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Stratigraphy and Paleoenvironmental Interpretation of the Paleocene–Eocene Transition in the Eastern Crimea

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Abstract—The study of nannofossils and dinoflagelate cysts from the Paleocene–Eocene transition in the Nasypnoe section, Eastern Crimea identified the bed corresponding to the global event referred as the Paleocene–Eocene Thermal Maximum (PETM). The assemblages of both groups of microphytoplankton display significant changes including the appearance of *Rhomboaster* spp., *Discoaster anartios* and *D. araneus* nannofossils and *Apectodinium augustum* and *Wilsonidium pechoricum* dinocysts featured for this event and major variations in the ratio of taxa resulted in domination of eutrophic and warm-water species. The paleoecological interpretation of nannofossil and dinocyst distribution suggests a drastic sea-level fall preceded the PETM and occurrence of two transgressive episodes during it.

Keywords: biostratigraphy, Paleocene–Eocene Thermal Maximum, dinocysts, nannoplankton, Eastern Crimea.

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INTRODUCTION

One of the major paleoecological crises among successive Mesozoic-Cenozoic biotic events is so-called Paleocene–Eocene Thermal Maximum (PETM). By development rate and many other parameters, the PETM is comparable with present climatic events. Recently, it has been shown that dramatic disruption of the carbon cycle and climatic warming associated with the PETM caused negative carbon and oxygen isotope excursions in the geological record (Kennett and Stott, 1991; Zachos et al., 2001; a.o.), reorganization of the oceanic current system (Nunes and Norris, 2006; Tripati and Elderfield, 2005), dramatic compositional turnovers in marine and terrestrial biotas (Thomas, 1998; Gibbs et al., 2006; Clyde and Gingerich, 1998; Wing et al., 2005), and widespread occurrence of sediments enriched in organic matter (Gavrilov et al., 2003; Speijer and Wagner, 2002). Despite extensive study of involved into PETM phenomena and the great volume of recently obtained information, the causes of its occurrence and precise succession of the associated events are still poorly understood.

In the northeastern Peri-Tethys, the PETM is pronounced as sapropelitic bed (SB, Muzylev, 1994) featured by significant enrichment in TOC, drastic carbon and oxygen isotope excursions (up to 20%, Gavrilov et al., 1997), and prominent turnovers in microplankton assemblages (Stupin and Muzylev, 2001; Gavrilov et al., 2003). The study of nannofossil variations within SB of Caucasian and Central Asia sections revealed dramatic decrease in nannofossil abundance comparing to embedding sediments, occurrence of so-called “excursion Taxa” (e.g. the species whose stratigraphic distribution ranges Carbon Isotope Excursion - CIE) namely *Rhomboaster* spp. and asymmetrical discoasterids (*Discoaster anartios* and *D. araneus*), and changes in relative abundances of taxa caused warm-water and eutrophic species domination in the assemblages (Gavrilov et al., 2003). Besides, domination of *Apectodinium* genus and occurrence of “excursion species” *A. augustum* are shown in some areas (Akhmetiev and Zaporozhets, 1996; Iakovleva et al., 2001; Crouch et al., 2003).

Paleogene deposits in the Eastern Crimea are poorly exposed, and thus inadequately studied. Outcrops of Paleogene rocks in unnamed gullies southwards of the village of Nasypnoe (6 km westward of the city of Feodosiya) are better exposed than elsewhere in the area. This succession is the reference Paleogene section for the Eastern Crimea (*Stratigrafiya*..., 1984). The succession includes, from bottom to top, the Danian Feodosiya Formation, uncomformably overlain by sandy-clayey sequence tentatively correlated with the Thanetian Kacha Horizon of Western Crimea, which is superposed by the Nasypkoi Strata correlative with the Eocene Bakhchisarai and Simferopol horizons. Despite the multiple studies (Nemkov and Barkhatova, 1961; Shutskaya, 1970; Gorbach, 1972, a.o.), the age of lithostratigraphic units remains problematic.

Recent study of foraminifera, nummulites and nannofossils (Bugrova et al., 2002) from sandy-clayey sequence revealed its late Selandian to Thanetian age. The age of sequence was defined as non-subdivided interval of NP6-NP9 nannofossil zones, Acarinina acarinata planktonic foraminifera zone, Karreiella zolkaensis benthic foraminifera zone, and SBZ3 nummulite zone (at the base of the section). The stratigraphy of the upper part of this sequence and transition to the Nasypkoi Strata remained unresolved, because of the gap in field observation. The overlying Nasypkoi Strata were dated as early Ypresian and correlated with upper part of the Bakhchisarai Fm. and basal Simferopol beds of the stratotype region (Western Crimea). Bugrova et al. (2002) noted that microfossils from upper part of the sandy-clayey sequence should be studied in greater detail as this interval contains characteristic agglutinated foraminifers of the Karreiella zolkaensis zone which are indicators of oxygen deficiency in bottom waters. In the same part of the section, the appearance of planktonic foraminifers of the Morozovella aequa zone indicating the Paleocene–Eocene transition was recorded. However, the actual level of Paleocene–Eocene boundary has not been recognized because neither foraminiferal nor nannofossil markers were found in the interval studied. A similar assemblage was identified by authors in the sections of Kerchenskii Peninsula, Crimea and low-calcareous to carbonate-free deposits of the Goryachii Klyuch Fm. in the northwestern Caucasus and central Ciscaucasia.

Our interest in this sandy-clayey sequence is based on the possible occurrence of the beds related to PETM. Apparently, the Nasypnoe section of eastern Crimea represents the westernmost region of PETM manifestation in the northeastern Peri-Tethys, where this interval is composed of mostly siliciclastic sediments. In westerly areas, for instance Suvlukaya section near Bakhchisarai, the Paleocene–Eocene transition corresponds to hiatus spanning the NP9-NP10 nannofossil zones. To reveal the peculiar microfossil changes across the Paleocene–Eocene boundary in the eastern Crimea, we thoroughly studied nannofossil and dinocyst assemblages and recognized biostratigraphic zones based on both groups. Dinocysts of the Nasypnoe sections were studied for the first time.

MATERIALS AND METHODS

Lithology of Studied Section

In 2008, Yu.O. Gavrilov and E.A. Shcherbinina sampled the section exposed in an unnamed gully (45°02′00″N, 35°17′11″E) southwestward of the village of Nasypnoe. Rock samples have been collected from isolated test pits in the covered intervals on the gully slopes; hence the lithological boundaries are only provisionally defined. The following lithological units have been identified in the right slope of the gully from base to top (Fig. 1):

Feodosiya Formation

1. Compact yellowish gray bioclastic limestone; exposed thickness is ~2 m.
2. White, highly porous, clastic *Lithothamnium* limestone with fragments of mollusks and coal clasts; thickness varies along the strike, commonly ranging 0.5 to 0.8 m.

Upsection, 1.8 to 2.0 m thick interval is unexposed.

Sandy-Clayey Sequence

3. Gray soft sandy to silty clay with isolated several cm thick intercalations of bioclastic material in the lower part; thickness is ~2.2 m.
4. Soft yellowish-gray 0.6 m thick sandy clay.
5. Plastic calcareous clay ~1.3 m thick, gray in the lower part and dark gray in the upper part.
6. Rusty-gray clay ~1.7 m thick with rare silty intercalations.
7. Gray laminated mudstone; discovered thickness ~3.5 m.

Hence, the sapropelitic horizon, very distinct in the eastern sections of the northeastern Peri-Tethys and corresponding to the PETM interval, is not pronounced visually in the Nasypnoe section.

Methods

Three-step chemical treatment of palynological samples using standard procedure of the Laboratory of Paleofloristics, Geological Institute, Russian Academy of Sciences (GIN), was applied. Each sample was first treated in 10% HCl solution to dissolve carbonate components of the rock, and then in a 5% Na_2HPO_4OH solution with subsequent removal of clay minerals by decanting. Palynomorphs were separated from the precipitate by centrifuging in heavy liquid with a specific weight of 2.25 g/cm^3 (KJ + CdJ solution) and collected into test tubes filled with glycerol for subsequent preparation of smear slides and microscopic examination. Rock samples and studied smear slides are hosted at the Laboratory of Paleofloristics, GIN RAS, Moscow. Representative assemblages of microphytoplankton (over 130 species in total of dinocysts, acritarchs, prasinophytes, spores and pollen of terrestrial plants) are identified in all samples. Samples 19 and 20 were missed in palynomorph study. The counte of not less than 200 palynomorph specimens was made in each smear slide studied. Biostratigraphic units were defined based on quantitative and taxonomic changes in palynomorph assemblages. Paleoenvironments were reconstructed following Powell et al. (1996) from diagrams showing abundance ratios of different palynomorph groups and dinocyst ecogroups.

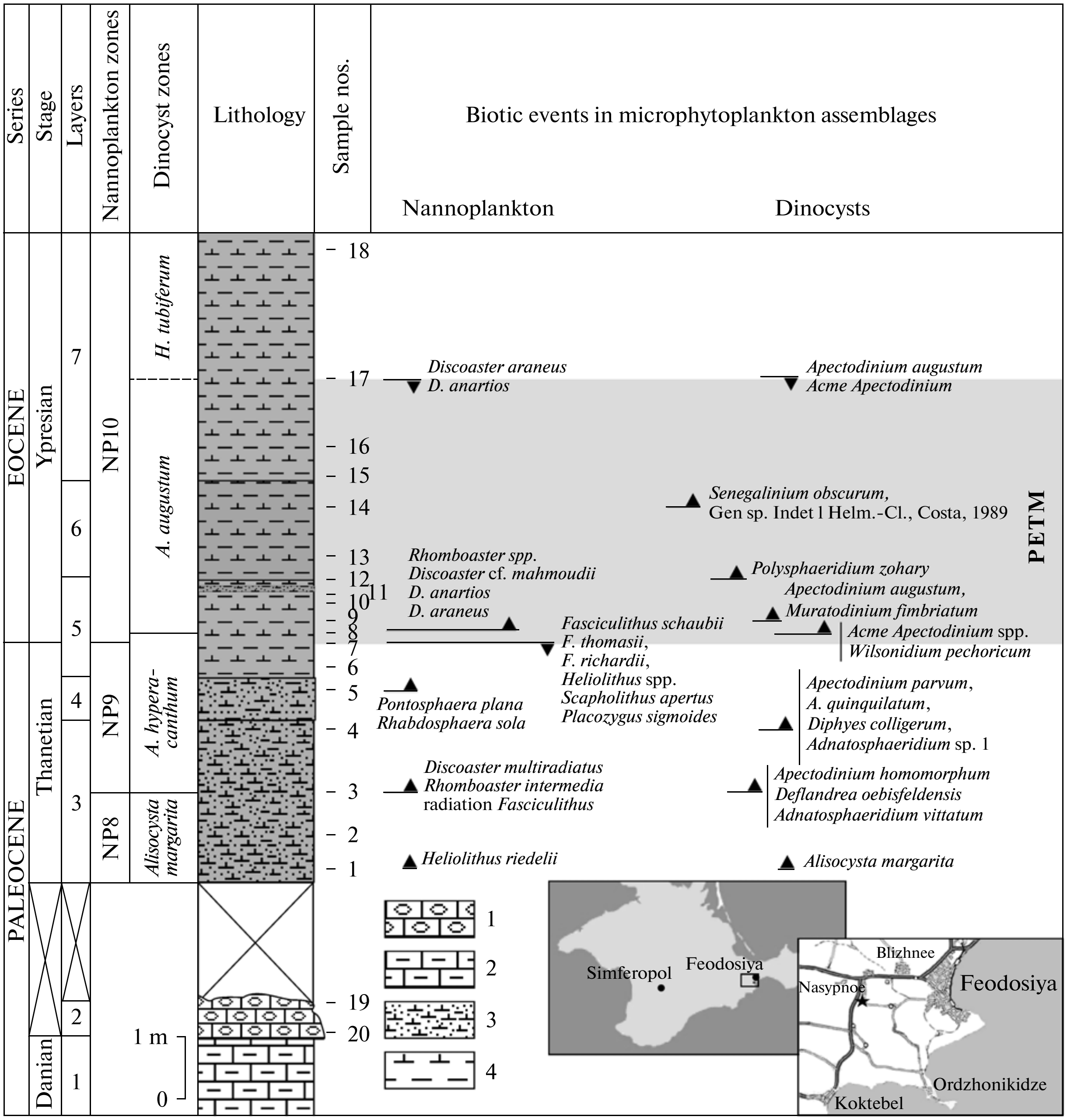
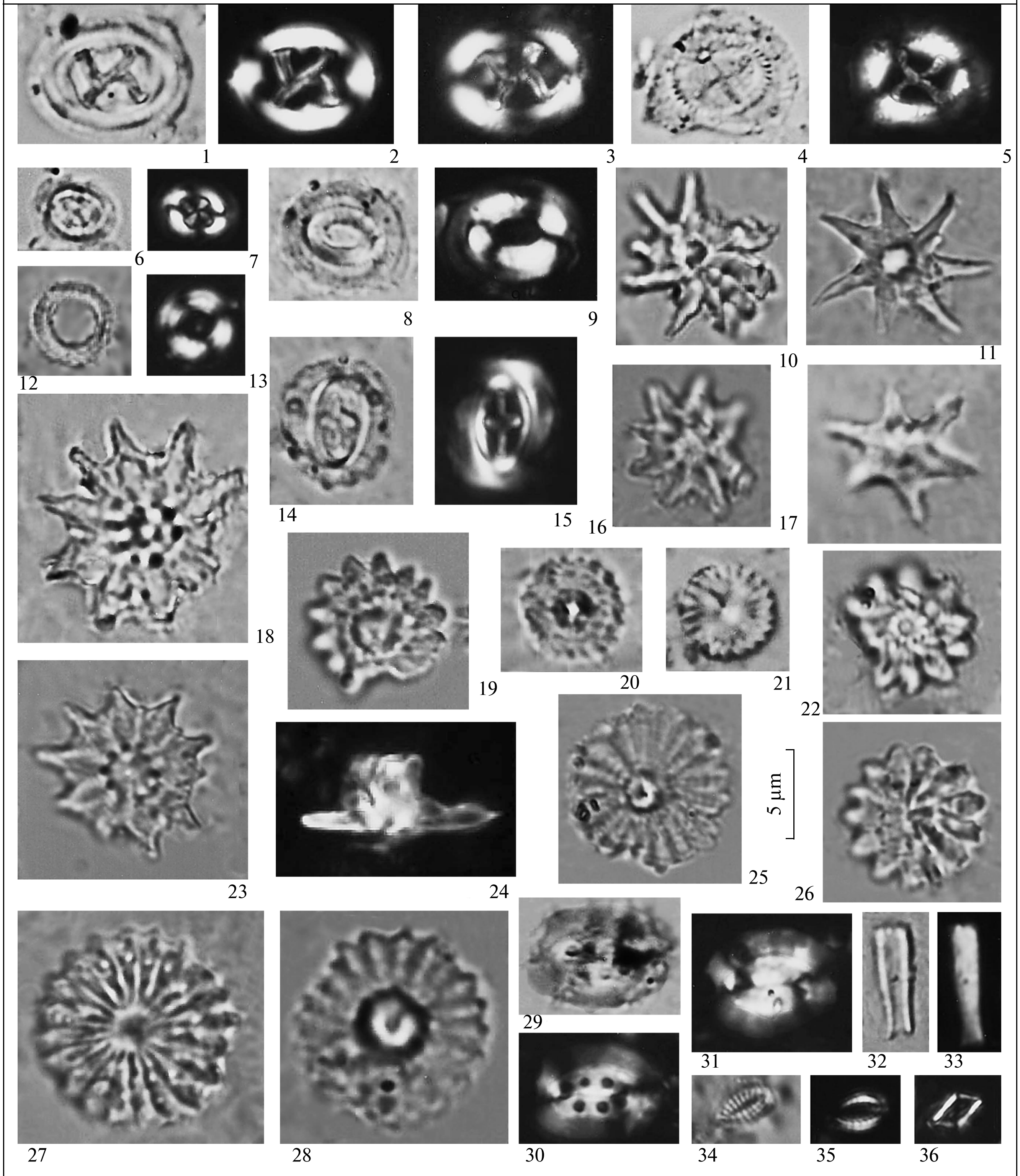


