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A high resolution Lutetian-Bartonian planktonic foraminiferal zonation in the Crimean-Caucasus region of the northeastern Peri-Tethys

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Abstract

The traditional Middle Eocene zonation in the Crimean-Caucasus region contains 4 zones. The infrazonal scale contains 7 subdivisions ranked as subzones. The lower boundaries of the zones are defined on first or last appearances of stratigraphically important species. Six stages can be recognized in the evolutionary and ecological progression of the planktonic foraminifers. The similarity and unidirectional morphologic and taxic evolution in the rapidly evolving group of planktonic foraminifera in the Crimean-Caucasus Region and Tethys provide a firm basis for correlation of Lutetian-Bartonian zonations and regional and international (standard) Tethyan stages.

1. Introduction

The early studies of planktonic foraminifera from Crimea and North Caucasus and their zonal subdivision by Subbotina (1936) and Morozova (1939) before the Second World War were a pioneering achievement and preceded the recently widely used Caribbean scale (Berggren and Norris, 1997; Berggren and Pearson, 2005) by over half a century. The first official variant of a Crimean-Caucasian Paleogene zonal scale was published in Resolution (1963). This traditional Paleocene-Eocene scale survived with small changes until the recent Crimean-Caucasian Paleogene scheme introduced by Akhmetiev and Beniamovsky (2003, 2006) and Koren' (2006) (Fig. 1).

In the former Soviet Union (FSU), however, there were special ideas on the content of the Middle and Upper Eocene conflicting with those in the rest of the world, and special Crimean Paleocene-Eocene stages were used (Grossgein and Korobkov, 1975). Only since the early 1980s has the Paleogene stratigraphy of the USSR been aligned 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 Paleogene schemes of the USSR since 1989 (Resolutions..., 1989). However, its detailed correlation with planktonic foraminiferal zones is still under discussion (Akhmetiev and Beniamovsky, 2003, 2006; Bugrova et al., 2008).

The partly infrazonal subdivision of the Crimean-Caucasian Paleogene zones was already proposed starting from the 1970's (Shutskaya, 1970; Korovina 1970; Krashenninikov and Muzylöv 1975; Bugrova 1986). Evolutionary stages in the development of Paleogene 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 a correlation with the Paleogene standard scale by Berggren and Pearson (2005) should be achieved. Their reliable correlation is only possible if sufficiently detailed scales are available and Crimean-Caucasian Paleogene planktonic foraminifera are taxonomically revised because obsolete generic and specific names are still used by Russian paleontologists (Bugrova, 2005; Bugrova et al. 2008). The first variant of the detailed scale (Beniamovsky, 2001) was not supported in general (Bugrova 2005; Koren' , 2006; Bugrova et al., 2008) in Russia, although it can also be considered as the rejuvenation of the traditional scale, "popularized" for the international community. Moreover, it contains 30 zonal biostratigraphical subdivisions in the Paleocene-Eocene and exceeds the standard scale (consisting of 17 zones) in details. The Beniamovsky (2001) infrazonal scale was used by Ukrainian specialists (Gozhik et al., 2006) in the biostratigraphic subdivisions in the Crimean shelf and also in recognizing gaps in the North Cis-Caucasian sections near Mineral'nye Vody (Akhmetiev and Beniamovski, 2006) not observed by using the traditional scale. The infrazonal scale has been updated by Benyamovskiy (Beniamovski, 2006; Akhmetiev and Beniamovski, 2006). For convenience the biostratigraphic subdivisions of the infrazonal scale are marked not only by their index taxa but also by numbers (for zones) and letters (for subzones) (Fig. 1). Biostratigraphic units of the infrazonal scale, in addition to being named by their index species, are assigned a number (for zones) and a character — a, b, c (for subzones). The abbreviation "PF" stands for "planktonic zones of the Paleogene of Crimean-Caucasus region". The version of the high resolution zonation proposed herein is a result of studies extending over a decade by the author of this work and his colleagues (Benyamovskiy, 2001; Akhmetiev and Benyamovskiy, 2006; Beniamovski, 2006; Benyamovskiy, 2009; Benyamovskiy, 2011a,b; Zakrevskaya et al., 2011).

2. Materials and methods

The high resolution Middle Eocene planktonic foraminiferal biostratigraphy of the Crimean-Caucasus Region presented here incorporates data from five key sections (Fig. 2). In these sections planktonic foraminifera occur together with calcareous nannofossils (Beniamovski et al., 2003; Zakrevskaya et al., 2011).

The composite Bakhchisaray Section in Crimea (44°47' N, 33°53'E) was sampled at the quarry of the concrete factory (samples 1–46) and the ravine, cutting the SW slope of Kazantash Mountain (samples 47 – 98). This composite section consists at the base of the Keresta Fm. (quarry outcrop) topped by the Kuma Fm. (quarry and ravine outcrops). The Keresta Fm. (32 m thick in exposures) includes marls in its lower part and alternating marls and limestone in the upper part, whereas the Kuma Fm. (57 m thick) is mainly characterized by grey and black marls with grey-green intercalations in its uppermost part (Fig. 3). Aside from fine (millimetre-scale) lamination and the rhythmical alternations (approx. 0.5 m thick) in the middle part when relatively light marls alternate with 3 - 5 cm thick beds of darker marls, numerous fish remains are typical for the Kuma Fm. Several bentonite layers occur in the lower part. In the upper part of Kuma Fm. plant debris become abundant. The Kuma Fm. conformably overlays the Keresta Fm. However between the quarry and ravine sections due to a dense vegetation cover several meters of the lowermost Kuma Fm. are absent.

A second section is situated along the Gubs River banks at the southern edge of the village of Barakaevskaya SE of Maikop, western Cis-Caucasia (44°14' N, 40°52' E), where in addition to small planktonic foraminifers, our parallel study was focused on large foraminifers – nummulitids and orthophragminins, analyzed by Yelena Zakrevskaya (Russia) and György Less (Hungary). The Gubs section has been described by Zakrevskaya et al. (2011) (Fig. 4).

The most complete Kheu Section (Fig. 2) SE of Nalchik, near Gerpegesh village (43°24' N, 43°38' E), continuously exposed along the banks of the Kheu River, has been described by Gavrilov et al. (2000). Here we discuss only the Keresta Fm. (white limestones and marls, about 15 m thick) and the Kuma Fm. (coffee- to dark-brown marls, 50 m thick) (Fig.5). Lithology is very similar to the Crimea section.

