 | SBZ 19B–20 |

The evolution of this species serves as a first-class tool in determining the age of several our samples. This evolution can directly be observed from the middle to the uppermost part of the Şamlar section in four populations in superposition (see Table 7 and Figure 41, also for the other populations).

### ***Heterostegina gracilis*** **Herb 1978**

Figures 19c and 40C

This, easily identifiable species with granules (being a key taxon for the late Priabonian SBZ 20 Zone) could only be found in hard limestones. It coexists in sample Karaburun KARAB 20 (Figure 40C) with highly advanced *Asterocyclina stellata* cf. *buekkensis,* whereas in sample Çatalca ÇAT.B 6 (Figure 19c) it exists with *Spiroclypeus* sp. and *Praebullaleolina afyonica*.

### **Genus *Spiroclypeus* Douvillé 1905**

### ***Spiroclypeus sirottii*** **Less & Özcan 2008**

Figure 40D, E

According to Less & Özcan (2008) Eocene *Spiroclypeus* in the western Tethys are exclusive for the Priabonian. They are not related to the Oligo–Miocene representatives of the genus, and differ from them in having a much tighter spire. The numerical characterization of the genus is based on the system introduced by Drooger & Roelofsen (1982) for *Cycloclypeus*. The explanation of measurements and counts executed in the equatorial section of each megalospheric specimen (Figure 31C) are given in the header of Table 7 where biometric data are also tabulated. The Priabonian forms were classified by Less & Özcan (2008) into two species by using the mean number of undivided post-embryonic chambers (parameter X) as follows: *S. sirottii* Less & Özcan (SBZ 19) with $X_{mean}$ < 2.7, and *S. carpaticus* (Uhlig) (SBZ 20) with $X_{mean}$ > 2.7. In the northern part of the Thrace Basin only the former occurs in sample Kırklareli KIRK 19. In the thin sections from profile Çatalca B random sections of *Spiroclypeus* (Figure 19a) could be identified only at the generic level, although based on their tight spire they surely belong to the Priabonian lineage of the genus.

## Conclusions

*Synthesis of Palaeontological Data*

We have found rich and mostly well-preserved larger foraminiferal assemblages in the upper Palaeogene deposits of the northern and eastern part of the Thrace Basin. We have focused on nummulitids and orthophragmines, isolated specimens of which can abundantly be found in the Soğucak Limestone. Practically all forms known from other Western Tethyan upper Bartonian and Priabonian larger foraminiferal sites (NE Spain, Serra-Kiel *et al*. 2003; N Italy, Papazzoni & Sirotti 1995; Hungary, Less *et al*. 2000; E Turkey, Özcan *et al*. 2007a) have been recognized in the Thrace Basin (for the southern part see Özcan *et al*. 2010a); only the absence of *Nemkovella strophiolata* is striking. The westernmost occurrence of *Heterostegina armenica* and *Orbitoclypeus haynesi* known so far can be found in the Thrace Basin, in addition to forms recorded from more western territories, and which are dominant. This strong western Tethyan affinity of the larger foraminiferal fauna of the Thrace Basin allows us to apply the western Tethyan larger foraminiferal stratigraphical subdivision in Palaeogene shallow benthic (SBZ) zones, introduced by Serra-Kiel *et al*. (1998) and Cahuzac & Poignant (1997), and later refined for the late Bartonian and early Priabonian by Less *et al*. (2008).

**Figure 42.** **(a-g, k, l)** *Heterostegina reticulata hungarica* Less *et al*., **(a, b)** ŞAM.A 14, E.09.197., **(c)** ŞAM.A 14, E.09.198., **(d)** ŞAM.A 14, E.09.199., **(e)** ŞAM.A 16, E.09.200., **(f)** ŞAM.A 24, E.09.201., **(g)** HAC 9, E.09.202., **(k)** Akören 1, E.09.203., **(l)** Akören 1, E.09.204. **(h)** *Heterostegina reticulata* ex. interc. *multifida* (Bieda) et *hungarica* Less *et al*., Şamlar 1, E.09.205. **(i, j)** *Heterostegina reticulata helvetica* Kaufmann, Şamlar 2, **(i)** E.09.206., **(j)** E.09.207. **(m–p)** *Heterostegina reticulata* ex. interc. *helvetica* Kaufmann et *reticulata* Rütimeyer, AKÖR.B 19, **(m)** E.09.208., **(n, o)** E.09.209., **(p)** E.09.210. **(q)** *Heterostegina reticulata reticulata* Rütimeyer et *mossanensis* Less *et al*., ÇAT.A 3, E.09.211. **(r, s)** *Heterostegina reticulata mossanensis* Less *et al*., KIRK 19, **(r)** E.09.212., (S) E.09.142. c– B-form, all the others– A-forms. b, n– external views 10×, all the others: equatorial sections, 20×.