Fig. 1. Geographic locality of the Nasypnoe section, lithology of the Paleocene–Eocene transition, and most significant biotic events in nannoplankton and dinocyst assemblages: (1) Lithothamnium limestone, (2) bioclastic limestone, (3) sandy to silty clay, (4) clay.

Plate I. Nannofossils from the Paleocene–Eocene deposits of the Nasypnoe section:

(1) *Chiasmolithus bidens*, Sample 5; (2) *C. bidens*, the same sample, polarized light (PL); (3) *C. bidens*, Sample 1, PL; (4) *Chiasmolithus consuetus*, Sample 6; (5) *C. consuetus*, the same sample, PL; (6) *Chiasmolithus titus*, Sample 5; (7) *C. titus*, the same sample, PL; (8) *Coccolithus pelagicus*, Sample 6; (9) *C. pelagicus*, the same sample, PL; (10, 11) *Discoaster anartios*, Sample 10; (12) *Coccolithus robustus*, Sample 2; (13) *C. robustus*, the same sample, PL; (14) *Campylosphaera eodela*, Sample 6; (15) *C. eodela*, the same sample, PL; (16) *Discoaster araneus*, Sample 9; (17) *Discoaster* cf. *mahmoudii*, Sample 10; (18) *Discoaster falcatus*, Sample 5; (19) *Discoaster splendidus*, Sample 5; (20) *Discoaster lenticularis*, proximal side, Sample 13; (21) *D. lenticularis*, distal side, Sample 14; (22) *Discoaster mohleri*, proximal side, Sample 1; (23) *Discoaster mediosus*, Sample 5; (24) *Discoaster salisburgensis*, lateral side, Sample 14; (25) *D. salisburgensis*, Sample 5; (26) *Discoaster mohleri*, distal side, Sample 15; (27) *Discoaster multiradiatus*, distal side, Sample 9; (28) *D. multiradiatus*, proximal side, Sample 7; (29) *Ellipsolithus distichus*, Sample 6; (30) *E. distichus*, the same sample, PL; (31) *Ellipsolithus macellus*, Sample 13, PL; (32) *Rhabdosphaera sola*, Sample 5; (33) *R, sola*, the same sample, PL; (34) *Hornibrookina arca*, Sample 6; (35) *H. arca*, the same sample, PL; (36) *Scapholithus apertus*, PL, Sample 5.

Plate I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Nannofossils were studied in smear slides made by standard technics (Bown, 1998) from all samples using Olympus BX-41 microscope and photographing was made with Infinity X videocamera. The ratios of different paleoecological groups in nannofossil assemblages were statistically assessed by counting their species among 300 specimens in random fields of view.

Characteristic nannofossil and dinocyst taxa are figured in Plates I–VI.

RESULTS AND DISCUSSION

Nannofossils

Despite mainly low carbonate content in the sampled clayey rocks, nannofossil assemblages are rather diverse (over 55 species in total have been identified within the sampled section interval) and characterized by moderate to good preservation. Rare redeposited Cretaceous nannofossil taxa are presented throughout the interval studued. In the *Lithothamnium*-bearing limestone nannofossils were not found.

The nannofossil assemblage from basal part of the sandy-clayey sequence (samples 1 and 2, Plate 1) is relatively abundant and diverse including common *Coccolithus* spp., *Prinsius martinii*, diverse helioliths (*Heliolithus kleinpellii, H. riedelii, H. bukryi*, a. o.), frequent *Toweius* spp., *Discoaster mohleri*, and some other forms (Plates I and II). This assemblages is featured for NP8 nannofossil zone. Total abundances of cold-water chiasmoliths and warm-water discoasters are low and approximately equal (Fig. 2), that more likely indicates temperate conditions. The abundance of eurytopic *Coccolithus* spp. is higher than that of eutrophic *Toweius* spp.

In Sample 3, total nannofossil abundance drops and the ratio of ecologic groups changes significantly. The NP9 zonal marker *Discoaster multiradiatus* and *Rhomboaster intermedia* appear at this level and remarkable fasciculith radiation with occurrence of large daedal nannoliths (*Fasciculithus schaubii, F. alanii, F. richardii, F. tonii*, a.o.; Plate II), although their total abundance remains to be almost the same. The abundance *Prinsius, Heliolithus*, and, to a lesser extent, *Coccolithus* reduces, whereas the content of *Discoaster* spp. and *Toweius* spp. increases. In the Sample 4, nannofossil abundance and diversity dramatically decline, sediment becomes more silty and contains glauconite that more likely evidences short-lived sea-level fall. *Discoaster multiradiatus* and *Toweius pertusus* dominate low-abundant nannofossil assemblage. Upsection (samples 5–7), nannofossils become to some extent recovered in abundance, although their total abundance remains to be relatively low, but species diversity significantly increases. New taxa *Rhabdosphaera sola* and *Pontosphaera* plana first appear and *Zygodiscus herlyni, Neochiastozygus junctus*, and *Scapholithus apertus* also first occur at this level. Such an early appearance if pontosphaerids and rhabdosphaerids in the middle of NP9 zone in its current understanding has never been reported from the northeastern Peri-Tethys. Their appearance was recently considered to be related to the sapropelitic bed corresponding to PETM (N. Muzylev, pers. communication; Gavrilov et al., 2003). However, the first *Pontosphaera* spp. appear just in NP9 zone in the shelf sediments of New Jersey (Bybel and Self-Trail, 1995). A gradual increase in the nannofossil abundance and diversity and appearance of new taxa are more likely associated with a rapidly progressing transgression and formation of new ecological niches.

The first occurrence of *Rhomboaster* spp. (Plate III), the marker of the PETM onset and lower boundary of NP10, is found in Sample 8, where we identified also the asymmetrical "excursion species" *Discoaster anartios, D. araneus*, and *D.* cf. *mahmoudii* (Plate I). *Transversopontis pulcher* also first appear at this level, while *Scapholithus apertus* and *Placozygus sigmoides*, which survived during the Cretaceous/Paleogene extinction event, heliolths and all

Plate II. Nannofossils from the Paleocene–Eocene deposits of the Nasypnoe section:

(1) *Bomolithus conicus*, Sample 1, PL; (2) *Heliolithus kleinpellii*, Sample 6; (3) *H. kleinpellii*, Sample 2, PL; (4) *Heliolithus riedelii*, Sample 2; (5) *H. riedelii*, the same sample, PL; (6) *H. riedelii*, lateral side, Sample 2; (7) *H. riedelii*, the same sample, PL; (8) *Heliolithus universus*, Sample 2; (9) *Heliolithus universus*, the same sample, PL; (10) *Heliolithus universus*, lateral side, Sample 1, PL; (11) *Heliolithus* sp., Sample 1, PL; (12) *Heliolithus bukryi*, lateral side, Sample 2; (13) *H. bukryi*, the same sample, PL; (14) *Heliolithus* sp., Sample 1, PL; (15) *Heliolithus* sp., Sample 7, lateral side; (16) *Heliolithus* sp., the same sample, PL; (17) *Fasciculithus tonii*, Sample 6; (18) *F. tonii*, the same sample, PL; (19) *Fasciculithus mitreus*, Sample 6, PL; (20) *Fasciculithus involutus*, Sample 2, PL; (21) *F. involutus*, the same sample, PL; (22) *Fasciculithus* cf. *involutus*, Sample 2, PL; (23) *Fasciculithus schaubii*, Sample 3, PL; (24) *Fasciculithus thomasii*, Sample 3; (25) *F. thomasii*, the same sample, PL; (26) *Fasciculithus aubertae*, Sample 1, PL; (27) *Fasciculithus sidereus*, Sample 3, PL; (28) *Fasciculithus tympaniformis*, Sample 10, PL; (29) *Fasciculithus bobii*, Sample 1, PL; (30) *Fasciculithus* sp. 1, Sample 3, PL; (31) *Fasciculithus* sp. 2, Sample 3; (32) *Fasciculithus* sp. 2, the same sample, PL; (33) *Fasciculithus* sp. 3, Sample 2, PL; (34) *Sphenolithus primus*, Sample 6, PL; (35) *Toweius* sp., Sample 14, PL; (36) *Toweius pertusus*, Sample 15; (37) *T. pertusus*, the same sample, PL; (38) *Toweius eminens*, Sample 1; (39) *T. eminens*, the same sample, PL; (40) *Toweius tovae*, Sample 7; (41) *T. tovae*, the same sample, PL; (42) *Toweius* sp., Sample 3; (43) *Toweius* sp., the same sample, PL; (44) *Toweius occultatus*, Sample 16, PL; (45) *Toweius serotinus*, Sample 5; (46) *T. serotinus*, the same sample, PL; (47) *Neochiastozygus chiastus*, Sample 2, PL; (48) *N. chiastus*, the same sample, PL; (49) *Neochiastozygus concinnus*, Sample 2; (50) *N. concinnus*, the same sample, PL; (51) *Neochiastozygus denticulatus*, Sample 15; (52) *Neochiastozygus distentus*, Sample 6; (53) *N. distentus*, the same sample, PL; (54) *Neochiastozygus* cf. *distentus*, Sample 6, PL; (55) *Neochiastozygus junctus*, Sample 9; (56) *N. junctus*, the same sample, PL; (57) *Zygodiscus herlyni*, Sample 5; (58) *Pontosphaera plana*, Sample 5; (59) *Transversopontis pulcher*, Sample 10.