Resolution of the 5th Plenary Meeting of the Paleogene Commission of the USSR (1963)			Resolution of the 16th Plenary Meeting of the Paleogene Commission of the USSR (1989)			Akhmetiev & Beniamovsky, 2003		Infrasonal scale (Beniamovsky, 2001; Akhmetiev & Beniamovsky, 2006; Benyamovskiy, 2009, 2011 with additionals)	
Subepoch	Stage	Zones	Subepoch	Stage	Zones	Stage	Zones	Subzones	
Late Eocene	Bodakian	of planktonic foraminifera	Middle Eocene	Bartonian	*Globigerina turcmenica* (*Truncorotaloides rohri*)	Bartonian	*Subbotina turcmenica* PF14	*Subbotina instabilis*-*Tenuitella postcretacea* (PF14b)	Middle Eocene
						Lutetian		*Globigerinatheka* ex gr. *index* (=*Subbotina azerbaidjanica*)-*Catapsydrax unicavus* (PF14a)	
		Hantkenina alabamensis & *Globigeinoides subconglobatus*			*Hantkenina alabamensis*		*Hantkenina alabamensis* PF13	*Hantkenina australis* (PF13c)	
								Globigerinatheka index (Pf13b)	
								Globigerinatheka subconglobata (PF13a)	
		Acarinina rotundimarginata		Lutetian	*Acarinina rotundimarginata*		*Acarinina rotundimarginata* PF12	*Turborotalia frontosa* (PF12b)	
								Guembelitrioides nuttalli (PF12a)	
Middle Eocene	Simpheropolian	*Acarinina crassaeformis*			*Acarinina bullbrooki*		*Acarinina bullbrooki* PF11		
Early Eocene	Bakhchisaraian	*Globorotalia aragonensis*	Early Eocene	Ypresian	*Globorotalia aragonensis*	Ypresian	*Morozovella aragonensis* PF10	*Turborotalia boweri*/ *Globigerinatheka micra* (PF10c)	Early Eocene
								Morozovella caucasica (PF10b)	
								Morozovella aragonensis s.s. (PF10a)	

Figure 1: Historical background of Eocene planktonic foraminiferal zones in the Crimean-Caucasian regional scheme.

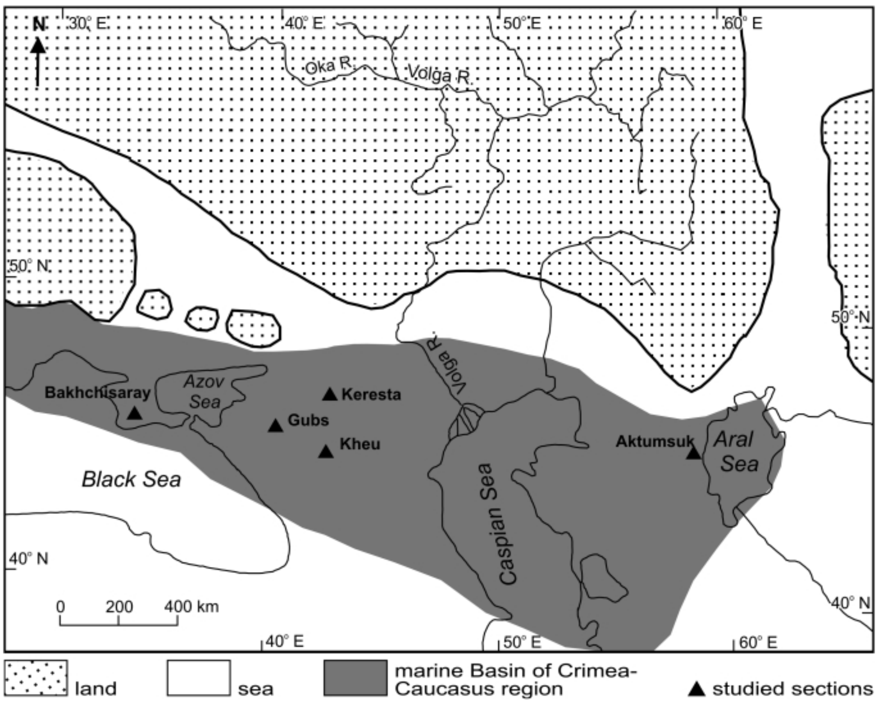

Figure 2: Outline of the middle Eocene Crimean-Caucasus basin in the Northeastern Peri-Tethys and locations of the five studied sections in the modern geographic setting.

The Keresta Section, (the strato-type section of the Keresta Fm.) Rostov Region, near Pervanoyskoe village (46°20' N, 43° 42' E) represents the northernmost facies of the Kuma Fm. (Fig. 6). This section has been retrieved from a drill-hole with 100% recovery on the bank of the Keresta Ravine in 1995. Description of the section and sampling was made by V.A. Musatov and N.G. Muzylöv. The Keresta Fm. (8 m thick) consists of white clayey marls and calcareous marls in the lower part and thin limestone beds (1 m thick) at the top. The Solonka Fm. (10 m thick; equivalent to the Kuma Fm.) consists of brown-grey calcareous clays in the lower part and green-grey calcareous clays in the topmost 4 m. It unconformably overlays the Keresta Fm.

The Aktumsuk Section SW coast of Aral Sea (44°37' N and 58°20' E), where the lithostratigraphic nomenclature of N Turkmenistan was applied (Saperson and Zheleznov 1962; Muzylöv et al. 1990; Khodzhakhmedov 2001), represents the north-easternmost facies. The Ilyaly Fm. (20 m thick; equivalent to the Keresta Fm.) consists mainly of white marls and soft limestone and contains several bentonite beds (Fig. 7). The Kurtysh Fm. (15 m thick; equivalent to the Kuma Fm.) consists of light-grey and brownish marls.

3. High resolution Lutetian-Bartonian planktonic foraminifers zonation of the Crimean-Caucasus region

The lower boundaries of the zones and subzones are defined datum on first (FAD) or last appearances (LAD) of species of stratigraphically important taxa of the genera *Subbotina*, *Guembilitrioides*, *Acarinina*, *Turborotalia*, *Hantkenina*, *Globigerinatheka*, *Catapsydrax* and *Tenuitella* (Fig. 8).

Acarinina bullbrooki Interval Zone (PF 11) (Orue-Etxebarria et al., 1984). Definition: Biostratigraphic interval between of the FAD of *Acarinina bullbrooki* (acme) and the FAD of *Guembilitrioides nuttalli*. Approximate age: late early Eocene – the beginning of middle Eocene (Late Ypresian-Initial Lutetian). Characteristic elements of this zone include *Acarinina bullbrooki*, *Morozovella caucasica*, *M. aragonensis*, *Subbotina inaequispira*, *S. senni*, *S. pseudoeocaena*, *S. linaperta*, *Acarinina pentacamerata*, *A. coalingensis*, *A. pseudotopilensis*, *A. boudreauxi*, *Turborotalia boweri*, *Pseudohastigerina wilcoxensis* and *Globigerinatheka micra*. Although the base of the Lutetian in the Crimean-Caucasus region is traditionally drawn at the base of this zone, the FAD of *Acarinina bullbrooki* (which is probably co-eval with that in the low latitude belt) cannot be a marker for the base of the Middle Eocene because the FAD of this species is fixed in the late Ypresian (Orue-Etxebarria et al., 1984; Berggren et al., 1995; Berggren and Pearson, 2005; Pearson et al., 2006; Payros et al., 2007; Molina et al., 2011; Wade et al., 2011). The lowest occurrence of *Turborotalia* (*T. boweri*) is also recorded from this subzone. I agree with Orue-Etxebarria et al. (1984, 2006), Gonzalvo & Molina (1998) and Molina et al. (2006) in separating *T. boweri* from *T. frontosa* (Subb.) instead of joining them (Pearson et al., 2006; Payros et al., 2008) since they have different morphotypes and represent two different evolutionary stages of this genus (see later). In the zonal schemes of Spain the *Turborotalia boweri* Zone is placed into the Ypresian (Molina et al., 2006).

Acarinina rotundimarginata Interval Zone (PF12) (Subbotina, 1953). Definition: Biostratigraphic interval between of the FAD of *Guembelitriodes nuttalli* and the FAD of *Globigerinatheka subconglobata*. Approximate age: the beginning of Middle Eocene (Early Lutetian). This zone is divided into two subzones: (1) *Guembelitriodes nuttalli* Interval Subzone (PF12a) and (2) *Turborotalia frontosa* Interval Subzone (PF 12b).

