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Middle Eocene nannofossils and geological events of the northeastern peri-Tethys

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The middle Eocene zonation, being one of the most intricate problems of Paleogene nannofossil zonal scales, represents a severe difficulty for subdivision and correlation of sediments of this age over the northeastern peri-Tethys. Two coexistent nannofossil standard zonal scales (Martini 1971; Okada & Bukry 1980) solve the problem of determination of the middle Eocene nannofossil zones by alternative pathways. Both schemes use the same zonal marker (FO of *Nannotetrina quadrata*) for the lower boundary of both NP15 and CP13 Zones. The upper boundary of NP15 Zone corresponds to the LO of *Rhabdosphaera gladius* and that of CP13 Zone is defined as the FO of *Reticulofenestra umbilicus*, and these stratigraphical levels are hardly correlated. Three subzones are established within the CP13 Zone; the range of CP13b is determined by first and last occurrence of *Chiasmolithus gigas*. The goal of this paper was to elaborate a zonal subdivision of the middle Eocene sediments of the northeastern peri-Tethys and to correlate geological events all over the area.

The middle Eocene sediments are widespread all over the southern part of the former Soviet Union from Crimea and North Caucasus to the Dnieper-Donetz depression and Middle Volga reaches in the north and Central Asia in the east. Within the Crimea-Caucasus area, they are represented by the Keresta and Kuma Formations. Sediments of the Keresta Fm. are composed of rhythmic alternation of white, light gray or greenish limestones and marls. They accumulated during the prominent lower middle Eocene transgression, when similar facies spread up to the Dnieper-Donetz depression. The Keresta/Kuma Fm. boundary corresponds to a short regressive episode, marked by a short hiatus at the base of the Kuma Fm. in a number of sections, for instance, in a borehole drilled through the Keresta Fm. stratotype (Fig. 3). During the following transgression of lesser amplitude than that of Keresta Fm. time, a significant shift in sedimen-

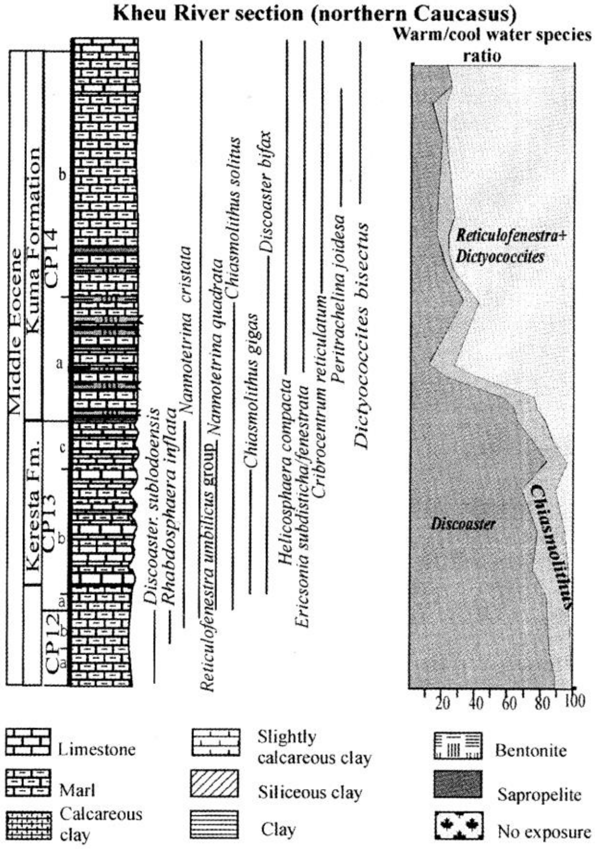

Fig. 1. Middle Eocene deposits of the Kheu River section (central North Caucasus) and ranges of the main nannofossil marker species.

