Integrated Biostratigraphy of Eocene Deposits in the Gubs Section (Northern Caucasus) with special Attention to the Ypresian/Lutetian Boundary and to the Peritethyan-Tethyan Correlation

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Abstract: The Ypresian to Priabonian Gubs river section, in the Adygean high of the northern slope of the Caucasus, is a rare locality, in whichYpresian–Lutetian representative larger benthic foraminifera coexist with planktonic Foraminifera and calcareous nannoplankton. This provides a good opportunity to apply and refine the zonal Ypresian–Lutetian scheme of the Crimean-Caucasus region, to correlate the zonal subdivision of the three most important Palaeogene groups of microfossils and to give a new insight on the position of the Ypresian/Lutetian boundary.

About 50 species and subspecies of larger foraminifera, represented by orthophragmines (*Discocyclina, Nemkovella, Orbitoclypeus* and *Asterocyclina*) and nummulitids (*Nummulites* and *Operculina*) are identified and one new species (*Orbitoclypeus barkhatovae*) is introduced. Based mainly on phylogenetic successions of orthophragmines (mostly *Orbitoclypeus* and also *Discocyclina*) the section is correlated with the SBZ 11-15 zones of the Tethyan shallow benthic scale and with the OZ 7-11 zones of the orthophragminid scale. The planktonic foraminiferal zonal subdivision of the Gubs Eocene is based on the infrazonal detailed regional Crimean-Caucasus scale whose PF 10a to 13b, 14a and 16 zones/subzones corresponding to the P 7 to 12 and 15 zones of the standard scale could be recognized. The calcareous nannoplankton allowed establishment of the NP 12 to 19–20 zones.

Our results are mostly in accord with those from the Southern Pyrenees, where the GSSP of the Ypresian/Lutetian boundary was recently fixed in the Gorrondatxe section at the boundary of the NP 14a/b calcareous nannoplankton subzones defined by the first appearance of *Blackites inflatus*. This boundary corresponds in the Gubs section to about the base of the SBZ 12 larger foraminiferal zone, having formerly indicated the base of the late Cuisian. In terms of planktonic foraminifera it falls within the *Acarinina bullbooki* (PF 11) Zone, formerly placed into the early Lutetian in the Crimean-Caucasus regional scale. The appearance of warm-water *Hantkenina* may reflect palaeogeographic conditions (hydrology, deepness, currents) for particular areas and cannot be applied as a marker for the Ypresian/Lutetian boundary.

Key Words: North-Western Caucasus, Ypresian–Lutetian, orthophragmines, nummulitids, planktonic foraminifera, nannoplankton, correlation

Gubs Kesiti (Kuzey Kafkaslar) Eosen Çökellerinin Birleştirilmiş Biyostratigrafisi, İpreziyen/Lütesiyen Sınırı ve Peritetis-Tetis Korelasyonu

Özet: İpreziyen–Priaboniyen Gubs istifi Kafkaslar kuzey yamacında Adygean yükseliminde yer almakta olup, İpreziyen–Lütesiyen kısmı iri bentik foraminifer, planktonik foraminifer ve kalkerli nannoplanktonların beraberliği ile temsil edilir. Bu durum Kırım-Kafkas bölgesi İpreziyen–Lütesiyen biyostratigrafisinin uygulanması, ayrıntılandırılması ve farklı fosil gruplarının deneştirilmesine ve İpreziyen/Lütesiyen sınırı hakkında daha ayrıntılı yorum yapmamıza olanak vermektedir. Orthophragmines (*Discocyclina, Nemkovella, Orbitoclypeus* ve *Asterocyclina*), ve nummulitidler (*Nummulites* ve *Operculina*) ile temsil edilen 50 tür ve alt-tür tayin edilmiş olup, yeni bir orthophragminid takson, *Orbitoclypeus barkhatovae* n. sp., tanımlanmıştır. Esas olarak orthophragmines grubu temel alınarak çalışılan istif Tetis SBZ 11-15 sığ bentik zonları ve OZ 7-11 orthophragmines zonları ile korele edilmiştir. Gubs kesitinde planktonik foraminifer biyostratigrafisinde Kırım-Kafkas zonasyonu temel alınmış olup, tanımlanan PF 10a-13b, 14a ve 16 zon ve

alt zonları standart zonasyonda P 7-12 ve 15 zonlarına karşılık gelmektedir. Kalkerli nannoplanktonlardan ise NP 12-19–20 zonları ortaya konmuştur. Elde edilen veriler, İpreziyen/Lütesiyen sınırı için yakın zamanda Gorrondatxe kesitinde (güney Pireneler) GSSP'nin NP 14a/b sınırında *Blackites inflatus* ın ilk ortaya çıkışı ile tanımlandığı duruma benzerlik göstermektedir. Önceki çalışmalarda geç Kuiziyen'in tabanına karşılık geldiği varsayılan SBZ 12 zonunun tabanının Gubs kesitinde İpreziyen–Lütesiyen sınırına karşılık geldiği ortaya konmuştur. Planktonik foraminiferler kapsamında Kırım-Kafkas bölgesel biyostratigrafisinde daha önceleri erken Lütesiyen içinde tanımlanan bu sınır *Acarinina bullbooki* (PF 11) zonu içinde kalmaktadır. Sıcak-su taksonu olan ve bölgesel paleocoğrafik durumları yansıtan *Hantkenina*'ın ilk ortaya çıkışı İpreziyen/Lütesiyen sınırını karakterize etmek için kullanılamaz.

Anahtar Sözcükler: Kuzey-Batı Kafkaslar, İpreziyen–Lütesiyen, orthophragminidler, nummulitidler, planktonik foraminifer, nannoplankton, korelasyon

Introduction

In recent years the late Ypresian to middle Lutetian interval has been actively discussed in order to define the base of the Lutetian stage (Bernaola *et al.* 2006; Larrasoaña *et al.* 2008; Ortiz *et al.* 2008; Payros *et al.* 2009). The complex investigation of Spanish sections in the Betic Cordilleras and Pyrenees, including biostratigraphic analysis, based on planktonic and larger benthic foraminifera and on calcareous nannoplankton, as well as on magnetostratigraphical and mineralogical studies, allowed to fix the Ypresian–Lutetian boundary at the boundary of the NP 14a/b calcareous nannoplankton subzones (marked by the first occurrence of *Blackites inflatus*) and proposed the Gorrondatxe section in Northern Spain for the GSSP (Molina *et al.* 2011). The authors of these publications (see above) only compared the transitional Ypresian–Lutetian interval of Spain with stratotypical regions of Western Europe, and did not consider other areas of western Eurasia. Some important profiles in the wide extent of the Northern Peritethys covering the early–middle Eocene interval, also should be considered in correlation between the Tethyan and Peritethyan basins.

One of the best profiles to provide new insights into the above problems is the Gubs section, situated in the Adygean high of the north-western slope of the Caucasus. It is known as typical for shallow marine terrigenous-carbonate Palaeogene deposits of the Adygean structural-facial zone (Figure 1). Like other Palaeogene sections of the North-western Caucasus, it was described by Grossgeim (1958, 1960). Later it was mentioned in the monograph by Shutskaya (1970) and then characterized in the reference book for the Palaeogene of USSR (Grossgeim & Korobkov 1975). Nine species of *Nummulites*, *Discocyclina* and *Asterocyclina* from the nummulitic limestone of Gubs, mentioned by Grossgeim (1958) and identified by O.V. Okropiridze, enabled them to be assigned to the *N. distans* Zone (Nemkov 1967). The section was re-sampled by E. Zakrevskaya in 1999 in order to study larger foraminifera (Figure 2). Based on the preliminary identification of larger and planktonic foraminifera it was clear that this section is of great importance for the Palaeogene stratigraphy, not merely in the Northern Caucasus but also across the entire Crimean-Caucasian region of the Northern Peritethys, as it contains the most diverse Lutetian larger foraminiferal assemblage of the North-eastern Peritethys. Except in the South-western Caucasus, the Lutetian in other Peritethyan basins (especially the middle-upper part), is represented either by hemipelagic chalky limestones (Crimea, Northern Cisaralia), or by slightly calcareous terrigenous deposits (the northern margin of the Caspian Sea, Ciscaucasia, the lower reaches of the Volga river and the Mangyshlak peninsula) with poor assemblages of larger foraminifera.

The results of the study of larger foraminifera from the Gubs section are presented in three works. In the paper related to transitional Lower–Middle Eocene shallow water deposits of the North-eastern Peritethys (Zakrevskaya 2004) seven photographs of orthophragmines were given. The list of larger foraminifera from this section was presented in the biostratigraphic review of this group (Zakrevskaya 2005). Finally, the local larger foraminiferal zones, elaborated for this section, were included in the Caucasus scheme of the Palaeogene (Koren' 2006). Planktonic foraminifera from Gubs were only identified by N.N. Borisenko (Grossgeim 1958), while the calcareous nannoplankton was not studied at all.
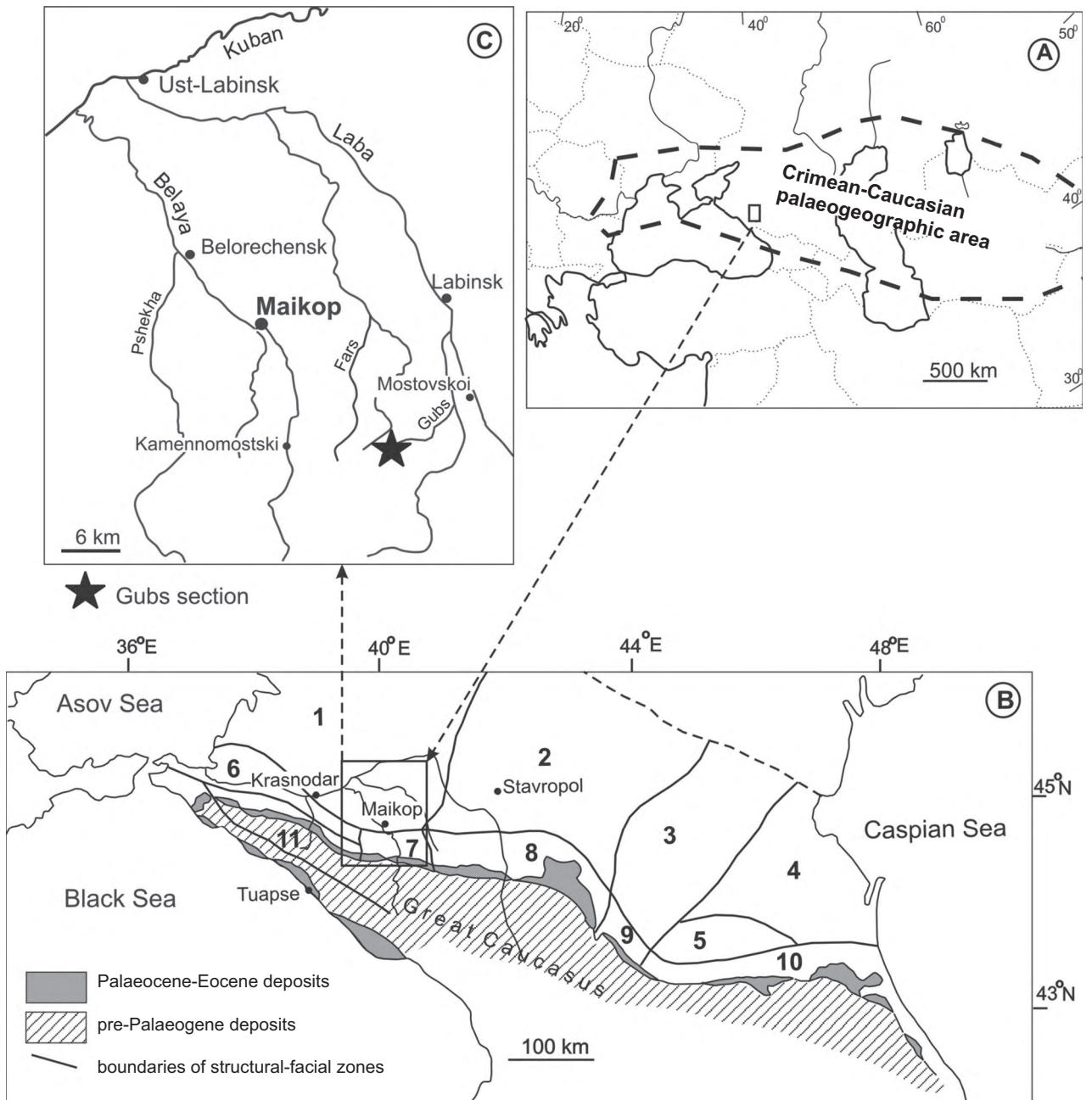
Figure 1. Geographic and geological position of the Gubs section. (**A**) The Crimean-Caucasian palaeogeographic realm in the north-eastern part of the Tethys; (**B**) structural-facial scheme of the Northern Caucasus and Ciscaucasus in the Palaeocene–Eocene (after Akhmeťev & Beniamovsky 2003 with changes); (**C**) locality map of the Gubs section in the southern part of the Adygean area. Structural-facial zones: 1– Tikhoretskaya, 2– Stavropolskaya, 3– Tersko-Kumskaya, 4– Kochubeevsko-Tarumovskaya, 5– Tersko-Sunjenskaya, 6– West-Kubanskaya, 7– Adygeiskaya, 8– Central, 9– Nalchikskaya, 10– Chernogorsko-Dagestanskaya, 11– Abino-Gunaiskaya.

Therefore, the main purpose of our work was the palaeontological and biostratigraphic study of larger benthic foraminifera, planktonic foraminifera and calcareous nannoplankton from the same samples of the lower–middle Eocene of the Gubs section. In addition, the latter two groups have been investigated from the Priabonian part of the profile.
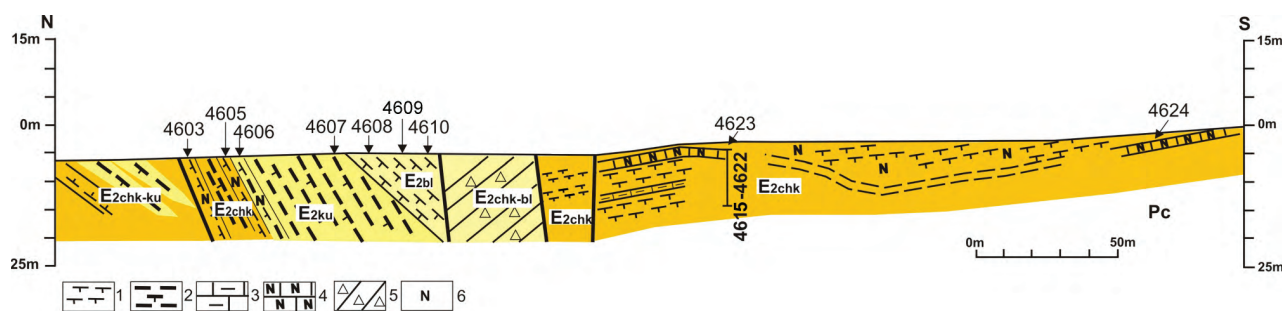
Figure 2. Geological profile of Eocene beds along the Gubs river. 1– calcareous clay and marl, 2– slightly carbonaceous clay, rich in organic matter, 3– organogene marly limestone, 4– nummulitic limestone, 5– tectonic breccia, 6– larger foraminifera, E_2chk– Cherkessk formation, E_2ku– Kuma Formation, E_2bl– Beloglinka Formation, Pc – Palaeocene, 4603–4624 – number of samples.

Larger foraminifera are represented by nummulitids (*Nummulites, Operculina*) and by the two families of orthophragmines (Discocyclinidae: *Discocyclina, Nemkovella*; Orbitoclypeidae: *Orbitoclypeus, Asterocyclina*).

In the recent investigation by E. Zakrevskaya and G. Less morphometric analysis of orthophragmines from this area was first applied and resulted in the subspecific taxonomy of this group. Therefore the first target of our investigations into larger foraminifera is to refine their taxonomy based on their detailed documentation. The zonation of Ypresian–Lutetian deposits by subdivision of local zonal assemblages and their correlation with the SBZ and OZ zones of the Tethyan shallow benthic scale (Serra-Kiel *et al.* 1998) and orthophragminid zonal scale (Less 1998), respectively, was the second target of our investigation.

Simultaneous study of planktonic foraminifera has been carried out by V. Beniamovsky in order to analyze the distribution of planktonic foraminifera and to establish the composition of zonal assemblages. Special attention was paid to mark the main events causing discrepancies of the detailed infrazonal Crimean-Caucasian scale (Beniamovsky 2001, 2009) from the standard Palaeogene planktonic foraminiferal scale of the Tethyan realm (Berggren & Pearson 2005; Pearson *et al.* 2006) in the context of the Peritethys-Tethys connection. The detailed infrazonal Crimean-Caucasian scale differs from the traditional Crimean-Caucasian scale (Yarkin 1989) in having more detail, containing 30 Palaeogene subzones instead of the 17 zones in the traditional subdivision.

The calcareous nannoplankton were investigated by M. Báldi-Beke in order to correlate them with the above two groups of foraminifera. The NP zones and subzones of Martini (1971) and CP zones and subzones of Okada & Bukry (1980) were identified.

However, the Gubs section appears to be too condensed to detect all zones/subzones using a considerable number of samples (some zones/subzones are represented only in one or two of them), so we only could identify the presence of zones/subzones in particular samples but not their exact boundaries, which are marked mostly with dashed lines in our figures.

Figured specimens lacking a letter prefix or prefixed by ZE are stored in the Invertebrate Collection of Vernadsky State Geological Museum of the Russian Academy of Sciences (RAS), Moscow, Russia, while those prefixed by E. are in the Eocene collection of the Geological Institute of Hungary (Budapest).

Abbreviations for biozones are: CP– Palaeogene calcareous nannoplankton zones (Okada & Bukry 1980); E– Eocene tropical/subtropical planktonic foraminiferal zones (Berggren & Pearson 2005); NP– Palaeogene calcareous nannoplankton zones (Martini 1971); OZ– Orthophragminid zones for the Mediterranean Palaeocene and Eocene (Less 1998) with correlation to the SBZ zones; P– Palaeogene tropical/subtropical planktonic foraminiferal zones (Blow 1969), updated by Berggren *et al.* (1995); PF– Palaeogene planktonic foraminiferal zones of the Crimean-Caucasian realm (Beniamovsky 2001), updated by Beniamovski (2006, 2009 and this

work); SBZ– shallow benthic foraminiferal zones for the Tethyan Palaeocene and Eocene (Serra-Kiel *et al.* 1998) with correlations to the planktonic and magnetic polarity zones. The correlation of the P, NP, SBZ and OZ zones is presented in Less *et al.* (2011, figure 2).

Material and Methods

Samples were collected from different types of rocks – marls, marly limestones and biogenic limestones at different intervals: 0.5–0.6 m in marly rocks and 0.1–0.3 m in nummulitic limestones. We studied isolated specimens of larger foraminifera from marls and marly limestones and their natural splits from hard limestones (samples 4621, 4622, 4622a, Figure 2). Thirteen samples were investigated for larger foraminifera; sixteen samples of marls and marly limestones for planktonic foraminifera and for nannoplankton. Planktonic and larger foraminifera were derived from soft rocks by the standard method of washing out through a sieve with 100 and 250 μm cells. Lithological analysis of hard rocks was supplemented by examination of six thin-sections.

Larger foraminifera were studied and identified in thin-sections, prepared through the equatorial plane by either splitting or thin-sectioning (about 400 thin-sections were prepared from free tests). For free specimens the external view, especially important for the specific determination of *Orbitoclypeus* and *Nummulites*, was also taken into consideration. Using the terminology of Less (1998), the outer cross diameter of the deuteroconch (d) was measured in 710 orthophragminid specimens in order to characterize taxa.

Due to the absence of microspheric specimens of large forms of *Nummulites* and the limited number of whorls in their megalospheric generation, most species were classified following an open nomenclature. On the basis of qualitative parameters (e.g., shape of septa and chambers, peculiarities of the spire form) the phylogenetic position could be reliably achieved. The position within phylogenetic lineages was determined quantitatively, using the medium cross diameter of the protoconch (P) and the expansion rate of the whorls. This typological approach for species determination was applied

by Schaub (1981). As well as the accepted sense of 'aff.' (phylogenetically closed, identified in open nomenclature), in some cases the prefix 'aff.' has been used for intermediate forms of species status according to the Schaub's classification (*Nummulites* aff. *irregularis*, *N.* aff. *nitidus, N.* aff. *laxus*).

In this work we applied the classification of Schaub (1981) for large *Nummulites* (the *N. nitidus*, *N. pratti*, *N. distans*, *N. irregularis* and *N. praelucasi* groups). For small Lutetian *Nummulites* of the *N. variolarius* group we followed Jarzeva *et al.* (1968) and Blondeau (1972), while for orthophragmines the biometrical classification of Less (1987, 1998) was applied.