(1) *Guembelitriodes nuttalli* Interval Subzone (PF 12a) (in this paper). Definition: Biostratigraphical interval between the FAD of *Guembelitriodes nuttalli* and the FAD of *Turborotalia frontosa*. This subzone contains an assemblage similar to the preceeding zone with the addition of *Guembelitriodes nuttalli*, *Pseudohastigerina micra* and acme *A. rotundimarginata*. The FAD of *G. nuttalli* was proposed as the marker event of the Ypresian/Lutetian boundary by Berggren and Pearson (2005), but

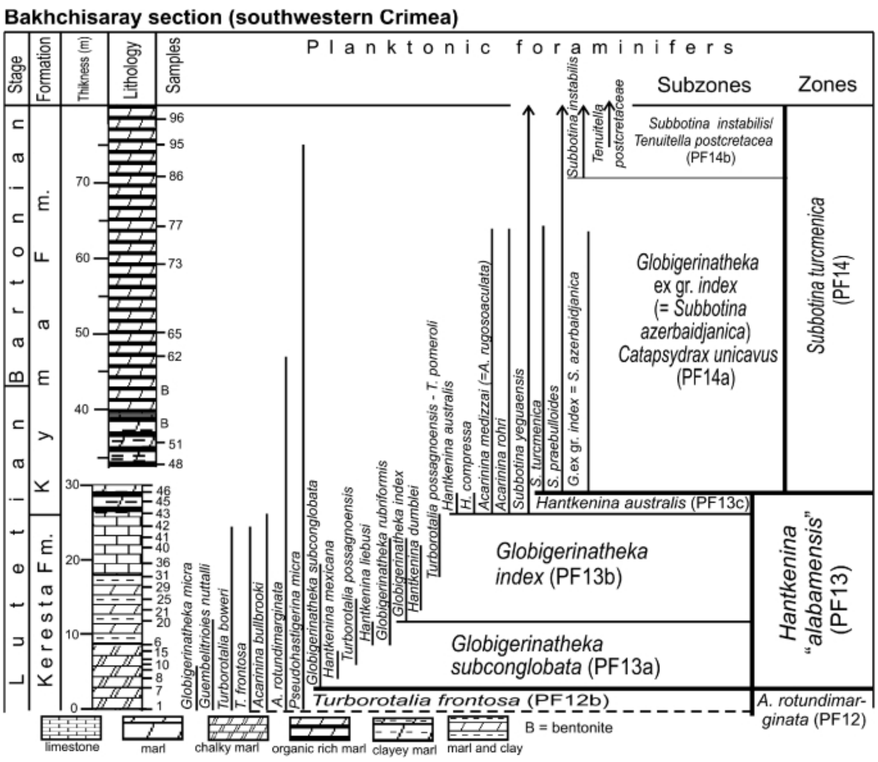

Figure 3: Distribution of planktonic foraminifera and high-resolution zonation Middle Eocene in the Bakhchisaray section (southwestern Crimea).

according to Wade et al (2011) the first occurrence of this taxa is later than the Ypresian/Lutetian boundary.

(2) *Turborotalia frontosa* Interval Subzone (PF 12b) (in this paper). Definition: Biostratigraphical interval between the FAD of *Turborotalia frontosa* and the FAD of *Globigerithatheka subconglobata*. Characteristic elements of this zone include *Subbotina eocaena*, *Globigerinatheka micra*, *Acarinina bullbrooki*, *A. rotundimarginata*, *Pseudohastigerina micra* and *Morozovella caucasica*. The assemblage of this subzone is characterized by the FAD of *Turborotalia possagnoensis* and rare occurrences of *Clavigerinella eocaenica* and *C. caucasica* in the upper part on this subzone.

The *Hantkenina "alabamensis"* Interval Zone (PF 13) (as *Glogigerinoides subconglobata – Hantkenina alabamensis* Zone by Schutzkaya, 1970 and Hantkenina alabamensis Zone by Krascheninnikov and Muzylöv, 1975). Definition: Biostratigraphical interval between the FAD of *Globigerinatheka subconglobata* and the LAD of *Hantkenina australis*. Approximate age: middle middle Eocene (Middle-Late Lutetian). The zone is subdivided into three subzones: (1) *Globigerinatheka subconglobata* Interval Subzone (PF13a), (2) *Globigerinatheka index* Interval Subzone, (3) *Hantkenina australis* Interval Subzone (PF 13c).

(1) *Globigerinatheka subconglobata* Interval Subzone (PF13a) (Bolli, 1957). Definition: Biostratigraphical interval between the FAD of *Globigerinatheka subconglobata* and the FAD *Globigerinatheka index*. In the lower part of this Subzone PF13a is characterized by the appearance of *Globigerinatheka subconglobata*, *Hantkenina nuttalli*, *H. mexicana*. Higher in this subzone the appearance *Hantkenina liebusi*, *Globigerinatheka rubriformis* and *G. korotkovi* occurs. The appearance of *Hantkenina dumblei* occurs in the upper part of this subzone together with the first appearance of *Hantkenina australis* (variety of this species with a thin test).

(2) *Globigerinatheka index* Interval Subzone (PF 13b) (Beniamovsky, 2001). Definition: Biostratigraphical interval between the FAD of *Globigerinatheka index* and the FAD of *Hantkenina australis* (variety of this species with a thick and massive test). The assemblages of the lower part of this subzone is characterized by the disappearance of *Hankenina liebusi*, *H. dumblei* and *H. australis* (variety of this species with a thin test). The upper and uppermost parts of this subzone are characterized by the appearance of *Acarinina topilensis*, *Subbotina turcmenica*, *Globigerinatheka* ex gr. *index* (= *Subbotina azerbaidjanica*) and *Acarinina rohri*, *A. medizzai* (= *A. rugosoaculeata*).

(3) *Hantkenina australis* Interval Subzone (PF13c) (Beniamovsky, 2001). Definition: Biostratigraphical interval between the FAD of *Hantkenina australis* (variety of this species with a thick and massive test) and LAD of this zonal taxon. In Russia *Hantkenina australis* is named incorrectly as *Hantkenia alaba-*