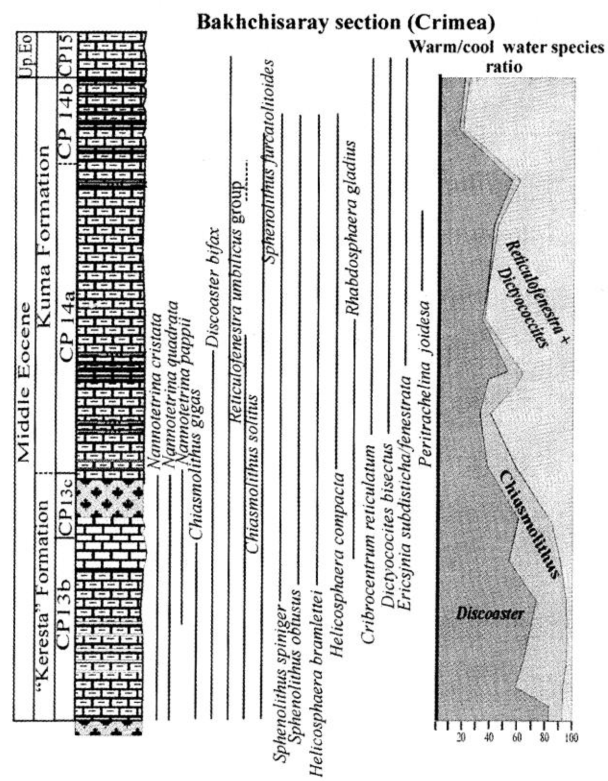

Fig. 2. Middle Eocene Bakchisaray section (Crimea) (legend see Fig. 1).

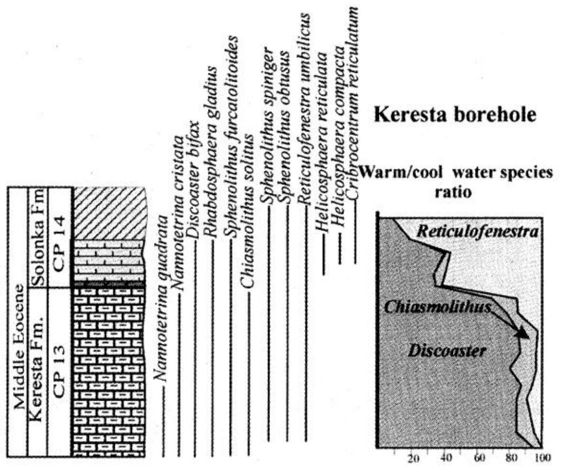

Fig. 3. Middle Eocene sediments of borehole drilled at Keresta locality (lower Volga-Don interstream) (legend see Fig. 1).

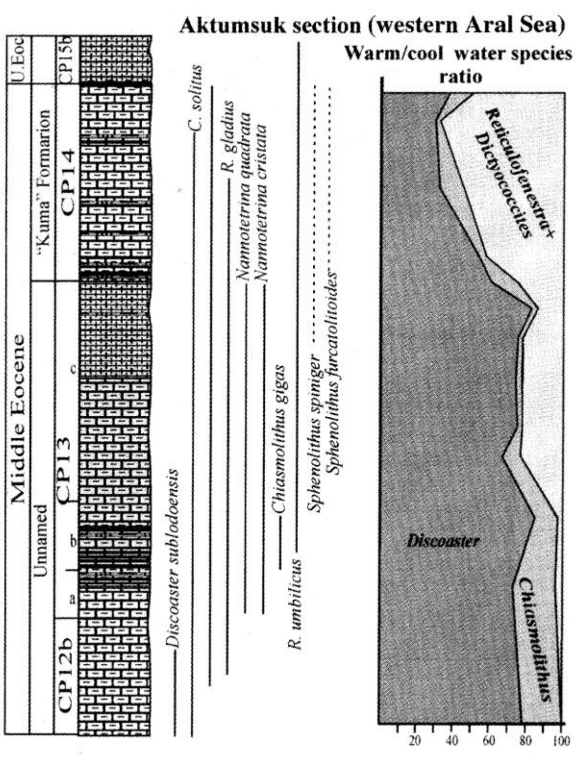

Fig. 4. Middle Eocene deposits of Aktumsuk section (western Aral Sea, Uzbekistan) (legend see Fig. 1).

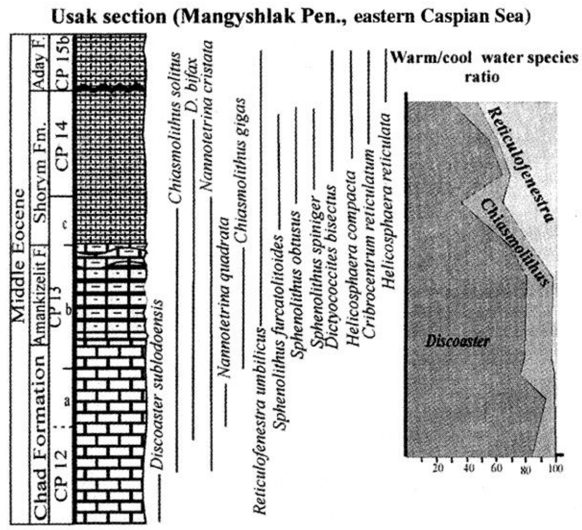

Fig. 5. Middle Eocene deposits of Usak section Mangyshlak Peninsula, eastern Caspian Sea, Kazakhstan) (legend see Fig. 1).