The evolution of some forms could easily be traced. Among them the most important is that of the *Heterostegina reticulata* lineage in the Şamlar section (see also Figure 41). We also could observe the superposition of the first appearance of this species above *H. armenica* in the Hacımaşlı profile. The record on reticulate *Nummulites* is, however, contradictory. The size increase of the proloculus can well be followed in the Kırklareli section, although an opposite trend can be observed in the lower and middle part of the Şamlar profile, which we think to be local and ecologically controlled.

In addition to orthophragmines and nummulitids discussed in the systematic section, a rather diverse assemblage of other benthic foraminifera has also been recognized, including *Praebullalveolina afyonica* Sirel & Acar (Figure 19b), *Calcarina* sp. (Figure 40r, A), *Silvestriella* sp., *Chapmanina* sp., *Gyroidinella* sp., *Asterigerina* sp., *Eoannularia* sp., *Halkyardia* sp. and *Sphaerogypsina* sp.

*Synthesis of Biostratigraphical Data*

The ages of our larger foraminiferal sites have been determined based on (i) the occurrence and developmental stage of *Heterostegina armenica*, *H. reticulata* and *H. gracilis*, (ii) the presence/absence of large *Nummulites* (*N. aturicus*, *N. biedai*, *N. maximus*, *N. lyelli*), (iii) the presence/absence of genus *Spiroclypeus*, (iv) the developmental stage of reticulate *Nummulites* (*N. garganicus*/*hormoensis* vs. *N. fabianii* corresponding to late Bartonian vs. Priabonian), (v) the occurrence and developmental stage of orthophragmines, and (vi) the occurrence of *Nummulites striatus* (Bartonian), *N. budensis* (Priabonian), *N. vascus*, *N. bouillei* and *Operculina complanata* (lower Rupelian).

Based on these characteristics the stratigraphical subdivision of larger foraminiferal assemblages of N and E Thrace is as follows:

(1) The oldest assemblage has been found in the lower part of the Akören A section in samples AKÖR.A 1 and 2, and dated as close to the early/late Bartonian (SBZ 17/18) boundary, based on the presence of *Nummulites striatus*, *N. aturicus* and *N.* ex. interc. *garganicus-hormoensis* and the absence of genus *Heterostegina* that can, however, be ecologically controlled as well.

(2) The middle upper Bartonian (SBZ 18B Subzone) is widely recorded in the eastern part of the Thrace Basin and in the northern margin of the Çatalca block, based on the occurrence of *Heterostegina armenica tigrisensis* (in the upper part of the Akören A section, in samples AKÖR.A 16 and 19), *H. a. hacimasliensis* (in the lower part of the Hacımaşlı section, in samples HAC 3, 5 and 7), and *H. reticulata hungarica* (in the middle part of the Şamlar section, in samples ŞAM.A 13–16 and 24; in the upper part of the Hacımaşlı section, in samples HAC 8 and 9; and in sample Akören 1). Large *Nummulites* occur in various quantities in these samples, as well as less developed reticulate *Nummulites* (*N. garganicus*, *N. hormoensis* and their intermediates). Diverse orthophragmines mark the OZ 14 Zone, corresponding to the SBZ 18 to 19A time-span.

When representatives of genus *Heterostegina* are missing, a (tentatively close to middle) late Bartonian age is determined, based on the presence of *Nummulites hormoensis* (in the lower part of the Şamlar section, in samples ŞAM.A 4 and B 5, and in sample Kırklareli KIRK.A 15), or giant *Nummulites* (*N. maximus* in sample Akören AKÖR.B 6 or *N.* cf. *aturicus* in sample Şamlar ŞAM.B 7) and on the position of these samples in the given section.