The specific identification of most planktonic foraminiferal genera, such as *Subbotina, Acarinina, Turborotalia, Globigerinatheka, Hantkenina* and *Catapsydrax,* was made according to Pearson *et al.* (2006). For *Acarinina rotundimarginata*, *Subbotina turcmenica* and *S. azerbaidjanica*, the classification of Subbotina (1953), Subbotina *et al.* (1981) and Khalilov (1967) was used.

In this paper we adopt the standard stage Ypresian for the entire lower Eocene. Since the late Ypresian is not subdivided in the standard scale, we adopt for this time-interval the Cuisian, widely used in larger foraminiferal biostratigraphy. At the same time we use for the traditional subdivision of the Ypresian the Crimean-Caucasus scale, i.e. the *Morozovella subbotinae* s.l. Zone corresponds to the early Ypresian, whereas the *Morozovella aragonensis* s.l. Zone corresponds to the late Ypresian.

Geological Setting

According to Grossgeim (1960) and Khain (2001) the studied region is located in the eastern part of the Palaeozoic Adygean high (Grossgeim 1960; Khain 2001), which is subdivided into local positive and negative structures. This submeridional, transverse high is located in the western part of the North Caucasian monocline, which is bordered to the north by the Stavropol high of the Scythian plate (Ciscaucasus) and to the south by the folded block structure of the Greater Caucasus meganticlinorium (Main Ridge of Greater Caucasus). The Adygean high separates the Western and Eastern Cubanian Alpine skirt depressions. In the Palaeocene–Eocene the first

represented a flysch basin, while the second was a deep shelf with hemipelagic sedimentation. At the beginning of the middle Eocene the flysch basin was closed and hemipelagic sedimentation prevailed in both Cubanian basins.

Based on Grossgeim (1960) and Grossgeim & Korobkov (1975) the Palaeogene of the Adygean high is characterized by various lithologies, small thickness and several gaps. The lower Palaeocene in most localities consists of shallow water biogenic limestone and coarse sandstone containing crinoids, bryozoans, gastropods, red algae, common rotaliids and rare planktonic foraminifers (*Subbotina triloculinoides*). The middle and upper Palaeocene in most localities are absent or represented by carbonate-free clay, siltstone and sandstone. The uppermost Palaeocene to lowermost Eocene (Abazinka formation) consists of clayey siltstone and sandstone with agglutinated foraminifers and radiolarians. The Eocene is characterized by increasing carbonate sedimentation, but in some sections (Belaya river) sandy and clayey siliciclastic sediments compose the lower part of the Ypresian. The upper Ypresian to Lutetian consists of carbonate, mainly shallow water sediments of biogenic origin, rich in small benthic and planktonic foraminifera (so-called 'foraminiferal beds'). The upper part of the middle Eocene is represented in the North Caucasus by the very characteristic, widespread Kuma Formation, rich in organic matter and containing thin-walled planktonic and agglutinated foraminifera as well as fish remains. From the latest middle Eocene a certain homogenization of the environment can be observed, proven by the wide distribution of the upper Eocene Beloglinka Formation, comprising pelagic limestone and marl. During the early Palaeogene the siliciclastic supply into the Adygean basin came from the Southern Caucasian landmass (Grossgeim 1960).

Description of the Section

The studied section is situated on the Gubs river banks at the southern edge of Barakaevskaya village (Figure 1). The carbonate-rich Eocene deposits crop out 100 m to the north-east (downstream) from an outcrop of carbonate-free grey clayey siltstone (assigned to the uppermost Palaeocene to lower Eocene Abazinka formation) with no visible contact between them.

The Eocene deposits occur in a complicated block-folded structure, so our data do not coincide with those of Grossgeim (1958).

They constitute a W–E-trending asymmetrical synclinal structure and are referred to the Cherkessk, Kuma and Beloglinka formations with combined thickness of about 45 m (Figure 2). Only by tracing the stratigraphic position of separated blocks in the southern and northern limbs of the syncline we could recognize the normal succession of beds. In this composite section seven informal units were subdivided (Figures 2 & 3).

The *Cherkessk Formation* is represented by four units. The oldest beds crop out in the southern limb of the syncline, close to the small waterfall below the nummulitic limestone.

Unit 1 (about 4.5 m thick, the lowest part is under water) is represented by an irregular alternation of greenish sandy marls and marly limestones 0.8 m thick in the lower and 1.1 m thick in the upper part. The limestone of the lower part is more clayey; its microfacies is mudstone. It consists of abundant biogenic detritus (as well as complete shells) of mostly planktonic and rarely benthic small foraminifera and an inorganic sand-sized admixture of glauconite, pyrite and iron-oxides. The marl differs from the limestone in the rarity of benthic foraminifera and by a more abundant mineralogical admixture. In the upper part foraminiferal wackestone with an abundant sandy admixture of quartz, glauconite and pyrite can be observed. Beside foraminifera, rare remains of crinoids and red algae are present.

The first rare larger foraminifera appear in marls (sample 4618). In the upper limestone layer (sample 4619) and in the uppermost marls (samples 4620 to 4621a) they are more common and are associated with large rotaliids and textulariids.

Unit 2 (1–1.5 m thick), with a sharp base, consists of two beds of greyish-white foraminiferal limestone. Globigerinid wacke-packstone with smaller benthic and larger foraminifera, rare echinoderms and red algae forms the lower layer, while nummulitic grainstone with crinoids, rare rotaliids and red algae can be observed in the upper bed, at the top of which nummulitic grainstone passes into packstone.

Unit 3 (2 m of incomplete thickness) covers the limestone of Unit 2 following a sedimentary hiatus. It

is composed of greenish-grey marl with an admixture of glauconite, pyrite, iron oxides. The biogenic components are abundant planktonic, smaller and larger benthic foraminifera, remains of echinoderms, fishes and red algae. Both the macrofossils and larger foraminifera are often rounded; some of them (*Nummulites* from the *N. praelucasi*, *N. pratti*, *N. nitidus* and *N. irregularis* groups) were very probably redeposited.

The Eocene succession can be followed in the northern limb of the syncline.

Unit 4 (5 m of incomplete thickness) is composed of two layers of greenish-grey marls, subdivided by brownish, slightly carbonaceous clays. The composition of the inorganic admixture in the lower layer (sample 4603) is the same as in Unit 3; the biogenic remains include foraminifera, crinoids, fishes, ostracods and brachiopods. Larger foraminifera are abundant and often rounded.

The upper layer of greenish-grey marls (samples 4605, 4605a) is 2 m thick. It differs from the lower unit in the increase of carbonaceous material in the presence of thin (0.1 m) intercalations of nummulitic grainstones, and in larger number of *Nummulites*. Among the biogenic remains, beside foraminifera, echinoderms and fishes, the quantity of red algae is remarkable.

Kuma Formation

Unit 5 (1 m of incomplete thickness) is composed of brownish-grey, bedded marl with admixture of coarse quartz grains and glauconite. Fossils are represented by foraminifera, ostracods, bryozoans, echinoderms, brachiopods, fishes and red algae. Larger foraminiferal tests are often rounded (some nummulitids may be reworked), but they are well-preserved due to calcite filling.

Unit 6 (9 m thickness visible), after an approximate 7 m gap in the observation, the deposits of Unit 5 are succeeded by clays of the Kuma Formation. Larger foraminifera could not be found.

Beloglinka Formation

Unit 7 (12 m of incomplete thickness), overlying the Kuma Formation with angular unconformity, white marls of the Beloglinka Formation ('Belaya glina' means white clay) complete the Eocene section. This unit contains rich assemblages of planktonic foraminifera and calcareous nannoplankton, but larger benthic foraminifera are missing.

Results

Larger Foraminifera of the Gubs Section: Taxonomy and Biostratigraphy
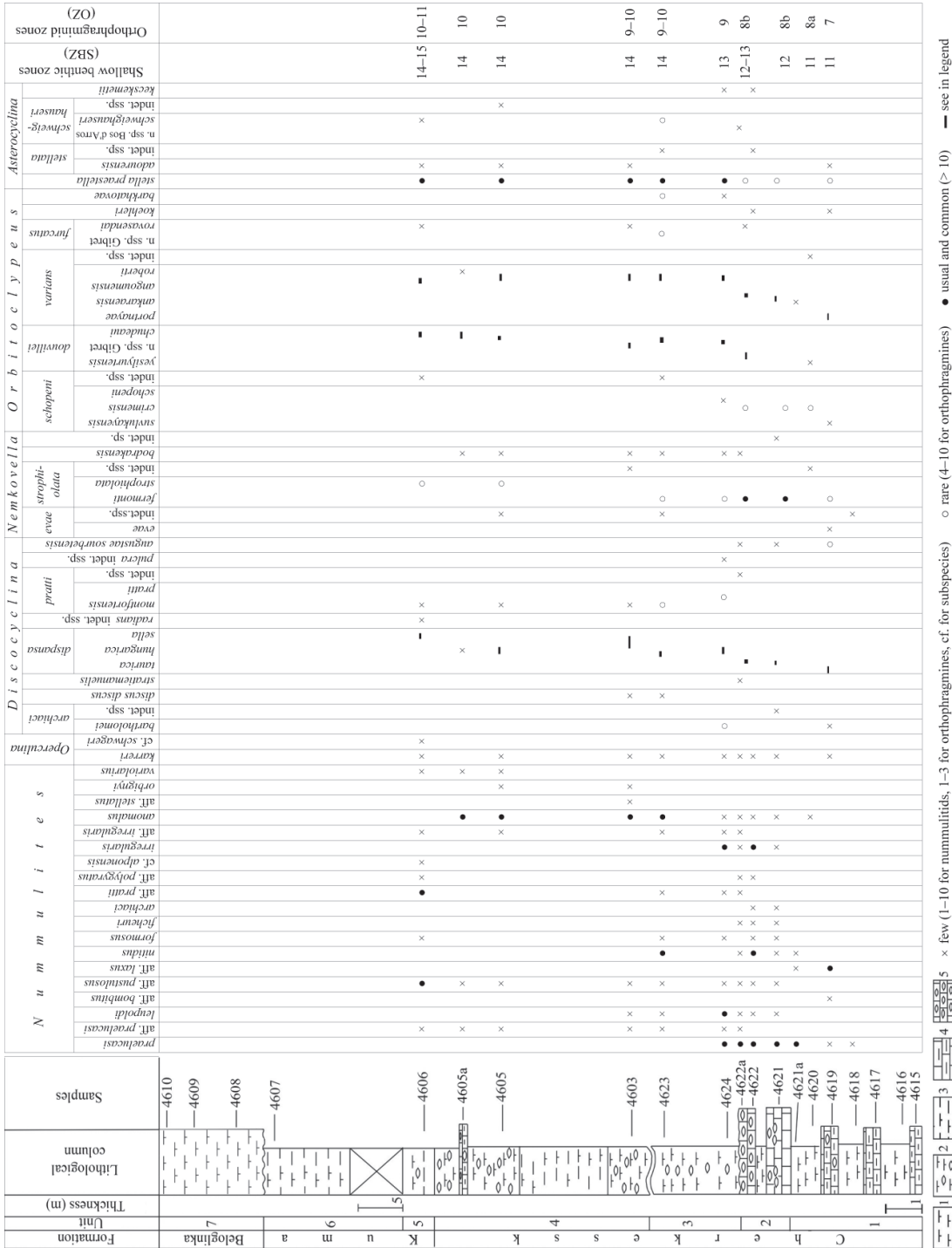
In the Gubs section larger foraminifera were found in the Cherkessk and Kuma formations. They belong to nummulitids and orthophragmines, and are represented by six Tethyan genera. Their distribution is shown in Figure 3. Based on larger foraminifera the SBZ 11–12 (middle–upper Cuisian by Serra-Kiel *et al.* 1998) and SBZ 14 (middle Lutetian) zones are easily recognized, whereas markers of the SBZ 13 (lower Lutetian) Zone are rather rare.

Larger foraminifera in the Gubs section are incompletely preserved. Microspheric forms of nummulitids are entirely missing, while among orthophragmines only some B-forms of genus *Nemkovella* were found. Moreover, the external part of larger foraminifera is also lacking: generally two whorls of large *Nummulites* and up to ten annuli of large *Discocyclina* (*D. archiaci*, *D stratiemanuelis*, *D. discus*) are preserved. It seriously hampers diagnosing nummulitids, therefore most 'large' species are determined in open nomenclature. This incomplete preservation (together with the occurrence of larger foraminifera only in some layers between pelagic marls) may be explained by displacement caused by high hydrodynamic activity.

Nummulitids from the Gubs Section

They are represented by *Nummulites* and *Operculina* shown in Figure 4. Contrary to the recent classification (Loeblich & Tappan 1987) we include the Eocene operculinoid forms (the so-called 'operculinoid assilinas') of the *O. alpina*, *O. granulosa*, *O. canalifera* and *O. ammonoides* groups within the genus *Operculina* and the assilinoid forms (the so-called 'assilinoid assilinas') of the *A. spira* and *A. exponens* groups in the genus *Assilina*. These last groups, usually abundant in the Eocene of Tethyan basins, are absent

Figure 3. Stratigraphic distribution of larger foraminifera in the Gubs section. 1– calcareous clay and marl, 2– calcareous clay with abundant nummulitids and orthophragmines, 3– slightly carbonaceous clay, rich in organic matter, 4– organogenic marly limestone, 5– nummulitic and foraminiferal limestone with larger foraminifera. Horizontal lines in the column of *Discocyclina dispansa, Orbitoclypeus douvillei* and *O. varians* are placed based on the evolutionary degree (corresponding to a given subspecies according to Figure 7) of the given population. Their width is proportional to the number of specimens whereas their length to the standard error (s.e.) of the mean outer cross diameter of the deuteroconch (d_{mean}) in the population.

a-e: 1mm

rest: 1mm

Figure 4.

from a wide swathe of the Northern Peritethys from the Eastern Crimea in the west to Central Asia in the east, as well as in the Paris Basin. We assume that this may be connected with the special hydrology of peri-platform seas, distributed here, and poorly connected with the open oceanic water.

Nummulites– Only representatives of non-granulose evolutionary lineages such as *N. praelucasi, N. pratti, N. nitidus, N. pustulosus, N. irregularis, N. distans, N. anomalus* and *N. variolarius* are present. Except for the last three all are characteristic for the Ypresian or late Ypresian to early Lutetian time-span.

According to the classification of Schaub (1981) the oldest (lower–middle Cuisian) taxa are *N. praelucasi* Douvillé, *N. leupoldi* Schaub and *N.* aff. *pustulosus* Douvillé. Nevertheless, in the Gubs profile they can be found up to the middle Lutetian, because of reworking. However, *N. leupoldi* in the Crimea is also known from the lower Lutetian, while in the Gorrondatxe section (Molina *et al.* 2011) *N.* cf. *leupoldi* is also recorded from the middle Lutetian. Compared to the typical forms, *N.* aff. *pustulosus* from the upper part of the section has a larger proloculus (0.5–0.6 mm) and more open spiral (Figure 4E). *N. nitidus* de la Harpe, *N. irregularis* Deshayes and *N. archiaci* Schaub first appear in the middle Cuisian in many sections of the Tethys and Peritethys. In the Gubs profile *N. irregularis* and *N. archiaci* are characteristic for SBZ 12 (upper Cuisian in Serra-Kiel *et al.* 1998), whereas *N. nitidus* and *N. irregularis* can also be followed up to the base of the middle Lutetian SBZ 14. At this level and up to the middle part of the middle Lutetian *N. pratti* d'Archiac & Haime, the successor of *N. archiaci*, also occurs.

Nummulites formosus de la Harpe, the last member of the *N. nitidus* lineage (recorded mostly from SBZ 12 and 13 corresponding to the late Ypresian and early Lutetian; Serra-Kiel *et al.* 1998) can also be found up to the middle Lutetian (SBZ 14). In the *N. distans* lineage, the presence of *N.* aff. *polygyratus* Deshayes (Figure 4s, t) and *N.* cf. *alponensis* Schaub (Figure 4u) in the SBZ 12 and SBZ 14–15 zones, respectively, does not contradict data from other regions.

Typical Peritethyan small *Nummulites* of the *N. variolarius* group (*N. variolarius* Lamarck and *N. orbignyi* Galeotti) could only be found in middle Lutetian deposits, starting from sample 4605. To sum up: despite the mixed composition of *Nummulites* and their incomplete preservation, some stratigraphical horizons can be recognized by the appearance of characteristic species, i.e. *N.* aff. *polygyratus* marks the SBZ 12, while *N. orbignyi* and *N. variolarius* indicate the SBZ 14–15 zones.

Most *Nummulites* in the given sequence are cosmopolitan for the Tethys, although they are most widespread in the north-eastern part of the Peritethys. The peculiarities of these assemblages are the absence of genus *Assilina* and of granulose *Nummulites* and the predominance of nummulitic species with an open spiral. Based on data from this and other profiles (Bakhchisarai, Loo, Gorrondatxe), the stratigraphic range of some *Nummulites* (*N. leupoldi, N. nitidus, N. formosus* and *N. irregularis*) appears to be wider than shown in the shallow benthic zonation by Serra-Kiel *et al.* (1998) and should be extended up to the early–middle Lutetian.

Operculina– Rare forms of this genus are represented by *O. karreri* Penecke and *O.* cf. *schwageri*

Figure 4. Nummulitidae from the Gubs section. (**a–b**) *Nummulites praelucasi* Douvillé, (a) sample 4622, 09794.01, (b) sample 4622a, 09799.04, (**c–d**) *N. leupoldi* Schaub, (c) sample 4624, 09815, (d) sample 4622, 09798, (**e**) *N.* aff. *bombitus* Hottinger, sample 4619, 09785.04, (**f**) *N. irregularis* Deshayes, sample 4622, 09797.02, (**g**) *N.* aff. *irregularis* Deshayes, sample 4622a, 09801, (**h**) *N.* ex gr. *irregularis* Deshayes, sample 4624, 09816, (**i–l**) *N. ficheuri* (Prever), (i) sample 4621, 09790.03, (j–l) sample 4622a, (j) 09804., (k) 09803.02, (l) 09800, (**m–o**) *N. archiaci* Schaub, (m–n) sample 4621, (m) 09789.02., (n) 09792, (o) sample 4622, 09795.02, (**p–r**) *N.* aff. *pratti* d'Archiac & Haime, (p–q) sample 4624, (p) 09817.01, (q) 09817.02, (r) sample 4606, 09840, (**s–t**) *N.* aff. *polygyratus* Deshayes, (s) sample 4622, 09794.02, (t) sample 4622a, 09806, (**u–v**) *N.* cf. *alponensis* Schaub, sample 4606, 09841, (**w–x**) *N. nitidus* de la Harpe, (w) sample 4621, 09793, (x) sample 4622a, 09805, (**y–z**) *N.* aff. *nitidus* de la Harpe, sample 4623 (y) 09825, (z) 09826, (**A–B**) *N. formosus* de la Harpe, sample 4606, 09842, (**C–F**) *N.* aff. *pustulosus* Douvillé, (C) sample 4621, 09791, (D) sample 4622, 09797.01, (E–F) sample 4606, (E) 09843, (F) 09844, (**G**) *N. anomalus* de la Harpe, sample 4603, 09831, (**H–I**) *N. variolarius* (Lamarck), (H) sample 4605, 09832, (I) sample 4606, 09845, (**J–K**) *N orbignyi* (Galeotti), sample 4603 (J) 09829, (K) 09830, (**L–M**) *Operculina* cf. *schwageri* Silvestri, sample 4606, (L) 09846, (M) 09847, (**N**) *Operculina karreri* Penecke, sample 4606, ZE.09.89. All– A-forms; a–u, w–A, C–J, L– equatorial sections, v, B, K, M– external views, a–e: ×15, rest: ×10.

Silvestri (present only in sample 4606 and in fact a transitional form between *O. parva* and *O.schwageri* with a proloculus of around 90 μm in diameter), two cosmopolitan lower and middle Eocene species of the *O. alpina* group.

Orthophragmines from the Gubs Section

The name 'orthophragmines' is an informal collective term comprising two independent families, Discocyclinidae and Orbitoclypeidae. They are abundant in the Gubs section. More details about their architecture (including the discriminative qualitative features for separating the four different Tethyan orthophragminid genera) are given in Less (1987), Ferràndez-Cañadell & Serra-Kiel (1992), Ferràndez-Cañadell (1998) and Less & Ó. Kovács (2009).