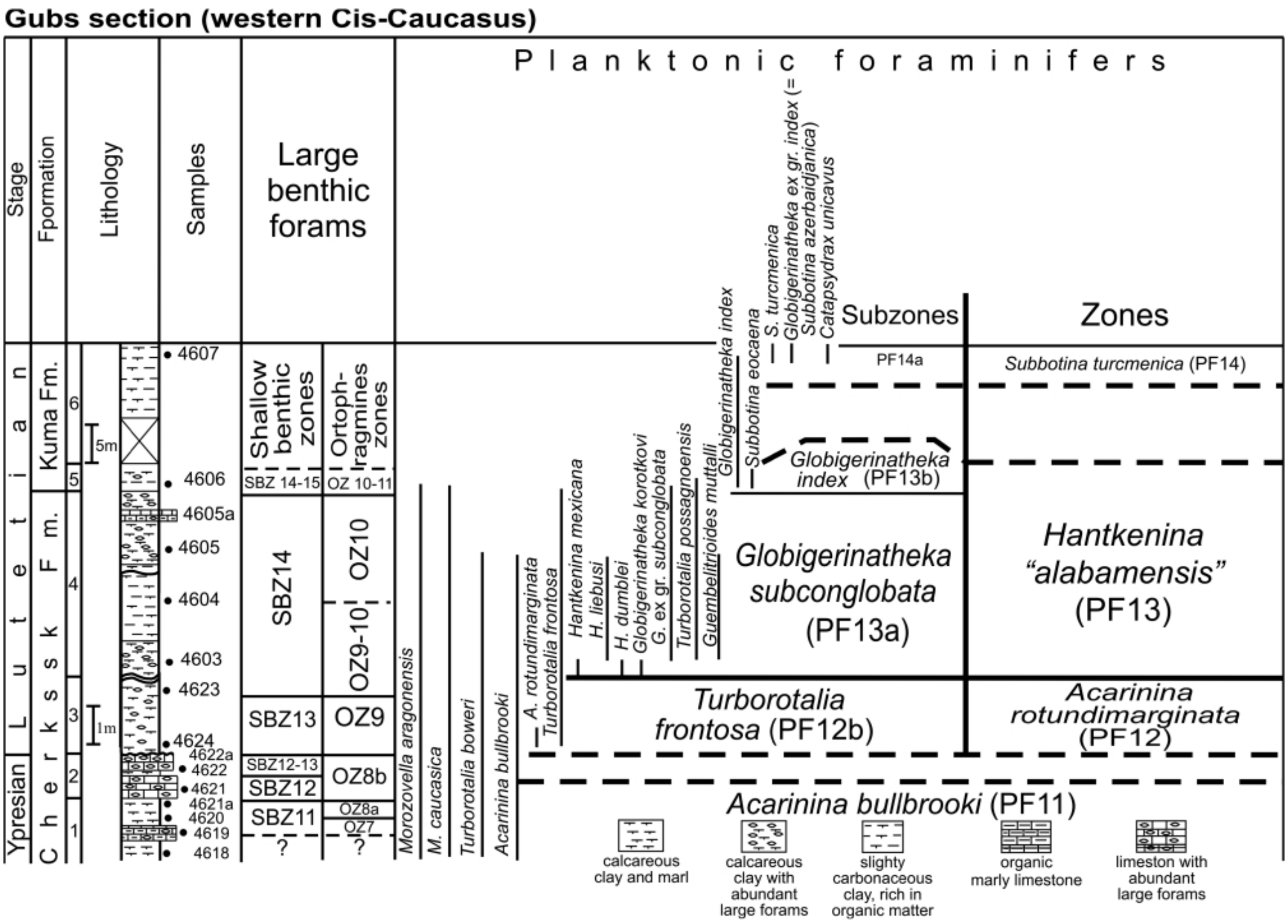

Figure 4: Distribution of planktonic foraminifera and high-resolution zonation Middle Eocene in the Gubs section (western Cis-Caucasus).

mensis – index species of the traditional zone of the Middle Eocene of the Crimean-Caucasus scale. The lower part of this subzone is characterized by the appearance of *Hantkenina compressa*, *Subbotina yeguensis*, *Catapsydrax unicavus* and the disappearance of all turborotaliids and *Globigerinatheka index*.

Subbotina turcmenica Interval Zone (PF14) (as *Globigerina apertura* Zone by Subbotina, 1960, *Globigerina turcmenica* Zone by Korovina, 1970 and by Schutskaya, 1970). Definition: Biostratigraphical interval between the LAD of *Hantkenina australis* (variety of this species with a thick and massive test) and the FAD of *Globigerinatheka tropicalis*. Approximate age: Late Middle Eocene (Latest Lutetian and Bartonian). The zone is subdivided into two subzones: (1) *Globigerinatheka* ex gr. *index* (= *Subbotina azerbaidjanica*) – *Catapsydrax unicavus* Interval Subzone (PF 14a), and (2) *Subbotina instabilis* – *Tenuitella postcretacea* Interval Subzone (PF 14b).

(1) *Globigerinatheka* ex gr. *index* (= *Subbotina azerbaidjanica*) (this paper). Definition: Biostratigraphical interval between the LAD of *Hantkenina australis* (variety of this species with a thick and massive test) and the FAD of *Subbotina instabilis* (acme). Characteristic elements of this zone include *Subbotina praebulloides*, *S. yeguaensis*, *S. turcmenica*, *S. instabilis* (rare), *Globigerinatheka* ex gr. *index* (= *Subbotina azerbaidjanica*), *Acarinina rotundimarginata*, *A. rohri*, *A. medizzai* (= *A. rugosoaculeata*), *Pseudohasigerina micra*.

(2) *Subbotina instabilis* – *Tenuitella postcretacea* Interval Subzone (PF 14b) (this paper). Definition: Biostratigraphical interval between of the FAD of *Subbotina instabilis* (acme) and the FAD of *Globigerinatheka tropicalis*. Characteristic elements of this zone include *Tenuitella postcretacea*, *Subbotina praebulloides*, *S. yeguaensis*, *S.* aff. *turcmenica*, *S. instabilis* (acme), *Globigerinatheka* ex gr. index (= *Subbotina azerbaidjanica*) (rare), *Acarinina rohri*, *A. medizzai* (= *A. rugosoaculeta*), *Pseudohasigerina micra*.

4. Phylogenetic trends

The developed infrazonal scale presented here is largely based on taxa of the genera *Turborotalia*, *Clavigerinella*, *Globigerinatheka* and *Hantkenina* (Fig. 9).

4.1 The genera Turborotalia

The author of this article distinctly distinguish two stages of *Turborotalia phylogenesis* – initial – *T. boweri* (Bolli) (boxlike

