Paleocene/Eocene transition in the northeastern Peri-Tethys area: Sokolovskii key section of the Turgayb Passage (Kazakhstan)

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Paleocene/Eocene transition in the northeastern Peri-Tethys area : Sokolovskii key section of the Turgay Passage (Kazakhstan)

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Key words. – Lithology, Biostratigraphy, Transgressive-regressive cycle.

Abstract. – Lithology, microfossils, and stratigraphy of the uppermost Paleocene – lowermost Eocene predominantly terrigenous and siliceous sediments from the Sokolovskii section located in the Turgay Passage, northern Kazakhstan, were studied. Among the microfossils, calcareous nannofossils, radiolarians, and especially dinocysts proved to be useful for age determinations, correlation with standard zonal schemes, and for paleoecological reconstructions. The NP8 *(Heliolithus riedelii)* nannoplankton Zone, the *Acarinina subsphaerica* and *A. acarinata* (lowermost part) planktonic foraminifera Zones, the *Petalospyris foveolata* regional radiolarian Zone, the *Moiseivia uralensis* diatom Zone were recognised, as well as four dinocysts zones : the *Alisocysta margarita, Apectodinium hyperacanthum, A. augustum,* and *Wetzeliella meckelfeldensis* Zones. Also, two transgressive-regressive cycles are distinguished. They are interrupted by short hiatuses; the upper one corresponds to the boundary between the *Apectodinium augustum* and *Wetzeliella meckelfeldensis* dinocyst Zones.

La transition Paléocène-Eocène dans la région nord-ouest de la Peritéthys : la coupe clé de Sokolovskii située dans le détroit du Turgay (Kazakhstan)

Mots clés. – Lithologie, Biostratigraphie, Cycle sédimentaire.

Résumé. – Ce travail discute la lithologie, micropaléontologie et stratigraphie des dépôts principalement terrigènes et siliceux du Paléocène supérieur et de l'Eocène inférieur de la coupe de Sokolovskii située dans le détroit du Turguay au nord du Kazakhstan.
Les datations, corrélations avec les échelles biozonales standard et reconstructions paléoécologiques que nous proposons reposent sur la micropaléontologie, en particulier sur les nannofossiles calcaires, les radiolaires et plus encore sur les dinokystes. La zone NP8 (zone à *Heliolithus riedeli*, nannofossile calcaire), la zone à *Acarinina subsphaerica* et la base de la zone à *A. acarinata* (foraminifères planctoniques), la zone régionale à *Petalospyris foveolata* (radiolaire) et la zone à *Alisocysta margarita*, à A*pectodinium hyperacanthum*, à *A. augustum*, et à *Wetzeliella meckelfeldensis*. De plus, deux cycles sédimentaires (transgression-régression) ont été différenciés, interrompus par de courts hiatus ; le plus récent correspond à la limite entre les zones à *Apectodinium augustum* et à *Wetzeliella meckelfeldensis*.

INTRODUCTION

The Paleogene deposits in the Sokolovskii iron-ore pit located near the town of Rudny, Kustanay city region, Northern Kazakhstan (fig. 1) are described. The section is located in the area of junction of two large cratonic structures – the West-Siberian and Turan plates. Study of the section may help resolving stratigraphic and paleogeographic problems : the age of the sediments was uncertain and the character of the connection between Peri-Tethys and West Siberian basins through the Turgay Passage during the Paleogene was not clear. The Turgay passage was connected with both areas and functioned with short interruptions, as a marine straight during the Cretaceous-early Paleogene. For a long time, this Paleogene sequence was described as the Tasaran Fm. and considered middle-upper Eocene [Boytsova, 1975]. Based on planktonic forami- nifers and nannoplankton of Zone NP8, the sediments of the Sokolovskaya Fm., composed of carbonate and non-carbonate sands and sandstones, were considered to be of Paleocene age [Beniamovskii *et al.*, 1989]. The overlying Polosataya Fm. which consists of mudstones and siliceous clays was considered to represent lower and middle Eocene [Podobina and Amon, 1992; Beniamovskii *et al.*, 1995].

We studied the assemblages of seven groups of microfossils and lithology in order to estimate the age of sediments and correlate them to standard stratigraphic schemes. Careful analysis of the microfossil assemblages

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allowed us to determine that the lower part of the clayey-siliceous Polosataya Fm. belongs to the upper Paleocene, and its upper part to the lowermost Eocene. Changes in lithology and composition of microfossil assemblages lead us to establish a late Paleocene to early Eocene transgressive-regressive cycles.

MATERIALS AND METHODS

Materials for this paper were obtained during a field trip (1996) of the Geological Institute RAS devoted to the study of Paleogene key sections in the Turgay depression. 42 samples collected in the Sokolovskii pit section were processed acoording common procedures of mechanic and chemical preparation and washing for the study of seven microorganisms groups : nannoplankton, benthic and planktonic foraminifers, radiolaria, diatoms, silicoflagellates, and dinocysts.

The section was correlated to the standard nannoplankton [Martini, 1971], the European dinoflagellate [Powell, 1992] and the silicoflagellate [Perch-Nielsen, 1976] biozonal schemes, and to regional schemes based on planktonic [Shutskaya, 1970] and benthic [Bugrova, 1988] foraminifers, radiolarians [Kozlova, 1994], and diatoms [Strelnikova, 1992].

In the lowermost part of the section (Sokolovskaya Fm.), calcareous nannofossils and foraminifera appeared to be most useful for stratigraphic subdivision, whereas in the uppermost part (Polosataya Fm.), changes in taxonomic composition of diatom and radiolarian assemblages are used for this purpose. At the same time, dinocyst were used for subdivision of the whole consequence.

Transgressive-regressive cycles were established on the basis of lithological changes and analysis of taxonomic composition of microfossil assemblages. The variations in planktic foraminifer assemblages provided the basis of estimation of transgressive-regressive fluctuations of Sokolovskaya Fm., and the ratio between open ocean and neritic genera of diatoms and radiolarians was calculated in all samples from the Polosataya Fm.

LITHOLOGY

The lithological composition of the section (the eastern wall of the Sokolovskii pit) is shown in figure 2.

The lower part of the section up to layer 4 is represented by dark-brown and yellowish-grey poorly sorted sands with small (up to 5-7 mm) hydrous ferric oxide concretions and with vegetal detritus. The sands are composed of quartz with glauconite admixture, rare spicular aggregates of authigenic calcite and encrustations of gypsum. The top of the beds is filled with ferric oxides which, in some places, form compactly cemented ferric encrustations.

The sandy-carbonate Sokolovskaya Fm. (layers 5-10), more than 20 m thick, is composed of light-grey, fine-grained, well-sorted, homogeneous sands with a slight admixture of coarse-grained sands at the base. The sands are weakly cemented by a carbonate-clayey cement, and consist of quartz-glauconite, with rare micro-globules of sulphides, carbonaceous detritus, ostracoda, and foraminifers (fragments of mollusca were found); glauconite of authigenic origin forms large plates, bud-shaped aggregates, fills cracks in grains of quartz, penetrates along the cleavage of plagioclase grains.