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Plate II

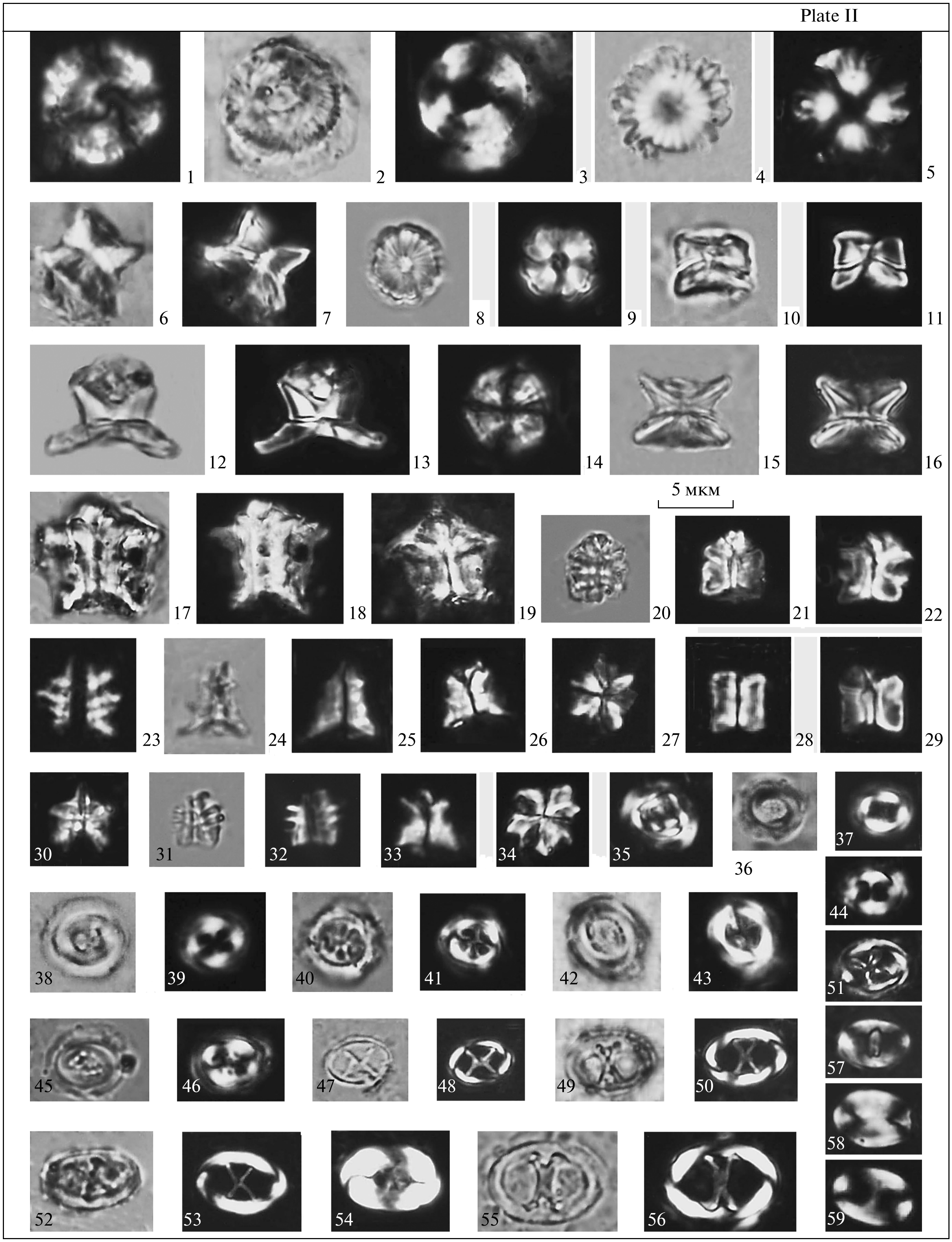
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Plate III

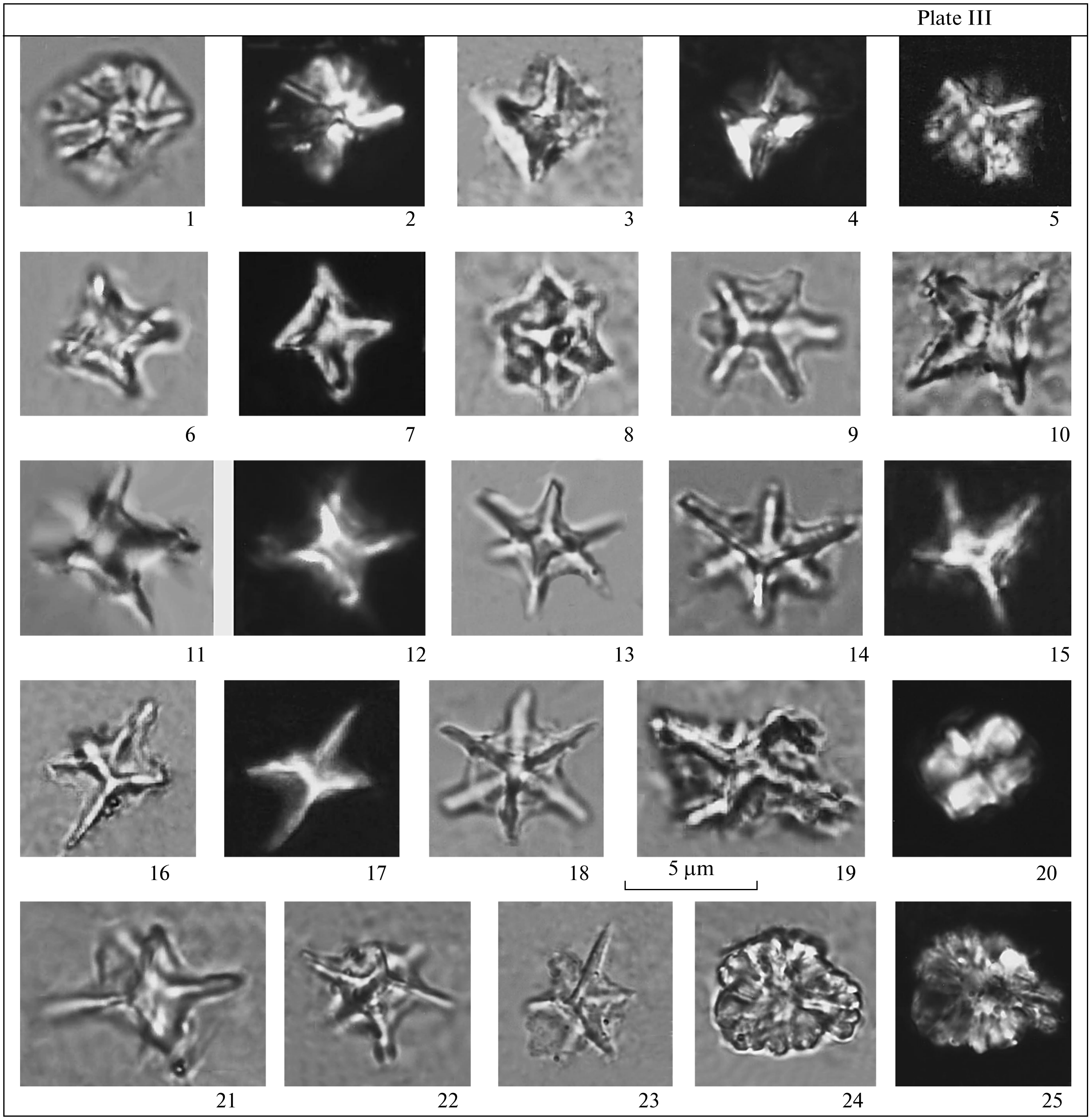


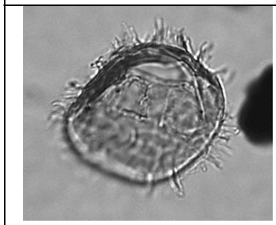
Plate III. Nannofossils from the Lower Eocene deposits of the Nasypnoe section:

(1) *Rhomboaster intermedia*, Sample 7, PL; (2) *R. intermedia*, the same sample, PL; (3) *R. intermedia*, Sample 7; (4) *R. intermedia*, the same sample, PL; (5) *Rhomboaster* cf. *cuspis*, Sample 7, PL; (6) *R. cuspis*, Sample 10; (7) *R. cuspis*, the same sample, PL; (8) *R. cuspis*, Sample 10; (9) *Rhomboaster bramlettei*, Sample 13; (10) *R. bramlettei*, Sample 15; (11) *R. cuspis*, Sample 14; (12) *R. cuspis*, the same sample, PL; (13) *R. calcitrapa*, Sample 11; (14) *Rhomboaster calcitrapa*, Sample 9; (15) *R. calcitrapa*, the same sample, PL; (16) *Rhomboaster bitrifida*, Sample 13; (17) *R. bitrifida*, the same sample, PL; (18) *Rhomboaster spineus*, Sample 13; (19) *Rhomboaster* sp. 1, Sample 11; (20) *Octolithus multiplus*, Sample 12; (21) *Rhomboaster bitrifida*, Sample 13; (22) *R. bitrifida*, Sample 18; (23) *Rhomboaster* sp. 2, Sample 13; (24) nannolith, Sample 13; (25) the same sample, PL.

Plate IV. Dinocysts from the Paleocene deposits of the Nasypnoe section (magnification ×500 in all the figures):

(1–3) *Alisocysta margarita*, Sample 1; (4) *Florentinia ferox*, Sample 2; (5) *Cordosphaeridium gracile*, Sample 1; (6) *Areoligera gippigensis*, Sample 1; (7) *Cerodinium speciosum*, Sample 1; (8) *Spinidinium densispinatum*, Sample 2; (9) *Thalassiphora pelagica*, Sample 2; (10) *Melitasphaeridium pseudorecurvatum*, Sample 2; (11) *Cordosphaeridium fibrospinosum*, Sample 1.