Principles of Specific and Intraspecific Taxonomy– All four Tethyan genera consist of several, long-living, simultaneously running evolutionary lineages considered to be species in the practice of Tethyan orthophragmines and with significant internal development allowing their morphometric subdivision into successive arbitrary subspecies. These species very often coexist in particular samples, in which they are distinguished by the combination of some clearly qualitative features, such as the external shape and other characteristics (see Özcan *et al.* 2007a, figure 2) and also of some primarily quantitative features – that are in fact evaluated qualitatively and, therefore, recognizable immediately by an experienced expert – such as the dimension of the A-form embryon and the shape and width of equatorial chamberlets.

The methodology of this so-called typological determination of species in one single sample is presented in detail by Less & Ó. Kovács (2009). It should be added that [according to Drooger's (1993) morphometric method] all specimens of a single sample, different from each other only in continuously followable quantitative details, are grouped together into one single population, which as a whole represents the evolutionary degree of the given species in the given sample. This also means that specimens in a given sample are only determined at species level, although their evolutionary degree

(the subspecific affiliation) can only be determined for the population as a whole.

According to Less (1998) orthophragminid subspecies are defined by biometric limits of the population means of the outer cross diameter of the deuteroconch in equatorial section (marked by 'd', see Figure 5). This quantitative feature has been chosen from among several other evolutionary parameters because it is most easily and objectively measurable and also it reveals the fastest and the least variable evolutionary progress. Other parameters, shown in Figure 5, are used to describe taxa in detail.

Grouped samples, close to each other and containing almost the same assemblages having similar parameters are evaluated both separately and jointly. However, the subspecific determination of particular species is given for the joint samples based on the total number of specimens. These data are marked in bold in Table 1. Because of limited space, a complete statistical evaluation is given only for deuteroconch size (d), the crucial parameter in subspecific determination. Subspecies are determined according to the biometrical limits presented in Figure 6. No subspecies is determined if only a single specimen is available from joint samples. If the number of specimens is two or three, the subspecies is determined as cf. If this number is four or more but the d_{mean} value of the given population is closer to the biometrical limit of the given subspecies than 1 s.e. of d_{mean}, we use an intermediate denomination between the two neighboring subspecies. In these cases we adopt Drooger's (1993) proposal in using the notation exemplum intercentrale (abbreviated as ex. interc.). Biometric data are summarized in Table 1.

The State-of-art of the Orthophragminid Zonation– Based on geological superposition, the accompanying fossils, and the mutual control of co-existing evolutionary lineages, the assemblages of coexisting subspecies (of different species) could be arranged into a succession that is in fact a zonation with Oppelian zones. Less (1998, see also for more details) distinguished eighteen such orthophragminid zones from OZ 1a to 16 (including OZ 1a, 1b, 8a and 8b, each in zonal rank) ranging from early Thanetian to late Priabonian. The stratigraphic ranges of particular orthophragminid taxa (subspecies and unsubdivided species) were evaluated by Less (1998) and updated
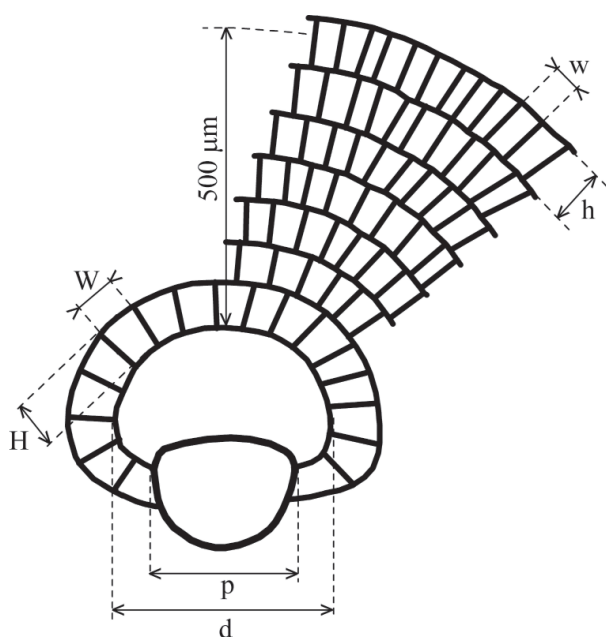
Figure 5. The measurement system of megalospheric orthophragmines in equatorial section (after Özcan *et al*. 2007a).

by Özcan *et al*. (2007a, b) and Less *et al*. (2007, 2011) based on new data, mainly from Turkey. Note that the arbitrary subdivision of the (supposedly gradual) evolutionary lineages causes overlaps between the stratigraphical ranges of neighbouring subspecies (Figure 7) since there are always spatial, ecological and random deviations from the 'medium' evolutionary track, and thus the latter has a range of variation.

Orthophragminid data have been integrated into the larger foraminiferal zonation of the Tethyan Palaeocene and Eocene, resulting in the establishment of twenty shallow benthic zones for the Mediterranean region (SBZ 1-20, Serra-Kiel *et al*. 1998). The correlation of OZ and SBZ zones for the late Ypresian and Lutetian is shown in the header of Figure 8.

The record for the orthophragminid zonation is rather uneven. At present it is quite dense for the early and middle Ypresian (OZ 2 to 6 corresponding to SBZ 5 to 10) and for the latest Lutetian to early Priabonian (OZ 12 to 14 corresponding to SBZ 16 to 19). In contrast, the late Ypresian to late Lutetian record (OZ 7 to 11 corresponding to SBZ 11 to 15) is rather poor, each orthophragminid zone is characterized only by

a few (two to four) key localities. The Gubs section is very important in this respect, since it covers this crucial time-interval, and provides new information both on the content of these zones and the range-charts of particular taxa. They are demonstrated in Figure 8 where updatings (compared with the range-chart by Özcan *et al*. 2007b) are shown in red. New data from the upper Lutetian levels of Gizlilimani (Gökçeada Island, W Turkey) based on Özcan *et al*. (2010) are also considered.

Orthophragminid Assemblages and Larger Foraminiferal Zonal Subdivision of the Gubs Section– The composition of orthophragmines (illustrated in Figures 9 to 12) and nummulitids in particular samples is shown in Figure 3. Unlike nummulitids the orthophragminid assemblages of the Gubs section are very similar to those from other parts of the Western Tethys. Only two of the most widespread lineages (*Discocyclina radians* and *Asterocyclina alticostata*) have not yet been found in Gubs, whereas *Orbitoclypeus barkhatovae* n. sp. seems to be endemic so far for the Northern Peritethys. It does not indicate, however, a permanent connection between the orthophragminid assemblages of the two realms, since there are significant differences in the evolutionary degree of particular lineages at some given levels (see e.g., Figure 8 for the diachronous first appearance of *Orbitoclypeus varians roberti* in the two realms). This is also confirmed by some minor morphological deviations, such as the very heavy undulation of *O. varians* in Gubs as compared to other Tethyan specimens.

The oldest orthophragminid assemblage can be found in sample 4619 (here we exclude sample 4618 containing only *Nemkovella evae* cf. *evae* Less). In this sample well-developed *Discocyclina archiaci* (*D. a.* cf. *bartholomei* (Schlumberger), based on two specimens) characteristic for OZ 7-9 and *Orbitoclypeus koehleri* Less (known so far from OZ 8a of the Bakhchisarai section in the Crimea) coexist with relatively primitive *Orbitoclypeus* such as *O. varians portnayae* Less (OZ 5-8a) and especially *O. schopeni* cf. *suvlukayensis* Less (based on three specimens). This taxon has been known so far from the late Ilerdian and early Cuisian (OZ 4-6): here we slightly extend its range into OZ 7, which is considered as the most probable age of sample 4619.

Table 1. Statistical data of the outer cross diameter of the deuteroconch (d, in µm) in the orthophragminid populations of the Gubs section.

Species	Sample	№	range	mean ± s.e.	Subspecies
Discocyclina archiaci	4619	2	770 – 780	775.0	cf. *bartholomei*
	4621	1		670.0	indet. ssp.
	4624	4	750 – 900	825.0 ± 43.3	*bartholomei*
D. discus	4623	2	1100 – 1350	1225.0	cf. *discus*
	4603	2	1000 – 1100	1050.0	cf. *discus*
D. stratiemanuelis	4622a	2	1100 – 1250	1175.0	–
D. dispansa	4619	4	150 – 210	185.0 ± 13.2	*taurica*
	4621	9	175 – 250	203.9 ± 7.0	*taurica*
	4622+4622a	41	160 – 300	218.0 ± 6.2	*taurica*
	4622	28	160 – 300	216.2 ± 7.3	
	4622a	13	175 – 300	221.9 ± 12.4	
	4624	17	175 – 350	257.3 ± 10.9	*hungarica*
	4623	18	200 – 300	246.4 ± 8.5	*hungarica*
	4603	7	200 – 400	307.2 ± 30.7	*sella–hungarica*
	4605+4605a	14	200 – 350	269.7 ± 10.2	*hungarica*
	4605	13	200 – 350	271.2 ± 10.9	
	4605a	1		250.0	
	4606	13	250 – 400	331.9 ± 13.9	*sella*
D. radians	4606	1		420.0	indet. ssp.
D. pratti	4622a	1		400.0	indet. ssp.
	4624	4	400 – 610	483.8 ± 51.4	*montfortensis–pratti*
	4623	5	350 – 550	460.0 ± 40.8	*montfortensis*
	4603	3	400 – 450	425.0	cf. *montfortensis*
	4605	3	400 – 500	441.7	cf. *montfortensis*
	4606	3	400 – 500	450.0	cf. *montfortensis*
D. pulcra	4624	1		700.0	
D. augustae	4619	4	100 – 125	112.5 ± 7.2	*sourbetensis*
	4621	3	125 – 150	141.7	cf. *sourbetensis*
	4622a	2	130 – 150	140.0	cf. *sourbetensis*
Nemkovella evae	4618	1		135.0	indet. ssp.
	4623	3	150 – 175	165.0	cf. *evae*
	4623	1		225.0	indet. ssp.
	4605	1		275.0	indet. ssp.
N. strophiolata	4619	7	90 – 125	112.9 ± 6.0	*fermonti*
	4620	1		100.0	indet. ssp.
	4621+4621a	10	90 – 125	113.5 ± 4.5	*fermonti*
	4621a	3	125	125.0	
	4621	7	90 – 125	108.6 ± 5.4	
	4622+4622a	13	75 – 170	116.5 ± 6.9	*fermonti*
	4622	8	75 – 170	118.1 ± 10.9	
	4622a	5	100 – 125	114.0 ± 5.8	
	4624	5	100 – 140	123.0 ± 6.4	*fermonti*
	4623	4	100 – 125	117.5 ± 5.9	*fermonti*
	4603	1		125.0	indet. ssp.
	4605	9	125 – 200	161.1 ± 8.4	*strophiolata*
	4606	8	125 – 200	164.4 ± 9.3	*strophiolata*
N. bodrakensis	4622a	3	75 – 90	85.0	
	4624	1		90.0	
	4623	3	75 – 90	80.0	
	4603	3	75 – 80	76.7	–
	4605+4605a	3	75 – 100	83.3	
	4605	2	75 – 100	87.5	
	4605a	1		75.0	
N. indet. sp.	4621	1		440.0	–
Asterocyclina stellata	4619	2	100 – 150	125.0	cf. *adourensis*
	4622	1		175.0	indet. ssp.
	4623	1		125.0	indet. ssp.
	4603	3	110 – 150	128.3	cf. *adourensis*
	4605	3	125 – 150	133.3	cf. *adourensis*
	4606	2	130 – 150	140.0	cf. *adourensis*
A. kecskemetii	4622	2	200 – 300	250.0	–
	4624	1		200.0	

Species	Sample	№	range	mean ± s.e.	Subspecies
A. stella	4619	5	75 – 150	97.0 ± 14.1	*praestella*
	4621	5	100 – 175	135.0 ± 12.7	*praestella*
	4622+4622a	9	75 – 175	123.9 ± 11.5	*praestella*
	4622	5	75 – 175	135.0 ± 17.0	
	4622a	4	75 – 140	110.0 ± 14.3	
	4624	10	75 – 150	100.0 ± 6.4	*praestella*
	4623	21	85 – 175	122.6 ± 4.8	*praestella*
	4603	11	75 – 125	108.2 ± 5.0	*praestella*
	4605	12	75 – 150	111.7 ± 6.0	*praestella*
	4606	21	80 – 190	128.1 ± 5.9	*praestella*
A. schweighauseri	4622a	2	375 – 400	387.5	cf. n. ssp. Bos d'Arros – *schweighauseri*
	4623	4	500 – 610	540.0 ± 26.1	*schweighauseri*
	4605	1		450.0	indet. ssp.
	4606	2	500 – 600	550.0	cf. *schweighauseri*
Orbitoclypeus schopeni	4619	3	250 – 275	258.3	cf. *suvlukayensis*
	4620	4	260 – 450	383.8 ± 42.5	*crimensis*
	4621+4621a	5	330 – 440	389.0 ± 18.1	*crimensis*
	4621a	1		400.0	
	4621	4	330 – 440	386.3 ± 23.0	
	4622+4622a	8	390 – 550	458.1 ± 24.5	*crimensis*
	4622	5	390 – 550	443.0 ± 30.8	
	4622a	3	400 – 550	483.3	
	4624	3	450 – 550	500.0	cf. *schopeni–crimensis*
	4623	1		700.0	indet. ssp.
	4606	1		550.0	indet. ssp.
O. douvillei	4620	3	225 – 250	233.3	cf. *yesilyurtensis*
	4622+4622a	8	200 – 300	269.4 ± 12.3	n. ssp. Gibret – *yesilyurtensis*
	4622	5	250 – 300	285.0 ± 10.0	
	4622a	3	200 – 280	243.3	
	4624	33	250 – 450	338.6 ± 10.5	n. ssp. Gibret – *chudeaui*
	4623	32	250 – 455	344.9 ± 9.0	*chudeaui* – n. ssp. Gibret
	4603	14	250 – 425	317.9 ± 15.4	n. ssp. Gibret
	4605+4605a	41	250 – 500	362.1 ± 8.4	*chudeaui*
	4605	29	250 – 450	359.0 ± 8.8	
	4605a	12	260 – 500	369.6 ± 19.5	
	4606	30	270 – 525	368.4 ± 12.4	*chudeaui*
O. varians	4619	5	120 – 175	144.0 ± 9.9	*portnayae*
	4620	1		175.0	indet. ssp.
	4621+4621a	9	160 – 250	195.0 ± 9.6	*ankaraensis*
	4621a	1		175.0	
	4621	8	160 – 250	197.5 ± 10.5	
	4622+4622a	31	150 – 250	207.4 ± 5.5	*angoumensis–ankaraensis*
	4622	18	150 – 250	202.8 ± 7.5	
	4622a	13	175 – 250	213.8 ± 7.9	
	4624	22	250 – 365	267.0 ± 6.3	*roberti*
	4623	13	200 – 345	270.4 ± 9.5	*roberti*
	4603	11	250 – 395	270.0 ± 13.9	*roberti*
	4605+4605a	18	175 – 360	271.4 ± 10.4	*roberti*
	4605	15	175 – 360	267.3 ± 11.7	
	4605a	3	250 – 325	291.7	
	4606	26	150 – 370	254.4 ± 8.4	*angoumensis–roberti*
O. furcatus	4622+4622a	3	260 – 300	280.0	cf. *rovasendai*
	4622	2	280 – 300	290.0	
	4622a	1		260.0	
	4623	7	240 – 300	275.5 ± 9.0	n. ssp. Gibret – *rovasendai*
	4603	2	270 – 320	295.0	cf. *rovasendai*
	4606	3	310 – 335	323.3	cf. *rovasendai*
O. koehleri	4619	1		570.0	–
	4622	1		750.0	
O. barkhatovae	4624	2	650 – 1150	900.0	–
	4623	7	650 – 1100	862.1 ± 62.2	

Although the orthophragminid assemblage of sample 4620 is rather poor, it contains a crucial population of *Orbitoclypeus douvillei* cf. *yesilyurtensis* Özcan with three specimens. Since this taxon characterizes the OZ 8a Zone of the Haymana Basin (Central Turkey), we identify this zone also for sample 4620, which is not in contradiction with the presence of *O. schopeni crimensis* Less.

Species /subspecies	d_mean (µm)
Asterocyclina alticostata	
gallica	<275
cuvillieri	275-350
alticostata	350-450
danubica	>450
A. schweighauseri	
n. ssp. Bos d'Arros	<400
schweighauseri	>400
A. stella	
praestella	<150
stella	>150
A. stellata	
adourensis	<150
stellata	150-190
stellaris	190-240
buekkensis	>240
Discocyclina archiaci	
bakhchisaraiensis	<305
staroseliensis	305-390
arhiaci	390-600
bartholomei	>600
D. augustae	
sourbetensis	<145
atlantica	145-180
olianae	180-225
augustae	>225
D. discus	
discus	<1350
adamsi	>1350
D. dispansa	
broennimanni	<160
taurica	160-230
hungarica	230-290
sella	290-400
dispansa	400-520
umbilicata	>520
D. fortisi	
fortisi	<850
simferopolensis	850-1100
anatolica	1100-1450
cairazensis	>1450
D. pratti	
montfortensis	<510
pratti	510-700
minor	>700
D. pulcra	
landesica	<800
pulcra	800-1000
n. ssp. Angoumé	1000-1250
balatonica	1250-1600
baconica	>1600
D. radians	
n. ssp. Caupenne	<240
noussensis	240-300
radians	300-375
labatlanensis	>375

Species /subspecies	d_mean (µm)
D. seunesi	
seunesi	<250
beloslavensis	250-310
karabuekensis	>310
D. spliti	
polatliensis	<800
spliti	800-1300
ajkaensis	>1300
D. trabayensis	
trabayensis	<125
elazigensis	125-170
vicenzensis	>170
Nemkovella evae	
evae	<260
karitensis	>260
N. strophiolata	
fermonti	<150
strophiolata	150-185
n. ssp. Padragkút	185-230
tenella	>230
Orbitoclypeus bayani	
kurucasileensis	<280
bayani	>280
O. douvillei	
douvillei	<200
yesilyurtensis	200-260
n. ssp. Gibret	260-340
chudeaui	340-425
pannonicus	425-580
malatyaensis	>580
O. furcatus	
palaeofurcatus	<200
n. ssp. Gibret	200-270
rovasendai	270-340
furcatus	>340
O. multiplicatus	
haymanaensis	<310
multiplicatus	310-420
kastamonuensis	420-550
gmundenensis	>550
O. munieri	
ponticus	<220
munieri	>220
O. schopeni	
ramaraoi	<195
neumannae	195-240
suvlukayensis	240-300
crimensis	300-500
schopeni	>500
O. varians	
portnayae	<165
ankaraensis	165-205
angoumensis	205-255
roberti	255-320
scalaris	320-400
varians	>400

Figure 6. Subspecies limits based on the size of the outer cross-diameter of the deuteroconch in orthophragminid taxa.
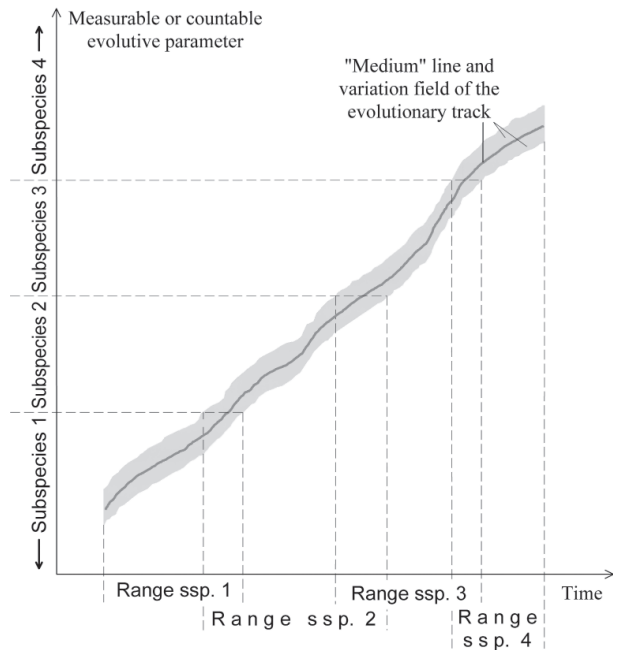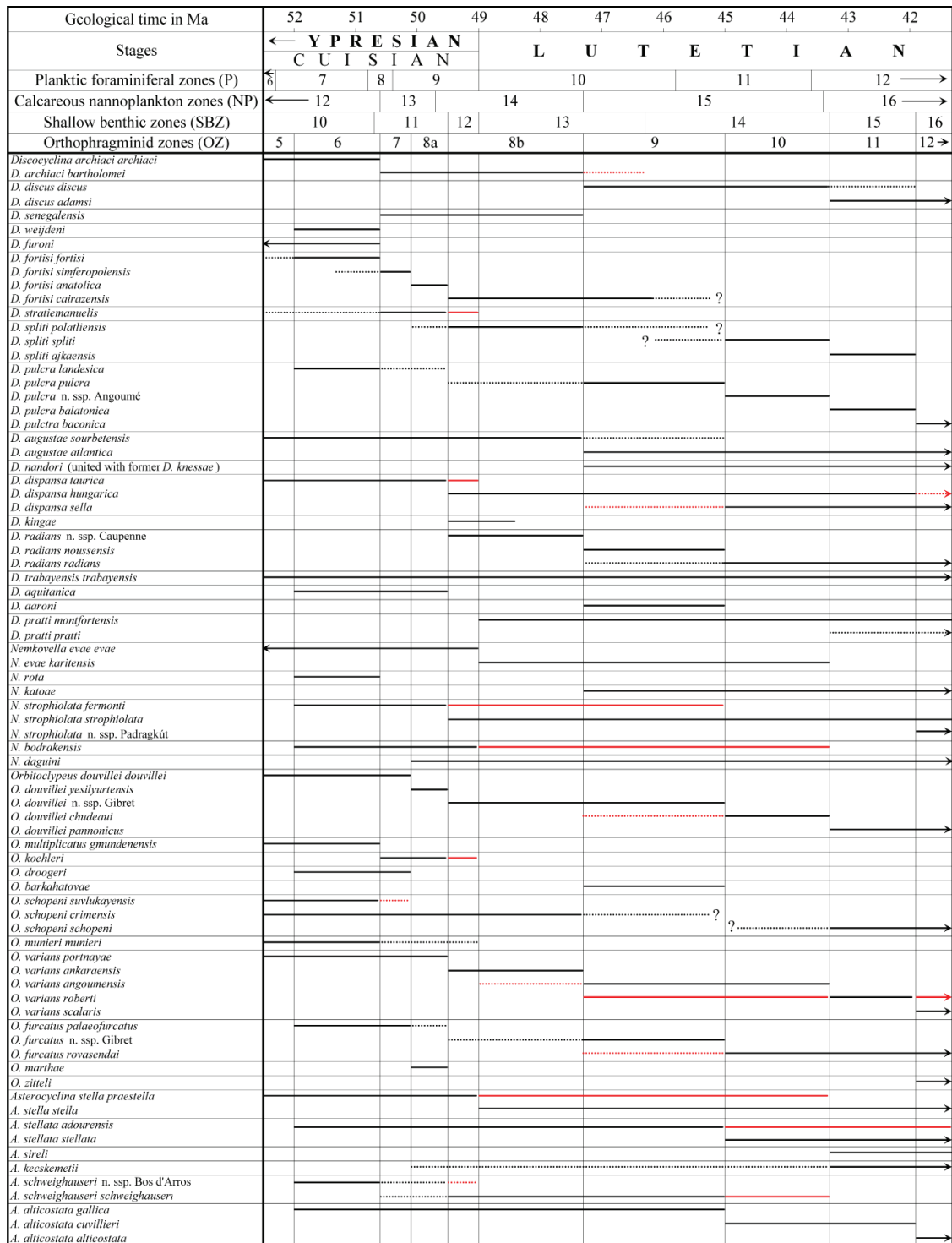

Figure 7. Relationship between the arbitrary subdivision of evolutionary lineages and the stratigraphic ranges of the obtained subspecies.