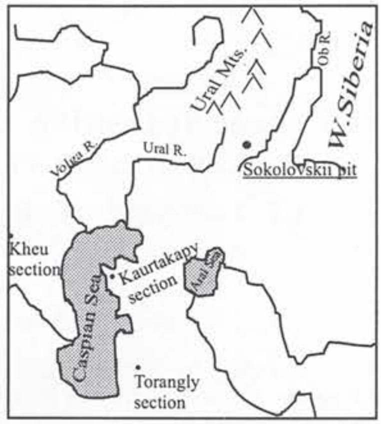


FIG. 1. – Geographical position of Sokolovskii pit.
FIG. 1. – *Localisation de la coupe de Sokolovskii.*

Layer 7 described as a bioherm containing cirripedia, scleractinian corals, ostracods, bivalvia, bryozoans is presented in the area of the Sokolovski and Sarbay pits [Beniamovskii *et al.*, 1989; Beniamovskii *et al.*, 1995; Podobina and Amon, 1992].

Upsection, the Polosataya Fm. (layers 11-17), consists of siliceous clays and clayey mudstones occasionally intercalated with horizons of thin-grained sandstones.

The unit of layers 11-13 is represented by grey, compact, strong, homogeneous, and thin-laminated siliceous clays. In slides, the aggregates of authigenic opal filling empty spaces and cracks in sediments and forming rims around single grains of quartz can be seen. Authigenous glauconite, microglobular pyrite, carboniferous detritus, and single pieces of calcareous shells occur in small amounts. The clay unit in middle part of the section is interrupted by horizons of sandstones that are 0,5 m thick. The sandstones are gray fine- and medium-grained, non-homogeneous, poorly-sorted, composed of quartz and glauconite with inclusions of micro-globular sulphides and ferric hydro-oxides. At the top of the unit, the clays are darker and include lenses of quartz-glauconite small-grained sands and siltstone, with inclusion of micro-concretions of sulphides and small Carboniferous parts.

The following unit (layer 14, including sample 15 of the layer 15) is readily characterised in the section by its very dark colour (up to black). It consists of alternation of siltstones, clays and sandstones. The clays are siliceous, compacted, layered, with an admixture of fine-grained quartz-glauconite sand, microglobules of pyrite and carboniferous detritus. The sandstones are fine- and medium-grained, quartz-glauconite, with clayey-siliceous cement (cement contains radiating aggregates of authigenic opal), and with abundant sulphides, Fe-hydroxide aggregations and thin dispersed carbonaceous detritus.

Upsection, up to the top of layer 15, light-grey, fine-grained, homogeneous, well-sorted, glauconite-quartz sandstones with sulphide micro-globules and fine carbonaceous detritus, and clayey-siliceous cement with radiating aggregates of authigenic opal occur.

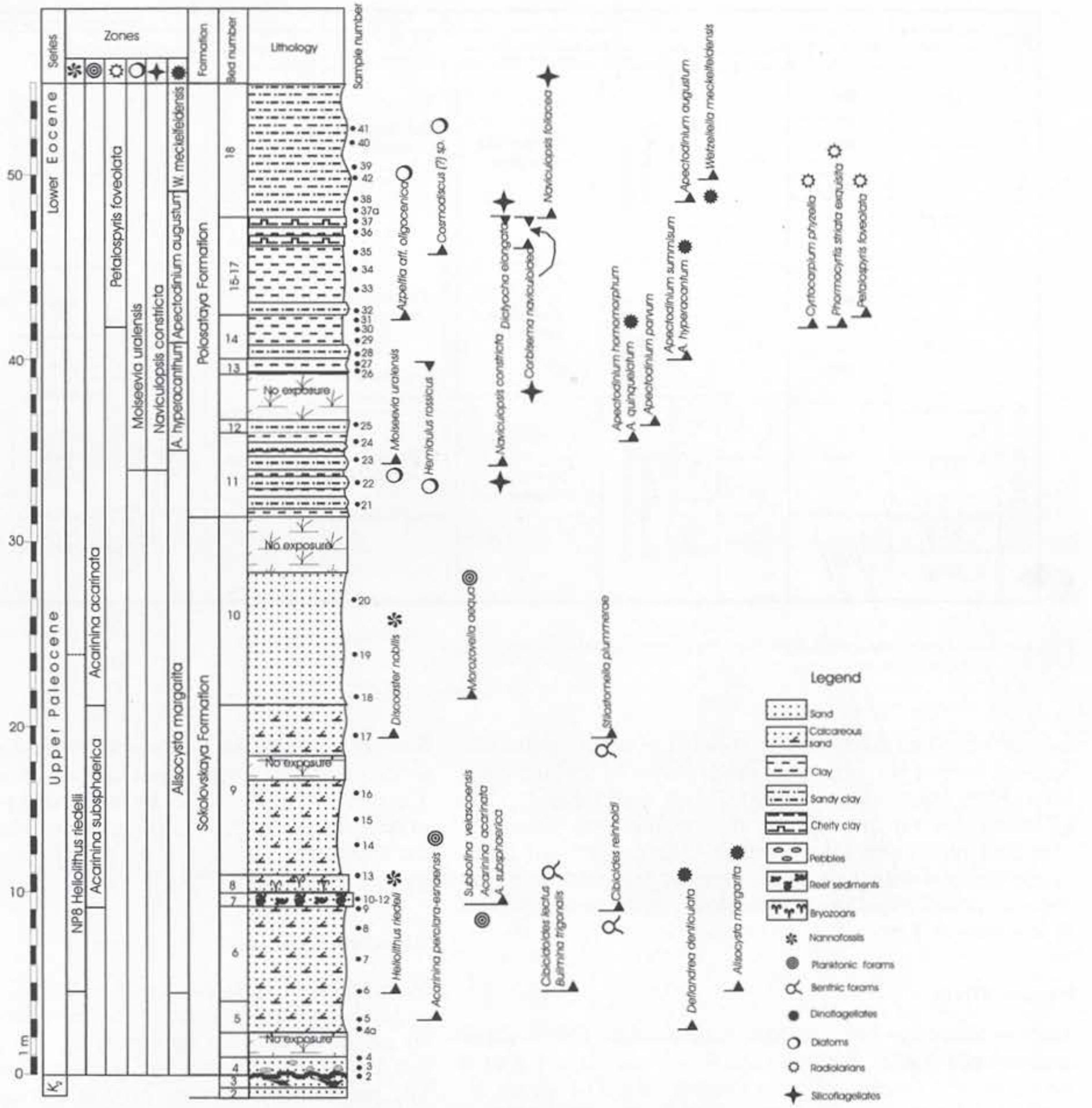


FIG. 2. – The Paleogene section of the Sokolovskii pit and main stratigraphical markers.
FIG. 2. – *Distribution des principaux marqueurs biostratigraphiques dans la coupe paléogène de Sokolovskii.*

Further upsection, the sandstones are overlain by light-grey siliceous mudstones, and clays (layers 16-17), with thin-grained quartz-glauconite material, with large amount of micro-globular pyrite and carbonate detritus.