(3) A latest Bartonian (SBZ 18C) age is assigned to samples ŞAMLAR 2 from the uppermost part of the Şamlar section and Akören AKÖR.B 19, based on the presence of *Heterostegina reticulata helvetica* and *H.* r. ex. interc. *helvetica-reticulata*, respectively, although *H. r.* ex. interc. *multifida-hungarica* from sample ŞAMLAR 1 (below ŞAMLAR 2) suggests the transition of the SBZ 18B/C subzones. Large *Nummulites maximus* (with rare B-forms) is still common in sample ŞAMLAR 1, but very rare in ŞAMLAR 2 and absent from AKÖR B 19, although this last assemblage is clearly redeposited. The assemblages in all three samples indicate outer shelf conditions with abundant orthophragmines (of the OZ 14 Zone) but lacking reticulate *Nummulites*. These conditions would have been favorable for genus *Spiroclypeus*, which, however, did not appear at this time.

The rather poor assemblage in some samples does not allow us to arrange them definitively into either the Bartonian or the Priabonian. These samples (Çatalca ÇAT.A 1 and 3, Kırklareli KIRK 12 and B 15) contain reticulate *Nummulites* intermediate between *N. hormoensis* and *N. fabianii*, and in the Çatalca samples *Heterostegina reticulata* ex. interc. *reticulata-mossanensis* indicates the same Bartonian/Priabonian (SBZ 18/19) transition. The lack of *Spiroclypeus* rather suggests Bartonian, but in the upper samples (ÇAT.A 10 and 11) of the ÇAT.A section the presence of *N. budensis* is more indicative of the Priabonian.

(4) A definite early Priabonian (SBZ 19) age is recognized for sample Kırklareli, KIRK 19 based on the coexistence of *Spiroclypeus sirottii*, *Heterostegina reticulata mossanensis* and *Nummulites fabianii* and on the orthophragminid assemblage marking about the boundary of the OZ 14/15 zones. Moreover, *H. r. mossanensis* indicates an earliest Priabonian (SBZ 19A) age. Some other samples (Kırklareli KIRK.D 1, DOLHAN 1, Kıyıköy KIY 1 and 2) containing *N. fabianii* with mean inner-cross proloculus diameter ($P_{mean}$) less than 250 µm can tentatively also be assigned to the lower Priabonian.

The age of samples Kıyıköy KIY 3, Pınarhisar PINAR.A 1 and Lalapaşa LALAP 5 and 12 containing (except for sample LALAP 5) good assemblages of *Nummulites budensis* cannot be determined more precisely than generally Priabonian (SBZ 19–20).

(5) The upper Priabonian (SBZ 20) is represented in the lower and middle part of the Karaburun section, based on the presence of *Heterostegina gracilis* and *Asterocyclina stellata* cf. *buekkensis* in sample KARAB 20. The first taxon is also present at the very base of the Çatalca (ÇAT.B) section, thus (taking into consideration the Priabonian image of the fauna throughout the whole section) it is also assigned to the SBZ 20 Zone. The same age is also assigned to the Pınarhisar (PINAR) samples (with the exception of PINAR.A 1) since in this section *Nummulites fabianii* populations with $P_{mean}$ (see above) more than 250 µm could be recorded, and also the transition into the laminite-bearing lower Oligocene can be seen in the field.

(6) The youngest larger foraminiferal assemblage with *Nummulites vascus*, *N. bouillei* and *Operculina complanata* occurs in the upper part of the Karaburun section in sample KARAB 24, and indicates an early Rupelian (SBZ 21) age.

*Synthesis of Palaeoenvironmental Data*

Based on different larger foraminiferal assemblages three main depositional environments corresponding to those in Arni (1965) and other authors (listed in the introduction of the description of localities) can be encountered, but they are partly different in the late Bartonian and in the Priabonian. This reorganization is very probably due to the extinction of giant *Nummulites* at the end of the Bartonian, after which their former ecological niche was occupied by other taxa. This process was described by Nebelsick *et al.* (2005) as facies shift and facies replacement. Two depositional palaeoenvironments took place in the middle shelf: one with high, and another with low water energy (the *Nummulites*-bank and the back-bank) whereas the third one (the fore-bank) refers to the outer shelf.