tation occurred, and monotonous sediments of the Kuma Fm. accumulated. They are composed of limestones or marls rich in organic matter, which gives a characteristic coffee color to the sediments. In the lowermost Kuma Fm. numerous bentonitic interlayers occur and siliceous microplankton appear. A dramatic decrease of benthic foraminifera at the base of the Kuma Fm. well known long ago (Subbotina 1960), attests to the occurrence of suboxic and anoxic environments. Transgressive–regressive cyclicity is better exhibited in the northern basin margin (Radionova et al. 1998). The sediments spread over the basin margins show reduced carbonate content as compared to the underlying Keresta Fm., absence of organic matter enrichment and increase of terrigenous and biogenic siliceous matter (Khokhlova et al. in press). A short-time regression is registered in the middle Kuma Fm. and coeval formations. Within the deepest part of the basin it is marked by an increase in reworked nannofossils only, but outside the Crimea-Caucasus area it is rather well pronounced. In the upper Kuma Fm., bentonitic interlayers disappear and benthic foraminifera become extinct, testifying of anoxia reinforcement.

The described geological events were accompanied by the following nannofossil events illustrated in Figs. 1–5 by examples from the main sections from different parts of the northeastern peri-Tethys.

The base of the Keresta Fm. corresponds to the CP13 (or NP15) Zone bottom, where *Nannotetrina quadrata* occurs and zonal markers of CP12 (NP14) Zone (*Discoaster sublodoensis* and *Rhabdosphaera inflata*) disappear just below this level in all sections with exposure of this boundary (Figs. 1, 4, and 5). The CP13b Subzone is clearly defined all over the area by the range of *Chiasmolithus gigas* and evidently corresponds to the transgressive maximum marked in particular in nannofossil diversity. A productivity outburst also led to greatly increased sedimentation rates. The presence of several interlayers of sediments rich in organic matter within the CP13b Subzone of the Aktumsuk section (Fig. 4) is circumstantial evidence of transgression as well. Notice that *C. gigas* is absent over the northern basin periphery. This is the possible reason for the absence of the CP13b

Subzone in the Keresta borehole (lower Volga-Don interstream, Fig. 3) and its distinctly reduced range in the Aktumsuk section, evidently due to a low frequency of the zonal marker.

Judging from the warm/cool water species ratio, only a slight temperature optimum can be noticed at this time relative a general background trend of an increase in cool water species (chiasmoliths and reticulofenestrids).

The only event that immediately marks the Keresta/Kuma Fm. boundary is the *Nannotetrina genus* extinction. Despite the essential environmental deterioration, nannofossil assemblages did not undergo sharp transformations. But new conditions initiated nannofossil blooms which resulted in gradual appearances of new species. Most of them (*Helicosphaera compacta*, *H. reticulata*, *Peritrachelina joidesa*, *Cribrocentrum reticulatum*, *Orthzygus aureus*, etc.) show much earlier first occurrences than established in the open ocean (Aubry 1992). However, they readily show diachrony in their first occurrence in different sections varying from CP14a Subzone bottom to top and can not be used even as regional correlative markers.

At the same time, an increase of reticulofenestrids occurs near the Keresta/Kuma Fm. (and coeval formations) boundary in all regions. Nevertheless, the first specimens of large *Reticulofenestra umbilicus* (about 14–16 μm) as a rule appear earlier (in CP13b Subzone) and consequently, its FO can not be used to establish the lower boundary of the CP14 Zone.

It is significant that the LO of *Rhabdosphaera gladius* marking the lower boundary of NP16 Zone is much higher up than at other places (close to lower boundary of CP14b [NP17] Zone). It is not the result of reworking, because *R. gladius* became the only survivor species of the CP13 Zone. So, the last occurrence of the *Nannotetrina* genus seems to be the most reliable datum for the Keresta/Kuma Fm. boundary as well as the CP13/CP14 Zone boundary in the northeastern peri-Tethys, although this zonal boundary will continue to be a matter of discussion.

The CP14a/CP14b Subzone (or NP16/NP17 Zone) is easy to establish by the LO of *Chiasmolithus solitus* in the southern part of the basin. It corresponds to the lower part of the Kuma Fm. including bentonitic interlayers. Because *C. solitus* disappears earlier over the northern basin margin, this boundary can be defined by the LO of *Discoaster bifax*, which occurs close to the LO of *C. solitus*.

General geological reasoning (as transgressive position within the sediment succession) and nannofossil zonation (NP15 Zone) suggest that the Keresta Fm. corresponds to the Lutetian of western Europe. At the same time, correlation of the Kuma Fm. to the Bartonian (NP17 Zone) seems to be logical considering nannofossil age determinations of Aubry (1983).

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