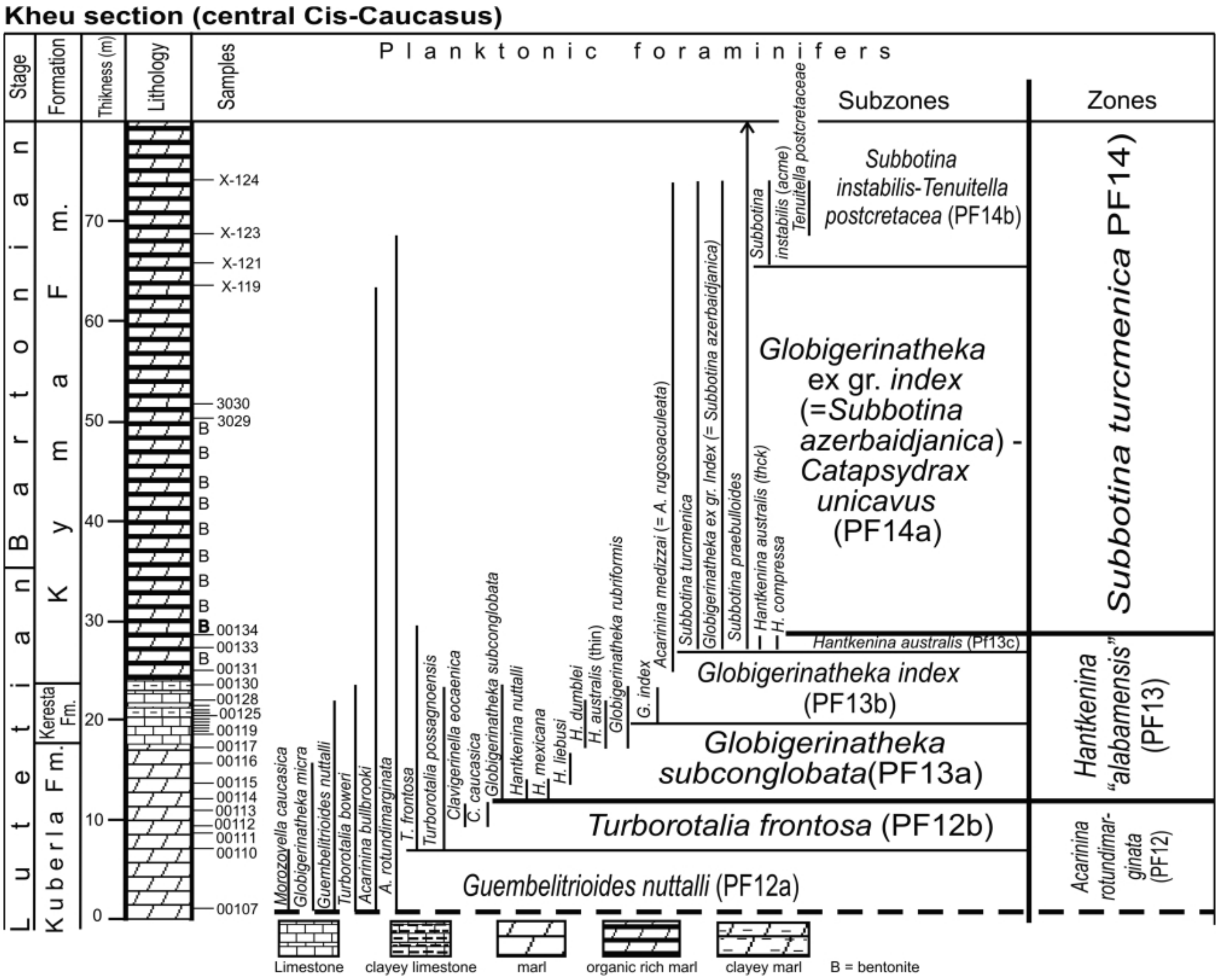

Figure 5: Distribution of planktonic foraminifera and high-resolution zonation Middle Eocene in the Kheu section (central Cis-Caucasus).

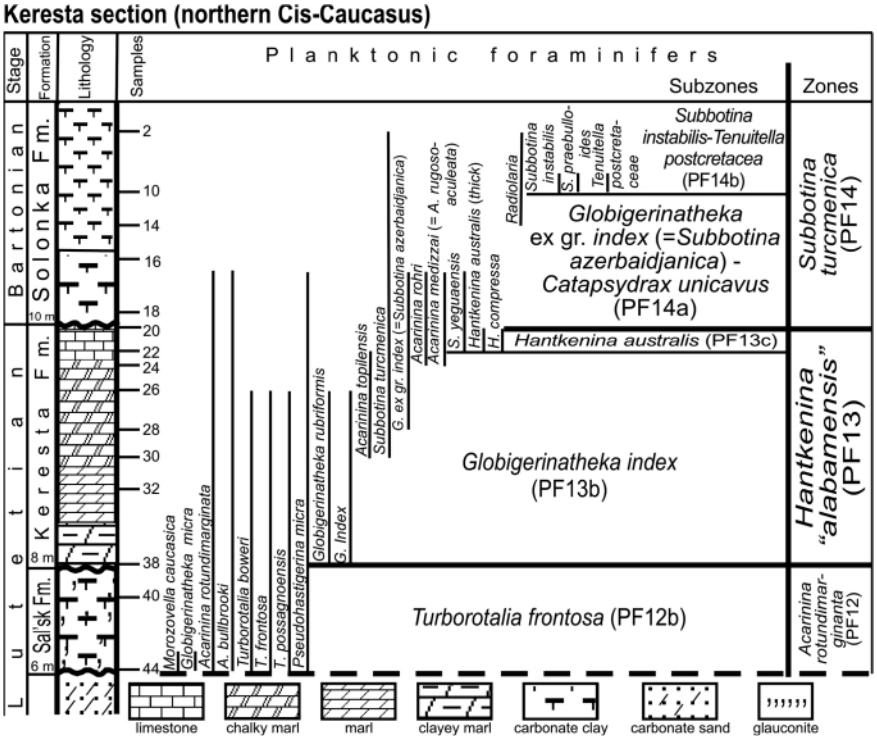

Figure 6: Distribution of planktonic foraminifera and high-resolution zonation Middle Eocene in the Keresta section (northern Cis-Caucasus).

form, which corresponds to the holotype of this species by Bolli, 1957, p.163, plate 36, fig. 1) and a descendant form – *Turbotrotalia frontosa* (Subbotina), which corresponds to the holotype of this species by Subbotina, 1953, p. 84, plate XII, Fig. 3). It should be noted that also Blow (1979) distinguished these two taxa – *boweri* and *frontosa* but other authors as Stainforth et al. (1975), Pearson et al. (2006) and Payros et al. (2008) considered the species *Globigerina frontosa* Subbotina, 1953 and *Globigerina boweri* Bolli. 1957 as synonymous. In the Crimea-Caucasus region *Turborotalia boweri* occurs in the upper Ypresian and is used as index-taxa for the uppermost Ypresian (Zakrevskaya et al., 2011). According to Payros et al. (2007) the first occurrence of primitive *T. frontosa* (= *T. boweri* as I be-