In general, the facies of the Sokolovskii pit change considerably over very short distances. Although the regularity and common structure of the Formations remain constant, some features are different even in correlative layers on opposite sides of the pit. In the Sokolovskii Fm., the number and thickness of bioherm layers changes, and they are totally absent in the northern wall of the pit. In the Polosataya Fm., the amount of silica and terrigenous compound is various.

The section terminates with an intercalation of gray sandy clays and fine- and medium- grained mudstone and sandstone with a siliceous clayey cement. In all sediments authigenic glauconite, carbonaceous detritus, and globular pyrite are abundant.

RESULTS

Stratigraphy

The results of micropaleontological and stratigraphical study are shown in figures 2 and 3 and table I-3.

Calcareous nannofossils

The lowermost occurrence of Paleogene nannofossils is at the base of Sokolovskaya Fm., in layer 5 (fig. 2, table I). Within the lowermost part of the carbonate sands (layers 5-6), the nannofossil assemblage is not very diversified, but characterizes a normal marine environment. The most var-

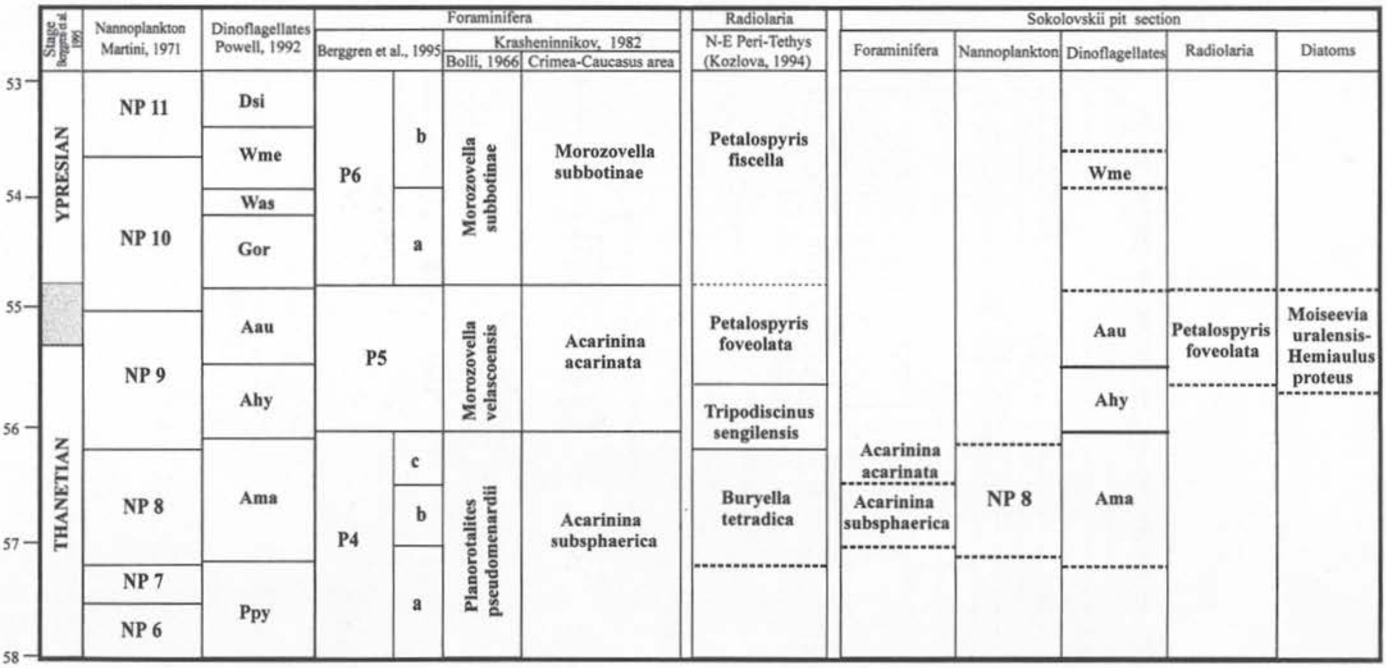


FIG 3. – The Thanetian-Lower Ypresian microfossil zonal scheme.
FIG. 3. – *Echelle biozonale à microfossiles pour le Thanétien et l'Yprésien.*

ied and abundant nannofossil assemblage occurs in the uppermost part of the carbonate sands (layer 9) and indicates Zone NP8 (*Heliolithus riedelii* Zone) (see table I). The helioliths are rather small in this section, but unusually abundant relative to other species. The nannofossil abundance sharply decreases at the base of layer 10 only rare specimens being evidently reworked can be seen upwards in Polosataya Fm.

Foraminifers

The Sokolovskaya Fm. includes three planktic foraminiferal assemblages (fig. 2, table I). The lower one (layers 5-6) is very poor and consists of three species only. The second assemblage (layers 7-9) is characterised by the appearance of *Subbotina velascoensis* (CUSHMAN), *Acarinina nitida* (MARTIN) (=*A. acarinata* SUBBOTINA, 1953), *A. subsphaerica* SUBB., *Morozovella cf. acuta* (TOULMIN) and *Pseudohastigerina* sp., that allows to determine the *Acarinina subsphaerica* Zone of the regional Crimea-Caucasus scheme [Shutskaya, 1970]. In the lowermost part of layer 10, the third assemblage is found, in which *Morozovella aequa* (CUSHMAN et RENZ) and *Acarinina soldadoensis* (BRÖNNIMAN) appear ; we refer it to the *Acarinina acarinata* Zone. The only species *Subbotina velascoensis* (CUSHMAN) is present in sample 20, and foraminifera are absent in the uppermost part of layer 10 and Polosataya Fm.

Three benthic foraminiferal assemblages are established in the same part of the section. The lower assemblage includes *Cibicidoides succedens* BROTZEN, *C. favorabilis* VASSILENKO, *C. howelli* (TOULMIN) = *C. lectus* VASSILENKO, *Bulimina trigonalis* TEN DAM=*B. paleocenica* BROTZEN, *B. rozenkrantzi* BROTZEN. The middle assemblage occurs in the layers with *Cibicides reinholdii* TEN DAM, where the index species and *Alabamina midwayensis* BROTZEN appear. Both assemblages are considered to belong to the *Bulimina trigonalis* regional Zone [Bugrova,1988]. The upper assemblage is characterized by the disappearance of several species present in the underlying zone and the occurrence of *Stilostomella plummerae* CUSHMAN and *Ramulina globifera* BRADY.