This latter taxon is also identified from samples 4621a and 4621 (discussed here jointly due to their similar larger foraminiferal composition), the zonal affiliation of which is determined by the presence of *Orbitoclypeus varians ankaraensis* Özcan & Less, characteristic for OZ 8b. The youngest occurrence of the associated *O. schopeni crimensis* is also known from this zone (samples Is 366 and 382 from the Ein Avedat section in Israel), while the stratigraphic range of *Discocyclina dispansa taurica* Less, recorded so far up to the OZ 8a Zone, has to be extended at least to the top of the Ypresian, since it also occurs abundantly in the overlying samples 4622 and 4622a. This is also true for *Nemkovella strophiolata fermonti* Less, the range of which should be extended even to the end of OZ 9. Although the OZ 8b Zone crosses the SBZ 12/13 boundary, samples 4621a and 4621 very probably belong still to the SBZ 12 Zone, based on their nummulitids (*N. archiaci, N. formosus* and *N. nitidus*).

Samples 4622 and 4622a (discussed jointly) contain a rather rich and slightly more advanced orthophragminid assemblage, compared to the

Geological time in Ma	52	51	50	49	48	47	46	45	44	43	42
Stages	← **Y P R E S I A N** C U I S I A N				**L**	**U**	**T**	**E**	**T**	**I**	**A**	**N** →
Planktic foraminiferal zones (P)	6	7	8	9		10			11		12 →	
Calcareous nannoplankton zones (NP)	← 12		13		14			15			16 →	
Shallow benthic zones (SBZ)	10		11	12	13			14		15	16	
Orthophragminid zones (OZ)	5	6	7	8a	8b		9		10	11	12 →	

Discocyclina archiaci archiaci
D. archiaci bartholomei
D. discus discus
D. discus adamsi
D. senegalensis
D. weijdeni
D. furoni
D. fortisi fortisi
D. fortisi simferopolensis
D. fortisi anatolica
D. fortisi cairazensis
D. stratiemanuelis
D. spliti polatliensis
D. spliti spliti
D. spliti ajkaensis
D. pulcra landesica
D. pulcra pulcra
D. pulcra n. ssp. Angoumé
D. pulcra balatonica
D. pulctra baconica
D. augustae sourbetensis
D. augustae atlantica
D. nandori (united with former *D. knessae*)
D. dispansa taurica
D. dispansa hungarica
D. dispansa sella
D. kingae
D. radians n. ssp. Caupenne
D. radians noussensis
D. radians radians
D. trabayensis trabayensis
D. aquitanica
D. aaroni
D. pratti montfortensis
D. pratti pratti
Nemkovella evae evae
N. evae karitensis
N. rota
N. katoae
N. strophiolata fermonti
N. strophiolata strophiolata
N. strophiolata n. ssp. Padragkút
N. bodrakensis
N. daguini
Orbitoclypeus douvillei douvillei
O. douvillei yesilyurtensis
O. douvillei n. ssp. Gibret
O. douvillei chudeaui
O. douvillei pannonicus
O. multiplicatus gmundenensis
O. koehleri
O. droogeri
O. barkahatovae
O. schopeni suvlukayensis
O. schopeni crimensis
O. schopeni schopeni
O. munieri munieri
O. varians portnayae
O. varians ankaraensis
O. varians angoumensis
O. varians roberti
O. varians scalaris
O. furcatus palaeofurcatus
O. furcatus n. ssp. Gibret
O. furcatus rovasendai
O. marthae
O. zitteli
Asterocyclina stella praestella
A. stella stella
A. stellata adourensis
A. stellata stellata
A. sireli
A. kecskemetii
A. schweighauseri n. ssp. Bos d'Arros
A. schweighauseri schweighauseri
A. alticostata gallica
A. alticostata cuvillieri
A. alticostata alticostata

Figure 8. Updated orthophragminid range-chart and zonation for the late Ypresian to upper Lutetian. Updates are marked in red. Dashed lines indicate uncertain occurrence. *Orbitoclypeus multiplicatus gmundenensis* (for diagnosis see Figure 6) was introduced by Dulai *et al.* (2010). 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); new considerations on the Ypresian/Lutetian boundary are not yet figured.
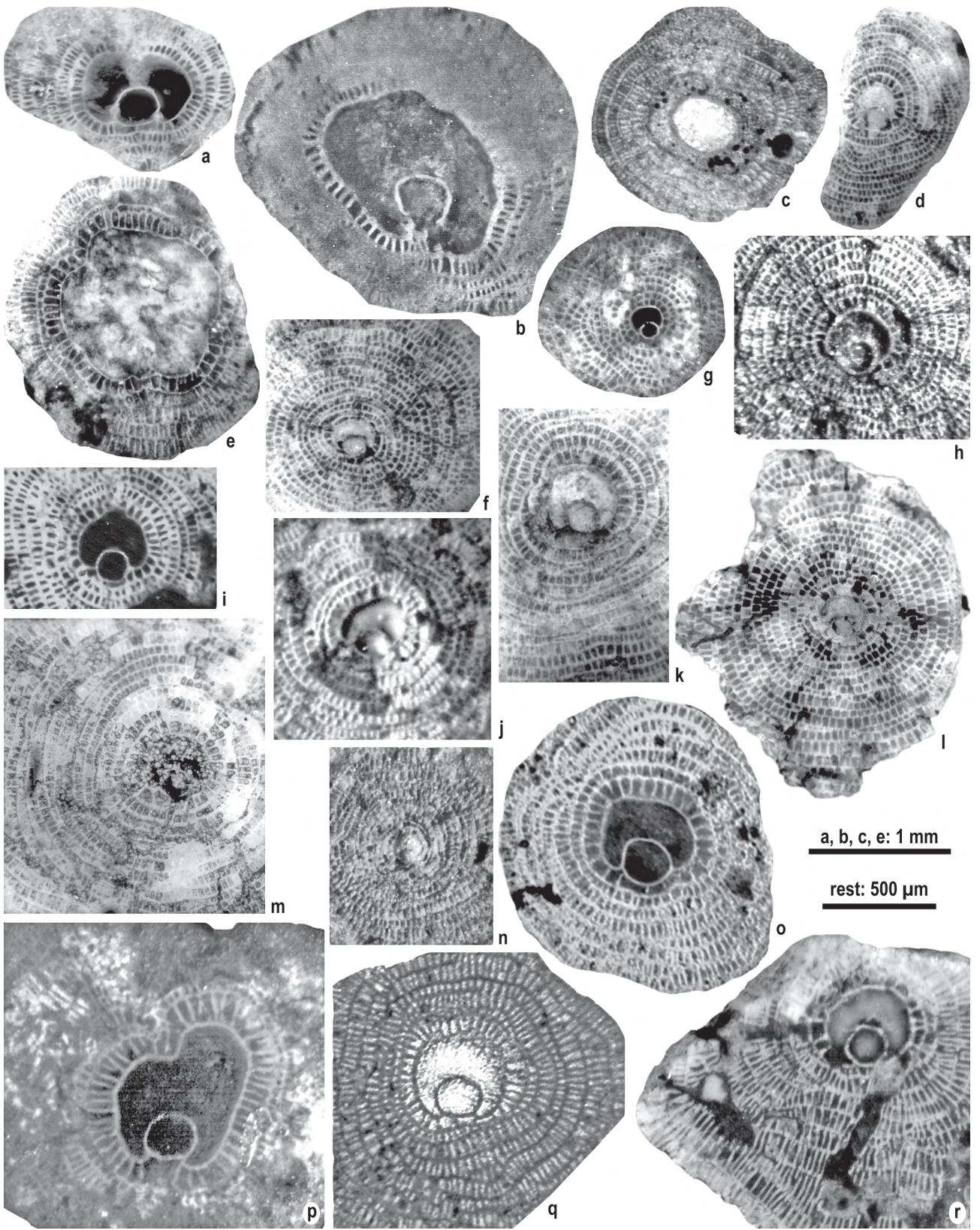
Figure 9.

a, b, c, e: 1 mm

rest: 500 µm

underlying samples discussed above, although they also belong to the OZ 8b Zone, based on the coexisting *Orbitoclypeus douvillei* ex. interc. n. ssp. Gibret et *yesilyurtensis* Özcan (suggesting the vicinity of the OZ 8a/b boundary) and *O. varians* ex. interc. a*ngoumensis* Less et *ankaraensis* Özcan & Less (approximately at the OZ 8b/9 boundary). Part of the other orthophragminid components (*Discocyclina dispansa taurica, Asterocyclina stella praestella* Less and *Nemkovella strophiolata fermonti*) are rather characteristic for the Ypresian, while the other part (*Discocyclina pratti* (Michelin), the highly advanced *Orbitoclypeus schopeni crimensis* and *O. furcatus* cf. *rovasendai* (Prever) instead indicates the Lutetian. Nummulitids, characterized by the appearance of *Nummulites* aff. *polygyratus* and *N.* aff. *irregularis,* also suggest an intermediate stratigraphic position of these samples between the SBZ 12 and 13 zones.

The orthophragminid assemblage of sample 4624 is considerably more advanced than that of the underlying beds (see also Figure 3), marked by the appearance of *Discocyclina dispansa hungarica* Kecskeméti, *Orbitoclypeus douvillei* ex. interc. n. ssp. Gibret et *chudeaui* (Schlumberger) and *O. varians roberti* (Douvillé), all characteristic of the Lutetian. Meanwhile the presence of *D. archiaci bartholomei* still indicates that this sample cannot be younger than the lower Lutetian SBZ 13 Zone. In averaging the ranges of the above taxa, the lower part of the OZ 9 Zone is suggested for the age of this sample, but with the range of *O. varians roberti* greatly extended into this zone.

The orthophragminid assemblages of samples 4623 and 4603 are quite close to each other (unlike planktonic Foraminifera, which are definitively younger in sample 4603). The main difference, compared to sample 4624, is the appearance of *Discocyclina discus* cf. *discus* (Rütimeyer) substituting

for *D. archiaci bartholomei*, which already indicates the middle Lutetian SBZ 14 Zone, together with *Orbitoclypeus douvillei* n. ssp. Gibret (the introduction of an official new name for this taxon was not possible because of the absence of a well-preserved and representative specimen serving as holotype for it in sample 4603). The first occurrence of *Nummulites orbignyi,* characteristic for the middle–upper Lutetian of North-Perithethyan areas, is marked in sample 4603. In terms of the orthophragminid zonation the coexistence of the above taxa with *O. varians roberti*, *D. dispansa hungarica* and *D. d.* ex. interc. *sella* d'Archiac et *hungarica* Kecskeméti suggests an intermediate position between the OZ 9 and 10 zones.

Typical *Orbitoclypeus douvillei chudeaui* (Schlumberger) and *Nemkovella strophiolata strophiolata* Gümbel are the new elements in the jointly discussed samples 4605 and 4605a. The first taxon is a marker for the OZ 10 Zone, corresponding to the late part of the middle Lutetian SBZ 14 Zone. Other components of the orthophragminid assemblage agree with this age, allowing for the extension of the range of *O. varians roberti*.

The youngest orthophragminid assemblage of the Gubs section can be found in sample 4606, although its composition is very similar to that of the directly underlying samples. The only considerable change that can be observed is the appearance of *Discocyclina dispansa sella* d'Archiac, which allows this sample to be located at about the boundary of the OZ 10/11 and SBZ 14/15 zones, respectively, i.e. to the late middle Lutetian. Note that the evolutionary degree of *Orbitoclypeus varians* in this sample (*O. v.* ex. interc. *angoumensis* et *roberti*) is in accord with the age expected from our previous data (Less 1998; Özcan *et al.* 2007b).

Figure 9. Discocyclinae from the Gubs section. **(a)** *Discocyclina archiaci* cf. *bartholomei* (Schlumberger), sample 4619, 09782, **(b)** *D. discus* cf. *discus* (Rütimeyer), sample 4623, 09818, **(c)** *D. pulcra* (Checchia-Rispoli) indet. ssp., sample 4624, 09812, **(d, f–h, k)** *D. dispansa taurica* Less, (d) sample 4621, 09788, (f, k) sample 4622a, (f) 09809, (k) 09802.01, (g) sample 4619, 09784, **(h)** sample 4622, 09794, **(e)** *D. stratiemanuelis* Brönnimann, sample 4622a, 09799.01, **(i, j, l)** *D. dispansa hungarica* Kecskeméti, (i) sample 4624, 09811, (j, l) sample 4623, (j) 09819, (l) E.09.213, **(m)** *D. dispansa sella* (d'Archiac), sample 4606, E.09.214, **(n)** *D. augustae* cf. *sourbetensis* Less, sample 4622a, 09802.02, **(o, q, r)** *D. pratti* cf. *montfortensis* Less, (o) sample 4603, 09827, (q, r) sample 4606, (q) 09834, (r) 09835, **(p)** *D. pratti* ex. interc. *montfortensis* Less et *pratti* (Michelin), sample 4624, 09813.01. All– A-form, equatorial sections; a, b, c, e: ×25, rest: ×40.
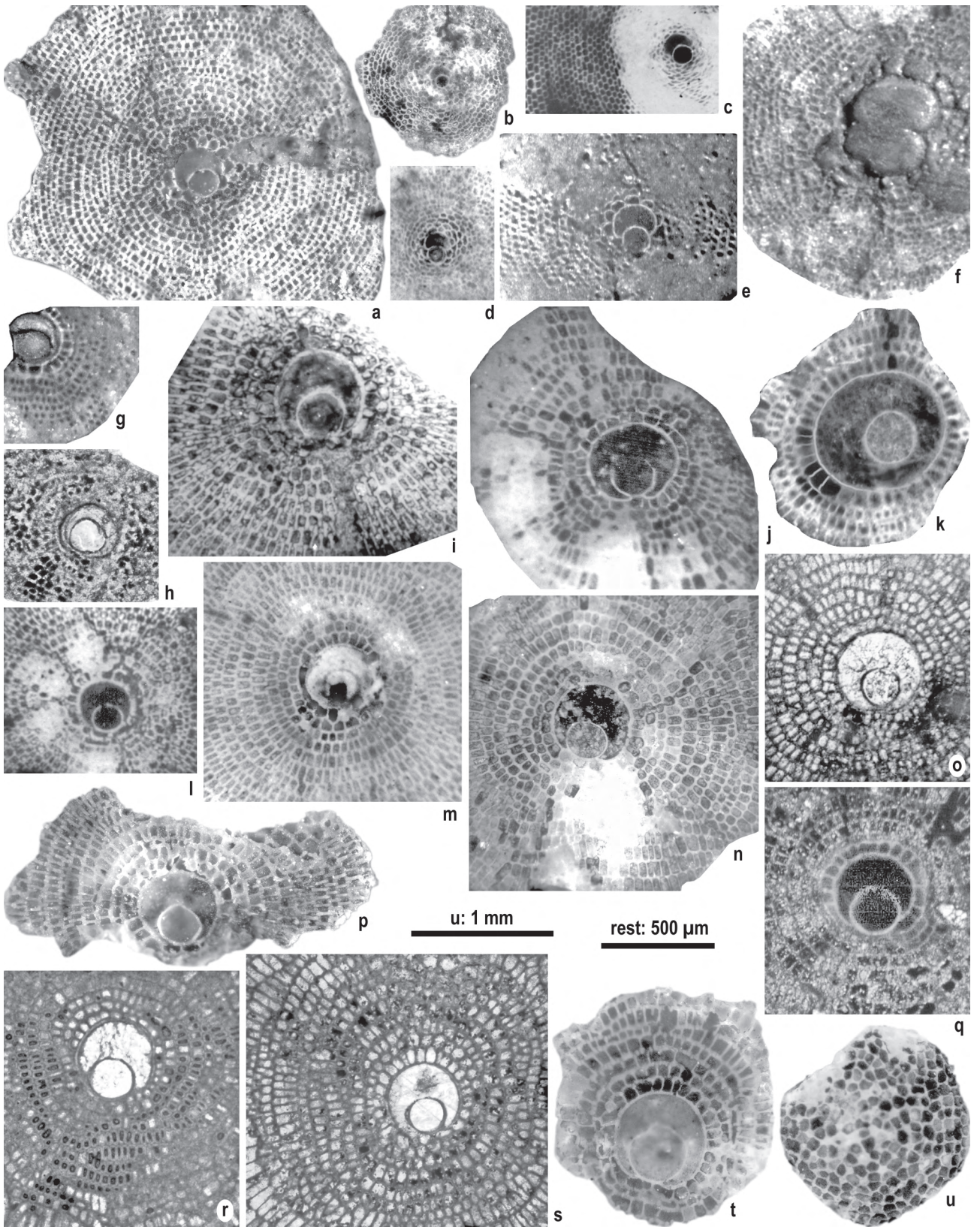
Figure 10.

u: 1 mm

rest: 500 µm

Problems of Zonation by Larger Foraminifera in the Peritethyan Area

The zonal scheme of the Tethyan Palaeocene and Eocene using larger foraminifera (Serra-Kiel *et al.* 1998) was constructed using materials from the Mediterranean and Central Europe, including data from the Crimean lower Eocene and from the Armenian middle Lutetian to Priabonian. Early Eocene zones of the Tethys can easily be recognized and followed in the Peritethyan area, to which the Gubs profile belongs. They are correlated with the *N. planulatus*, *N. distans* and *N. polygyratus* Zones of the Peritethyan (Crimean-Caucasian) scale established by Nemkov (1967) based on data from the Crimea, Mangyshlak and Northern Cisaralia and adapted to contemporary subdivisions by Zakrevskaya (2005). The Tethyan middle Eocene SBZ scale cannot be used directly for the Peritethys because of the absence of zonal *Nummulites* species. A unified Peritethyan larger foraminiferal zonation is also missing for this interval: only local scales are established (Koren' 2006). These are the lower Lutetian *Assilina spira abrardi* Zone in the Crimea, the middle Lutetian beds with small *Nummulites* (*N. orbignyi* and *N. variolarius*) in the lower Volga river region, North Peri-Caspian region and Northern Cisaralia, as well as the lower Lutetian horizon with *Nummulites* aff. *leupoldi* and the middle Lutetian one with *Discocyclina pratti pratti* in the Mangyshlak area.