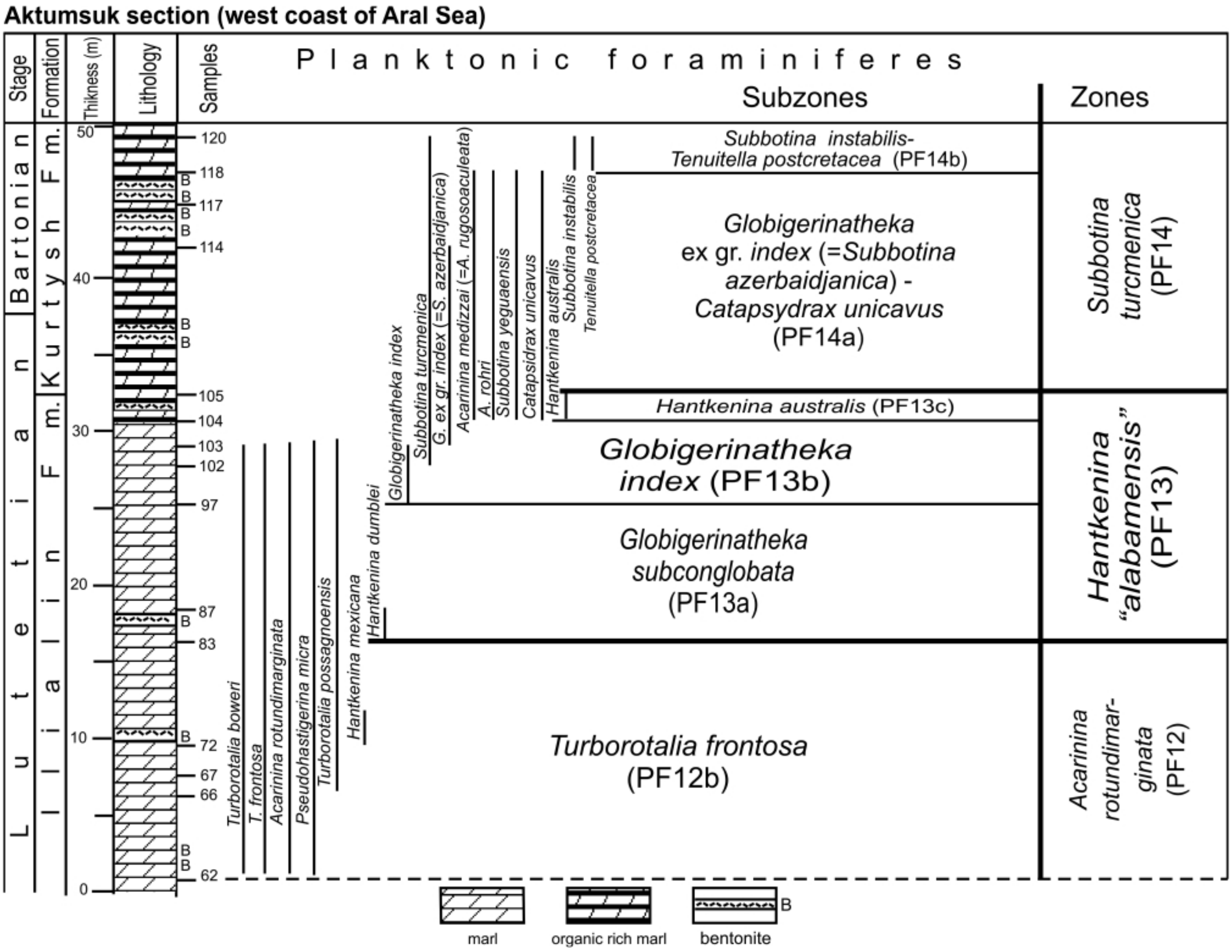

Figure 7: Distribution of planktonic foraminifera and high-resolution zonation Middle Eocene in the Aktumsuk section (west coast of Aral Sea).

lieve) is the planktonic foraminiferal event that lies closest to the age of the base of the Lutetian Stratotype at Gorrondatxe section (Payros et al., 2008; Molina et al., 2011).

4.2 The genera *Globigerinatheka*

The oldest small form – *Globigerinatheka micra* – appeared in the Latest Ypresian in the Crimea-Caucasus region where this taxa was first described by Schutskaya (1958) in the *Morozovella aragonensis* Zone. Pearson et al. (2006) considered the small-sized *G. micra* as a junior synonym of the larger *Subbo-*

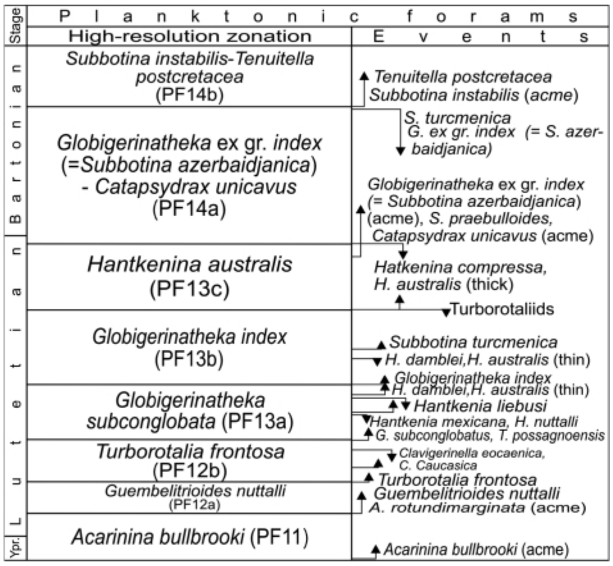

Figure 8: Bioevents. The main methodological approach which allowed to subdivide the traditional zones into two or three subzones, is analysis of the moments of appearance and disappearance of species of stratigraphically important genera: *Acarinina*, *Guembelitrioides*, *Turborotalia*, *Clavigerinella*, *Hantkenina*, *Globigerinatheka*, *Subbotina*, *Catapsydrax* and *Tenuitella*.

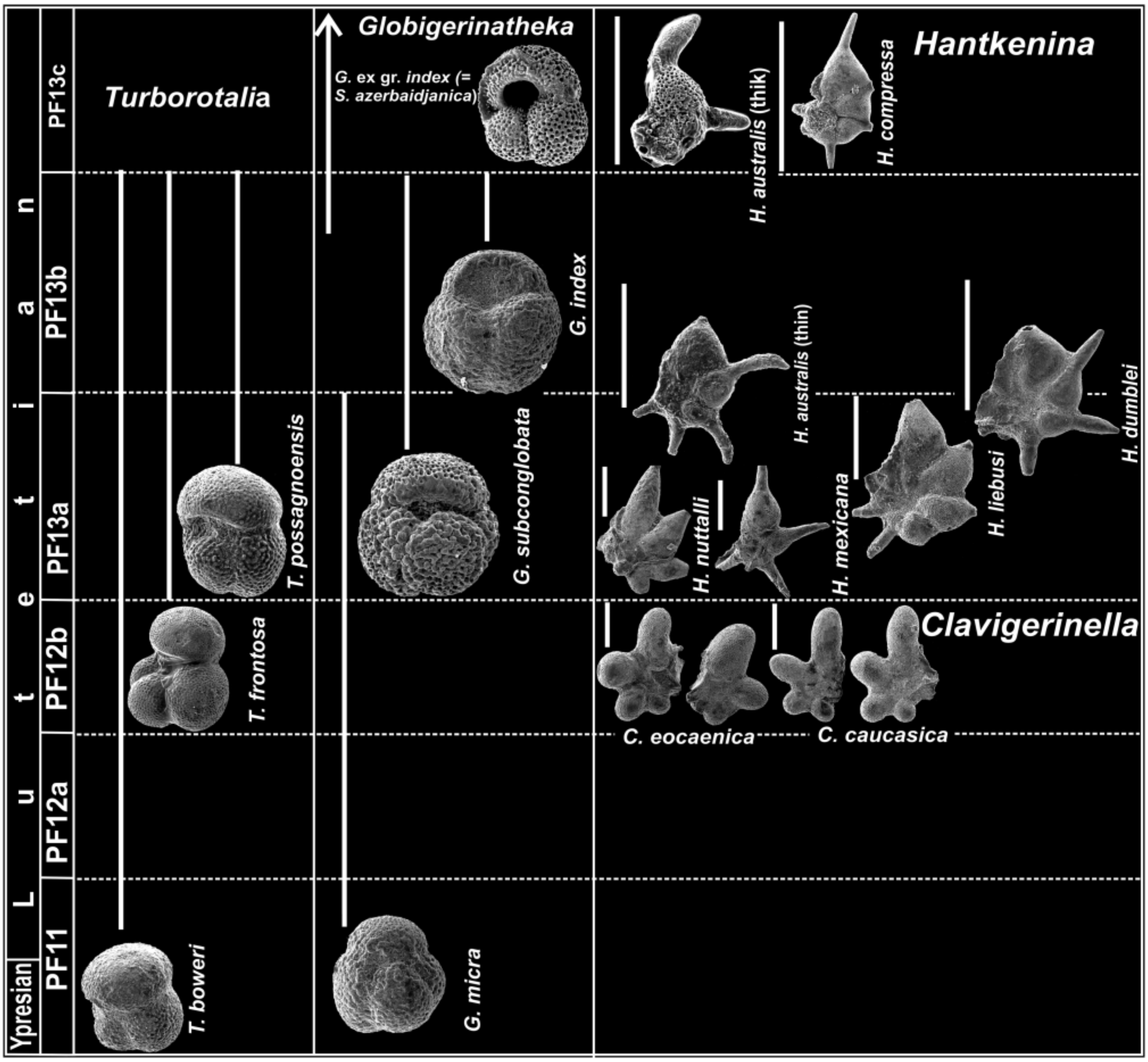

Figure 9: The sequence of the phylogenetic development *Turborotalia*, *Globigerinatheka* and *Hantkenina* genera in the Middle Eocene of Crimea-Caucasus region.