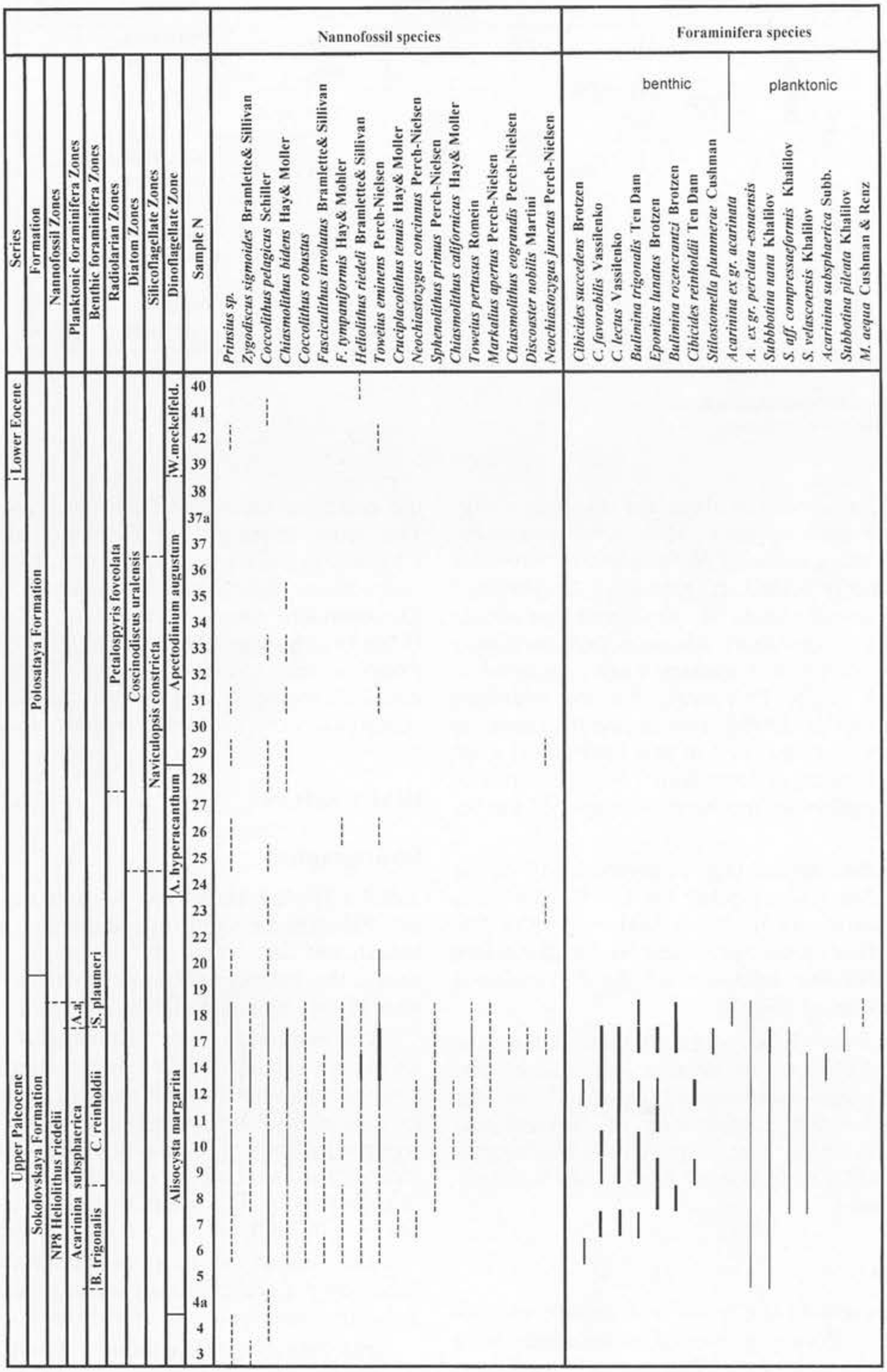
Dinoflagellate cysts

Dinoflagellate cysts occur consistently in the Sokolovskaya and Polosataya Formations. This is the reason why this fossil group is the most important for the age determination and estimation whether the section is continuous or not. The presence of markers used in European dinoflagellate zonations allowed us to recognize four dinoflagellate zones. The detailed description of the dinoflagellate assemblages will be done elsewhere [Iakovleva *et al.*, in preparation]. In this paper we present only our main stratigraphic results. The distribution of selected dinoflagellate species is shown in the figure 4. Layers 5-11 of the Sokolovskaya Fm., belong to the *Alisocysta margarita* Zone as indicated by the presence of its marker *Deflandrea denticulata*. Layers 12-14 (Polosataya Fm.), samples 24-29 belong to the *Apectodinium hyperacanthum* Zone as characterized by the first occurrence of *Apectodinium homomorphum* in layers 12-14, samples 24-29. Layers 14-18, samples 29-42 belong to the *Apectodinium augustum* Zone as indicated by the first occurrence of marker *A. augustum*. Layer 18, samples 42-41 (uppermost part of the Polosataya Fm.) belongs to the *Wetzeliella meckelfeldensis* Zone as characterized by the first occurrence of *W. meckelfeldensis*.

Diatoms and silicoflagellate

The diatoms are present in layers 11-17 of the Polosataya Fm. and indicate the *Moisseevia uralensis* diatom Zone. In

TABLE I. – The distribution of nannofossils and foraminifera in the Sokolovskii pit.
TABL. I. – *Distribution des nannofossiles calcaires et foraminifères planctoniques dans la coupe de Sokolovskii.*



the regional diatom zonal scheme [Glezer, 1979] this zone is referred to as the *Coscinodiscus uralensis* Zone. The age of this zone, according different workers, has varied from middle Eocene to late Paleocene, and at last was established as late Paleocene [Strelnikova,1992]. In the Sokolovskii section, the stratigraphic markers important for age determinations were found.

The diatom index-species *Moisseevia (Coscinodiscus) uralensis* appears in layer 11 of the Polosataya Fm. (table III); its abundance gradually increases upsection and reaches 9% of the whole assemblage at the top of diatomaceous sequence (sample 37). In layers 11-12, the index-species is accompanied by *Coscinodiscus argus, C. oculus-iridis, C. obscurus, C. decrescens, C. decrescenoides,* and *Fenestrella antiqua.* For the majority of *Coscinodiscus*, very large dimensions of valves are typical. Representatives of *Hemiaulus, Pyxidicula, Proboscia, Triceratium* genera are sparse in these layers.