The construction of local zonation may be useful for correlation between neighbouring localities and to characterize the peculiarities of regional assemblages. Our recent study suggests that two of the local zones selected in the Gubs section can be correlated with larger foraminifera-bearing beds of the Inal and Loo sections (Zakrevskaya *et al.* 2009). These are the *Discocyclina archiaci bartholomei – D.*

augustae sourbetensis beds of the SBZ 11 (middle Cuisian in Serra-Kiel *et al.* 1998) Zone (Gubs – 4619 and Inal – In 78a) and the late middle Lutetian (SBZ 14–15) beds with small *Nummulites* (*N. variolarius* and *N. orbignyi*), *Orbitoclypeus douvillei chudeaui*, *Discocyclina dispansa sella* and *Nemkovella strophiolata strophiolata* in Gubs (4606) and Loo (L38 and L37). Samples 4621 to 4622a (SBZ 12–?13) from the Gubs section containing *Nummulites polygyratus* and *Orbitoclypeus varians ankaraensis* (assigned in this work to the basal Lutetian, based on the early Lutetian nannofossils of the underlying sample 4621a) may refer in age to samples IN84a and 072372b in the Inal section, although the orthophragminid composition of those beds is different and characterized by *O. douvillei* n. ssp. Gibret. Larger foraminiferal assemblages described from samples 4624, 4623 and 4603 of the Gubs section can only tentatively be correlated with samples L41, 071619a, L40 and L39 of the Loo section, since those assemblages are rather poor.

Unlike other Peritethyan profiles, the whole late Ypresian to middle Lutetian interval of the Gubs section is characterized by representative orthophragminid assemblages. Therefore, and because of the absence of Tethyan zonal *Nummulites* species, here we use the Tethyan orthophragminid scale in order to correlate local assemblages with the Tethyan SBZ zones.

Systematic Part

Since most orthophragminid taxa (Figures 9–12) found in the Gubs section were described in detail in the last few years, we do not repeat their description here with the exception of the newly introduced *Orbitoclypeus barkhatovae*. The most detailed descriptions of species can be found in the revision by

Figure 10. Nemkovellae and Orbitoclypei from the Gubs section. **(a)** *Nemkovella evae* Less indet. ssp., sample 4623, E.09.215, **(b–d)** *N. strophiolata fermonti* Less, (b) sample 4619, 09785.01, (c) sample 4623, 09820, (d) sample 4622a, 09803.01, **(e)** *N. strophiolata strophiolata* (Gümbel), sample 4606, 09836, **(f)** *Nemkovella* sp., sample 4621, 09789.01, **(g, h)** *Orbitoclypeus schopeni* cf. *suvlukayensis* Less, (g) sample 4619, 09785.02, (h) sample 4620, 09787, **(i, j)** *O. schopeni crimensis* Less, (i) sample 4622, 09797.03, (j) sample 4622a, 09799.02, **(k)** *O. koehleri* Less, sample 4619, 09783, **(l, m)** *O. douvillei* ex. interc. n. ssp. Gibret et *yesilyurtensis* Özcan, (l) sample 4622, 09796, (m) sample 4622a, 09808, **(n, o)** *O. douvillei* ex. interc. n. ssp. Gibret et *chudeaui* (Schlumberger), sample 4624, (n) E.09.216., (o) 09814, **(p)** *O. douvillei* ex. interc. *chudeaui* (Schlumberger) et n. ssp. Gibret, sample 4623, E.09.217, **(q)** *O. douvillei* n. ssp. Gibret, sample 4603, 09828, **(r–u)** *O. douvillei chudeaui* (Schlumberger), sample 4606, (r) 09837, (s) 09838, (t, u) E.09.218. All– A-forms. a–t– equatorial sections, ×40; u– rosette, ×25.
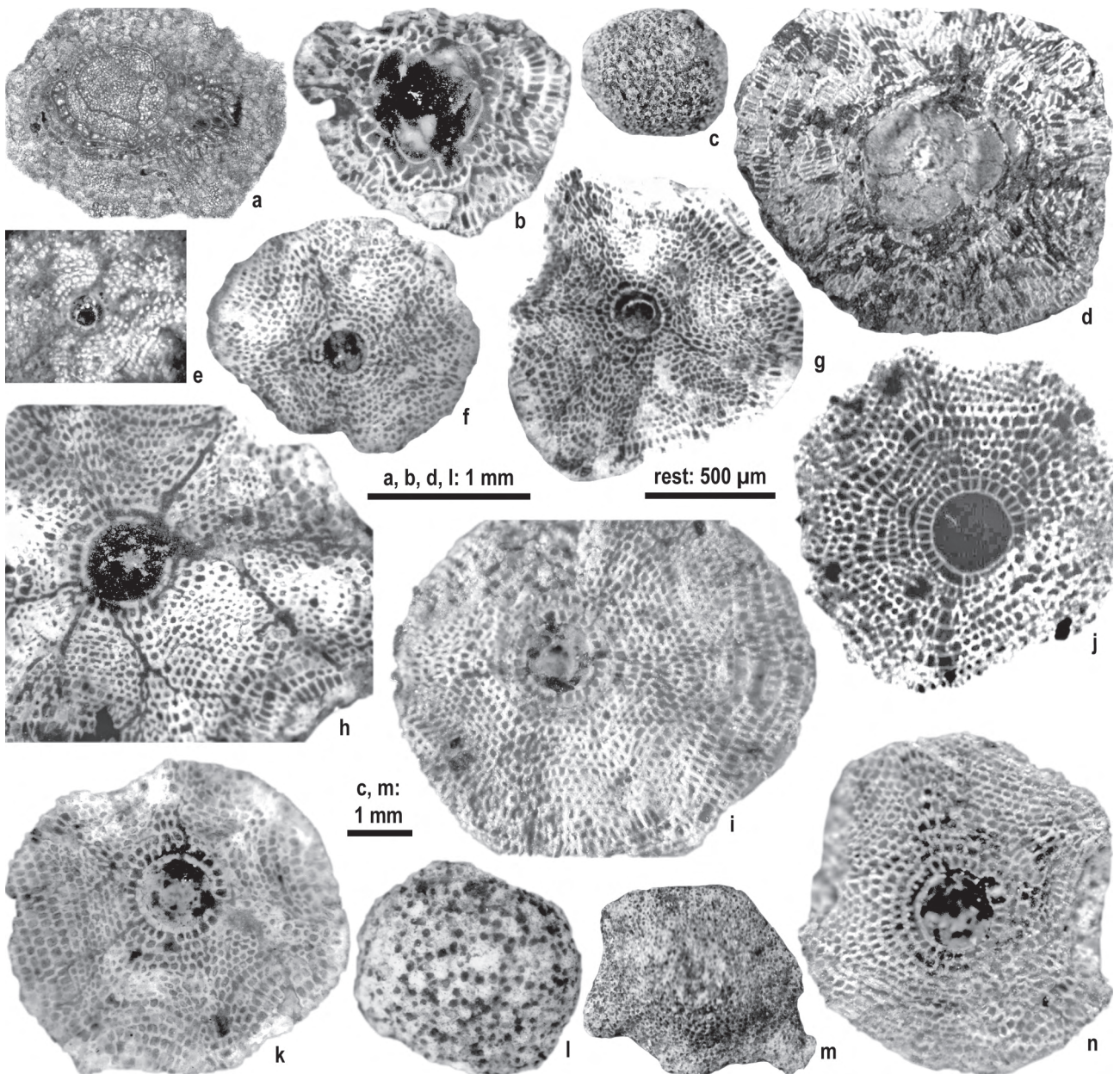
Figure 11. Orbitoclypei from the Gubs section. **(a–d)** *Orbitoclypeus barkhatovae* n. sp., (a) sample 4624, 09813.02, (b–d) sample 4623, (b) E.09.219, (c, d) holotype, 09821, **(e)** *O. varians portnayae* Less, sample 4619, 09785.03, **(f)** *O. varians* ex. interc. *angoumensis* Less et *ankaraensis* Özcan & Less, sample 4622a, 09807, **(g)** *O. varians ankaraensis* Özcan & Less, sample 4621, 09790.01, **(h–j)** *O. varians roberti* (Douvillé), (h) sample 4624, E.09.220, (i) sample 4623, E.09.221, (j) sample 4605a, 09833, **(k, l)** *O. varians* ex. interc. *angoumensis* Less et *roberti* (Douvillé), sample 4606, (k) E.09.222, (l) E.09.223, **(m)** *O. furcatus* cf. *rovasendai* (Prever), sample 4606, 09839, **(n)** *O. furcatus* ex. interc. n. ssp. Gibret et *rovasendai* (Prever), sample 4623, E.09.224. All– A-forms. c, m– external views, ×10; l– rosette, ×25; all the others– equatorial sections, a, b, d: ×25, rest: ×40.

Less (1987), while the most up-to-date ones for most of them (including their subspecific subdivision, also summarized in Figure 6) are located in Özcan *et al.* (2007a, b). Supplementary information for *Nemkovella bodrakensis* and *Asterocyclina stella* can be found in Less & Ó. Kovács (2009) while this is the first mention of *Orbitoclypeus koehleri* since Less (1987).
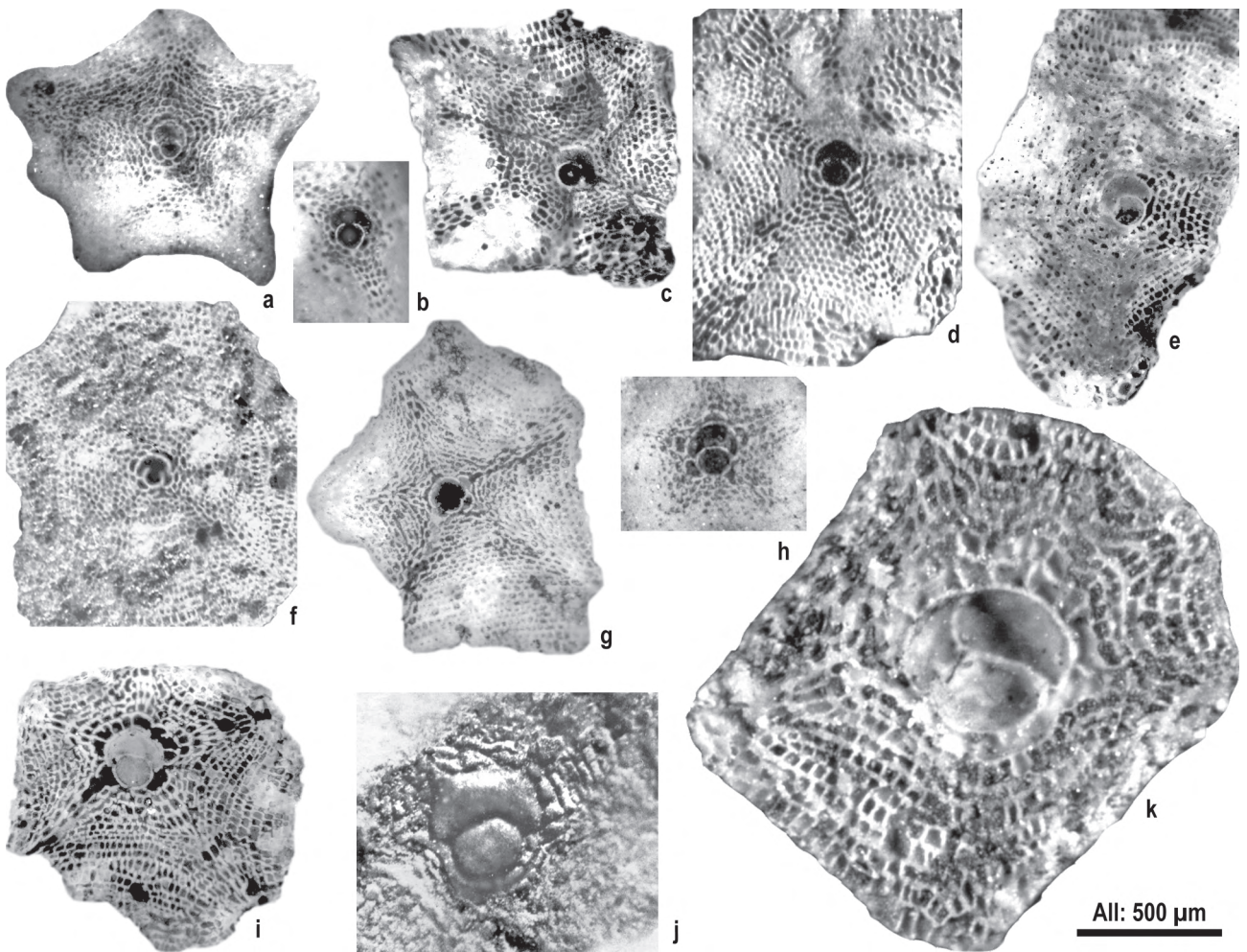
Figure 12. Asterocyclinae from the Gubs section. **(a–e)** *Asterocyclina stella praestella* Less, (a) sample 4621, 09790.02, (b) sample 4622a, 09799.03, (c) sample 4623, E.09.225, (d) sample 4623, 09823, (e) sample 4606, E.09.226, **(f, g)** *A. stellata* cf. *adourensis* Less, (f) sample 4619, 09786, (g) sample 4603, E.09.227, **(h)** *A. stellata* (d'Archiac) indet. ssp., sample 4622, 09795.01, **(i)** *A. kecskemetii* Less, sample 4624, E.09.228, **(j, k)** *A. schweighauseri* Less, (j) sample 4622a, 09810, (k) sample 4623, 09824. All– A-form, equatorial sections, ×40.

Order Foraminiferida Eichwald 1830

Family Orbitoclypeidae Brönnimann 1946

Genus *Orbitoclypeus* Silvestri 1907

Orbitoclypeus barkhatovae n. sp.

Figure 11a–d

Etymology– Named in honour of the late Nina Nikolayevna Barkhatova, Russian expert of larger Foraminifera.

Holotype– Preparation 09821, Figure 11c, d.

Depository– Invertebrate Collection of Vernadsky State Geological Museum RAS, Moscow, Russia.

Paratype– Another specimen from sample 4623 of the Gubs section illustrated in Figure 11b

Type Locality– Sample 4623 of the Gubs section.

Type Level– Middle Lutetian, SBZ 14 Zone, OZ 9–10 zones.

Diagnosis– Medium-sized, moderately inflate forms with 'chudeaui'-type rosette. The embryon is multilepidine, the two chambers are very large. The 'pratti'-type adauxiliary chamberlets are numerous, very wide and variably high. The elongated equatorial chamberlets are wide and very high. The annuli are undulated with many waves, their growth pattern is of 'pulcra' type.

Description: External morphology (Figure 11c)– Usually small- and medium-sized (2 to 4 mm), moderately inflate forms with no distinct umbo. The rosette is of the 'chudeaui' type. The granules are coarse (80 to 120 µm in diameter), somewhat larger in the centre than in the periphery. Each granule is surrounded by 5 to 7 lateral chamberlets whose size is smaller than that of the granules.

Internal Morphology: The Equatorial Section of A-forms (Figure 11a, c, d, for abbreviations see Figure 5)– The very large embryon is of the multilepidine type. The very large protoconch of irregular shape (p= 400–700 µm) subdivides the very large deuteroconch (d= 650–1150 µm) into two to four parts. The 'pratti'-type adauxiliary chamberlets are numerous (N= 30–50), very wide (W= 60–100 µm) and variably high (H= 60–150 µm). The rectangular to very slightly hexagonal equatorial chamberlets are arranged in distinctly undulated annuli with 8–12 waves. The elongated equatorial chamberlets are wide (w= 35–40 µm) and very high (h= 80–120 µm, n= 6–8), their growth pattern is of 'pulcra' type.

The Equatorial Section of B-forms- No microspheric specimens have been found yet.

Axial Section– The species could not be studied in this section because of the limited number of specimens.

Remarks– Only a few of these forms were found, confined to samples 4623 and 4624 (see Table 1). Although no microspheric specimens have been found, their affiliation to genus *Orbitoclypeus* could be deduced, based on the absence of the annular stolons of the equatorial chamberlets also manifested in their slightly hexagonal shape, on the very large, irregular, multilepidine embryon, on the undulated annuli and subordinately on the type of the rosette. *Orbitoclypeus droogeri* (recently introduced by Less & Ó. Kovács 2009 from the late Ypresian of Horsarrieu, SW France), is the only species of this genus to have such a large embryon, has a centrilepidine embryon, the annuli are circular, and the equatorial chamberlets are much less elongated. Thus, the introduction of the

new species is verified. Its closest ancestor might also be *O. koehleri* with somewhat smaller (d= 550–750 µm) deuteroconch, known from the upper Ypresian of the Crimea in the OZ 8a Zone and also occurring sporadically in the OZ 7 (sample 4619) and OZ 8b (sample 4622) of the Gubs section. We have no knowledge of any descendant of *O. barkhatovae*.

Range– It is known so far only from the lower Lutetian (sample 4624, OZ 9, SBZ 13) and middle Lutetian (sample 4623, OZ 9–10, SBZ 14) of the Gubs section.

Biostratigraphical Analysis of Planktonic Foraminifera from the Gubs Section

Historical Background

The study of planktonic foraminifera from the North Caucasus and Crimea and their zonal subdivision by Subbotina (1936) and Morozova (1939) before the Second World War was a pioneer achievement and preceded the recently widely used Caribbean scale (Berggren & Norris 1997; Berggren & Pearson 2005). The first official variant of the Crimean-Caucasian Palaeogene zonal scale was published in Reshenie (1963). This traditional Upper Palaeocene–Eocene scale, based on the works of many outstanding experts, survived with small changes until the recent Crimean-Caucasian Palaeogene scheme introduced by Akhmeťev & Beniamovsky (2003, 2006) and Koreň (2006) (Figure 13).

In the USSR, however, there were special ideas on the content of the Middle and Upper Eocene contradicting with that in the rest of the world, and special Crimean Palaeocene–Eocene stages were used (Grossgeim & Korobkov 1975). Only since the early 80s has the Palaeogene stratigraphy of the USSR been considered in accordance with the international standard, i.e. the content of Eocene subepochs has been modified and the international stages have been re-introduced. Middle Eocene, as containing Lutetian and Bartonian stages, has been used in the Palaeogene schemes of the USSR since Yarkin (1989). However, its detailed correlation with planktonic foraminiferal zones is still under discussion (Akhmeťev & Beniamovsky 2003, 2006; Bugrova *et al.* 2008).

Resolution of the 5th Plenary Meeting of the Palaeogene Commission (1963)			Resolution of the 16th Plenary Meeting of the Palaeogene Commission (1989)			Akhmet'ev & Beniamovsky (2003)		Infrazonal scale (Beniamovsky 2001, Akhmet'ev & Beniamovsky 2006 with additions - marked by bold)
Subepoch	Stage	Zone	Subepoch	Stage	Zone	Stage	Zone	Subzone
Upper Eocene — Bodrakian — Almian		*Bolivina antegressa*	Upper Eocene	Priabonian	*Turborotalia centralis*	Priabonian		*Turborotalia centralis* PF 17
		Globigerinoides conglobatus & large *Globigerina*			*Globigerina corpulenta*			*Subbotina corpulenta* PF 16
					Globigerapsis tropicalis			*Globigerinatheka tropicalis* PF 15
		of planktonic foraminifera	Middle Eocene	Bartonian	*Globigerina turcmenica* (*Truncorotaloides rohri*)	Bartonian	*Subbotina turcmenica* PF 14	*Subbotina praebulloides* PF 14b
								Subbotina azerbaidjanica / **Catapsydrax sp.** PF 14a
		Hantkenina alabamensis & *Globigerinoides subconglobatus*			*Hantkenina alabamensis*	Lutetian	*Hantkenina "alabamensis"* PF 13	*Hantkenina australis* PF 13c
								Globigerinatheka index PF 13b
								Globigerinatheka subconglobata / **Hantkenina dumblei** PF 13a
		Acarinina rotundimarginata			*Acarinina rotundimarginata*		*Acarinina rotundimarginata* PF 12	*Hantkenina liebusi* PF 12b
								Turborotalia frontosa PF 12a
Middle Eocene	Simferopolian	*Acarinina crassaeformis*		Lutetian	*Acarinina bullbrooki*			*Acarinina bullbrooki* PF 11
		Globorotalia aragonensis	Lower Eocene	Ypresian	*Globorotalia aragonensis*	Ypresian	*Morozovella aragonensis* PF 10	**Turborotalia boweri** / *Globigerinatheka micra* PF 10c
								Morozovella caucasica PF 10b
								Morozovella aragonensis s.s. PF 10a

Figure 13. Historical background of Eocene planktonic foraminiferal zones in the Crimean-Caucasian regional scheme. Index-taxa, introduced in this work, are shown in bold.