(1) Low water energy middle shelf (back-bank) conditions are characterized in the late Bartonian by the predominance of reticulate *Nummulites* (*N. garganicus* and *N. hormoensis*) and/or *N. striatus*. *Heterostegina armenica* can also be found, while giant *Nummulites* (of the *N. perforatus* group) and cosmopolitan forms (*Assilina* ex. gr. *alpina*, *Operculina* ex. gr. *gomezi* and some radiate *Nummulites* such as *N. incrassatus* and *N. chavannesi*) are scarcer. Orthophragmines, *Heterostegina reticulata* and large flat *Nummulites* of the *N. millecaput* group (*N. maximus*) are completely missing. Back-bank conditions in the late Bartonian have been recognized not only in the lower part of the Hacımaşlı (samples HAC 3, 4 and 7), Akören (samples AKÖR.A 1 and 2), Kırklareli (sample KIRK.A 15) and Şamlar sections (samples ŞAM.A 4, B 5 and 7) but also in the middle part of the last profile (samples ŞAM.A 18 and 22).

An almost complete change of the faunal association in the back-bank depositional environment happened at about the Bartonian/Priabonian boundary, since *Nummulites striatus* and *Heterostegina armenica* became extinct, and simultaneously reticulate *Nummulites* moved to the high water energy *Nummulites*-bank in order to occupy the former niche of giant *Nummulites* (*N. lyelli* and the representatives of the *N. perforatus* group).

Thus, in the Priabonian *Nummulites budensis* became the most dominant among larger Foraminifera in this depositional environment (recognized in samples Çatalca ÇAT.A 10 and 11, Lalapaşa LALAP 5 and 12, Kıyıköy KIY 3 and Pınarhisar PINAR.A 1) where it associates with some less abundant radiate *Nummulites* such as *N. incrassatus*, *N. chavannesi* and *N. cunialensis* and with *Operculina* ex. gr. *Gomezi*: meanwhile reticulate *Nummulites* (*N. fabianii*), *Heterostegina*, *Spiroclypeus* and orthophragmines are completely missing.

(2) *Nummulites*-bank conditions corresponding to a high water energy middle shelf environment in the late Bartonian are characterized by the predominance of giant *Nummulites* (*N. lyelli* and of the *N. perforatus* group: *N. aturicus* and *N. biedai*) associated with *Heterostegina armenica*. Other forms, such as reticulate (*N. fabianii*) and radiate (*N. incrassatus*, *N. chavannesi*) *Nummulites*, *Operculina* ex. gr. *gomezi*, *Assilina* ex. gr. *alpina* and orthophragmines are rare or sporadic. These conditions could be recognized in the middle of the Hacımaşlı (sample HAC 5), Akören (samples AKÖR.A 16 and 19) and Şamlar sections, but in this last case the larger foraminiferal facies is replaced by coral reefs.

After the extinction of giant *Nummulites* and *Heterostegina armenica* towards the very end of the Bartonian reticulate *Nummulites* (*N. fabianii*) formed *Nummulites*-banks in the Priabonian. They formed almost monospecific accumulations, transiting into and/or facially interfingering with coral reefs, as observable in the Kırklareli and Pınarhisar sections. Subordinate *N. incrassatus* can also be found in this facies, but all the other forms are extremely rare. These almost monospecific banks of *N. fabianii* are recognized in Kırklareli (samples KIRK 12, B 15 and D 1), Dolhan, Pınarhisar (samples PINAR 1, 6 and 9) and in Kıyıköy (samples KIY 1 and 2).

(3) Open marine, outer shelf fore-bank conditions corresponding to the deeper part of the photic zone belong to the third palaeoenvironmental type. They are marked both in the late Bartonian and Priabonian by the common occurrence of orthophragmines and of *Heterostegina reticulata* and *H. gracilis*. They are accompanied by *Nummulites maximus* (which can even predominate, as in sample Akören AKÖR.B 6) in the upper Bartonian and with *Spiroclypeus* in the Priabonian. Reticulate *Nummulites* can only occasionally be found, as in samples Şamlar SAM.A 14 and Kırklareli KIRK 19, where they were very probably transported from a shallower setting. The outer shelf depositional environment is characteristic for samples Şamlar SAM.A 13–16 and 24 (with a somewhat less diverse orthophragminid assemblage for all of them, maybe because of a somewhat shallower environment due to the proximity of coral reefs), for the upper part of the Şamlar (samples ŞAMLAR 1 and 2), Hacımaşlı (samples HAC 8 and 9) and Akören (samples Akören 1, AKÖR.B 6 and 19) sections. In the Priabonian it could only be recognized in sample Kırklareli KIRK 19, in the lower part of the Çatalca CAT.B section and in the lower and middle parts of the Karaburun profile (in sample KARAB 20). In transgressive sequences the outer shelf facies is very frequently topped by aphotic pelagic marls with no larger Foraminifera.