Series	Stage	Standard zonations: Nannoplankton	Standard zonations: Planktic forams	Dinoflagellates: Costa&Manum, 1988	Dinoflagellates: Powell, 1992	Dinoflagellate zonation of Sokolovskii pit (This paper)	Regional Formations
Lower Eocene	Ypresian	NP11	P6b	D6	Wme	Wetzeliella meckelfeldensis	Polosataya
		NP10			Was		
				D5	Gor		
Upper Paleocene	Thanetian	NP9	P6a		Aau	Apectodinium augustum	
			P5	D4 (part)	Ahy	Apectodinium hyperacanthum	Sokolovskaya
			P4 (part)				
		NP8			Ama	Alisocysta margarita	

FIG. 4. – Dinoflagellates stratigraphical scheme.
FIG. 4. – *Echelle biozonale à dinokystes.*

In layers 13-17, composed of clays, the siliceous plankton abundance increases notably. *Moisseevia uralensis, Grunowiella gemmata*, species of *Hemiaulus (H. febriatus (=H. polymorphus* var. *frigidus), H. gibbosus), Sheshukovia (Sh. gombosii, Sh. sundbyense, Sh. flos),* and *Pyxidicula* genera dominate the assemblages. *Melosira architecturalis* appears. The above-mentioned species were suggested to constitute potencial of the Paleocene/ Eocene boundary [Fenner, 1994; Fourtanier, 1991]. Two important events in diatom evolution are distinguished in this interval : the appearances of the genera *Golovenkinia (=Coscinodiscus polyactis*) and *Gyrocylindrus* in the middle part of the sequence.

The silicoflagellate assemblage in layers 11-17 of the Polosataya Fm. (table II) is typical for the *Naviculopsis constricta* Zone [Martini, 1971; Perch-Nielsen, 1985]. The presence of the marker species proposed by Perch-Nielsen [1976] to distinguish the subzones of the *Naviculopsis constricta* Zone is typical (fig. 2).

The first appearance of *Dictyocha elongata* is found in layer 11, and the last occurrence of *Corbisema disymmetrica (=C. naviculoidea)* in layer 17 of the Polosataya Fm. The first appearance of *Naviculopsis foliacea* and *N. foliacea* var. *tumida* which are characteristic species of the middle early Eocene is observed in the upper part of clayey unit.

Radiolaria

Radiolarians are present in the lower and middle units of the Polosataya Fm. Poorly preserved radiolarians were found in the first lower unit of the "Polosataya" Fm. (layers 11-13), and an abundant assemblage in second lower unit (layers 14-17, samples 29-39, fig. 2). The presence of *Petalospyris foveolata* in both assemblages indicates that they probably belong to the *Petalospyris foveolata* regional Zone (fig.3).

The base of the zone is determined by G. Kozlova [Kozlova, 1999] using the first appearance of the index species, which is morphologically distinctive and usually abundant in terminal Paleocene sediments of epicontinental boreal area. 42 species of radiolarians were determined in the zone, the most significant ones are shown in table III. The most abundant are cosmopolitan species : such as *Circodiscus circularis* (CLARK et CAMPBELL), *Spongodiscus americanus* (KOZLOVA), *Calocyclura acroria* (FOREMAN), *Thecosphaera rotunda* BORISSENKO, *Spongotrochus nativus* (LIPMAN), *Spongasteriscus cruciferus* CLARK et CAMPBELL, *Phormocyrtis striata exquisita* (KOZLOVA), *Theocalyptra aurelia* FOREMAN, *Petalospyris foveolata* EHRENBERG, *P. senta* (KOZLOVA), *Cryptocarpium physella* (FOREMAN).

DISCUSSION

Stratigraphy

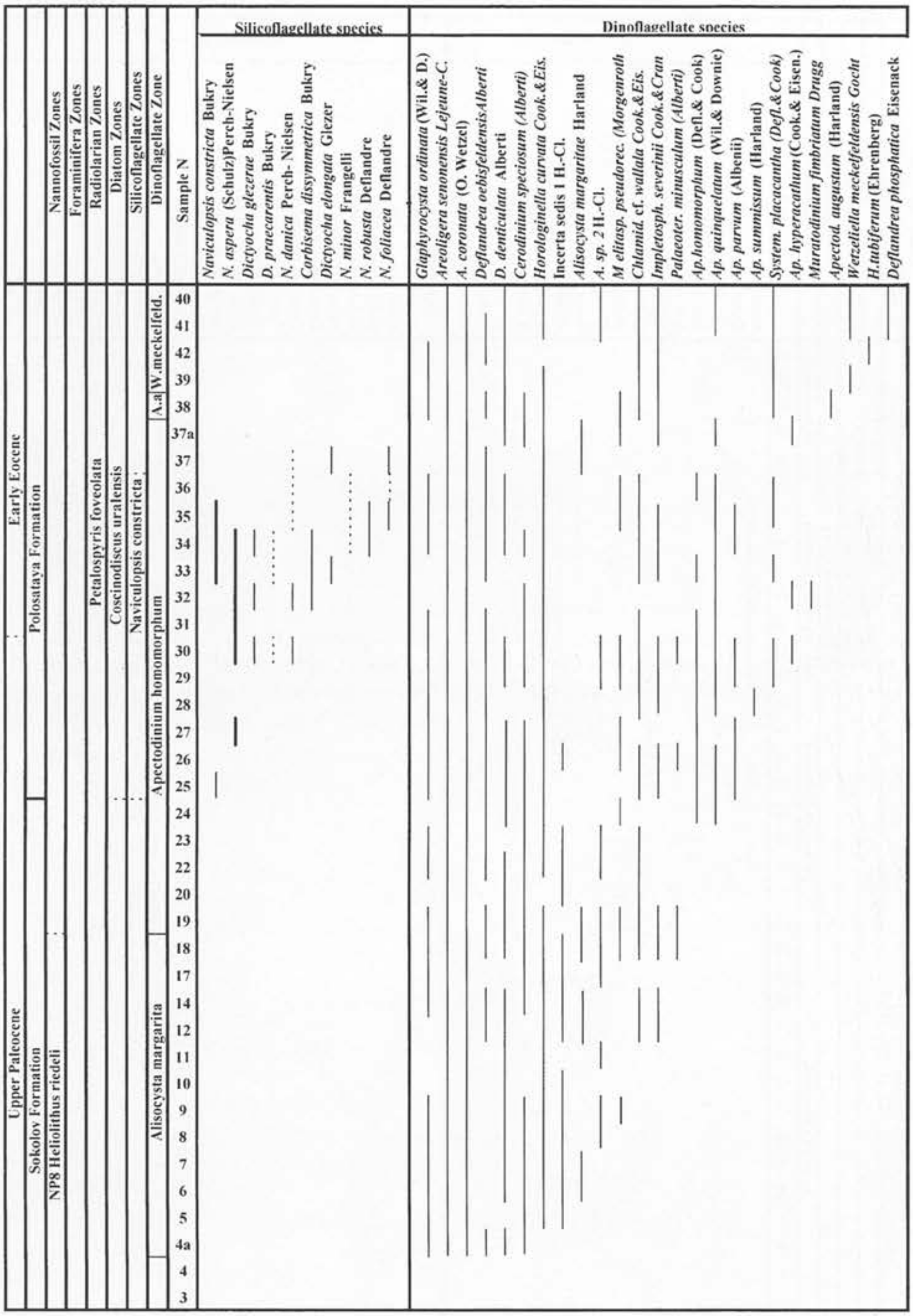
Since a Global Stratotype Section and Points (GSSP) for the Paleocene/Eocene boundary has not yet been established, our data about the ranges of various microfossils across the Paleocene-Eocene boundary elucidate the position of this boundary in the northern Kazakhstan.