Plate IV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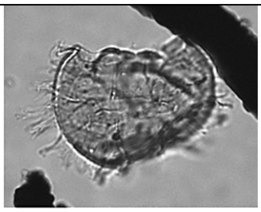
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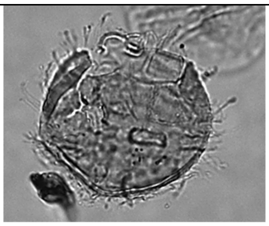
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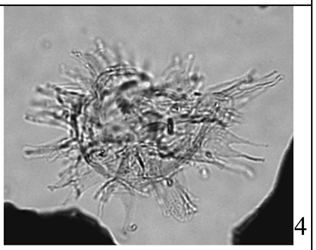
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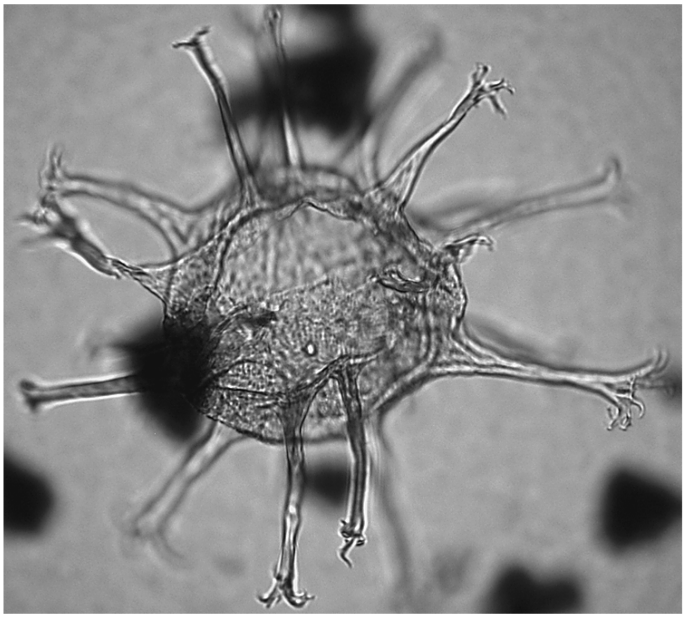
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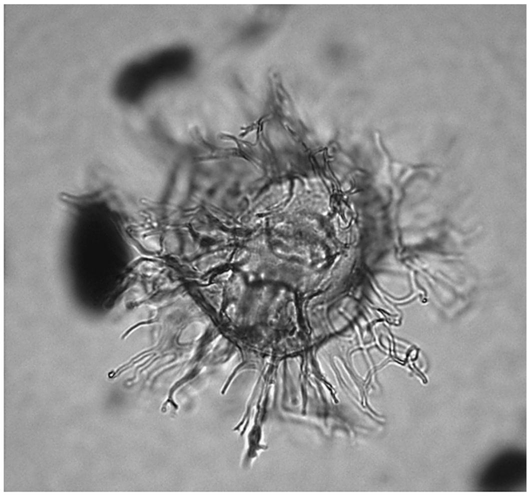
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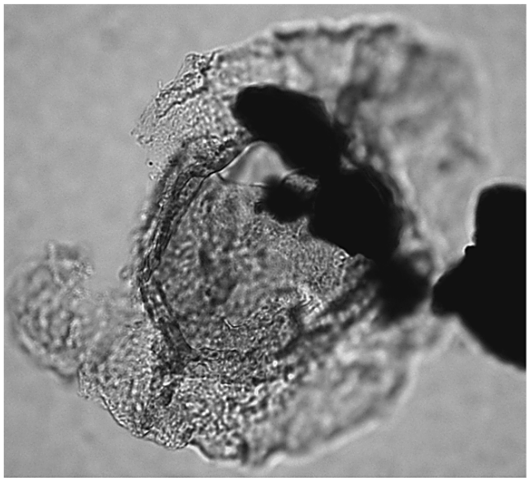
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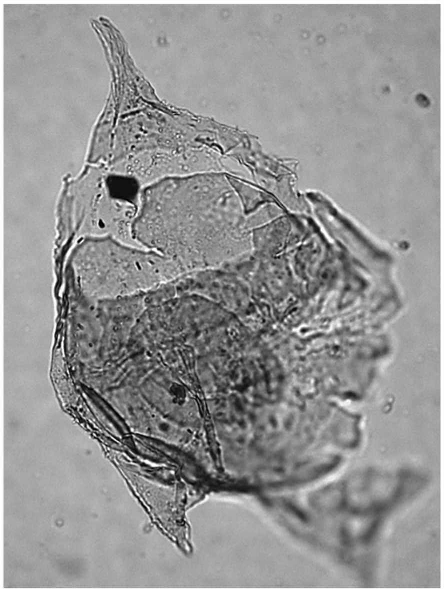
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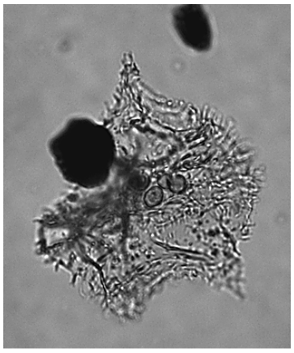
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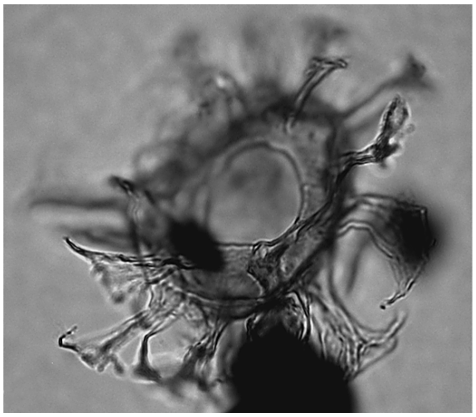
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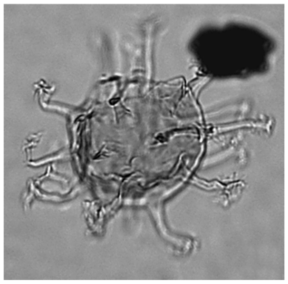
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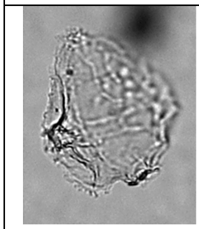
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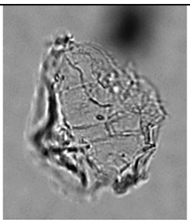
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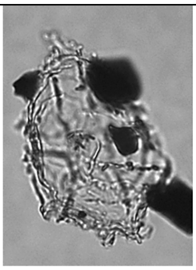
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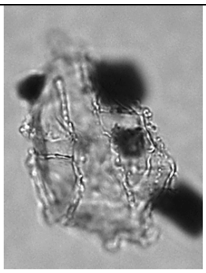
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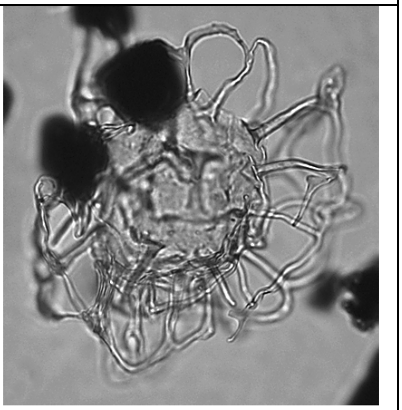
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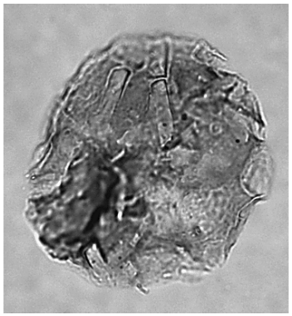
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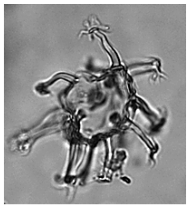
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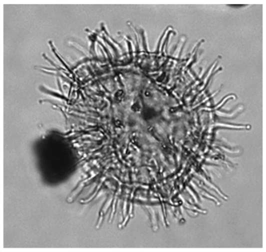
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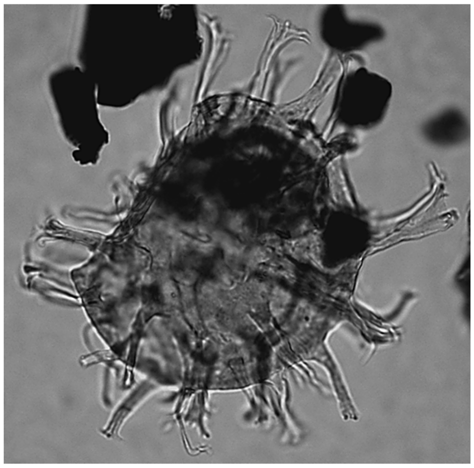
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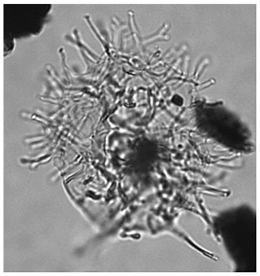
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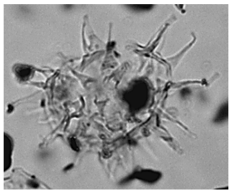
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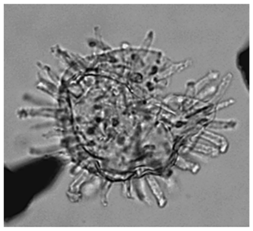
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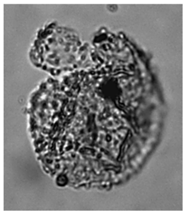
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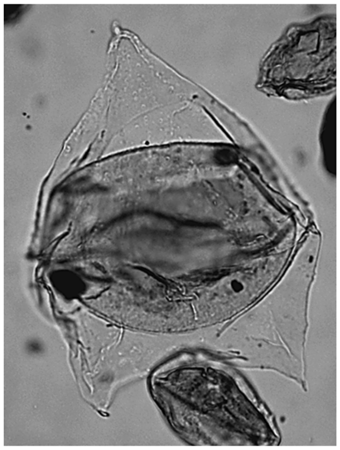
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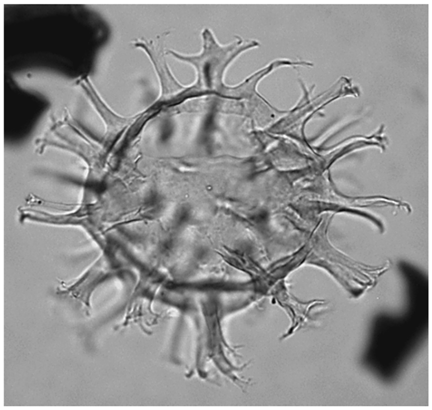
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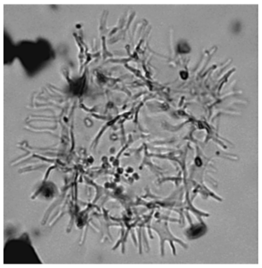
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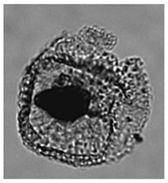
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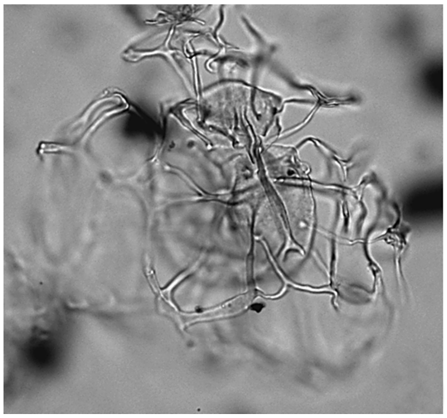
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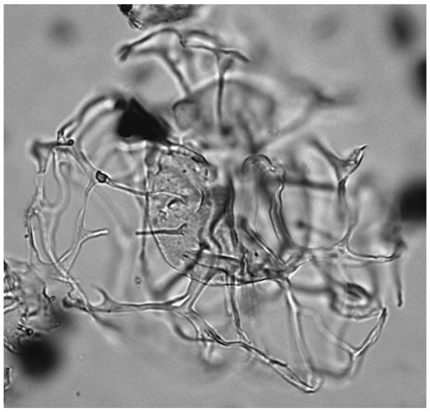
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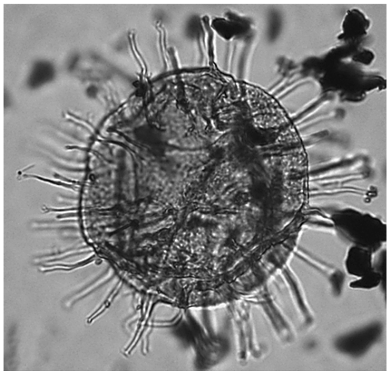
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Plate V. Dinocysts from the Paleocene deposits of the Nasypnoe section (magnification ×500 in all the figures):
(1–4) *Phthanoperidinium crenulatum*, Sample 3; (5) *Adnatosphaeridium robustum*, Sample 3; (6) *Noremia* sp., Sample 3; (7) *Melitasphaeridium pseudorecurvatum*, Sample 3; (8) *Operculodinium* sp,, Sample 3; (9, 14) *Apectodinium homomorphum*: (9) Sample 3, (14) Sample 4; (10) *Cleistosphaeridium* sp., Sample 5; (11) *Polysphaeridium zoharyi*, Sample 5; (12) *Cordosphaeridium inodes*, Sample 3; (13, 15) *Kallosphaeridium* spp., Sample 4; (16) *Deflandrea oebisfeldensis*, Sample 5; (17) *Fibrocysta axiale*, Sample 5; (18, 19) *Adnatosphaeridium vittatum*, Sample 5; (20) *Operculodinium uncinispinosum*, Sample 4.

larger fasciculiths which appeared at the base of the underlying nannofossil zone, become disappeared at the base of this interval. A bloom of warm-water discoasters in this interval is apparently an indication of considerable warming (Fig. 3). As distinct from the other sections of the northeastern Peri-Tethys (Gavrilov et al., 2003), where high abundance of discoasterids is recorded throughout the PETM interval, their peak abundance recorded in the Nasypnoe section appeared to be very short-lived. Upsection, abundance of discoasters becomes lower and they are represented mostly by “excursion species”. Contrarily, the abundance of *Rhomboaster* spp. increases upsection, reaching maximal value at the level of Sample 13 (Figs. 2 and 3), where this taxon and *Toweius* spp. represent more than 80% of the nannofossil assemblage. Evidently, this level of distinct domination of rhomboasters, where even eutrophic *Toweius* are relatively reduced in abundance, corresponds to the PETM culmination, when environmental conditions were most baneful for nannoflora, although all negatively affected factors are still poorly understood. The low abundance of calcareous dinocysts *Thoracosphaera* spp. (Fig. 2) is also noteworthy, as this group is indicative of stress environments and frequently attains high abundance in habitats unfavorable for nannoflora. Angori et al. (2007) showed that their content is relatively high in the PETM interval of pelagic sedimentary successions. This specific nannofossil assemblage remains up to the level of Sample 17 and species diversity and ratio of taxa reach pre-PETM values in the uppermost part of the section studied (Sample 18). Total nannofossil abundance persists to be relatively low at this level, that is more likely related to the beginning of sea-level fall. Species composition of nannofossil assemblage, however, differs from the precrisis nannoflora. Besides characteristic Paleocene taxa that became extinct at the PETM level, fasciculiths and *Coccolithus robustus* disappear also. In the hemipelagic settings, fasciculiths become gradually replaced by oligotrophic species *Zygrhablithus bijugatus* (Giusberti et al., 2007; Monechi and Angori, 2006; Tremolada and Bralower, 2004), which is mostly absent at the Paleocene–Eocene transition of the northeastern Peri-Tethys. It has not been found in the Nasypnoe section either. In the uppermost part of interval studied, rhomboasters decrease in abundance, but both short-arm and long-arm forms persist to be presented. The pre-crisis *Coccolithus*/*Toweius* ratio is restored here, and small *T. pertusus*/*callosus* significantly dominate among *Toweius*. The re-entry of nannofossil taxa that populated the basin before the crisis most likely indicates the post-PETM restoration of mesotrophic conditions.

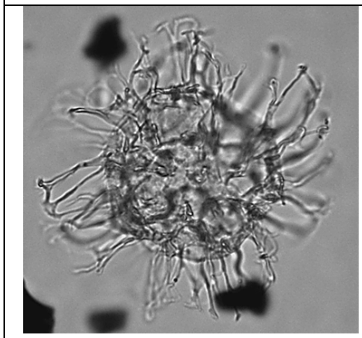
Based on the compositional variations in the nannofossil assemblages, we recognize successive stages of paleoecological changes recorded in the Paleocene–Eocene transitional beds in the section studied. The first stage showing the appearance of the largest discoasters (*D. multiradiatus*), fasciculiths and first rhomboasters corresponds to beginning of NP9 zone. First crisis in the nannofossil distribution featured by reduced abundance and diversity of nannofossils is found in the middle part of NP9. Later (upper part of NP9 zone), new nannofloral bloom occurs showing the appearance of the new genera *Pontosphaera* and *Rhabdosphaera*. This wellbeing was interrupted by a change in composition of nannoplankton communities, when many earlier existed taxa became extinct and several short-lived species appear. The range of nannofossil assemblage corresponding to the PETM covers 4 m of the section. Initial stage of this event is marked by a widespread occurrence of warm-water discoasters, whereas its culmination corresponds to the level of maximal abundance of rhomboasters. The subsequent gradual decline of rhomboasters was associated with progressing restoration of former ratios between different taxa. First indication of such a restoration is recorded already in upper part of the range of “excursion assemblage”. Thus, the PETM onset is marked in the section by dramatic compositional changes in nannofossil assemblages, whereas recovery phase appears to be very slow and gradual.

Dinocysts

The exposed lower part of the sandy-clayey sequence (samples 1 and 2) corresponds to the early Thanetian NP8 nannofossil zone (Fig. 1, Plate 2) and is characterized by occurrence of important stratigraphicaly dinocyst taxa, such as *Cerodinium speciosum, Alisocysta margarita*, and *Phthanoperidimum crenulatum* that enable the correlation of this interval to the Alisocysta margarita Zone of the West European dinocyst zonation (Powell, 1992; Powell et al., 1996) and Zone DP2b recognized in the Crimea (Andreeva-Grigorovich and Shevchenko, 2007). The composition of dinocyst assemblage is similar to that from the Pegwell Marls in the lower part of the Thanet Sand Formation at the 26N Chron (Powell et al., 1996).