tina senni. But other authors like Molina et al. (2011) regarded this taxa as an intermediate species between *S. senni* and *Globigerinatheka subconglobata*, as its aperture is very different from that of aperture of *S. senni*, being similar to that of *G. subconglobata*, but lacks the typical secondary apertures of the latter. It should be noted that Schutskaya (1958) regarded *G. micra* as subspecies of *G. subconglobata* under the name of *G. subconglobata micra*. A descendent form – *Globigerinatheka subconglobata* becomes widespread in the beginning of the Lutetian. *Globigerinatheka index* appears later. In the end of the *Lutetian Globigerinatheka index* evolved to a variety of *Globigerinatheka* ex gr. *index* that in Russian-language literature appears under the name of *Subbotina azerbaidjanica*. According to Berggren and Norris (1997, p. 35 and table 5) *Subbotina azerbaidjanica* is a junior synonym of *Globigerinatheka index*.

4.3 The genera *Clavigerinella* and *Hantkenina*

Hantkenina mexicana and *H. nuttalli*, the earliest/oldest hantkeninids in the Crimean-Caucasus region, appeared in the first half of the Lutetian. According to Pearson et al. (2006) *H. nuttalli* is regarded as synonym of *H. mexicana*. The exemplar of *H. nuttali* of Khey section North Caucasus (see Fig. 9 this paper) is identical to the holotype of *H. nuttalli* of Pearson et al. (2006, plate 8.10, fig. 2 and 3) and *"H. nuttalli"* of Rögl and Egger (2010, fig. 3/10). According to Pearson et al. (2006) *H. mexicana* evolved from *H. singanoae*, which so far was only found in Tanzania and Austria. Rögl and Egger (2010, 2011) report on the finding of a newly discovered *H. gohrbandti*, which is considered to be a real ancestor of the genus *Hantkenina*. *H. singanoae* and *H. gohrbandti* are absent in Crimea-Caucasus region. In this region the beginning of evolutionary lineage from *Clavigerinella* to *Hantkenina* are represented by *Clavigerinella eocaenica* and *C. caucasica* (from clavigeinellids) and *H. mexicana* and *H. nuttalli* (from hantkeninids) (Fig. 9).

Higher up, *H. mexicana* and *H. nuttalli* are replaced by a descendent form – *Hantkenina liebusi*. This species "evolved from *H. mexicana* by forward progression to the tubulospine and

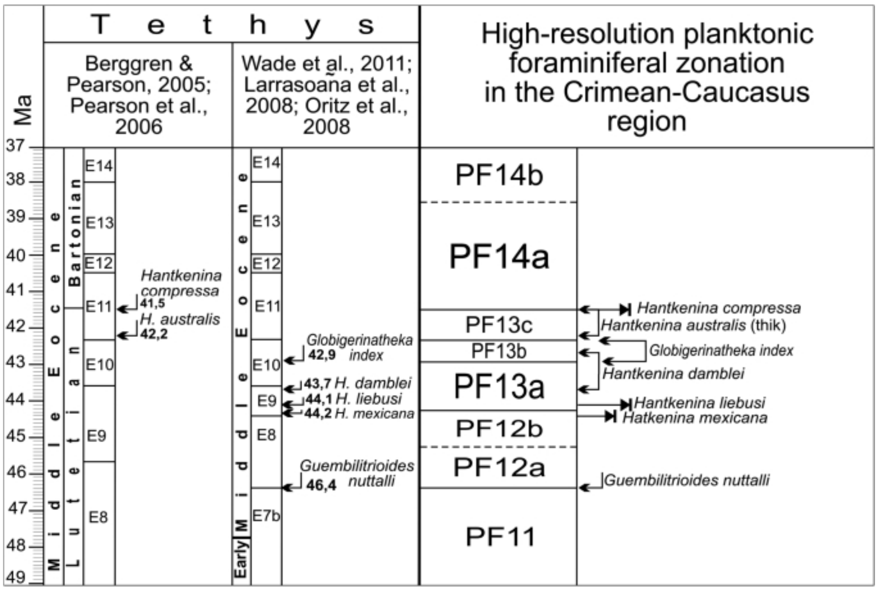

Figure 10: Comparison of Middle Eocene zonation by planktonic foraminifers of the Tethys and Crimean-Caucasus region, based on the identity of the successions of appearance of some stratigraphically important species.

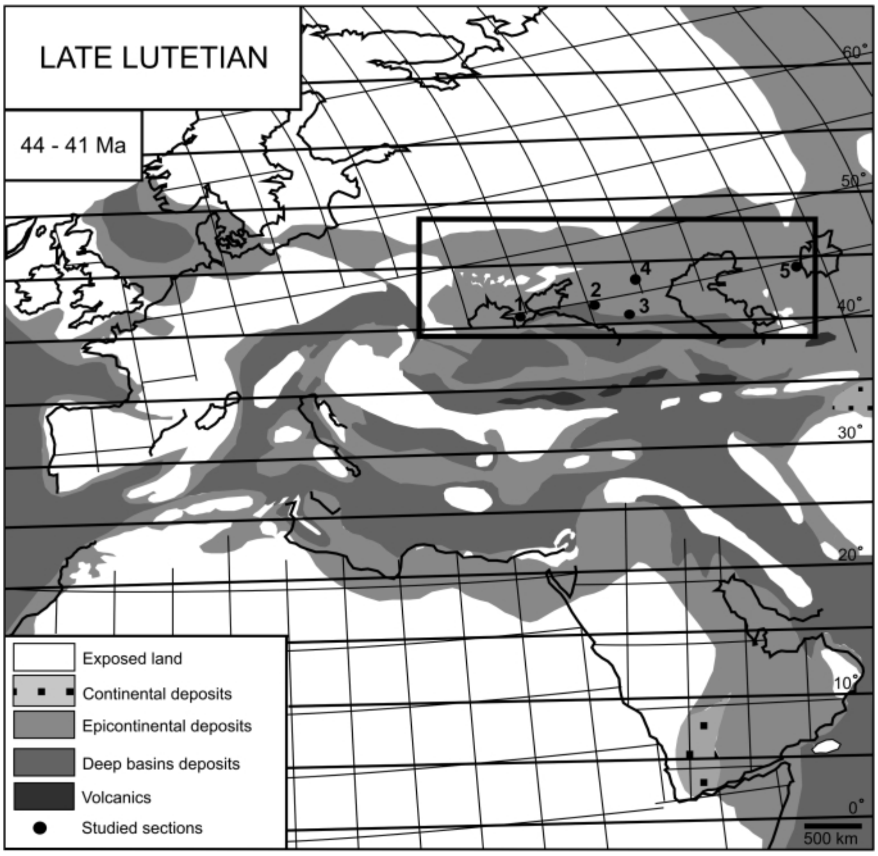

Figure 11: The paleo-position of the studied sections shown in a simplified paleogeographic map of the Peri-Tethys, based on the map for the Late Lutetian in the Peri-Tethys Atlas (Meulenkamp et al., 2000).

closer appression of chambers " (Pearson et al., 2006, p. 242).