The integrated study of microplankton from the Sokolovskii pit section allowed us to elucidate the stratigraphic interval and possible continuity of the sequence. The recognition of the *Acarinina subsphaerica* and *A. acarinata* (lower part) planktonic foraminifer Zones and NP8 *Heliolithus kleinpelli* nannoplankton Zone leads us to conclude that the Sokolovskaya Fm. is upper Paleocene and allows us to correlate it with Tethyan and Atlantic zonations (fig. 3).

The base of the *Acarinina subsphaerica* Zone is established by the occurrence of index species and *A. acarinata, Subbotina velascoensis, Morozovella* cf. *acuta*.

The base of the *Acarinina acarinata* Zone is marked by the appearance of *Acarinina soldadoensis* and *Morozovella aequa*. This zone was firstly established by E.K. Shutskaya [1970] in the Bakhchisaray section (Crimea) using the first occurrence of *Acarinina soldadoensis.* V.A. Krasheninnikov [1982] correlated this zone with the *Morozovella velascoensis* Zone of the Caribbean zonation. The first occurrence (FO) of *A. soldadoensis* (together with some other species) is the level used for delineation of the P4c Subzone [Berggren *et al.*, 1995]. In several Tethyan sections (including the Kaurtakapy section in the Mangyshlak Pen., Kazakhstan), Molina established the *Microglobigerina*

TABLE II. – The distribution of silicoflagellates and dinocysts in the Sokolovskii pit.
TABL. II. – *Distribution des silicoflagellées et dinokystes dans la coupe de Sokolovskii.*



soldadoensis Zone using FO of this species and correlates it to the C4F Subzone [Molina *et. al.*, 1998].

Morozovella aequa is a very important marker, too. Despite the fact that its FO is located at the base of *Acarinina subsphaerica* Zone, the sharp increase in its abundance occurs in the upper part of the *Acarinina acarinata* Zone [Krasheninnikov, Muzylöv, 1978] and in the base of the *Morozowella subbotina* [Bugrova, 1988] in numerous Caucasian sections. Shutzkaya [1970] established the *Morozovella aequa* Zone in the Lowermost Eocene. In addition, Beniamovskii and Stupin observed high abundances of *M. aequa* in the middle part of upper Thanetian sapropel bed of the North Caucasus corresponding to LPTM event [Muzylöv *et al.*, 1996].

An assemblage of benthic foraminiferas characteristic of the *Bulimina trigonalis* Zone spread over northern shallow water area of northern Peri-Tethys. It is present in the northeastern Europe [Brotzen, 1948; Vinkel, 1988], the south of the European part of Russia, the Turgay Depression [Beniamovskii, 1998].

In the upper part of the Sokolovskaya Fm., the assemblage of *Bulimina trigonalis* Zone gives way to poor assemblage of *Stilostomella plummerae.* The benthic foraminiferal assemblage impoverishment seems to be due to regressive

TABLE III. – The distribution of radiolaria and diatoms in the Sokolovskii pit.
TABL. III. – *Distribution des radiolaires et diatomées dans la coupe de Sokolovskii.*

trend in the basin. At the same time, the occurrence of *Stilostomella* genus species indicates the oxygen depletion, because this species is considered an indicator of anaerobic environment [Kaiho, 1994].

The dinoflagellate zones recognized in the Sokolovskii pit section are compared with those of the dinoflagellate zonation of Powell [1992] for northwestern Europe (fig. 4). The Powell's dinoflagellate zones are calibrated with the nannoplankton [Martini, 1971] and planktonic foraminiferal zones [Berggren *et al.*, 1995].

First established by Heilmann-Clausen [1985] in Denmark, the *A. margarita* Zone is calibrated now with nannoplankton Zones NP6-NP8 and planktonic foraminiferal Zone P4 (pars) [Powell, 1992]. The *A. margarita* zone recognized in the Sokolovsky Fm. corresponds to its European homologue. In the present section, we recognized the upper part of the European zone which corresponds to Zone NP8 and the *Acarinina subsphaerica – A. acarinata* (pars) Zone. Consequently, the chronostratigraphical age of the Sokolovskaya Fm. in the interval between samples 4a-24 is Thanetian.

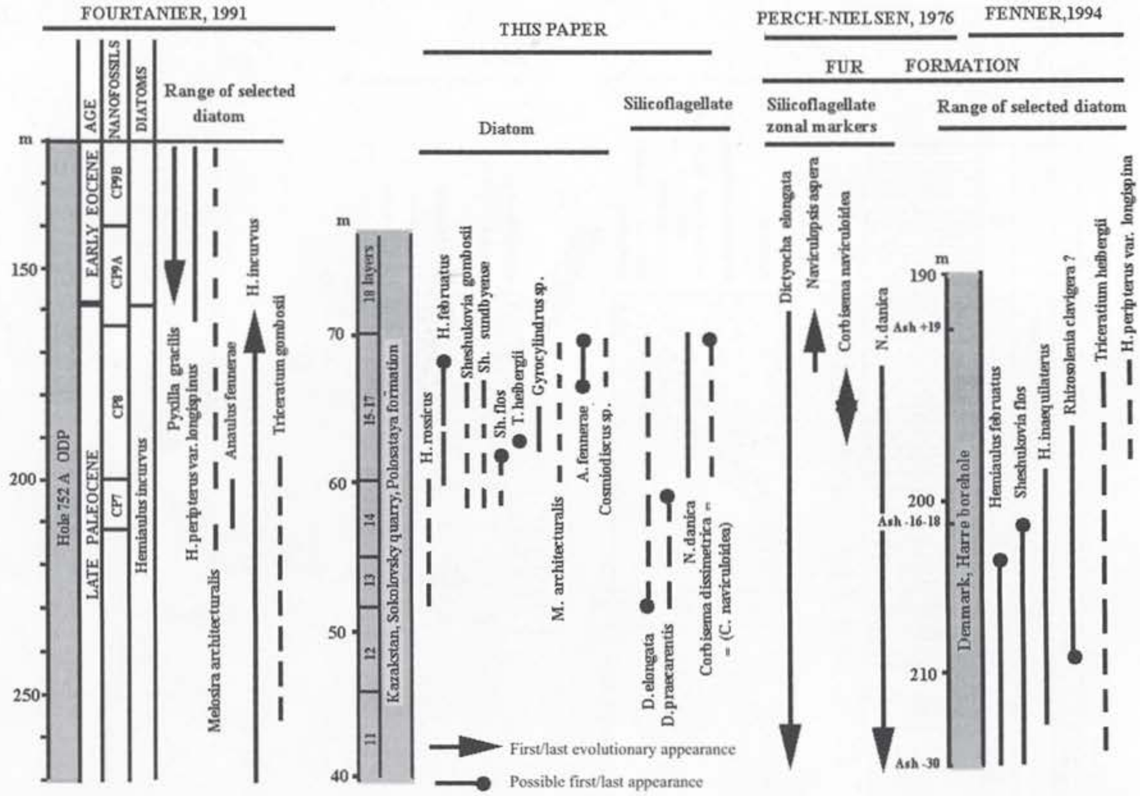


FIG. 5. – Correlation of diatom marker species.
FIG. 5. – *Corrélations entre espèces marqueurs parmi les diatomées.*

The *Apectodinium hyperacanthum* Zone recognized in the present work, corresponds to the European homologue. The *A. hyperacanthum* Zone, established by Caro [1973] in the Spanish Pyrenees, is determined as the interval between the FO of *Apectodinium homomorphum* and *Apectodinium augustum*. According to Powell [1992] this zone is calibrated with Zone NP9 (pars) and with Zones P4 (pars)-P5 (pars). Hence, the chronostratigraphical age of the lower part of the Polosataya Fm (samples 24-29) in the Sokolovskii pit section is Thanetian.