In Sample 3, first occurrence (FO) of *Apectodinium homomorphum* is defined. This species marks lower boundary of the Apectodinium hyperacanthum Zone

Plate VI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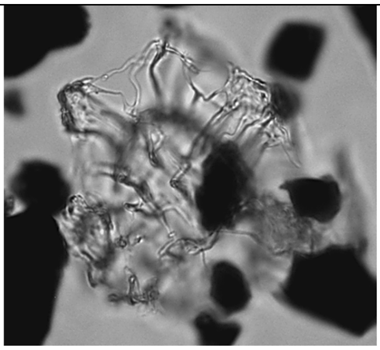
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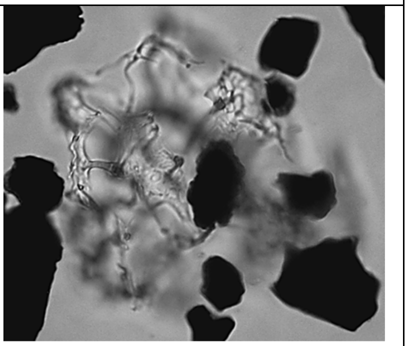
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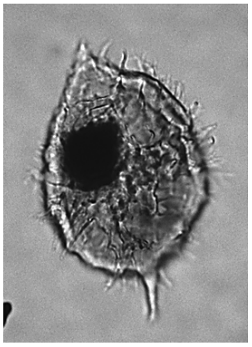
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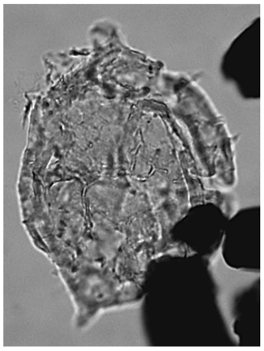
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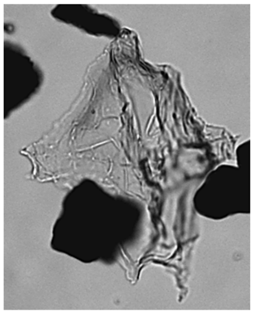
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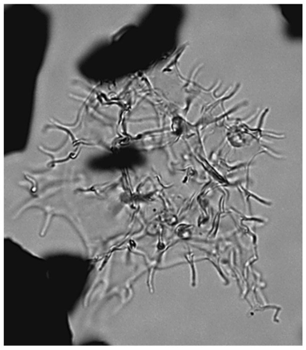
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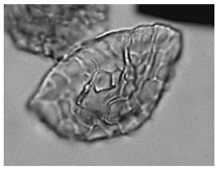
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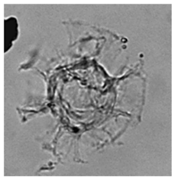
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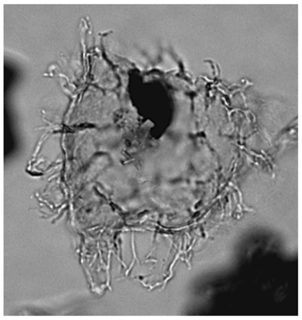
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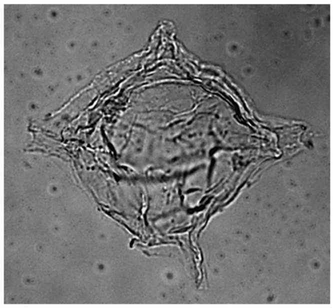
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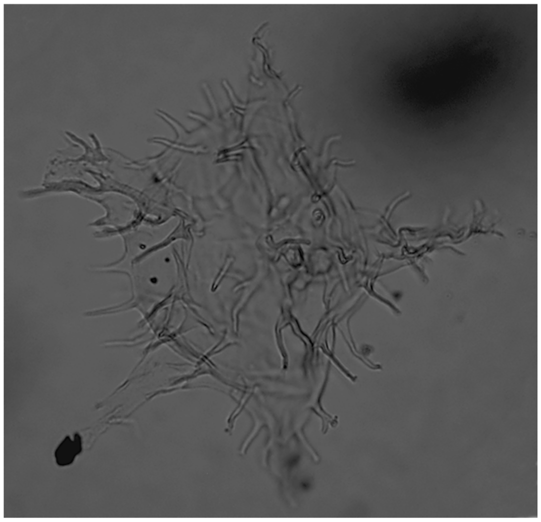
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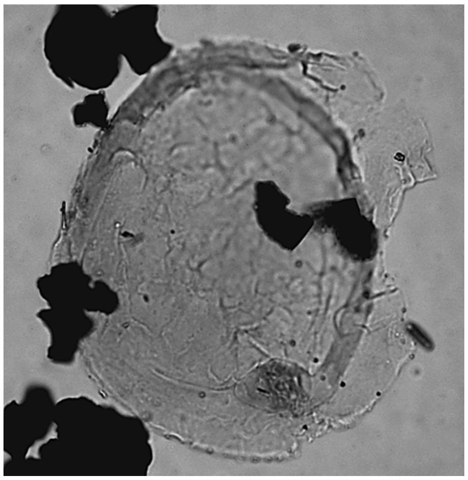
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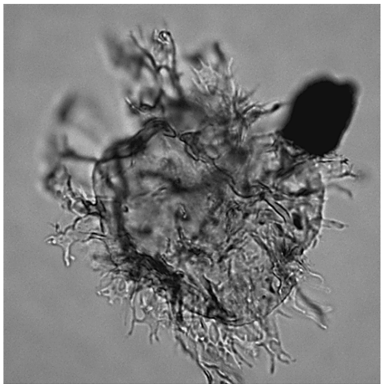
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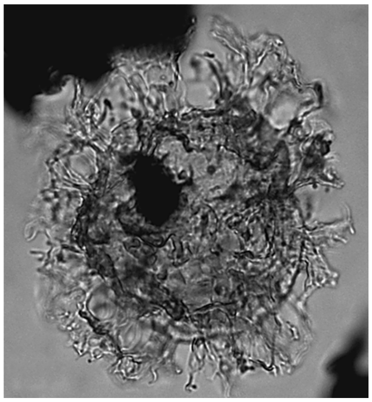
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Plate VI. Dinocysts from the Paleocene–lower Eocene deposits of the Nasypnoe section (magnification ×500 in all the figures): (1–3) *Adnatosphaeridium* sp. 1: (1) Sample 6; (2, 3) Sample 7; (4) *Lanternosphaeridium lanosum*, Sample 7; (5) aff. *Kenleya* sp., Sample 8; (6, 12) *Wilsonidium pechoricum*: (6) Sample 7, (12) Sample 16; (7) *Apectodinium quinquelatum*, Sample 7; (8) *Batiacasphaera* sp, Sample 10; (9) *Schizosporis reticulatus*, Sample 7; (10) *Reticulatosphaera actinocoronata*, Sample 10; (11, 15, 16) *Glaphyrocysta–Areoligera-group*, Sample 8; (13) *Apectodinium augustum*, Sample 9; (14) Gen sp. indet 1 sensu Heilmann-Clausen et Costa, 1989, Sample 17.

in West European sections (Powell, 1992; Powell et al., 1996), DP3 zone in Crimea (Andreeva-Grigorovich and Shevchenko, 2007), standard D4c zone (Luterbacher et al., 2004), Viborg 5 zone in Denmark (Heilmann-Clausen, 1994), and DP6a subzone of the North Sea (Mudge and Bujak, 1996). In the Nasypnoe section, this zone correlates to the late Thanetian NP9 zone and span interval from Sample 3 to Sample 7. Besides the FO of zonal marker, FOs of *Adnatosphaeridium vittatum*, *A.* sp. 1., *Diphyes colligerum, Hystrichokolpoma* sp., and *Operculodinium severinii* are recorded in this interval. Dinocyst assemblage of lower part of this interval is characterized by significant amount of *Spiniferites* spp. and *Achomosphaera* spp., but upward the give the way to different species of *Apectodinium* genus and *Deflandrea oebisfeldensis.* Diversity and abundance of *Apectodinium* increase upsection reaching 20% at the top of this zone. The FO of *Wilsonidium pechoricum* is found in Sample 7. Single redeposited Cretaceous spores and pollen and rare dinocysts are observed. The maximum abundance of redeposited palynomorphs (10%) is detected at the base of A. hyperacanthum zone.

The higher interval of the section (samples 8-17) corresponds to the Apectodinium augustum zone correlated to the early Eocene NP10 nannofossil zone. The dinocyst zone ranges from the FO of *Apectodinium augustum* (Sample 9) to the last occurrence (LO) of this species (Sample 17) and corresponds to the *Apectodinium* acme. Despite the absence of marker species in the Sample 8, abundance of *Apectodinium* exceeds 30% in the dinocyst assemblage that means the onset of the *Apectodinium* acme and can be considered as a criterion defining lower boundary of the relevant zone (Heilmann-Clausen, 1985). In this section, *Apectodinium augustum* range cover interval between Samples 9 and 17. Recent study in different world regions showed that FO of *A. augustum* and *Apectodinium* acme are associated with the negative carbon isotope excursion (CIE) related to the PETM and defining the Paleocene–Eocene boundary (Crouch et al., 2001, 2003; Luterbacher et al., 2004; Aubry et al., 2007).

Considerable peak of abundance of *Areoligera* spp. (49%) and *Glaphyrocysta* spp. is detected in the Sample 8 and another abundance peak of these taxa (33%) is found in the Sample 12. Within Apectodinium augustum zone, FOs of *Fibrocysta* essentialis, *Polysphaeridium* cf. *zoharyi*, *Adnatosphaeridium multispinosum, A. reticulense, A. robustum*, and Kenleya-group (*Kenleya* cf. *pachycerata*, aff. *Kenleya* sp., *Muratodinium fimbriatum, Lanternosphaeridium lanosum*) are recorded. Appearance of these taxa in the same zone is typical in sections of different regions of Asia and Europe (Iakovleva et al., 2001; Crouch et al., 2003; Iakovleva and Heilmann-Clausen, 2007).

Diversity of dinocysts decreases in Sample 18, abundance of *Apectodinium* spp. consists 23% and diverse *Spiniferites* species become to dominate that makes this assemblage similar to late Thanetian one. It is noteworthy that dinocyst assemblages recognized above the Paleocene–Eocene transition in different regions varies in composition and stratigraphic range that more likely reflects specific hydrological regimes of the basins. In most basins, a regressive episode (erosion and/or change in lithology) is detected. For instance, Zone E1 established in the North Sea sediments above the A. augustum Zone corresponds to the *D. oebisfeldensis/Glaphyrocysta ordinata* peak and characterizes the so-called North Sea biotic crisis (Mudge and Bujak, 1996). Similar distribution pattern of dinocysts has been observed in sections of the London basin (Powell et al., 1996), Volga regions (Aleksandrova and Radionova, 2006), and the Trans-Urals (Vasil'eva, 2000). As dinocys assemblage of Nasypnoe section is not similar to any known from other areas, we can provisionally only correlate this interval to the Hystrichosphaeridium tubiferum Zone (E1) of the North Sea (Bujak and Mudge, 1994).

The ratio of different palynomorph groups varies throughout the section (Figs. 4 and 5). The palynospectra of the lowermost Alisocysta margarita zone (samples 1 and 2) are dominated by dinocysts (about 80%) including the diverse *Spiniferites*, representing 56% of all dinocysts, and other goniaulacoid taxa that is characteristic of neritic open marine habitats. Significant amount of *Incertae sedis* sp. 1 sensu Heilmann-Clausen, 1985 (9%) is found in the Sample 1 that most likely suggests fresh water input into surface water of the basin.

The upper Thanetian deposits of the Apectodinium hyperacanthum Zone (samples 3-7), shows a gradual increase in abundance of spores and pollen of higher plants with their maximum concentration at the uppermost part of this interval (43%; Sample 7). Abundance of heterotrophic taxa (*Apectodinium* spp., Deflandrea-group) and green algae accepted as indicators of lowered salinity and nutrient-rich environment (Sluijs et al., 2005) increases simultaneously. Goniaulacoid dinoflagellate cysts show a general decline accompanied by an increase in the abundance of *Operculodinium* spp. and Cordosphaeridium-group indicating relatively shallower habitats. Progressing growth in abundance of subtropical *Apectodinium* genus characterizes the late Thanetian warming (Brinkhuis et al., 1994). Among spores and pollen of higher plants, spores and angiosperm pollen quantitatively predominate with gymnosperm pollen being less frequent. Abundance ratios of this kind among the terrestrial palynomorphs suggest a lowland character of landscapes in surrounding land areas. Hence, the dynamics of changes in palynomorph assemblage from the base upward in the section evidence a successive shallowing of the basin during accumulation of the late Thanetian sediments and lowering of the base level of erosion in adjacent land.

In the Apectodinium augustum Zone (Sample 8) corresponding to the PETM onset, important biotic turnover is recorded, and dinocysts again represent more than 80% of all palynomorphs. In greater part of this zone (samples 8-15), dinocyst ecogroups are of variable composition and characterize unstable hydrological conditions during sedimentation. Prevailing heterotrophic taxa belong to the genera *Apectodinium* and *Deflandrea*, *Wilsonidium pechoricum*, and new, constantly occurring Kenleya-ecogroups. The *Apectodinium* peak has been regarded as interrelated not only with higher temperature, but also with considerably higher concentration of nutrients in seawater (Powell et al., 1996; Crouch et al., 2001, 2003; Brinkhuis et al., 2006). It is acknowledged as well that dinocysts of this genus are tolerant to significant salinity fluctuations, because their peak is recorded in sediments deposited in basins with lowered salinity and in open oceans. The high specific diversity of the genus and the *Apectodinium* peak indicate a highstand (Sluijs et al., 2007).

In deposits of the Apectodinium augustum Zone, the relative abundances of *Spiniferites* and *Cordosphaeridium* neritic groups are comparatively low suggesting that they accumulated in proximity to the coastline during the PETM.

In the PETM epoch, the most distinct changes are recorded in the Deflandrea-group. The Areoligera-ecogroup of presumably photosynthetic dinocysts dominating in basal part of Apectodinium augustum zone (Sample 8) is suggested to be indicator of high-energy coastal habitats (Powell et al., 1996) and evidences the transgressive pulse the PETM onset. A comparable situation has been described from New Zealand, where Crouch et al. (2003) studied dinocysts from the CIE interval of the Tawanui section and interpreted the high relative abundance of *Glaphyrocysta* as a result of taxa transportation from the inner neritic zone of the basin. However, highly abundant Areoligera-group (Fig. 5) oppressed mainly heterotrophic dinocysts (*Apectodinium* spp., Deflandrea-group, *Wilsonidium pechoricum*) that is difficult to explain exceptionally by taxa transportation from neritic zone of the basin. Another peak of the Areoligera-group abundance (33%) and simultaneous high relative abundance (13%) of green algae and acanthomorphic acritarchs are recorded in Sample 12 that enable to suggest two transgression phases across the PETM transition in the Eastern Crimea.