H. liebusi gives way in Middle Lutetian to *Hantkenina dumblei*, which evolved from *H. liebusi* by "increase in the rate of chamber expansion, closer appression of the chambers and forward migration of the tubulospines" (Pearson et al., 2006, p. 237). Remarkably, together with *H. dumblei*, the first appearance of *Hantkenina australis* (variety of this species with a thin test) is recorded here. It appears to be most common at the high southerly and northerly extremes of the hantkenenid latitudinal range suggesting it was more tolerant of cold water than other hantkeninids. In Russia *Hantkenina australis* is named incorrectly as *Hantkenia alabamensis* (Pearson et al., 2006, p.232), the index species of the traditional zone in the Middle Eocene of the Crimean-Caucasus scale. Another variety of *H. australis* with a thick and massive test (Fig. 9), along with *H. compressa*, appears near the Lutetian – Bartonian boundary. *H. compressa* coexists with *H. australis* in the upper middle Eocene in New Zealand (Pearson et al., 2006). *H. compressa* evolved from *H. dumblei* by a reduction in chamber height and tightening of the planispiral coiling (Pearson et al., 2006).

5. Comparison of the Middle Eocene planktonic foraminiferal zonation of the Tethys and the Crimean-Caucasus region and overview on environmental changes

Correlation of the planktonic foraminiferal zonation of the Crimea-Caucasus region with the standard (sub)tropical one (Berggren et al. 1995; Pearson et al., 2005; Wade et al., 2011) is limited to only a few events in common (Fig.10). The problem of correlating the standard and regional scales may be caused by the relatively high paleolatitude (41° to 44°N) of the studied sections in the Crimean-Caucasus region (Fig. 11). During the Middle Eocene the surface water temperature in the Crimean-Caucasus region varied in response to several phases of climate fluctuations, which reflected regional cooling or warming and "global" signals (Fig. 12).

The initial relatively cool (latest Ypresian-early early Lutetian) phase is characterized by abundant acarinids: *Acarinina bullbrooki*, *A. pseudotopilensis*, *A. boudreauxi*, *A. rotundimarginata*. The cooling in the early early Lutetian was determined by carbon and oxygen isotopic ratio shifts in the nummulitides shells of the Bachchisaray section in the Crimea (Vetoshkina and Zakrevskaya, 2011). This was probably related to the well-known cooling at the transition of the Ypresian and Lutetian ages (Zachos et al., 2001).

The initial relatively cool (early early Lutetian) phase gave way to a very warm phase at the end of the early to the beginning of the middle Lutetian, favoring migration of tropical clavigerinellids and hantkeninids to the Crimean-Caucasus basin. The migration of tropical clavigerinellids in the Crimean-Caucasus basin reflects the climatic warming and concomitant raising water temperatures during the late early Lutetian (Fig. 12). The appearance of tropical hantkeninids is connected to the thermal optimum, which rendered migration into the Crimean-Caucasus basin (Benyamovskiy et al., 2003; Zakrevskaya et al., 2011). This thermal phase is recorded in the Spanish basins as well (Ortiz et al., 2008; Larrasoaña et al., 2008): "the occurrence of *Clavigerinella eocaenica* and *C. jarvisi* jast before the appearance of hantkeninids might provide evidence for an excursion of tropical species due to an increase in seawater temperature" (Oritz et al., 2008, p. 401).

Globigerinatheka index is a relatively cold-water species (Premoli Silva and Boersma, 1988). The disappearance of tropical hantkeninids in the late Lutetian (*Globigerinatheka index* Subzone time) reflects the cooling of water masses.

At the Lutetian/Bartonian boundary, a short-lived warming phase is recorded, with hantkeninids (*Hantkenina australis* and *H. compressa*) once again migrating to the basin. This warm excursion is considered to be the expression of the Middle Eocene Climatic Optimum (MECO), originally identified by Bohaty and Zachos (2003) based a distinct negative shift in $\delta^{18}O$ values (~1.0‰) that is observed at 41.5 Ma (Bohaty et al., 2009).

In the latest Lutetian an extremely important restructuring took place in oxygen, trophic and salinity conditions of the water mass of the Crimean-Caucasus basin, where oligotrophic, aerobic and normal salinity (Kuberla-Keresta Basin environment) gave way to eutrophic – hypoxic-anoxic and episodically freshening water mass of the Kuma basin one, which caused a biotic crisis. This event re-

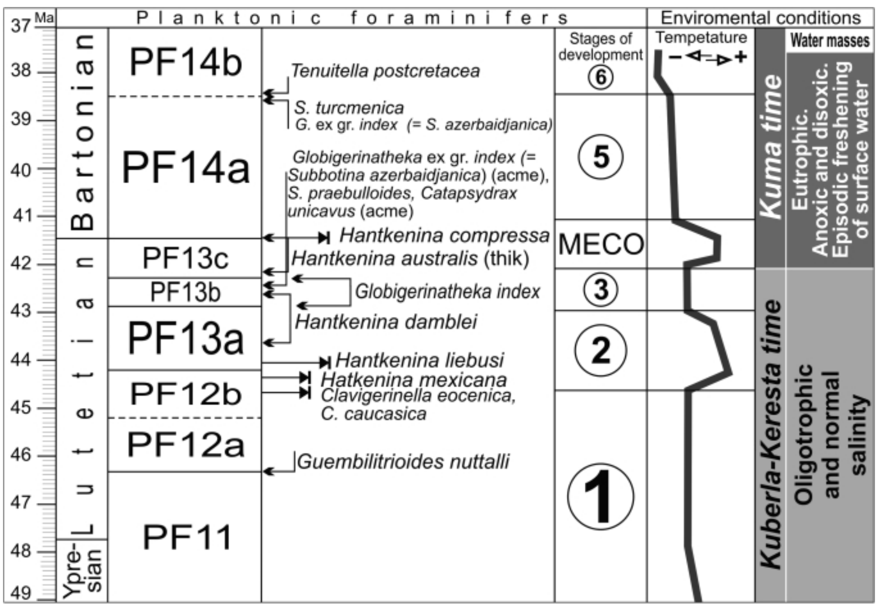

Figure 12: The sequence of the surface water temperature fluctuation, and two phases of changing of oxygen, trophic and salinity regimes of water mass and biotic events in the Middle Eocene Crimean-Caucasus basin.

sulted from the transformation of the open Crimean-Caucasus basin into a semi-isolated basin.

In the early Bartonian, the temperature of the anoxic Kuma Basin waters decreased, which, along with hypoxia, led to the disappearance of a large number of species and impoverishment of the assemblage and expansion of catapsydracids. The peak of cool water conditions is recorded in the late Bartonian. This is the time of expansion of cool water tenuitellids (Fig. 12).

6. Conclusions

The proposed high-resolution stratigraphic scale proposed here for the Paleogene of Crimean-Caucasus region of northern Peri-Tethys based on planktonic foraminifers has been obtained by our analysis of taxa succession, which is controlled by evolutionary and environmental changes.

In correlating Crimean-Caucasian zonal biostratigraphy with zones of the standard scale we identified the similarities and differences in the paleogeographic conditions between the Tethys Basin and the Crimean-Caucasus region basin of NW Peri-Tethys in the middle Eocene. They appear to have been most similar in the middle Lutetian, which coincide with thermal optima. They were still relatively similar around the Ypresian/Lutetian and Lutetian/Bartonian transition, while in the Bartonian environmental conditions were distinctively different in the two paleogeographic realms.

The elaborated infrazonal scale presented here provides an instrument for dating biostratigraphic zones, bioevents, as well as geological, paleogeographical, and paleoclimactic events.

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