The *Apectodinium augustum* Zone, recognized in the present work in the Polosataya Fm., corresponds to the west-European *A. augustum* Zone. According to Powell [1992] and taking into account the calibrations of Berggren *et al.* [1995] this dinoflagellate zone corresponds to the Paleocene-Eocene transition and is calibrated with Zones NP9 (pars)-NP10 (pars) and Zones P5 (pars)-P6a (pars). Consequently, the interval between samples 29-42 of the Polosataya Fm. corresponds to the uppermost Thanetian-lowermost Ypresian.

The youngest dinoflagellate zone recognized in the Sokolovskii pit section is the W*etzeliella meckelfeldensis* Zone. Established for the first time in the London Clay Formation [Costa and Downie, 1976], the European *W. meckelfeldensis* Zone is calibrated with Zones NP10 (pars)-NP11 (pars) and with Zone P6b [Powell, 1992]. These calibrations permit us to attribute the upper part of the Polosataya Fm. to the lower Ypresian.

It can be noted here that two dinoflagellate zones established in west Europe between the *A. augustum* and *W. meckelfeldensis* Zones – the *Glaphyrocysta ordinata* and *Wetzeliella astra* Zones, have not been recognized in the Sokolvsky pit section. This fact seems to be linked to the presence of a stratigraphical hiatus within the Polosataya Fm. We suggest that the Paleocene-Eocene section of the Sokolovskii pit is incomplete in the interval corresponding to the Paleocene-Eocene transition.

Assemblages of diatoms, silicoflagellates, and radiolarians is diversified enough to discuss a stratigraphic position of the siliceous unit. However, criteria for determination of the Paleocene-Eocene boundary are still unclear because of discontinuous distribution of siliceous plankton in Paleocene – lower Eocene sediments of the North Atlantic and adjacent epicontinental seas.

Lower Paleogene oceanic sections of sediments containing diatoms are few [Fourtanier, 1991; Fenner, 1991]. In the East Indian ocean (ODP site 752), the Paleocene-Eocene interval was studied (fig. 5) and a new zonation was proposed [Fourtanier, 1991] using *Hemiaulus peripterus, H. incurvus,* and *Pyxilla gracilis* as index species. The upper part of the *Hemiaulus incurvus* Zone was considered to be Eocene. Then, these zones of Fourtanier were used for the standard diatom scheme [Barron, Baldauf, 1995]. All these above-mentioned markers are absent in the Sokolovskii pit section. However, the presence of additional markers, i.e. *Melosira* aff. *architecturalis, Annaulus fennerae, Triceratium gombosii*, and absence of *Pyxilla gracilis* which is typical for the lower Eocene epicontinental sections of Russia, allow us to correlate the diatom assemblage of the Polosataya Fm. with that of the terminal Paleocene, i.e. the *Hemiaulus incurvus (b)* Zone in ODP 752 site. The stratigraphic range of *Annaulus fennerae*

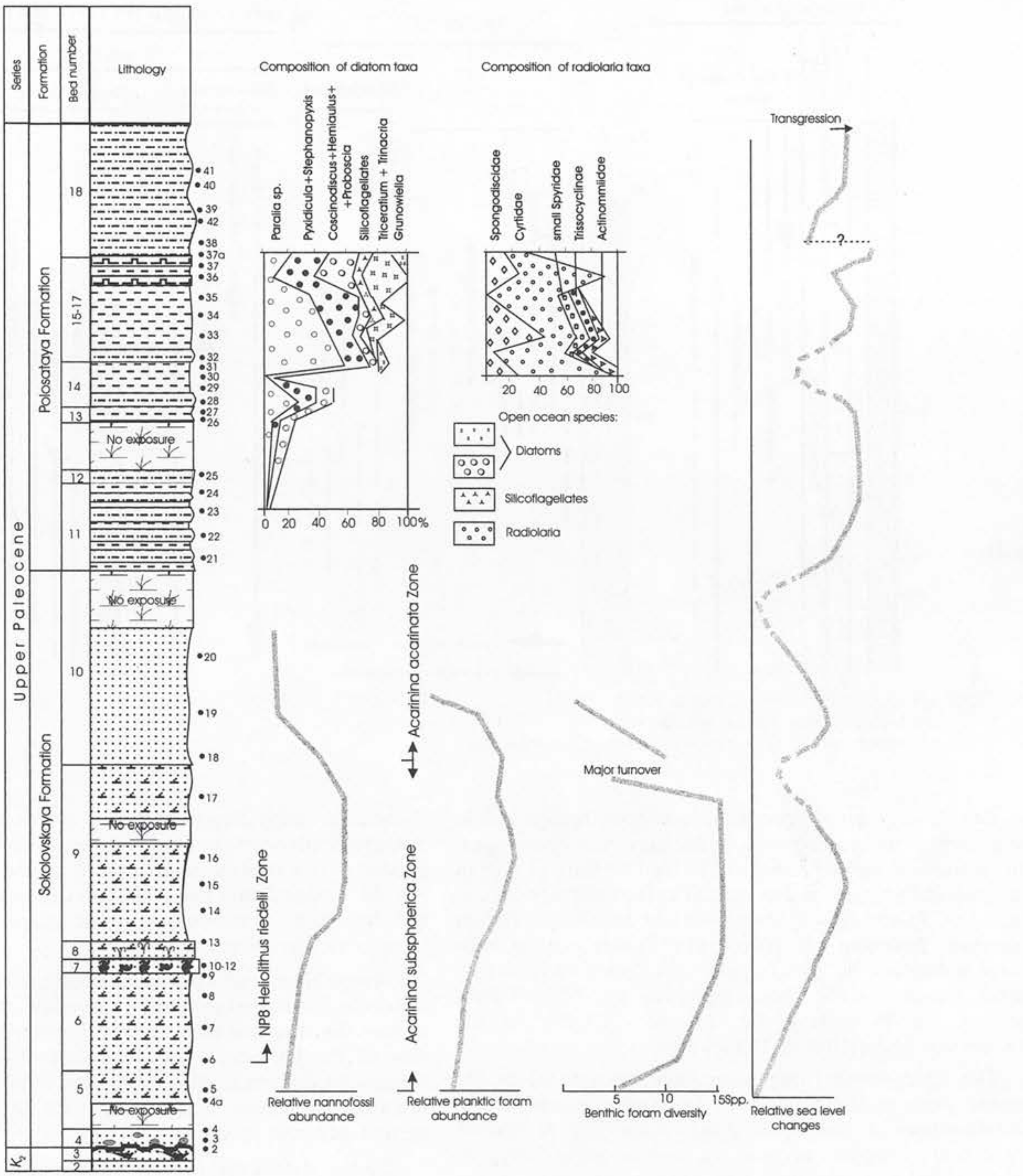


FIG. 6. – The main biotic and eustatic events in the Sokolovskii pit section..
FIG. 6. – *Principaux événements biotiques et eustatiques dans la coupe de Sokolovskii.*