A high relative abundance of Operculodinium-group (18.5%) in the Sample 15 which indicates shallower environment, can suggest reative shoaling.

Spores prevailing among palynomorphs of higher plants and low content of angiosperm and gymnosperm pollen suggesting widespread swamp areas on the surrounding land at the time of the Paleocene–Eocene transition.

Palynomorph assemblages from uppermost samples 16 to 18 suggest accumulation in normal marine conditions of a shelf platform.

CONCLUSIONS

Our study of nannofossils and dinocysts from the Paleocene–Eocene transition of Nasypnoe section revealed the occurrence of sediments accumulated during the global biotic crisis associated with PETM. The distribution of the “excursion taxa” of both microplanktonic groups and fluctuations in their relative abundance in the interval from Sample 7 to Sample 17 and suggest that this part of section corresponds to the PETM. Despite some difference between environmental trends inferred from analysis of nannofossil and dinocyst variations, several successive stages in the basin development can be recognized (Fig. 6).

Sediments of lower part of the sandy-clayey sequence (NP8 and Alisocysta margarita zones) were accumulated in neritic settings of a relatively cool mesotrophic basin populated by relatively abundant nannoflora and dinoflagellates communities.

In basal sediments of the NP9 and Apectodinium hyperacanthum zones, significant changes in composition of both microphytoplankton groups are defined. Within the upper Thanetian interval, abundance and diversity of dinocysts representing the warm-water heterotrophic genus *Apectodinium* increase upsection and suggest eutrophication and warming in the basin during this epoch. While the changes in palynomorph assemblages of the pre-PETM interval show a stable trend of gradual sea level fall with the regression maximum near the upper zonal boundaries, the nannofossil variations seems to be more complex.

Below the PETM interval there are two levels of increased abundance and diversification of nannofossils with intervening episode of a sharp decline in abundance and diversity (Sample 4) that most likely indicates drastic sea level fall. In the dinocyst assemblages, extremely low content of Deflandrea-group only corresponds to this nannofossil event. This scenario of dynamics in nannoplankton evolution differs

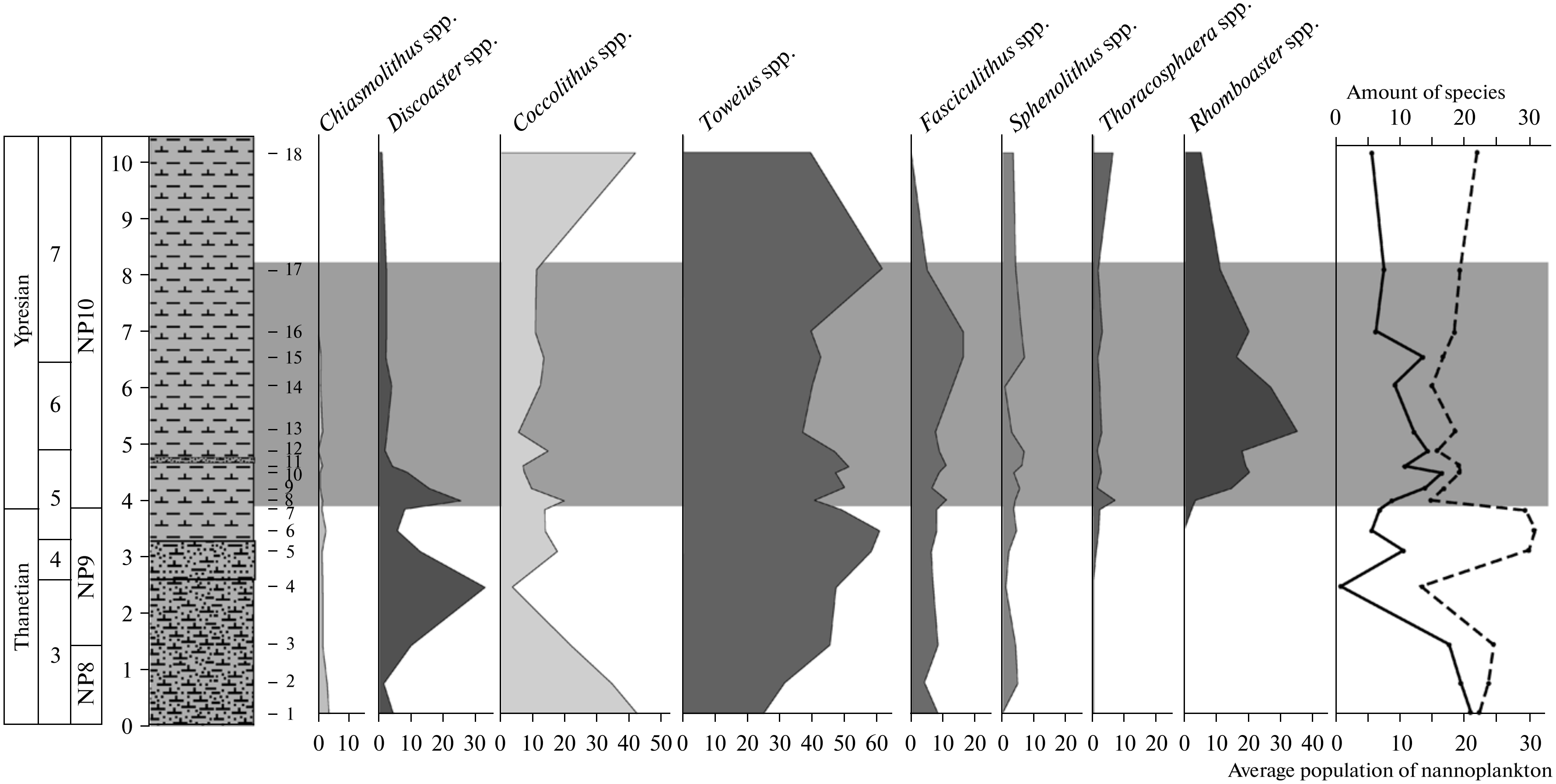

Fig. 2. Variations in relative abundances of nannoplankton taxa representing different paleoecological groups and in total amount of species (dashed line) and their average content (solid line) counted in 50 microscope's fields of view 0.2 μm in diameter. Taxa regarded as paleoecological markers are cool-water *Chiasmolithus* spp.; warm-water *Discoaster* spp.; eurytopic cosmopolitan *Coccolithus* spp.; eutrophic *Toweius* spp. and *Fasciculithus* spp.; warm-water oligotrophic *Sphenolithus* spp.; *Thoracosphaera* spp. indicative of unfavorable conditions; and short-lived *Rhomboaster* spp. specific of the PETM and originated at that time. Symbols for lithology as in Fig. 1.

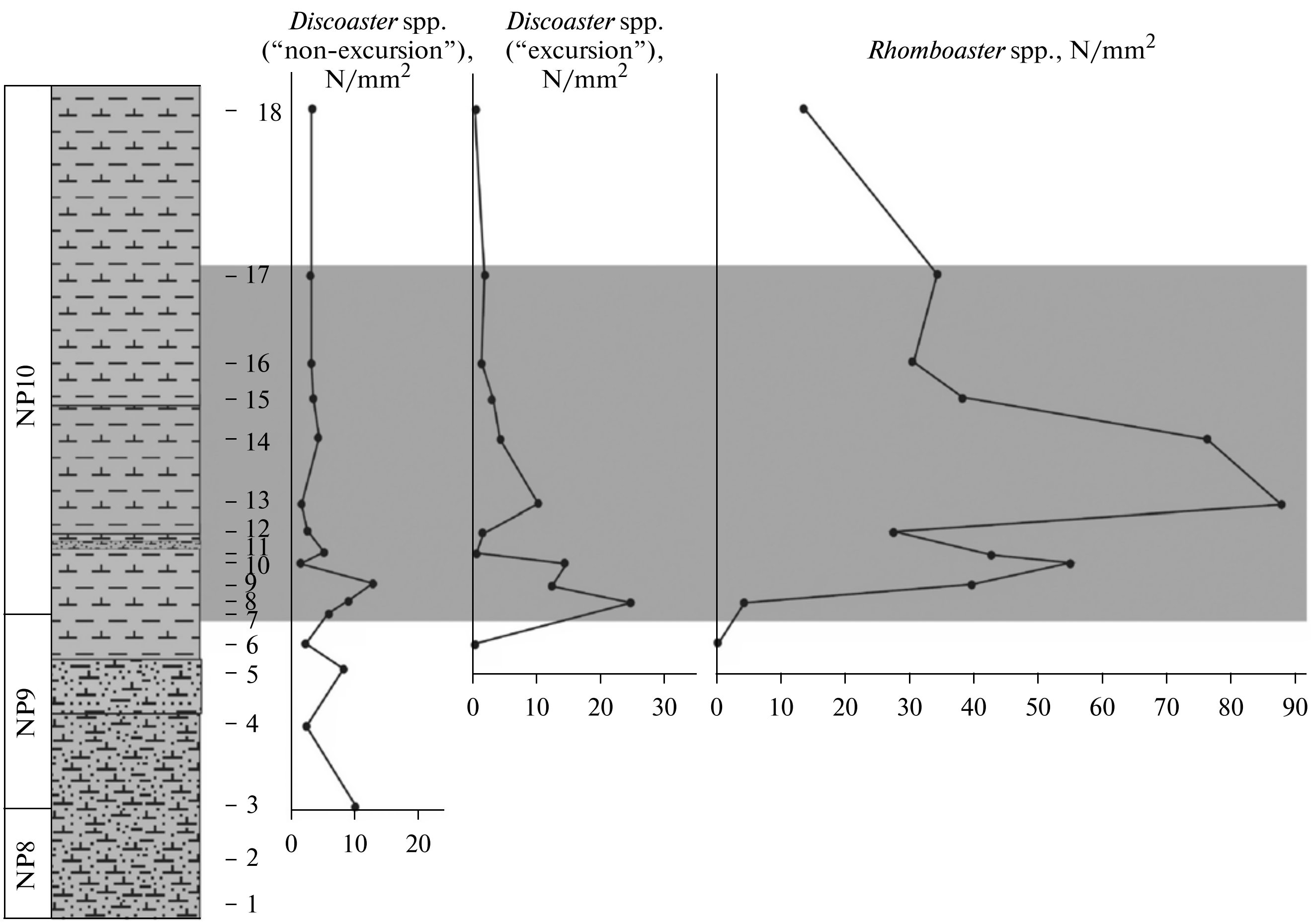

Fig. 3. Variations in abundance (amount of specimens per 1 mm^2 of preparation) of "non-excursion" *Discoaster multiradiatus, D. falcatus, D. splendidus, D. mediosus*, and "excursion" *Discoaster anartios, D. araneus* and *Rhomboaster* spp. Symbols for lithology as in Fig. 1.

from the eustatic trend established in the eastern regions of the northeastern Peri-Tethys (Caucasus and Central Asia), where sea level fall immediately predates the deposition of the corresponding to PETM sapropelitic horizon. In the Nasypnoe section, the regression episode and biotic crisis are separated by a considerable time span, when changes in composition of nannofossil assemblages were associated with appearance of new genera *Pontosphaera* and *Rhabdosphaera* which correspond to the PETM interval in other sections. This can be explained by the much greater thickness of the PETM deposits in the Nasypnoe section accumulated under conditions of enhanced influx of siliciclastics. On the other hand, this discrepancy might be explained by the presence of two short-term regressive pulses, which could be recognized in this shallow-water section only.

Sediments of the PETM interval accumulated during distinct transgression with two episodes of the basin deepening that is consistent with the scenario of the accumulation of organic-rich deposits in the northeastern Peri-Tethys (Gavrilov and Shcherbinina, 2004). In the Nasypnoe section, deposits of this interval contains all taxa, which are characteristic of nannofossil and dinocysts assemblages from the PETM record in the Peri-Tethys and other regions of the World. These are the short-lived "excursion" species of nannofossils *Rhomboaster* spp., asymmetric *Discoaster anartios, D. araneus,* and dinocysts of the subtropical genus *Apectodinium*, including its species *A. augustum* which is typical for this event. The warm-water dinocysts dominating the assemblage across the PETM interval imply a considerable warming in the basin, but a low relative abundance of discoasters remains poorly understood. A high abundance of eutrophic and stress species most likely suggest an excessive influx of nutrients into the basin, which produced negative impact on most nannoplankton and dinoflagellate taxa.