Detailed Subdivision of the Traditional Crimean-Caucasian Palaeogene Zonal Scale by Planktonic Foraminifera

The infrazonal subdivision of the Crimean-Caucasian Palaeogene zonal scale was originally proposed in the 1970s (Shutskaya 1970; Korovina 1970; Krashenninikov & Muzylöv 1975; Bugrova 1986). Evolutionary steps in the development of Palaeogene planktonic foraminifera were also considered in establishing biozones (Subbotina 1953; Shutskaya 1970; Bugrova 2005). In order to update the zonal scale of the Crimean-Caucasian realm, it should be correlated with the Palaeogene standard scale of Berggren & Pearson (2005). Their reliable correlation is only possible if sufficiently detailed scales are available and Crimean-Caucasian Palaeogene planktonic foraminifera are taxonomically revised, since obsolete generic and specific names are still used by Russian palaeontologists (Bugrova 2005; Bugrova *et al.* 2008). The first variant of the detailed scale (Beniamovsky 2001) was not generally supported (Bugrova 2005; Koren' 2006; Bugrova *et al.* 2008) although it can also be considered as the rejuvenation of the traditional scale, 'popularized' for the international community. Moreover, it contains 30 zonal biostratons in the Palaeocene–Eocene and

exceeds the standard scale (consisting of 17 zones) in detail.

The Beniamovsky (2001) infrazonal scale was used by Ukrainian experts (Gozhik *et al.* 2006) in the stratigraphic subdivision of the Crimean shelf and also in recognizing gaps in the Caucasian profiles near Mineral'nye Vody (Akhmeťev & Beniamovski 2006) not observed by using the traditional scale. The infrazonal scale has been updated by Beniamovsky (Beniamovski 2006; Akhmeťev & Beniamovski 2006) and also in this paper (by including data from the Gubs section and from new publications). For convenience, the biostratons of the infrazonal scale are marked not only by their index taxa but also by numbers (for zones) and letters (for subzones) (Figure 13).

Zones and subzones of the infrazonal scale are characterized by first and/or last occurrences of taxa (the most important ones are figured in Figure 14) and represent complex biostratigraphic units reflecting two natural processes. These are (i) the evolutionary-biological progress, connected with the irreversible development of taxa and (ii) the evolutionary-ecological process, connected with the interaction of environmental factors (temperature of the surface water, the gas regime, palaeogeographic changes, etc.) and planktonic foraminiferal assemblages.

Zonal Complexes of Planktonic Foraminifera in the Gubs Section

(1) The lower boundary of the *Morozovella aragonensis* (PF 10) Zone (not exposed in the Gubs section) is defined by the first and common occurrence of the zonal species. Other characteristic and dominant taxa are *Morozovella caucasica* (Glaessner), *Subbotina inaequispira* (Subbotina), *S. senni* (Beckmann), *Acarinina pentacamerata* (Subbotina), *A. triplex* (Subbotina), *A. pseudotopilensis* (Subbotina), *Turborotalia boweri* (Bolli) and *Globigerinatheka micra* (Shutskaya). In the Crimean-Caucasian regional scheme the Ypresian terminates with this zone, which (based on the first occurrences of index species) is correlated with zones P 7 (E 5) to the lower part of P 9 (E 7). The PF 10 Zone is subdivided into three subzones (Beniamovski 2001). All of them are recorded from the lower part of Unit 1 of the Cherkessk formation (Figures 15 & 16).

(1a) The lower boundary of the *Morozovella aragonensis* s.s. (PF 10a) Subzone (not exposed in the Gubs section) is defined by the first and common occurrence of both the zonal species and *Subbotina inaequispira* (Subbotina), which are present in sample 4615 together with *S. turgida* (Bolli), *S. pseudoeocaena* (Subbotina), *Morozovella marksi* (Martin), *Acarinina* aff. *pentacamerata* (Subbotina) and *Pseudohastigerina* cf. *micra* (Cole). The first occurrence of *M. aragonensis* (Nuttall) as a milestone in the evolution of this genus determines the base of the P 7 (E 5) Zone.

(1b) The base of the *Morozovella caucasica* (PF 10b) Subzone (corresponding to the base of the P 8 (E 6) Zone of the standard scale and reflecting a global event of phyletic change of species) is defined by the first occurrence of *M. caucasica*. This subzone is recorded in sample 4616 where the first occurrence of *Subbotina senni*, *Acarinina pentacamerata, A. triplex* and *A. pseudotopilensis* is observed as well. The similarity in the development of genus *Morozovella* in the Crimean-Caucasian and Mediterranean realms in the PF 10a and PF 10b Subzones (characterized by the mass occurrence of high forms) indicates the presence of a single Tethyan belt at this time, with common hydrological conditions.

(1c) The base of the PF 10c Subzone is defined in the Crimean-Caucasian infrazonal scale of Beniamovsky (2001) by the first appearance of *Globigerinatheka* (*G. micra*). The lowest occurrence of *Turborotalia* (*T. boweri*) is also recorded from this subzone, which is present in sample 4617 whereas *G. micra* is absent. We agree with Orue-Etxebarria *et al.* (1984), Gonzalvo & Molina (1998) and Molina *et al.* (2006) in separating *T. boweri* from *T. frontosa* (Subbotina) instead of joining them (Pearson *et al.* 2006) since they have different morphotypes and represent two different evolutionary stages of this genus. In the zonal schemes of Spain the *Turborotalia boweri* Zone is placed in the Ypresian (Molina *et al.* 2006).

(2) The base of the *Acarinina bullbrooki* (PF 11) Zone is diagnosed by the mass occurrence of the zonal taxon, and also marked by the first appearances of two new species (*Subbotina linaperta* (Finlay) and *Acarinina boudreauxi* Fleisher). This zone is first recorded from sample 4618 and can be followed
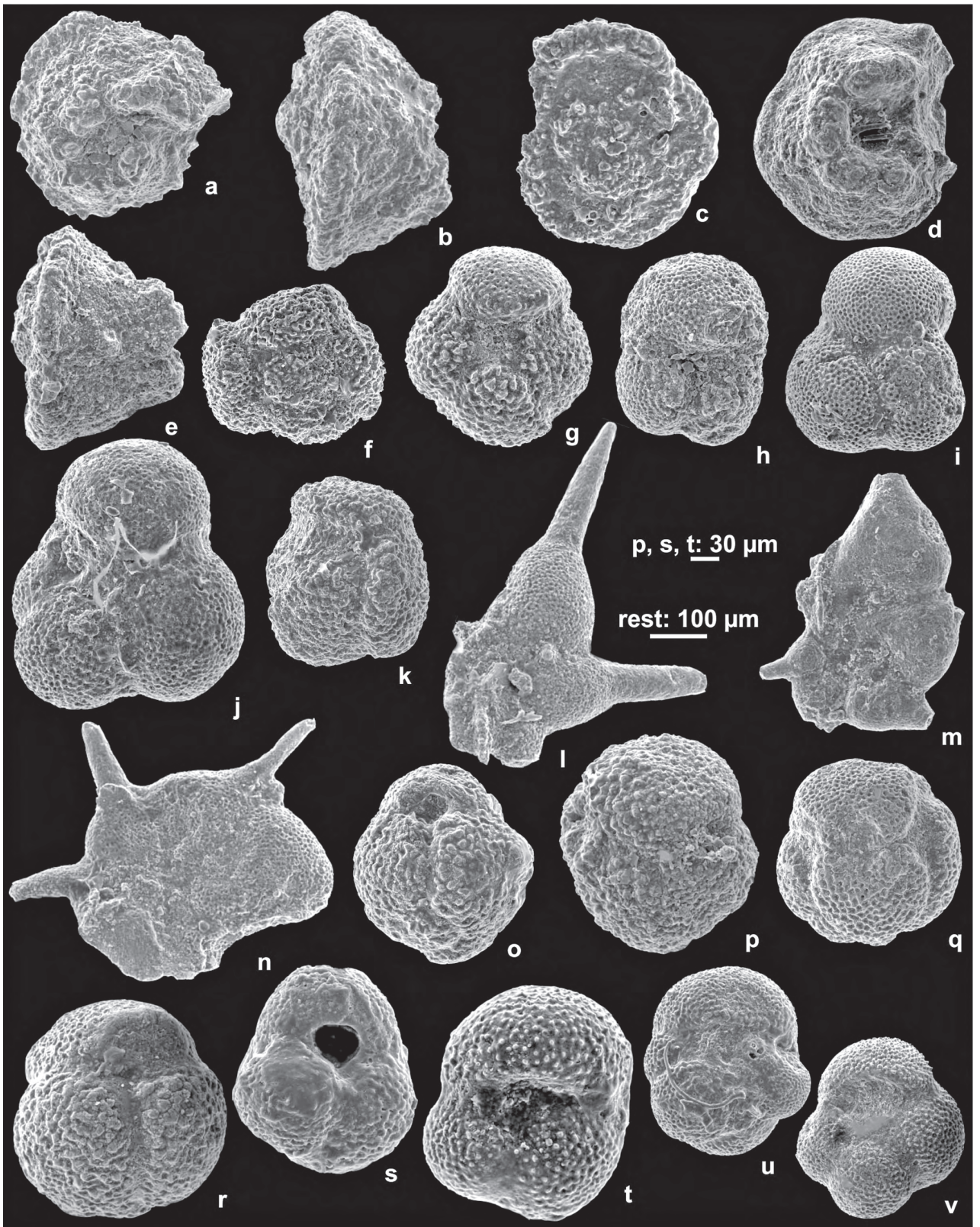
Figure 14.

throughout the middle and upper parts of Unit 1 (no plankton could be studied from Unit 2).

In the official scale for southern European Russia (see e.g., Bugrova 2005; Koren' 2006) the PF 11 Zone indicates the early Lutetian (Figure 13) and corresponds to the interval between the upper part of the NP 14a Subzone and the lower part of the NP 15a Subzone. The first occurrence of *A. bullbrooki* (Bolli) (probably coeval with that in the low latitude belt, see Boersma *et al.* 1987), however, cannot be a marker for the base of the Middle Eocene because it first appears in the late Ypresian (Orue-Etxebarria *et al.* 1984; Molina *et al.* 2011). The *Acarinina bullbrooki* Zone, as defined above, is missing from the standard scale (Luterbacher *et al.* 2004). Nevertheless, a zone with the same name but with narrower content (the interval between the FO of *A. bullbrooki* and the FO of *Turborotalia frontosa,* approximately corresponding to the late early part of P 9, around the NP 13/14 boundary and at least partly to the SBZ 12 Zone), thus corresponding to the late Ypresian, is present in the subdivision by Molina *et al.* (2011) based on the Gorrondatxe section (N Spain). Our new results tend to confirm this latter opinion (see in the correlation chapter).

(3) The base of the *Acarinina rotundimarginata* Zone (PF 12) is defined by the first appearance of the nominate taxon and also recognized by that of *Turborotalia frontosa* (Subbotina). According to Beniamovsky (2001, this work) the lowest occurrence of some other taxa, such as *Acarinina praetopilensis* (Blow) and *Hantkenina liebusi* Shokhina, can be observed at somewhat higher levels, which may serve to subdivide the PF 12 Zone into two parts, with index-species *T. frontosa* for the lower and *H. liebusi* for the upper part. The assemblage of sample

4624 from the base of the clay of Unit 3 in the Gubs section, contains *Acarinina rotundimarginata* Subbotina, *A. praetopilensis* and *Turborotalia frontosa* (together with forms transferred from the underlying sediments). In spite of the absence of *Hantkenina liebusi* (which does not allow correct identification of either the PF 12a or the PF 12b Subzone in the sense of Beniamovsky 2001), this assemblage already characterizes the higher part of the PF 12 Zone, as *Acarinina preatopilensis*, which appears in more continuous sections of the Mediterranean above *Turborotalia frontosa*, is already present here. Based on its position in the Gubs section, sample 4623, only containing taxa redeposited from lower stratigraphic horizons, is also attributed to this level.

Although the *A. rotundimarginata* Zone is traditionally placed in the Crimean-Caucasian scale in the middle Lutetian, its correlation with the standard scale is hampered since, according to Berggren & Pearson (2005) *A. praetopilensis* marks the Lutetian *Hantkenina nuttalli* (E8) Zone, although, based on Pearson *et al.* (2006), it first appears in the upper Ypresian of the Mediterranean realm. The base of the *Turborotalia praetopilensis* Zone in Spain is drawn at the first occurrence of this taxon. This zone includes either the terminal Ypresian and basal Lutetian (Larrasoaña *et al.* 2008; Ortiz *et al.* 2008), or only the basal Lutetian (Payros *et al.* 2009). In the last variant Molina *et al.* (2011) placed the *A. praetopilensis* Zone in the late early Lutetian, since they already attributed the upper part of the P 9 Zone (based on the correlation with the NP 15 Zone) in the early Lutetian.

Western experts (e.g., Pearson *et al.* 2006) do not consider *A. rotundimarginata* to be a valid species although the Russian specialists are convinced of it.

Figure 14. Significant planktonic foraminifera from the Gubs section. (**a, b**) *Morozovella aragonensis* (Nuttall), (a) spiral side, sample 4618, 09850, (b) edge view, sample 4615, 09848, (**c–e**) *Morozovella caucasica* (Glaessner), (c) spiral side, sample 4621a, 09852, (d) umbilical side, sample 4606, 09863, (e) edge view, sample 4603, 09855, (**f, g**) *Acarinina bullbrooki* (Bolli), (f) spiral side, sample 4618, 09851, (g) umbilical side, sample 4624, 09853, (**h**) *Turborotalia boweri* (Bolli) spiral side, sample 4617, 09849, (**i, j**) *Turborotalia frontosa* (Subbotina) (spiral side), (i) sample 4624, 09854, (j) sample 4605, 09862, (**k**) *Turborotalia possagnoensis* Toumarkine & Bolli, spiral side, sample 4603, 09857, (**l**) *Hantkenina mexicana* Cushman, edge view, sample 4603, 09856, (**m**) *Hantkenina liebusi* Shokhina, side view, sample 4603, 09858, (**n**) *Hantkenina dumblei* Weinzierl & Applin, side view, sample 4603, 09859, (**o**) *Globigerinatheka korotkovi* (Keller) umbilical side, sample 4603, 09860, (**p**) *Globigerinatheka* ex gr. *subconglobata* (Shutskaya), edge view, sample 4603, 09861, (**q**) *Globigerinatheka subconglobata* (Shutskaya), spiral side, sample 4606, 09864, (**r, s**) *Globigerinatheka index* (Finlay), (r) spiral side, sample 4606, 09865, (s) umbilical side, sample 4607, 09866; (**t**) *Subbotina azerbaidjanica* (Khalilov), umbilical side, sample 4607, 09867, (**u**) *Catapsydrax* sp., spiral side, sample 4607, 09869, (**v**) *Subbotina turcmenica* (Khalilov) (nomen nudum), spiral side, sample 4607, 09868.
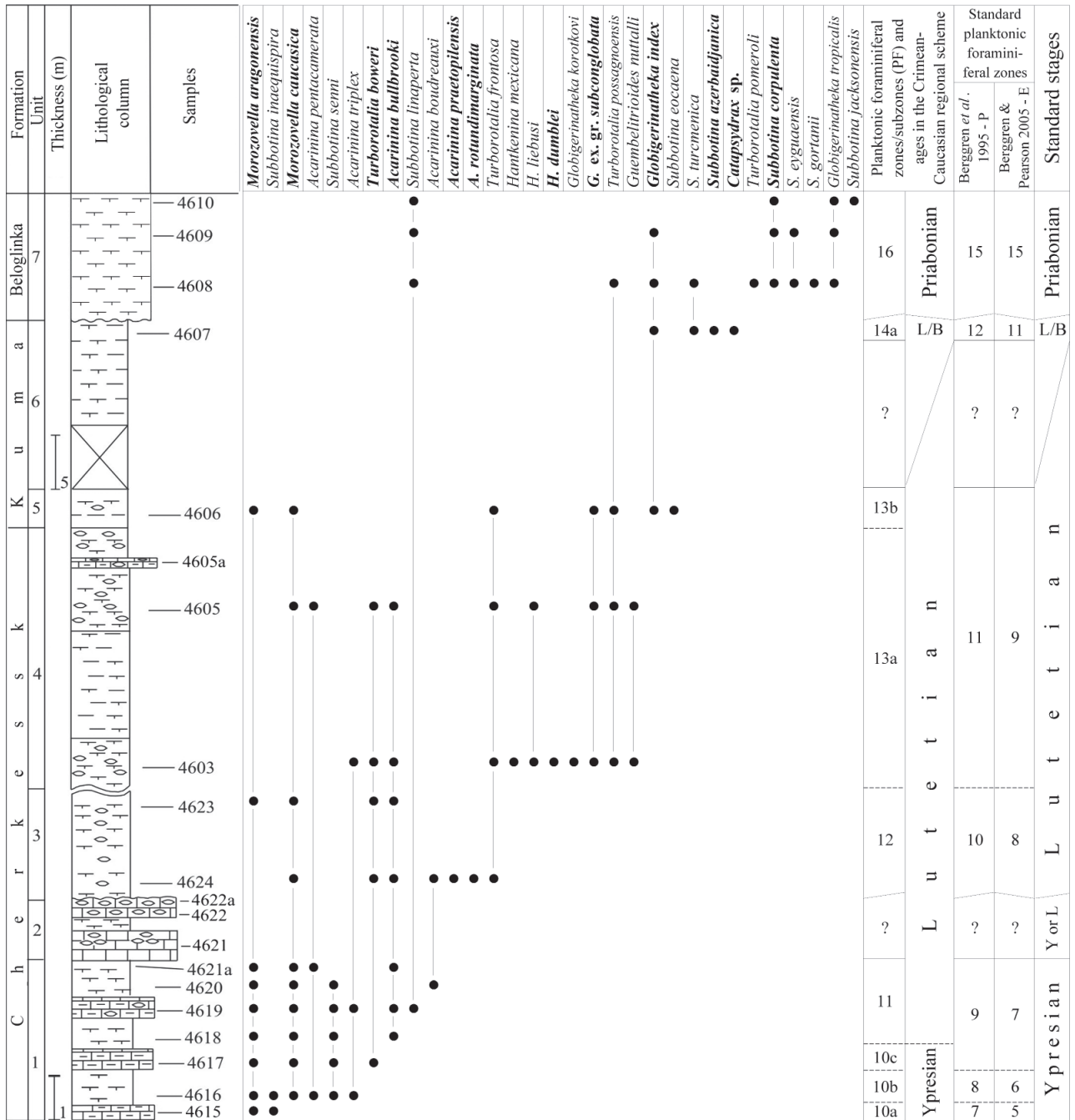
Figure 15. Stratigraphic distribution of significant planktonic foraminifera in the Gubs section. Zonal species are indicated in bold. Y– Ypresian, L– Lutetian, L/B– Lutetian or Bartonian.