### *Comments on Regional Geological Evolution during Eocene and Early Oligocene*

Three subregions can be encountered in the northern and eastern margins of the Thrace Basin.

(1) In the eastern part of the region, represented by the Şamlar and Hacımaşlı sequences, the basement is formed by Carboniferous siliciclastics of the İstanbul Zone. The Eocene transgression reached this area at about the beginning of the middle late Bartonian (SBZ 18B). The sequences reflect a general deepening trend, but with significant fluctuations, caused by the widespread formation of reefs. Shallow-water conditions only lasted about 1–1.5 million years, since the carbonate platform was still submerged in the latest Bartonian SBZ 18C Subzone. They are covered by pelagic marls of probable Priabonian and younger age.

(2) Rocks of the Istranca Massif form the basement near the Çatalca block where Eocene sections were investigated in the Çatalca and Akören sections. The centre of this block was emergent, since upper Priabonian (SBZ 20) Neptunian dykes in the basement rock are recognized in section Çatalca B. The submergence of the carbonate platform cannot be proved in this locality since neither signs of any deepening trend in the Eocene sequence nor pelagic marls between them and the Oligocene cover could be observed. This absence of deep-water deposits

may be primary (i.e. the carbonate platform was not submerged at all) or secondary (i.e. pelagic marls have been eroded). The Eocene transgression reached the northern periphery of the Çatalca block somewhat earlier than the central part, since in section Çatalca A a Bartonian/Priabonian boundary age (SBZ 18/19) could be recognized for the transgression. As in section Çatalca B neither deepening trends in the Eocene shallow-water sequence nor pelagic marls between them and the Oligocene cover may be observed. Further north, the periphery of the Çatalca block can be investigated near Akören. Here, the first marine deposits are dated as around the boundary of the early/late Bartonian (SBZ 17/18), thus the Eocene transgression is considerably earlier than in the two more central sections discussed above. As opposed to them, here both the deepening trend of the Eocene sequence and the submergence of the carbonate platform are recognizable. This last event is dated as latest Bartonian (SBZ 18C) when the centre of the Çatalca block was still emergent (see above). Thus, during the Bartonian–Priabonian, the Çatalca block was first an island, then a palaeohigh, the northern slope of which at least could be reconstructed. This latter is also proved by the discovery of canyon deposits in the lower part of section Akören A.

(3) The northern margin of the Thrace Basin was studied in sections at Lalapaşa, Kırklareli, Dolhan, Pınarhisar, Vize, Kıyıköy and Karaburun. In the reef formation of Vize, lying on the crystalline rocks of the Istranca Massif, however, we could not find larger Foraminifera, and thus the age is not specified. Therefore, this section is not discussed above. The timing of the Eocene transgression over the Istranca Massif could only be dated as late Bartonian (SBZ 18) near Kırklareli. Since in this area all the other ages are younger, we can reasonably suppose that the transgression reached this area either in the second half of the late Bartonian (SBZ 18B–C) or in the early Priabonian (SBZ 19). A shallow water palaeoenvironment is characteristic for all this third region during the whole Priabonian, but areas of inner and middle shelf conditions probably rimmed by reefs predominate over the outer shelf areas recognized only in sample Kırklareli KIRK 19 and in the lower–middle part of the Karaburun section. Within the middle shelf, local depressions are marked by the presence of *Nummulites budensis*. The Eocene/Oligocene transition is also shallow marine in the Pınarhisar area. This is the time of the moderate submergence in Karaburun since larger Foraminifera marking at least the proximity of the photic zone could also be observed in the lower Rupelian. Thus, in this region the (late Bartonian)–Priabonian–(Oligocene) carbonate platform had only been partly and moderately submerged and it formed the real northern margin of the Thrace Basin, most active during the Priabonian and early Oligocene, as also reconstructed by data from the southern part of the basin (Okay *et al*. 2010).

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