The restoration of biota after the crisis was gradual and nannofossils remain to be of low abundance that can indicate shallow depth of the basin after PETM

Table 1. Distribution and abundance rates of principal nannoplankton species in the Nasypnoe section

Nannoplankton zones	NP8		NP9					NP10										
Sample nos.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Chiasmolithus bidens	f	f	f		f	f	f	f	f	f		f	f	f				f
C. eograndis	f		f			f												
Coccolithus pelagicus	c	c	f	f	f	r	r	f	f	f	r	f	f	f	f	f	f	c
C. robustus	f	r	r	f	f	f					f							
Discoaster mohleri	f						f								f			
Fasciculithus aubertae	f				f	f	f	f	f	f	f	f	f	f	f	f	f	
F. involutus	f	f		f		f	f							f		f		
F. tympaniformis	f	f	f	f		f	f	f	f	f	f			f	f	f		f
Heliolithus kleinpellii	f	f				f												
H. riedelii	f	f				f	f											
Neochiastozygus concinnus	f	f				f	f						f					f
Prinsius martinii	r	f	f	f	f	f		f										
Sphenolithus primus	f	f	f	f	r	r	f	f	r	f	f	f	f	f	f	f	f	f
Toweius eminens	f	f	f	f	f	f	f											
T. occultatus	f	f	f		f	f											f	f
T. pertusus	f	f	f	f	c	r	c	c	c	c	c	c	c	c	c	r	f	f
Discoaster falcatus	f	f	f	f	f	f	f									f	f	f
Ellipsolithus distichus		f		f	f	f	f										f	
Lophodolithus nacens		f	f			f	f											f
N. chiastius		f	f		f											f	f	f
Toweius occultatus		f	f			r	f					f	f				f	f
D. multiradiatus			r	f	f	f	f	f	r	f	f	f	f	f	f	f		
Discoaster splendidus			f		f		f										f	
Fasciculithus alanii			f		f						f							
F. richardii			f		f	f	f											
F. sidereus			f				f				f	f						
F. schaubii			f			f												
F. thomasii			f		f	f												
Toweius tovae			f	f	f	f	f											f
Chiasmolithus consuetus					f	f	f				f			f				
Discoaster lenticularis					f	f	f						f	f				
D. salisburgensis					f													
Ellipsolithus macellus					f	f	f							f	f	f	f	
Neochiastozygus distentus					f		f		f	f	f	f						
Pontosphaera plana					f													
Rhabdosphaera sola					f	f	f					f	f		f	f	f	
Scapholithus apertus					f	f	f											
Zygodiscus herlynii					f	f	f										f	
Chiasmolithus titus					f	f					f	f				f		f
Toweius serotinus					f	f					f	f	f				f	f
Neochiastozygus junctus					f	f	f		f	f	f	f	f	f	f	f	f	f
Hornibrookina arca						f	f											f
Neochiastozygus concinnus						f	f											r
Campylosphaera eodela						f								f	f			f
Rhomboaster intermedia						f	f											
R. bramlettei								f	f	f	f	f	r	f	f	f	f	f
D. anartios								r	r	f	f		f		f			
D. araneus								f	r	f		f					f	
D. cf. *mahmoudii*								f	f	f	f		f		f			
Rhomboaster calcitrapa								f	r	c	c	r	c	r	r	f	f	f
R. spineus								f					f	f				
R. cuspis									f	f					f	f		f
Transversopontis pulcher									f	f	f		f		f	f	f	r

Note: (f) few (1 to 10 specimens per a mount; (r) rare (1 specimen at least in every second field of view); (c) crowded (up to 5 specimens in every field of view).

Table 2. Distribution and amount of palynomorphs in the Nasypnoe section

Taxa / **Sample nos.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Achomosphaera spp.	32	14	27	33	23	32	10	2	7	8	13		7	6	5	5	20	7
Spiniferites spp.	208	71	114	74	58	52	37	4	28	29	39	43	35	48	35	19	61	77
Cordosphaeridium divergense Eisenack, 1963	7	3	12	4	4	2	5		3	1								
Cordosphaeridium inodes (Klumpp) Eisenack, 1963	10	6	8	11	2	6			3	2	1		3	2	3		6	5
Cordosphaeridium fibrospinosum Davey et Williams, 1966	3	1																
Cordosphaeridium gracile (Eis.) Davey et Williams, 1966	4	1	3	1	2		1											1
Oligosphaeridium complex (White) Davey et Williams, 1966	4																	
Connextimura fimbriata (Morgenroth) May, 1980	2		1				2											
Hafniasphaera septata (Cook. et Eis.) Hansen, 1977	15	5	2	10							2						6	2
Glaphyrocysta cf. ordinata (Dav. et Will.) Stover et Evitt, 1978	4	4																
Glaphyrocysta sp.	1																	
Areoligera senonensis Lejeune-Carpentier, 1938	4	1																
Areoligera gippigensis Jolley, 1992	1																	
Areoligera sp.	5	1				1												
Alisocysta margarita Harland, 1979	5	7	1	2														
Alisocysta sp. 2 sensu Heilmann-Clausen, 1985	3					1	1											
Diphyes spinulum (Drugg) Stover et Evitt, 1978	15	3																
Diphyes sp.	2																	
Batiacasphaera sphaerica Stover, 1977	7	3																
Batiacasphaera sp.	23	4	7															
?*Surculosphaeridium* sp.	3																	
Paralecaniella indentata (Defl. et Cook.) Cook. et Eis., 1970	2		1		2	1				1								
Operculodinium uncinispinosum (de Coninck) Islam, 1983	9	2	16	16								7	5	12	8	17	9	11
Impagidinuim sp. 1 sensu Heilmann-Clausen, 1985	3	6																
Cometodinium? *comatum* Srivastava, 1984	11	4			8						1					1	1	
Melitasphaeridium pseudorecurvatum (Morgenr.) Bujak, 1980	6	7	6	6	2					1		1						
Cerodinium speciosum (Alberti) Lent. et Will., 1987	5	15	1															
Incertae sedis sp. 1 sensu Heilmann-Clausen, 1985	42	2																
indetermined chorate cysts	8	8	9	12			7		27	19	8							
Palaeotetradinium minusculum (Alberti) Stover et Evitt, 1978	1				2	1												1
Elytrocysta brevis Stover et Handerbol, 1994	3	2		12	2	1												

Table 2. (Contd.)

Taxa / **Sample nos.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Caligodinium amiculum Drugg, 1970	1																	
Kallosphaeridium brevibarbatum de Coninck, 1969	1	2		1		5	6	1	6	1	4	1	1	1	1	1	3	4
Cyclonephelium sp.	1																	
Cribroperidinium sp.	2				1		2				1	1					1	2
Hystrichosphaeridium tubiferum (Ehrenberg) Deflandre, 1937	3	3		5		1			1	3	2	1					2	3
Spinidinium densispinatum Stanley, 1965	1																	
Phthanoperidinium crenulatum (de Conin.) Lent. et Will., 1977	1	2	6	4	7	1	1	2		1		1				1		2
Phthanoperidinium paleocenicum Lucas-Clark, 2006		1																
Spinidinium echinoideum (Cook. et Eis.) Lent. et Will., 1976		3	4	5														
Thalassiphora pelagica (Eis.) Eisenack et Gocht, 1960		1					1											
Thalassiphora delicata Williams et Downie, 1966		3	12	1														
?*Cerebrocysta* sp.		3	5	4			1											
Cladopyxidium saeptum (Morgenr.) Stover et Evitt, 1978		1			1													
Areoligera coronata (Wetzel) Lejeune-Carpentier, 1938		1																
Operculodinium centrocarpum (Defl. et Cook.) Wall, 1967		1			6	17			22	2	5	1	4	7	21		10	10
Trigonopyxidia ginella (Cook. et Eis.) Down. et Sarjeant, 1965		1														1		
Alisocysta sp.		1																
Apectodinium homomorphum (Defl. et Cook.) Lent. et Will., 1977			3	8	35	16	6	1	76	18	29	24	32	49	22	41	43	23
Deflandrea oebisfeldensis Alberti, 1959			2	4	21	41	6	1	19	3	10	9	5	20	2	18	17	15
Deflandrea sp.			2			5	4						1					
Florentinia ferox (Deflandre) Duxbury, 1980			2															
Cribroperidinium wetzelii (Lejeune-Carpentier) Helenes, 1984			1														1	
Cordosphaeridium sp.			1		1	4	1		7								1	1
Areoligera cf. *senonensis* Lejeune-Carpentier, 1938			3	2													7	1
Spinidinium sp.			1															
Polysphaeridium cf. *subtile* Davey et Williams, 1966			2	1														
Diphyes cf. *appendiculare* Cookson et Eisenack, 1970			1															
Adnatosphaeridium vittatum Williams et Downie, 1966			3	13	2	2	3		1									3
Impagidinium cf. *velorum* Bujak, 1984			2	1			1											
Palaeocystodinium golzowense Alberti, 1961			1															
Senegalinium sp.			1															

Table 2. (Contd.)

Sample nos. Taxa	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Cerodinium diebelii (Alberti) Lentin et Williams, 1987			1															
Cerodinium sp.			5											2	1		1	
Apectodinium parvum (Alberti) Lentin et Williams, 1977				1	1			4	29	14	20	5	10	8	4	6	4	1
Apectodinium quinquilatum (Will. et Down.) Costa et Downie, 1979				1	9	5	6	2	3		3			4	9	8	15	1
Apectodinium sp.				3	19	12	19	33	34	29	38	18	41	35	23	29	56	20
Adnatosphaeridium sp. 1				1		1	3	1	3		7		4		2	7	4	1
Adnatosphaeridium robustum (Morgenroth) de Coninck, 1975				1							1	6		4	1	1		
Cribroperidinium cf. *tenuitabulatum* (Gerlach) Helenes, 1984				2														
Hystrichokolpoma sp.				1	1				2					1				
Operculodinium severinii (Cook. et Cranwell) Islam, 1983				1					2		1		1	3	1	3	2	
Diphyes colligerum (Defl. et Cook.) Cookson, 1965				5	5	2	1		1		1		2		3	5		3
Glaphyrocysta pastielsii (Defl. et Cook.) Stover et Evitt, 1978				1		1												
Glaphyrocysta cf. *vicina* (Eaton) Stover et Evitt, 1978				1														
Lingulodinium machaerophorum (Defl. et Cook.) Wall, 1967				1		4	4								1		2	
Kallosphaeridium capulatum Stover, 1977				3														
Cordosphaeridium exilimurum Davey et Williams, 1966				1						1								
Apectodinium hyperacanthum (Cook. et Eis.) Lent. et Will., 1977					4	3	4	11	11	10	17	13	17	16	13	9	12	5
Cerodinium speciosum glabrum (Gocht) Lent. et Will., 1987					8	2			1					1		1	5	
Operculodinium microtrianum (Klumpp) Islam, 1983					7		5		15	10	3		4	2	4	4		
Operculodinium sp.					2		11							6	8		2	5
Impagidinium sp.					1			1	8		3	2		1				3
Lentinia wetzelii (Morgenroth) Bujak in Bujak et al., 1980					2				1			8		1	3	2	3	
Senegalinium obscurum (Drugg) Stover et Evitt, 1978					1									10	2	11	2	7
Cleistosphaeridium sp.					1									1				
Kallosphaeridium sp.					3	2			3									2
Wilsonidium pechoricum Iakovleva et Heilm.-Clausen, 2007					4		2			1	2	1	5	19	1	19	24	2
Apectodinium paniculatum (Costa et Down.) Lent. et Will., 1977						10	7										5	3
Hystrichokolpoma cf. *unispinum* Williams et Downie, 1966						1	1				3							
Cordosphaeridium fibrospinosum Davey et Williams, 1966						2											2	1
Rottnestia borussica (Eisenack) Cookson et Eisenack, 1961						1	1		3				1					
Reticulosphaera actinocoronata (Bened.) Bujak et Matsuoka, 1986						1				2	8	4	6	3	4			

Table 2. (Contd.)

Taxa / Sample nos.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Hafniasphaera fluens Hansen, 1977						5	4											
Polysphaeridium sp.						1	1	1										
Hystrichokolpoma cf. *salacia* Eaton, 1976							1	1	4		1	3	3	2	4		2	
Hystrichosphaeropsis cf. *ovum* Deflandre, 1935							1			1	4	2	1	1	2		1	
Membranosphaera sp.							1											
Glaphyrocysta – *Areoligera* group							31	64	40	39	67	88	49	6	42	2	9	
Fibrocysta vectensis (Eaton) Stover et Evitt, 1978							3		2									
aff. *Kenleya* sp.								3	3	5	4		2	5	2	1	1	1
Lanternosphaeridium lanosum Morgenroth, 1966								1	13	7	2		1		2	1		
Apectodinium augustum (Harland) Lent. et Will., 1981									6	5	1	3	2	1	1	3	10	
Kenleya cf. *pachycerata* Cookson et Eisenack, 1965									4	1								
aff. *Wilsonidium pechoricum* Iakovleva et Heilm.-Clausen, 2007									2									
Muratodinium fimbriatum (Cookson et Eisenack) Drugg, 1970									1		2	5	1	5	1	4		1
Adnatosphaeridium multispinosum Williams et Downie, 1966									1									
Palaeoperidinium sp.									2									
Cribroperidinium tenuitabulatum (Gerlach) Helenes, 1984									3	3				2				
Deflandrea denticulata Alberti, 1959										1								
Melitasphaeridium asterium (Eaton) Bujak et al., 1980											1							
Fibrocysta essentialis (de Coninck) Brinkhuis et Zachariasse, 1988											5	2	1	1			2	
Impagidinium cornutum Matsuaka et Bujak, 1988											1							
Leiosphaeridia sp.											1							
aff. *Batiacasphaera* sp.											17	20			12			
Impletosphaeridium sp.												4	9	2	1	1		
Polysphaeridium cf. *zohary* (Rossignol) Bujak et al., 1980												4	4	6	2	8		1
Apteodinium sp.												1	1					
Cribroperidinium sp. A sensu Crouch, 2003													2					
Hafniasphaera graciosa Hansen, 1977														1				
Gen. sp. Indet. 1 sensu Heilmann-Clausen et Costa, 1989														2	2	2	25	
Areoligera cf. *coronata* (Wetz.) Lejeune-Carpentier, 1938																1		
Thalassiphora spinifera (Cook. et Eis.) Stover et Evitt, 1978																2		
Hystrichokolpoma cf. *rigaudiae* Deflandre et Cookson, 1955																1		

Table 2. (Contd.)