The correlation of this zone and also of the lower/middle Eocene boundary between the Crimean-Caucasian and Mediterranean realms is hampered by isolation of the former from the tropical belt (Figure 17). Therefore, the representatives of genus

Hantkenina and *Clavigerinella* – indicating high temperature and marking the base of the Middle Eocene by their first appearance, are very rare in the Crimean-Caucasian region and cannot serve as stratigraphical landmarks (Bugrova 2005; Bugrova *et*

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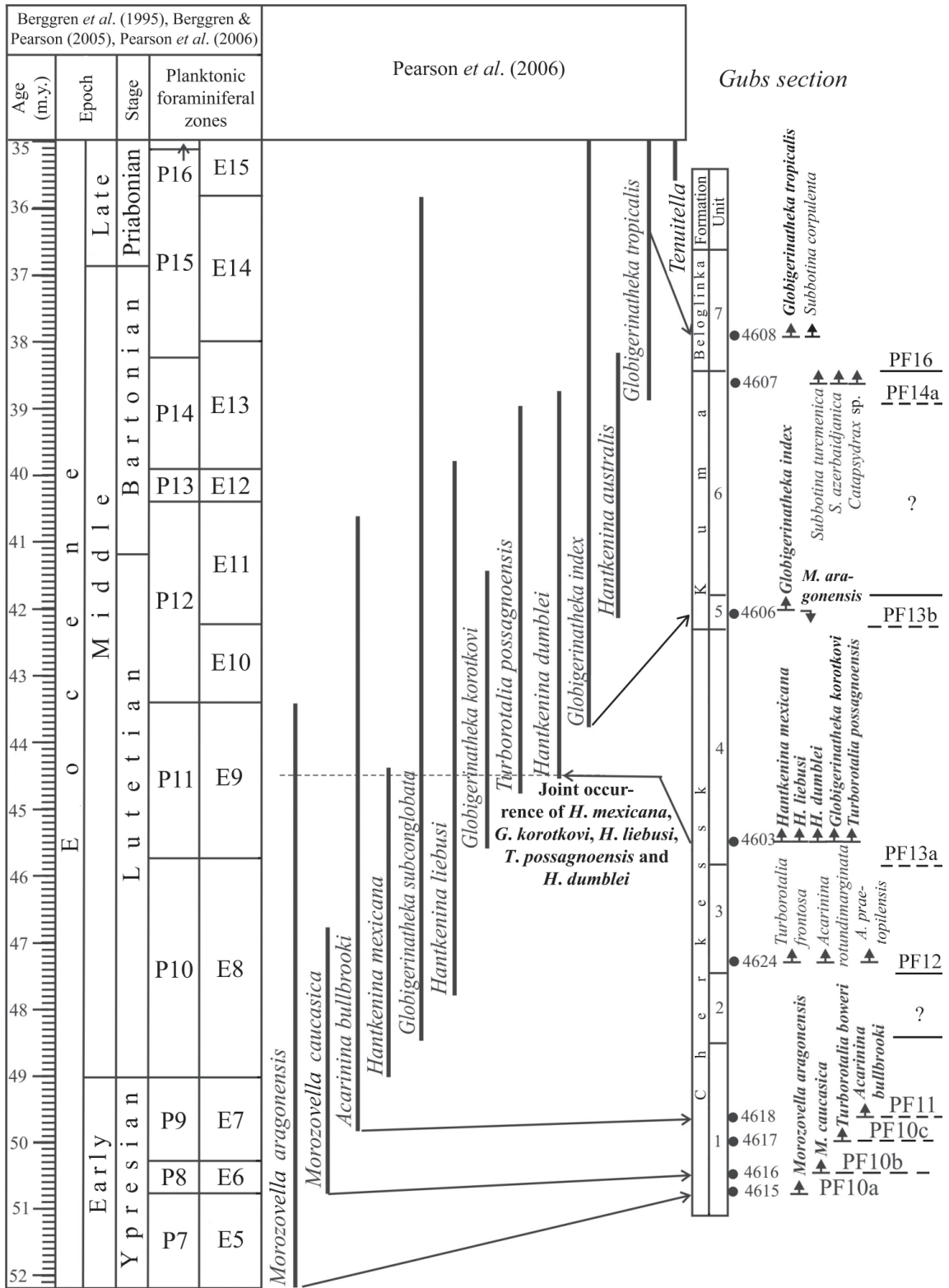
Figure 16. The position of biohorizons of the standard scale after planktonic foraminifera in the Crimean-Caucasian zonal scale and in the Gubs section. Zonal species of the standard scale are indicated in bold.
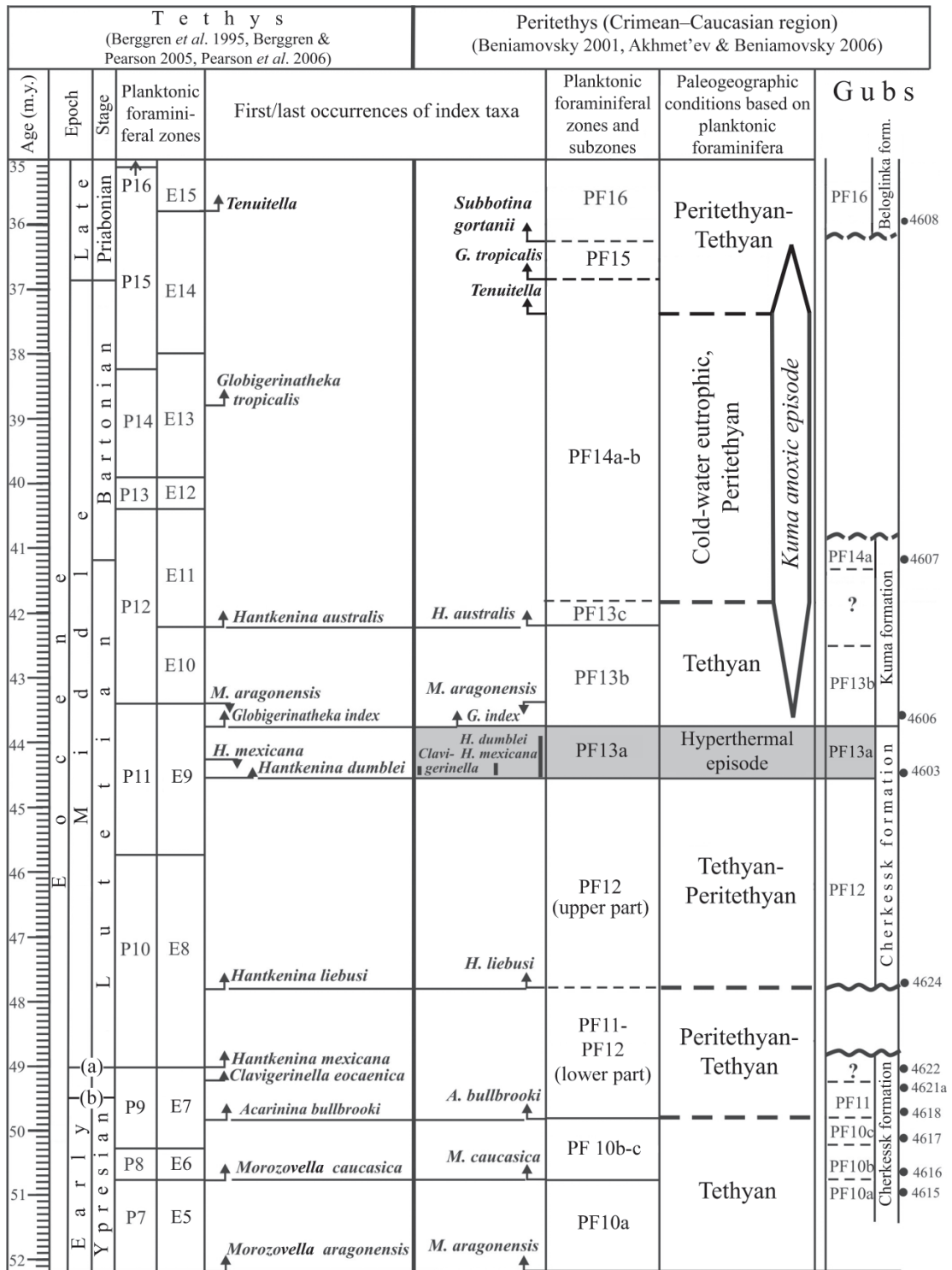
Figure 17. Correlation of Eocene zonal planktonic foraminiferal scales of the Crimean-Caucasian and Tethyan areas and their palaeobiogeographic ground. Similarities and differences in the zonal scales reflect the degree of palaeoenvironmental differentiation. The Ypresian/Lutetian boundary is indicated following **(a)** Luterbacher *et al.* (2004) corresponding to the P 9/10 boundary and **(b)** Molina *et al.* (2011) corresponding to the NP 14a/b boundary in the Gorrondatxe section.

al. 2008). Although *Hantkenina liebusi* Shokhina first appears in the higher part of the PF 12 Zone in some Peritethyan sections (Beniamovsky *et al.* 2003), this level should already be above the base of the Lutetian in the standard scale, since this species is not an ancestral form of genus *Hantkenina* (Figure 16). Thus, according to the standard scale, the Ypresian/Lutetian boundary should be very close to the base of the *A. rotundimarginata* Zone. The unconformable contact at the base of Unit 3 reflects the hiatus between the clay and the underlying limestone. Stratigraphically it may correspond to the lower part of the PF 12 Zone (Figure 17).

(4) We call the PF 13 Zone *Hantkenina* 'alabamensis' because of the long tradition of this name in the Russian literature, although according to Beniamovsky (2001, 2008) in reality it corresponds to *H. australis* (Finlay), which is marked by the above quotation marks. The PF 13 Zone in the Gubs section is recorded from units 4 and 5 (samples 4603 to 4606). Its base is defined by the first appearance of *Globigerinatheka subconglobata* (Shutskaya). Other new taxa such as *G. korotkovi* (Keller), *G. index* (Finlay), *Hantkenina mexicana* Cushman, *H. liebusi* Shokhina, *H. dumblei* Weinzierl & Applin, *Turborotalia possagnoensis* Toumarkine & Bolli, *Guembelitrioides nuttalli* (Hamilton) and *Subbotina eocaena* (Gümbel) first appear in this zonal assemblage as well. This zone is subdivided into three subzones (Figure 13), of which the lower and middle ones (Figure 15) are recognized in Gubs section.

(4a) The lower, *Globigerinatheka subconglobata/ Hantkenina dumblei* (PF 13a) Subzone is observed in Unit 4 (samples 4603 and 4605) and recognized by the appearance of *Globigerinatheka* ex gr. *subconglobata, G. korotkovi, Hantkenina mexicana*, *H. liebusi, H. dumblei, Turborotalia possagnoensis* and *Guembelitrioides nuttalli*. In correlating with the zonal subdivision of low latitudes (Berggren & Pearson 2005; Pearson *et al.* 2006), the assemblage of sample 4603 can be considered as corresponding to a narrow interval in the middle part of the middle Lutetian P 11 (E 9) Zone, in which the disappearing *Hantkenina mexicana* and the first appearing *H. dumblei* and *Turborotalia possagnoensis* coexist (Figure 16). The appearance of tropical *Hantkenina* is connected with the short-term hyperthermal optimum (Figure 17),

which made them able to migrate into the Crimean-Caucasian realm (Beniamovski *et al.* 2003).

(4b) The lower boundary of the *Globigerinatheka index* (PF 13b) Subzone is defined by the first occurrence of the named taxon, which indicates a further stage in the evolution of this genus. In the upper part of this subzone the first appearance of *Subbotina turcmenica* can be observed in some sections (Beniamovsky 2001). The upper boundary of the PF 13b Subzone is marked by the first appearance of *Hantkenina australis* (Beniamovsky 2001), the index taxon of the PF 13c Subzone, not recorded in the Gubs section. The PF 13b Subzone is observed in sample 4606, from the lower part of Unit 5, corresponding to the lower part of the Kuma Formation. This is the last occurrence of thermophilic *Morozovella* (*M. aragonensis* and *M. caucasica*), whereas representatives of genus *Hantkenina* are missing from this assemblage. Based on these characteristics sample 4606 should correspond to the upper part of the P 11 (E 9) Zone, where *G. index* first appears. Cooling and anoxia in the early period of the developing Kuma Basin are believed to be the main factors in the disappearance of *Hantkenina* and *Morozovella*, as well as in the first appearance of cold-water *Subbotina turcmenica* in the upper part of the *Hantkenina* 'alabamensis' Zone (Beniamovsky 2001; Bugrova 2005).

(5, 5a) The lower boundary of both the *Subbotina turcmenica* (PF 14) Zone and its lower *Subbotina azerbaidjanica/Catapsydrax* sp. (PF 14a) Subzone is defined by the disappearance of *Hantkenina australis* and (as a new element introduced herein) by the first appearance of *Catapsydrax* sp. and also of *Subbotina azerbaidjanica* (Khalilov), although this taxon is believed to be a junior synonym of of *Globigerinatheka index* by Berggren & Norris (1997: 35 and table 5). For this reason we introduce the second nominate taxon (*Catapsydrax* sp.) for the PF14a Subzone. The definition of the lower boundary of the *Subbotina turcmenica* Zone, which corresponds to the Kuma regiostage in the Crimean-Caucasian region, is hampered as the nominate species first appears in the *Hantkenina* 'alabamensis' Zone, as well as the last rare hantkenines usually present in the lower part of the *Subbotina turcmenica* Zone. The subdivision of this zone into two subzones by

the disappearance of *Subbotina azerbaidjanica* and *Acarinina rotundimarginata* and by the appearance of *Subbotina instabilis* and *S. praebulloides* is much less problematic.

Only the lower subzone is recognized in sample 4607 from the upper part of Unit 6, which still belongs to the Kuma Formation. This assemblage is very poor: *Globigerinatheka index* survives in abundance, but all the other taxa from the underlying assemblages disappear. Meanwhile, three new forms, *Subbotina turcmenica* Khalilov, *S. azerbaidjanica* (Khalilov) and *Catapsydrax* sp. first appear at this level. The correlation with the standard scale is problematic because of two factors. The first is the strong endemism of the fauna caused by the anoxia and cooling of the Kuma Basin (Beniamovski *et al.* 2003; Gavrilov & Shcherbinina 2007; Beniamovsky 2007, 2008). The second factor relates to taxonomic problems with *Subbotina turcmenica* (not considered as a valid taxon – nomen dubium – by non-Russian experts because of the lack of holotype) and with *S. azerbaidjanica* (see above).

(6) The Priabonian *Subbotina corpulenta* (PF 16) Zone is defined as the interval between the first appearance of *Subbotina gortanii* (Borsetti) and the last mass occurrence of *S. corpulenta* (Subbotina) and *Globigerinatheka index*. This zone is transitional between the *Globigerinatheka tropicalis* (PF 15) and *Turborotalia centralis* (PF 17) Zones, with which they are often included into one single zone (Beniamovsky 2001; Bugrova 2005).

In the Gubs section the PF 16 Zone is recognized in Unit 7 of the Beloglinka Formation (samples 4608 to 4610), overlying the upper Lutetian (– lower Bartonian?) Kuma Formation with angular unconformity. The planktonic foraminiferal assemblages of the two formations strongly differ from each other, not only because of the considerable age difference between them but also due to the appearance of cosmopolitan warm-water forms in the Beloglinka Formation, such as *Subbotina corpulenta*, *S. gortanii*, *S. jacksonensis* Bandy, *Turborotalia pomeroli* (Toumarkine & Blow) and *Globigerinatheka tropicalis* (Blow & Banner). These species start in the Mediterranean in the Bartonian (in the middle part of the P 14 and E 13 zones). Their migration into the Crimean-Caucasian region happened due to
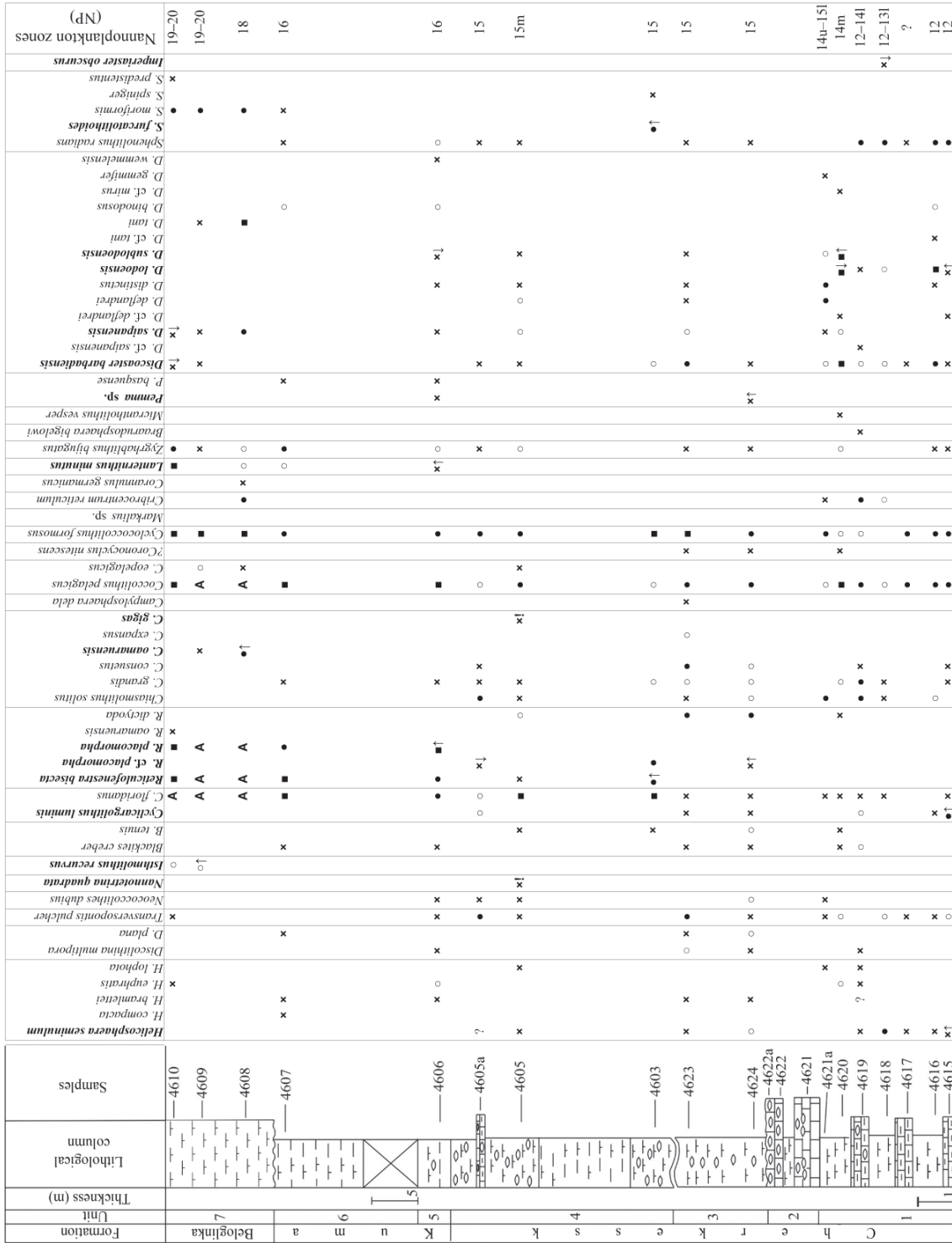
the warming of the surface water mass of the well-oxygenated Beloglinka Basin in the Priabonian.

Calcareous Nannofossil Biostratigraphy

From the Gubs river section the NP 12–20 zones of Martini (1971) have been proven: the distribution of taxa is shown in Figure 18. The lower two samples (4615 and 4616) are not older than NP 12 because of the presence of *Discoaster lodoensis* Bramlette & Riedel, since its FO marks the lower boundary of NP 12 and that of the equivalent CP 10 of Okada & Bukry (1980) and Bukry (1973). We were not able to separate the NP 12 and 13 zones since the marker genus, *Tribrachiatus* is missing from the studied samples. In the Possagno section (Italy) *Discoaster* Acme is characteristic for the NP 12 Zone (Agnini *et al.* 2006) and since a similar *Discoaster* abundance (mainly with *D. lodoensis*) occurred in sample 4616 we can conclude that the probable position of this sample is in NP 12. The age of the next sample upwards (4617) is rather uncertain; the following sample (4618), however, cannot be younger than the older part of the NP 13 Zone, based on the presence of *Imperiaster obscurus* Martini, which is unknown from younger levels.

The nannofossil assemblages in the next three samples upwards (4619, 4620 and 4621a) are crucial in locating the Ypresian/Lutetian boundary *sensu* Molina *et al.* (2011), who proposed to mark it in the GSSP of Gorrondatxe at the first appearance of *Blackites inflatus* (Bramlette & Sullivan), which subdivides the NP 14 Zone into two (NP 14a and 14b) subzones. Since the latter taxon could not be recognized in the Gubs section, we can rely instead upon the presence/absence of *Discoaster lodoensis* and *D. sublodoensis* Bramlette & Sullivan. The FO of *D. sublodoensis* defines the lower limit of NP 14 (and of the correlative CP 12a) Zone, but it is usually quite rare in the basal part of the zone (Bernaola *et al.* 2006; Molina *et al.* 2011), whereas *D. lodoensis* is common only in the lower part of NP 14 where, after a rapid decrease, it disappears (Agnini *et al.* 2006).

Based on the presence of *D. lodoensis* and the absence of *D. sublodoensis*, the lower sample (4619) cannot be younger than the lower part of the NP 14 Zone, so it still belongs to the Ypresian. The

Figure 18. Distribution of calcareous nannoplankton taxa (arranged according to Young & Bown 1997) in the Gubs section. ⋆– The position of sample 4620 based on the mass co-occurrence of *Discoaster lodoensis* and *D. sublodoensis* is in the middle part of the NP 14 Zone, although the lack of *Blackites inflatus* does not allow us to attribute it among the NP 14a and 14b Subzones.

relationship of the two taxa is opposite in the upper sample (4621a), indicating that it cannot be older than the higher part of the NP 14 Zone (the lower part of the NP 15 Zone cannot be excluded either). Consequently, sample 4621a already belongs to the Lutetian. Both crucial taxa occur in abundance in the middle sample (4620), most probably marking the middle part of the NP 14 Zone. Thus, this sample is quite close to the Ypresian/Lutetian boundary, although the exact location on either side of it cannot be determined, not only because of the absence of *Blackites inflatus* but also because of the lack of *B. piriformis* and *Nannotetrina cristata* first appearing very close to the NP 14a/b boundary in the Gorrondatxe section (Bernaola *et al.* 2006; Molina *et al.* 2011). Nevertheless, arguments for positioning sample 4620 in the Ypresian NP 14a Subzone (the absence of all three taxa mentioned above, together with the common occurrence of *Discoaster lodoensis*) seem to be slightly stronger than those for locating it in the Lutetian NP 14b Subzone, since the common occurrence of *D. sublodoensis* is already observed to start from the upper part of the NP 14a Subzone in the Gorrondatxe section (Bernaola *et al.* 2006; Molina *et al.* 2011).