is restricted to the uppermost Paleocene (Zone NP9). The presence of this species was noted by Fenner [1994] in the Fur Formation, where it was determined as *Meridion* sp. (pl.11, fig.15).

The silicoflagellate assemblage in layers 11-17 of the Polosataya Fm. is typical of the *Naviculopsis constricta* Zone. When comparing our data with those of Perch-Nielsen [1985], the FO of *Dictyocha elongata* in the bed 12 and last occurrence of *Corbisema disymmetrica (=C. naviculoidea)* in layer 17 of the Polosataya Fm. allows us to discuss a stratigraphic correlation with the Fur Fm. in the interval of –17 and + 19 ash layers.

Therefore, the siliceous part of the Polosataya Fm. most probably belongs to the terminal Paleocene.

It is necessary to note that several diatom and silicoflagellate species which are typical for the later horizons of the Paleogene, are found in Sokolovskii pit in Paleocene sediments for the first time. These are representatives of *Golovenkinia (=Coscinodiscus) polyactis* STRELNIKOVA very similar to *Azpeitia genus* and Coscinodiscus (*Cosmiodiscus*?) *denarius*, known and described in lower and middle Eocene deposits (Diatoms of the USSR, 1974) and silicoflagellates *Naviculopsis foliaceae*, which is the index-species of a lower Eocene Zone [Perch-Nielsen,1985].

The radiolarian index-species *Petalospyris foveolata* and corresponding assemblage were found in the Peri-Caspian basin associated with nannoplankton of Zone NP9 [Kozlova, 1994]. Although the index species and several species typical of the assemblage of the *Petalospiris foveolata* Zone described by G. Kozlova [1999] are present in the assemblage, approximately 65% of taxonomic composition of the assemblage consists of other species. Some of them were described from upper Paleocene sediments from different climatic zones of Atlantic : *Lophocyrtis pseudojaccia* (NISHIMURA, 1992), *Calocyclura acroria* (FOREMAN, 1973), etc. At least several species appearing in the Sokolovskii section are known from lower Eocene oceanic sediments also : *Eusyringium striata exquisita* (KOZLOVA, 1984), *Lychnocanoma anacolum* (FOREMAN, 1973), *Cryptocarpium phyzella* (FOREMAN, 1973), *Thyrsocyrtis hirsuta tensa* (KRASHENINNIKOV, 1960), *Thecosphaerella eocenica* (CLARK et CAMPBELL, 1942). Based on the taxonomic composition, the association of the *Petalospyris foveolata* Zone from the Sokolovsky section belongs just to the Paleocene-Eocene transition.

TRANSGRESSIVE-REGRESSIVE CYCLES

Based on lithologic analysis and composition of microfossil assemblages, two transgressive-regressive cycles are clearly distinct in the Sokolovskii section. Each one includes second-order cycles. The lower cycle (fig. 6) includes the Sokolovskii Fm. composed by carbonate sandstones with bioherms and superposed by carbonate-free sands. The calcareous sandstones yielded a nannoplankton assemblage of Zone NP8. The middle part of this sequence includes an intercalation of bioherm limestone with Bryozoa, Scleractinian corals, Cirripedia, Ostracodes, Bivalvia. Based on dinocysts, this part of the section is assigned to the *Alisocysta margarita* Zone. The lower cycle of the second order is related to the *Acarinina subsphaerica* foraminifera Zone, and the upper one, to the layers with *Morozovella aequa.*

The upper cycle of the section (Polosataya Fm.) begins and terminates with members of alternating siliceous clays and loose sandstones. Its middle part is composed of clays. It corresponds to the *Apectodinium augustum* Zone. The three cycles of second order envelop the lower and middle parts of the Polosataya Fm. For the analysis of cyclicity, the most important are changes in the abundance of neritic diatoms *Paralia – Pyxidicula*, *Trinacria – Triceratium*. These changes allowed us to distinguish second-order cycles in layers 11-13, 14-16, 17. Layer 17 displays a considerable increase in *Pyxidicula* and a decrease in *Paralia* abundances. As species of the genus *Paralia* are indicative of shallow-water environment, a decrease in their abundance can be considered as an evidence of open marine conditions during accumulation of the upper part of the section.

Changes in the abundance of oceanic diatoms of the genera *Coscinodiscus, Hemiaulus, Proboscia*, and increased abundances of *Grunowiella gemmata,* and silicoflagellates are critical in establishing marine conditions. The abundance of all three groups considerably increases in layers 14-17. Among open-marine diatoms, *Eoscinodiscus* is typical in layers 13-14, and *Hemiaulus, Proboscia,* and silicoflagellates, in layers 15-16.

Similar changes are observed in radiolarian assemblages. Changes in the Cyrtidae family abundance in layers 15-17 correlate well with the changes in *Eoscinodiscus, Hemiaulus,* and *Proboscia* abundances. Increased abundance of *Cyrtidae* and other warm-water radiolarian species known from coeval oceanic sediments suggests a stronger connection with the oceanic Tethys area in the terminal Paleocene

The sedimentological study of Sokolovskaya and Polosataya Fms. accompanied by the analysis of distribution and estimation of the ratio of marine to neritic species made it possible to elucidate the character of transgressive–regressive cyclicity, which correlates well with that in the North Sea [Moorkens, 1998].

CONCLUSIONS

An integrated micropaleontological and lithological study of the Paleogene deposits of the Sokolovskii pit allowed to determine the stratigraphic range of the regional lithological Formations and to recognize transgressive-regressive cycles in this section. The Sokolovskaya Formation and most of the Polosataya Formation belong to the upper Paleocene; the uppermost part of the Polosataya Fm. is lower Eocene.

The planktonic foraminifera assemblage found in the Sokolovskii section includes a significant number of Tethyan species. This indicates a connection between the Turgay Basin with the Tethys area during the terminal Paleocene. On the other hand, the composition of silicoflagellate and dinocyst assemblages in the studied section shows a good correlation with that of Northern Europe and North Atlantic, suggesting tight oceanic links of the Turgay Basin with the North Atlantic Basin via western Siberia and, apparently, Polar Ural.

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