Taxa / Sample nos.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Adnatosphaeridium reticulense (Pastiels) de Coninck, 1969																1		
Sum	459	195	269	257	247	248	208	141	406	228	339	290	273	310	263	252	394	243
Prasinophytes, acritarchs, and other palynomorphs																		
Acantamorh acritarchs			6	5							12	26	14		12	10		6
Mycrhystridium sp.	2				1													
Horologinella incurvata Cookson et Eisenack, 1962	1			1			2			1								
Fromea laevigata (Jiabo) Lent. et Will., 1981			1	1														
Fromea fragilis (Cook. et Eis.) Stover et Evitt, 1978				2			1											
Palambages sp.	2		1										1			1		
Green algae	5	6	21	33		25	24	4				21	6	2	12			
Tasmanites sp.						1							3					
Spirogyra sp.								2	14		1	1	3		1			
Pterospermella sp.					4			1									1	
Noremia sp.											6					3		
Leiosphaeridia sp.											1							
Scolecodonts			1	1														
Microforaminiferal linings			4															
Sum	10	6	34	43		26	27	7	14	1	20	48	27	2	25	14	1	6
Spores and pollen of higher plants																		
Spores	26	10	27	68	111	61	58	5	33	22	34	37	36	21	32	23	44	33
Pollen of gymnosperm	46	30	66	55	118	67	88	2	5	7	1	12	14	5	4	7	11	24
Pollen of angiosperm	15	3	9	49	80	48	37	9	8	19	21	10	18	6	7	4	6	7
Sum	87	43	102	172	309	176	183	16	46	48	56	59	68	32	43	34	61	64
Redeposited palynomorphs																		
Spores and pollen of higher plants	14	7	36	14	5	15	19		7	10	3			2				
Litosphaeridium arundum (Eis. et Cook.) Davey, 1979	1																	
Cribroperidinium muderogense (Cook. et Eis.) Davey, 1969	1			1		1	1											
Trithyrodinium sp.	1																	
Leberidocysta sp.	1																	
Aptea sp.		1																
Alterbidinium acutulum (Wilson) Lent. et Will., 1985			1															
Oligosphaeridium asterigerum (Gocht) Davey et Will., 1969							1											
Gonyaulacacysta sp.							1											
Odontochitina operculata (Wetzel) Defl. et Cook., 1955													1					
Sum	18	8	37	15	5	16	22	0	7	10	3	0	1	2	0	0	0	0

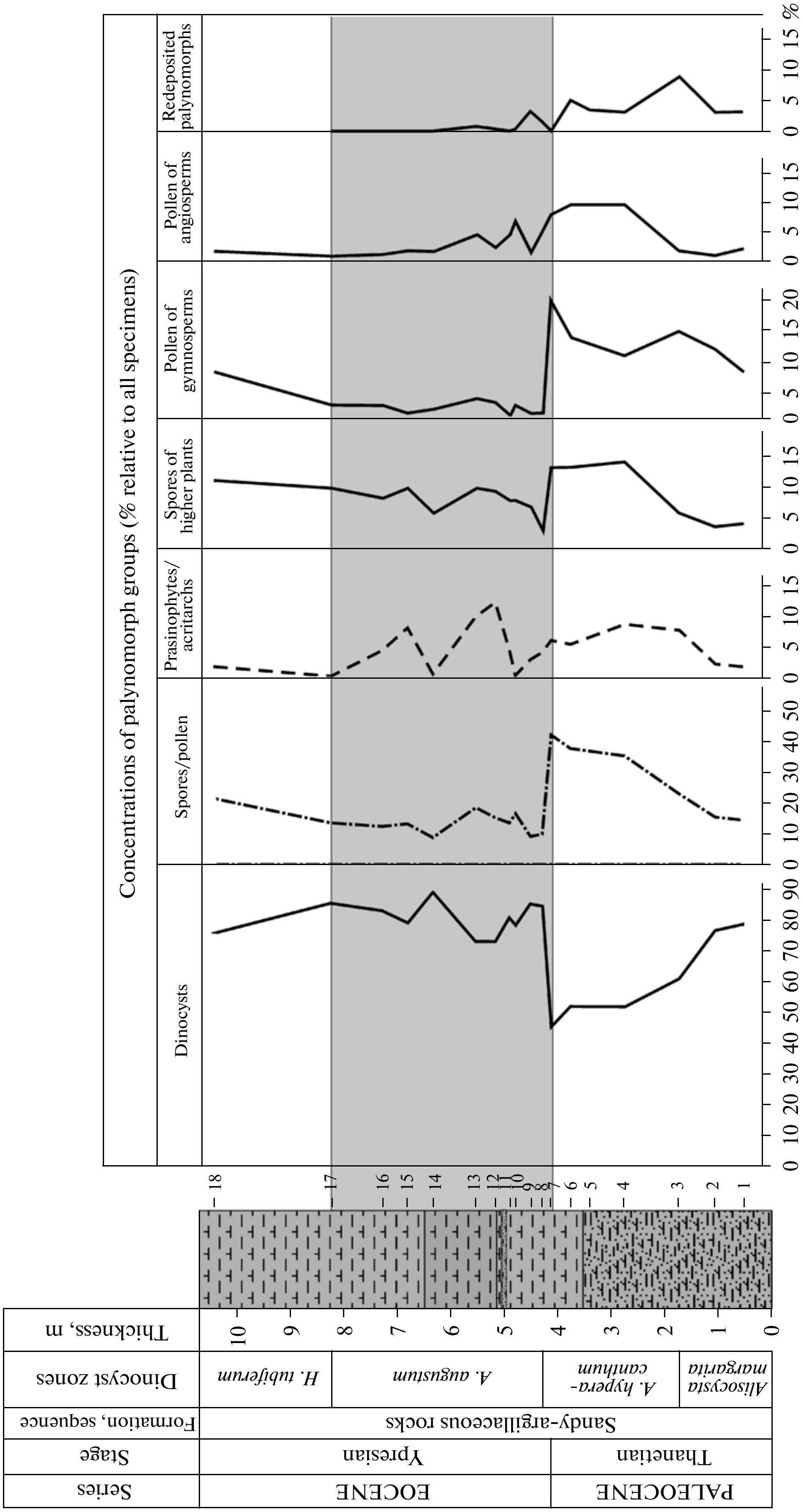

Fig. 4. Concentrations of palynomorph groups (%) at the sampling levels. Symbols for lithology as in Fig. 1.

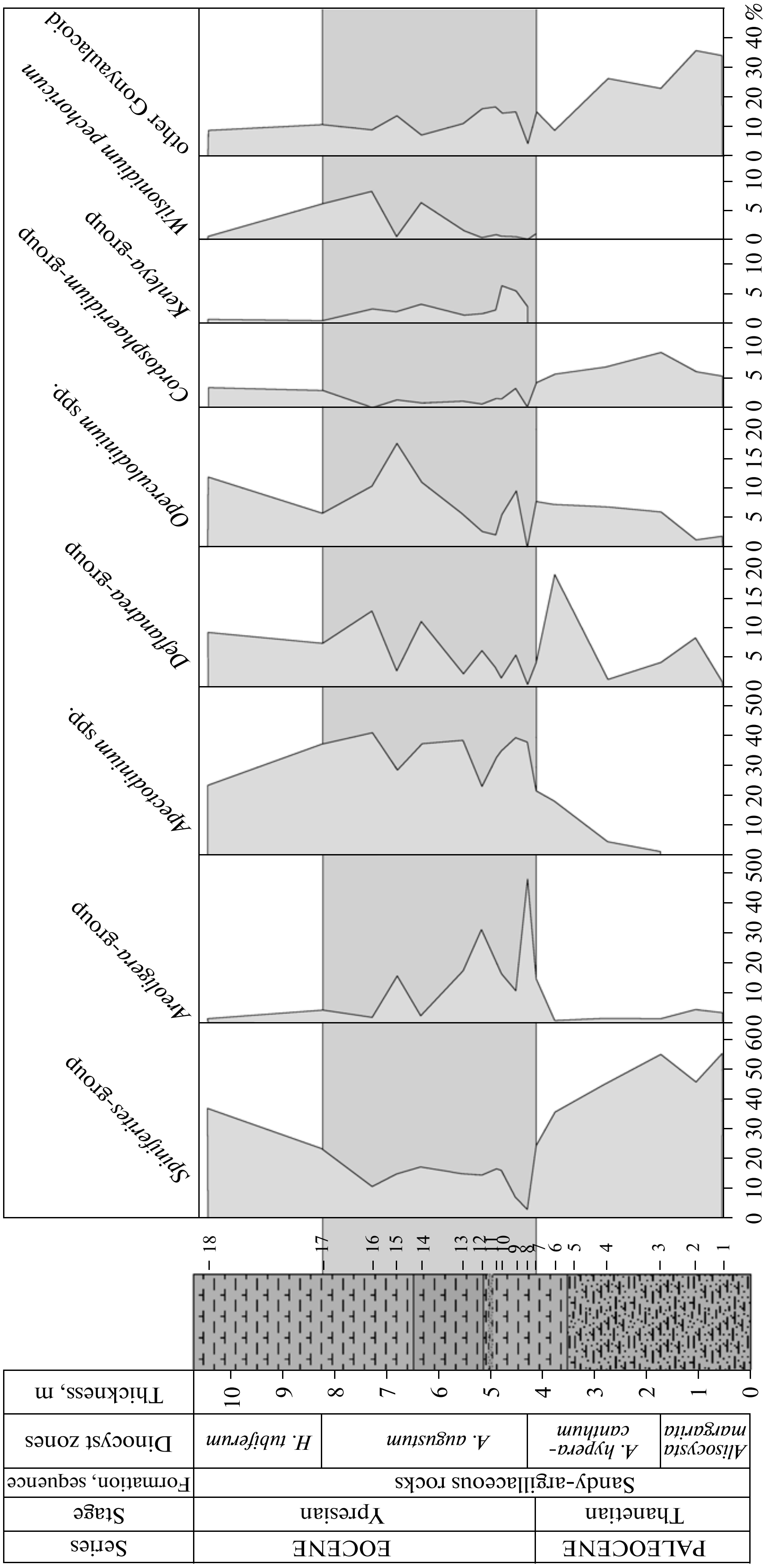

Fig. 5. Concentrations of ecologic dinocyst groups (% relative to all dinocysts) at the sampling levels. Symbols for lithology as in Fig. 1.

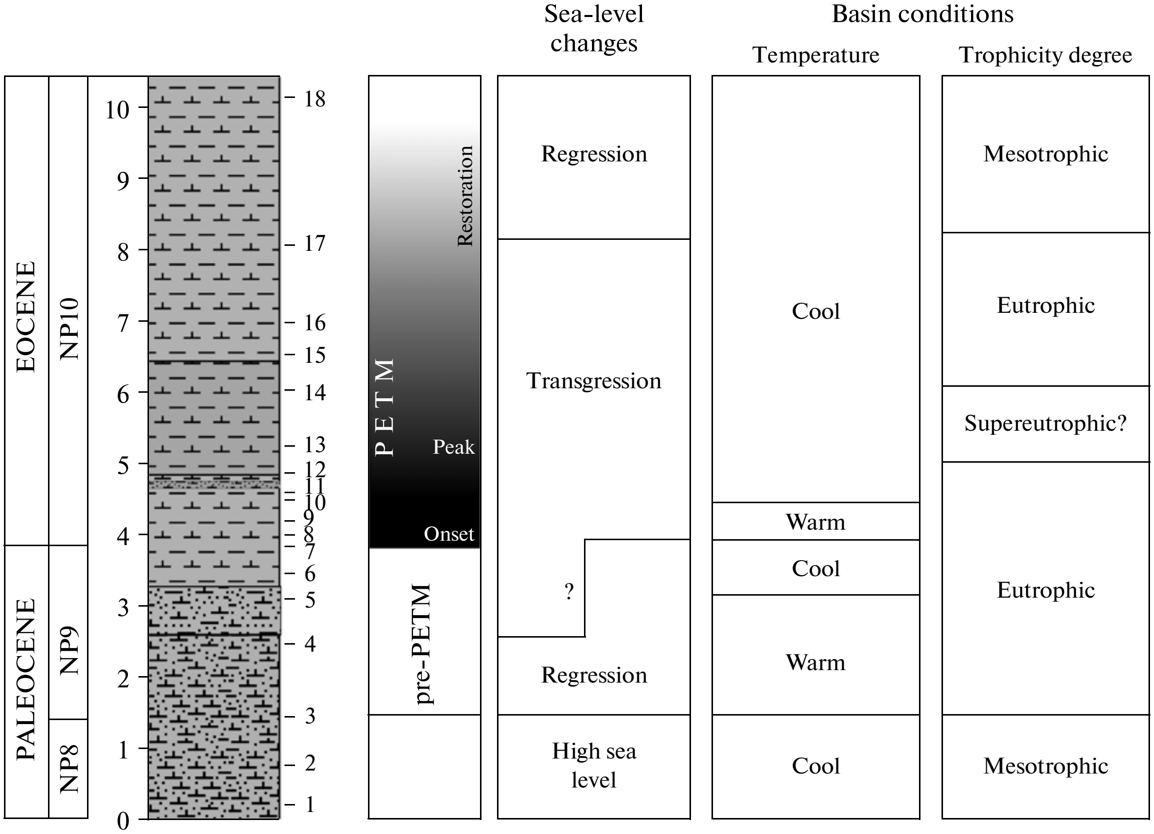

Fig. 6. Interpretation of the PETM paleoenvironments based on nannofossils and dinocysts. Symbols for lithology as in Fig. 1.

termination. It is supported also by relatively increased content of spores and pollen and relative decrease in abundance of dinocysts in the uppermost part of the section. At the same time, the restoration of dinocyst was accompanied by re-entry of all taxa, while nannofossil assemblages appeared to be substantially changed and lost many typically Paleocene taxa as a result of PETM impact.

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Reviewers E.M. Bugrova and M.A. Akhmetiev

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