In the next sample (4624) a typical Middle Eocene assemblage occurs with *Neococcolithes dubius* (Deflandre) and *Pemma sp.* Since the marker species for the upper boundary of NP 16 (*Chiasmolithus solitus* Bramlette & Sullivan) is present, this sample is not younger than this zone. A stratigraphically important form is *Reticulofenestra cf. placomorpha* (Kamptner) (older synonym of *R. umbilicus* Levin), which is smaller than the type and suggests a zonal position older than NP 16 (NP 15 or possibly uppermost NP 14). Spanish sections studied in recent years clearly show that *R. umbilicus* larger than 14 µm occurs from NP 16 (Molina *et al.* 2006) and *R. umbilicus* larger than 11µm (= *R. cf. placomorpha)* is present from the uppermost NP 14 (Larrasoaña *et al.* 2008). *Helicosphaera bramlettei* (Müller) has its rare FO in NP 15 (Perch-Nielsen 1985). Therefore, the nannoflora of sample 4624 probably belongs to the NP 15 Zone. In the next sample (4623) the nannoflora is similar to that of sample 4624.

The NP 15 Zone has been proven from samples 4603 to 4605a. In sample 4603 *Reticulofenestra* cf.

placomorpha, Sphenolithus furcatolithoides Locker (with FO in NP 15 according to Molina *et al.* 2006) and *R. bisecta* (Hay, Mohler & Wade) smaller than 10 µm (common already in this zone based on Monechi *in* Larrasoaña *et al.* 2008) refer to the NP 15 Zone. In sample 4605 *Nannotetrina quadrata* (Bramlette & Sullivan) and *Chiasmolithus gigas* (Bramlette & Sullivan), the zonal markers for NP 15 are present. *N. quadrata* occurs only in NP 15 (Perch-Nielsen 1985) whereas the range of *C. gigas* is restricted to Subzone CP 13b, corresponding to the middle part of NP 15. Finally, in sample 4605a, the presence of *Reticulofenestra* cf. *placomorpha* (see above) still suggests an age older than NP 16, most likely NP 15.

The next two samples (4606 and 4607) have typical assemblages for NP 16, with common and large *Reticulofenestra placomorpha* (Kamptner), and *Lanternithus minutus* Stradner, which cannot be older than this zone (Bukry 1973; Báldi-Beke 1984), and with *Discoaster sublodoensis* Bramlette & Riedel (present only in sample 4606) which disappears at the NP 16/17 boundary.

The NP 17 Zone could not be recognized in the Gubs section: it probably coincides with the sedimentary hiatus and angular unconformity between the Kuma and Beloglinka formations. In the three samples from the latter unit the very rich nannofloras belong to the late Eocene NP 18–20 zones. The assemblage of the lower sample (4608), with *Chiasmolithus oamaruensis* (Deflandre), is not older than NP 18 since this species first occurs in this zone and also marks the lower boundary of the late Eocene. In the two higher samples (4609 and 4610) *Isthmolithus recurvus* Deflandre occurs, the first appearance of which defines the lower boundary of NP 19. The separation of the NP 19 and N 20 zones of Martini (1971) later became impossible because the FO of *Sphenolithus pseudoradians* Bramlette & Wilcoxon, originally marking the base of the NP 20 Zone, happened much earlier, in the middle Eocene, and there are no other markers for this boundary. The top of the NP 20 Zone is defined by the LO of *Discoaster barbadiensis* Tan and *D. saipanensis* Bramlette & Wilcoxon, both recorded from the top two samples. Thus, sample 4608 marks the NP 18 Zone, whereas samples 4609 and 4610 the NP 19–20 zones.

Correlation Between Larger Benthic, Planktonic Foraminiferal and Calcareous Nannoplankton Zones in the Gubs Section

The correlation of zonal scales on three microfossil groups in the studied section (Figure 19) allowed us to determine both the position of several regional zones on the standard scale and the duration of sedimentary gaps.

The composition of planktonic foraminifera (*Morozovella aragonensis*, *M. caucasica*, *Turborotalia boweri*) from the lower part of the profile (samples 4615 to 4617 from the lower part of Unit 1) is characteristic both for the late Ypresian *M. aragonensis* s.l. interval zone (PF 10) of the Crimean-Caucasian realm and for the P 7–P 9 (lower part) Zones of the standard scale (Berggren & Pearson 2005). The calcareous nannoplankton determined from the lower two samples (corresponding to the PF 10a-b subzones and to the P 7–8 zones) are characteristic for the NP 12 Zone whereas the nannoflora from sample 4617 do not allow any detailed age determination. To sum up, the correlation of the planktonic foraminiferal and nannoplankton scale in the Gubs section does not contradict that in the standard scale.

By means of planktonic foraminifera the upper part of Unit 1 of the Gubs section (samples 4618 to 4621a) belongs to the *Acarinina bullbrooki* (PF 11) Zone of the Crimean-Caucasian scale (traditionally considered to be early Lutetian – see Figures 13 and 15) and to the P 9 Zone of the standard scale (corresponding to the latest Ypresian – see Figure 15), although some first occurring taxa such as *Turborotalia frontosa*, *Morozovella gorrondatxensis* and *Globigerinatheka micra* (indicating the late part of P 9) are not recorded from the Gubs section. Larger benthic foraminifera belonging to the SBZ 11 (samples 4619 and 4620) and SBZ 12 zones (sample 4621a) also indicate a late Ypresian age in the sense of Serra-Kiel *et al.* (1998). The calcareous nannoflora of these samples (discussed in detail in the previous chapter and playing crucial role in locating the Ypresian/Lutetian boundary), however, subdivide this interval into two parts. Samples 4618 and 4619 still belong to the Ypresian whereas sample 4621a already indicates the Lutetian. Sample 4620 (indicating the middle part of the NP 14 Zone) is intermediate between them, but we prefer to assign it

still to the terminal Ypresian. The Ypresian/Lutetian boundary (defined as the NP 14a/b boundary) falls within the P 9 Zone in both the Gorrondatxe (serving as GSSP for the Ypresian/Lutetian boundary, Bernaola *et al.* 2006; Molina *et al.* 2011) and Agost (Larrasoaña *et al.* 2008; Ortiz *et al.* 2008) sections, so our results from the Gubs section in this respect are in accord with those from Spain. In addition (as a new result), the *Acarinina bullbrooki* (PF 11) Zone of the Crimean-Caucasian realm also crosses the early/middle Eocene boundary.

The arrangement of larger benthic foraminiferal zones around the Ypresian/Lutetian boundary appears to be more complicated since it is different in the Gorrondatxe (Bernaola *et al.* 2006; Molina *et al.* 2011) and Agost (Larrasoaña *et al.* 2008) sections although nummulitids in both cases were determined by J. Tosquella (orthophragmines, although present in both profiles, have not been studied). In the Gorrondatxe section the lowest occurrence of *Blackites inflatus* is between a sample (Az 918), which can indicate either the SBZ 12 or the SBZ 13 Zone and another (Az 1070) which already clearly marks the SBZ 13 Zone. In contrast, *B. inflatus* first occurs in Agost, where it is already within the SBZ 11 Zone. The determination of nummulitids is, however, hard to check because the quality of images is generally poor from both profiles, reflecting the poor preservation. The composition of nummulitids is also somewhat different in the two sections since *N. laevigatus* and its relatives (*N. messinae* and *N. britannicus*), marking the base of the SBZ 13 Zone in the Gorrondatxe section, are missing in Agost.

The composition of nummulitids is even poorer in the Gubs section since representatives of the *Nummulites planulatus-laevigatus-*, *N. burdigalensis-perforatus-*, *N. partschi-lorioli-*groups and also of genus *Assilina* (in the traditional sense) are missing. Orthophragmines are more diverse in Gubs but these fossils have not been studied in the Spanish profiles. Nevertheless, the Ypresian/Lutetian boundary in the new interpretation (Molina *et al.* 2011) can probably be located at the base of the SBZ 12 Zone or, less probably, within the SBZ 11 Zone depending on the position of sample 4620 (Ypresian vs. Lutetian, see above). This positioning is in both cases closer to that in Agost than in Gorrondatxe. The differences of
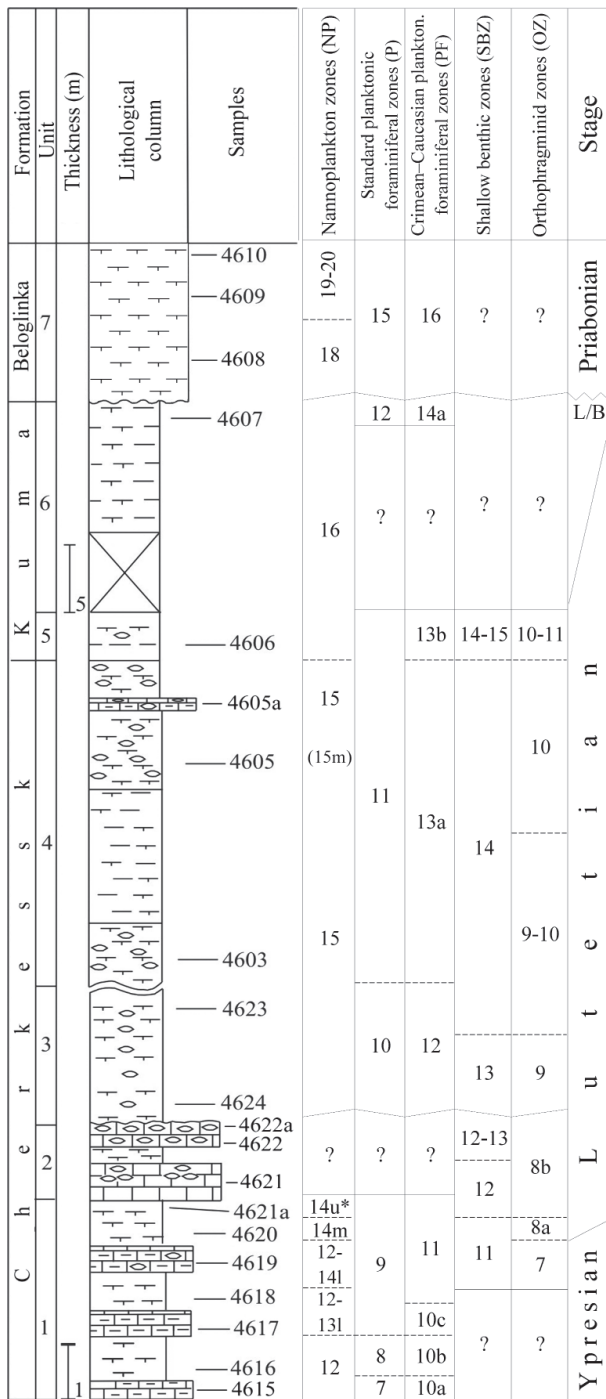
Figure 19. Correlation of zonal schemes by planktonic foraminifera, calcareous nannoplankton and larger foraminifera in the Gubs section. *– see in the last column of Figure 18. L/B– Lutetian or Bartonian.

No plankton could be investigated from the nummulitic limestone of Unit 2 of the Gubs section (samples 4621 to 4622a), which according to the new interpretation of the Ypresian/Lutetian boundary and based on the age of the underlying sample 4621a (see above) already belongs to the Lutetian. Larger Foraminifera indicate that the lowest sample (4621) still corresponds to the SBZ 12 Zone, but the other two already show intermediate features between the former and the SBZ 13 Zone. These zones are assigned by Serra-Kiel *et al.* (1998) to the terminal Ypresian and the basal Lutetian, respectively. Orthophragmines from all samples of Unit 2 belong to the OZ 8b Zone, passing through the early/middle Eocene boundary according to Less (1998).

The sedimentary hiatus between samples 4622a and 4624, i.e. between the nummulitic limestone of Unit 2 and the marly rocks of Unit 3 may quite well be estimated as corresponding to the SBZ 13 (?lower–middle part), OZ 8b (upper part), P 10 (lower part), PF 12 (lower part) zones and probably to the lower part of the NP 15 Zone, i.e. to some part of the lower Lutetian.

Despite the condensed character of the overlying sediments (samples 4624 to 4606), the correlation of scales of the three studied groups in the Gubs section (Figure 19) agrees well in this early–middle Lutetian interval with that in the standard scale (Luterbacher *et al.* 2004). Here, therefore, we do not go into details. The only small deviance is observed in sample 4606 at the very base of the Kuma Formation where (contrary to the standard scale) the uppermost part of the P 11 Zone may be recognized by the coexistence of the disappearing *Morozovella aragonensis* and the first appearance of *Globigerinatheka index* (Pearson *et al.* 2006), is already correlated with the lower part of the NP 16 Zone. At the same time this sample (the uppermost one containing larger benthic Foraminifera) already belongs to the PF 13b Subzone in the Crimean-Caucasian scale.

Up section, the lack of the PF 13c Subzone may be connected with sparse sampling in this interval. The position of sample 4607 in the PF 14a Subzone and NP 16 Zone does not allow it to be assigned confidently to either the Lutetian or the Bartonian.

In the overlying late Eocene Beloglinka Formation, in the *Subbotina corpulenta* (PF 16) Zone

the Ypresian/Lutetian boundary in different sections based on larger foraminifera should, however, be resolved in the very near future.

larger benthic foraminifera are absent, while rich nannofloral assemblages attributed to the NP18 and NP19–20 zones are present. The correlation of the lower part of the *S. corpulenta* Zone with the NP18 Zone does not exactly agree with the official scale for southern European Russia (Koren' 2006), in which the whole zone is correlated with lower part of the NP19–20 Zone. The missing PF 14b and 15 zones, as well as the NP17 Zone, roughly correspond to the (both sedimentary and angular) unconformity between the Kuma and Beloglinka formations.

Conclusions

Based on the same samples from the Gubs river section (Adygean High, North Caucasus) we first correlated the zones using larger benthic foraminifera, planktonic foraminifera and calcareous nannoplankton for the late Ypresian to middle Lutetian interval in the Crimean-Caucasian region. The Ypresian/Lutetian transition is compared with that of the Gorrondatxe (N Spain) section recommended for GSSP, where it was suggested that this boundary should be placed at the base of the NP 14b (= CP 12b) calcareous nannoplankton Subzone (Molina *et al*. 2011). Our results are as follows:

1. The Ypresian/Lutetian boundary *sensu* Molina *et al*. (2011, see above) can be located in the Gubs section (containing diagnostic nannofossil assemblages of the NP 14 Zone) within the *Acarinina bullbrooki* (PF 11) and the P 9 planktonic foraminiferal zones. The latter positioning is in good agreement with that in Gorrondatxe, whereas at least the lower part of the PF 11 Zone (indicating as a whole the early Lutetian in the Crimean-Caucasian scale) should be replaced into the late Ypresian. In terms of larger foraminifera the newly interpreted boundary (see above) corresponds in the studied profile to the base of the SBZ 12 Zone (equivalent to the base of the OZ 8b orthophragminid zones), or (less probably) it should be drawn within the SBZ 11 Zone, between the OZ 7 and 8a orthophragminid zones.

2. In the Gubs section a sedimentary hiatus is recognized at the top of the nummulitic limestone level (between samples 4622a and 4624). It corresponds to the SBZ 13 (?lower–

middle part), OZ 8b (upper part), P 10 (lower part), PF 12 (lower part) zones and probably to the upper part of the NP 14 and to the lower part of the NP 15 zones, i.e. to some part of the lower Lutetian. Above this hiatus the upper part of the *Acarinina rotundimarginata* Zone can be recognized based on *A. praetopilensis*, which is recorded in the Gorrondatxe section from the lower part of the NP 15 Zone. The lower part of the *A. rotundimarginata* (PF 12) Zone (containing *Turborotalia frontosa*, however with no *A. praetopilensis*) is missing from the Gubs section. In fact, the *Turborotalia frontosa* Zone in the Gorrondatxe section falls within the NP 14 Zone and crosses the Ypresian/Lutetian boundary (Bernaola *et al*. 2006; Molina *et al*. 2011).

3. The study of the Gubs material has shown the need to refine the taxonomic position of two zonal taxa: *Acarinina rotundimarginata* and *Turborotalia frontosa*. Pearson *et al*. (2006) doubted the validity of *A. rotundimarginata.* They also did not accept the validity of *T. boweri,* suggesting that it is the junior synonym of *T. frontosa.* This hampers discrimination of not only their nominate subzones but also the Ypresian and Lutetian.

4. The *Hantkenina* '*alabamensis*' (PF13) Zone, based on several warm-water zonal forms of the standard scale, can be well correlated with the P 11/E 9 and P 12/E 10 (lower part) zones, as well as with the NP 15 and 16 zones. In this part of the section larger foraminifera belong to the OZ 9–10, 10 and 10–11 zones, correlatable with the SBZ 14 and 14–15 zones. In general, the three main microfossil groups are well correlated with each other in this part of the profile (Figure 19). The small deviation in the relationship of the lower boundary of the P 12 and NP 16 zones was discussed previously.

5. Our new data from the Gubs section show that the lower part of the Kuma Formation, marking the beginning of the anoxic event in the Crimean-Caucasian region, belongs to the middle–late Lutetian SBZ 14–15, NP16 and P 11/E 9 zones. This modifies the old idea about the beginning of the anoxia happening only in the Bartonian.

6. Based on the Gubs section material the taxonomical content of late Ypresian to middle Lutetian Western Tethyan orthophragminid (OZ) zones have been both refined and correlated with other zonation systems. The stratigraphic ranges of some taxa have also been updated, as shown in red in Figure 8. As in the Crimea (Less 1987, 1998) the OZ 7, 8a and 8b (lower part) zones are correlated with the *Nummulites distans* and *N. polygyratus* Zones of the Crimean-Caucasian scale.

The establishment of a unified Crimean-Caucasian larger foraminiferal scale for the Lutetian is problematic because of their low diversity and sporadic distribution in most regions. It is possible, however, to recognize some local faunal horizons. Two of them, observed in the Gubs section, can be correlated with those in the sections (Inal and Loo) of the southern slope of the Caucasus (Zakrevskaya *et al.* 2009). These are the *Discocyclina archiaci bartholomei – D. augustae sourbetensis* levels of the SBZ 11 Zone (Gubs and Inal) and the late middle Lutetian (SBZ 14–15) beds with small *Nummulites*, *Orbitoclypeus douvillei chudeaui*, *Discocyclina dispansa sella* and *Nemkovella strophiolata strophiolata* (Gubs and Loo).

7. The infrazonal scale for planktonic foraminifera (Beniamovsky 2001) has been refined in this work by including *Turborotalia boweri*, *Hantkenina dumblei* and *Catapsydrax* sp. into the diagnosis of the PF 10c, PF13a and PF14a subzones, respectively, as index taxa. We also suggest that the name of the PF 13 Zone should be the *Hantkenina* 'alabamensis' Zone and to include the presence of *Acarinina praetopilensis* in future diagnosis of the PF12b Subzone (defined by Beniamovsky 2001). This latter will be possible when the order of first appearances of crucial taxa for subdividing the PF 12 Zone (*Acarinina rotundimarginata*, *Turborotalia frontosa*, *A. praetopilensis*,

Hantkenina liebusi and *H. mexicana*) is fixed in a continuous section.

8. In correlating Crimean-Caucasian zonal biostratons with zones of the standard scale we have identified the similarities and differences in the palaeogeographic conditions between the Tethyan and Peritethyan Eocene basins (Figure 17). They appeared to be closest in the late Ypresian and middle Lutetian, which coincide with thermal optima. They were still relatively close around the Ypresian/Lutetian transition and in the Priabonian, while in the late Lutetian and Bartonian these conditions were sharply different in the two palaeogeographic realms.

9. The distribution and taxonomical composition of larger foraminifera was affected mostly by temperature, but also by the depth and nutrition content of the given basin. This explains the similarity of Tethyan and Peritethyan nummulitic assemblages in the Ypresian and also their dissimilarity (or even their complete absence in some Peritethyan regions) in the Lutetian. Orthophragmines appear to be more cosmopolitan than nummulitids, although their taxonomical composition was also affected by the conditions listed above.

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