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Research paper

Early Eocene environmental development in the northern Peri-Tethys (Aktulagay, Kazakhstan) based on benthic foraminiferal assemblages and stable isotopes (O, C)

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ABSTRACT

The Aktulagay section in Kazakhstan provides an expanded northern Tethyan record of the middle Ypresian (calcareous nannoplankton zones NP11–13, ~54–50 Ma), including the Early Eocene Climatic Optimum (EECO). The marl sequence features a series of sapropel beds, observed throughout the Peri-Tethys, indicative of the basin-wide occurrence of episodic hypoxic events. In order to unravel the paleoenvironmental evolution at Aktulagay during this period of global warming, we investigated the benthic foraminiferal record by means of a detailed multivariate analysis of the >63 μm fraction, as well as through stable isotopic (C, O) investigations on excellently preserved benthic foraminiferal specimens.

The Alashen Formation (NP11 to lower NP12; ~54 to 52.5 Ma), in the lower part of the sequence, contains a diverse assemblage of deep outer neritic (~200–250 m) benthic foraminifera, with common *Pulsiphonina prima* and *Paralabamina lunata*. The seafloor conditions are interpreted as initially (54 Ma) well-ventilated and oligo- to mesotrophic, gradually changing to more eutrophic and oxygen-limited, culminating in more permanent low oxygen conditions and eutrophy in the sapropel-bearing Aktulagay B1 unit (middle NP12; ~52.5-52 Ma). The latter conclusion is corroborated by the dominance of *Anomalinoides acutus* and *Bulimina aksuatica* and the lower diversity. Also the upward migration of endobenthic species to the sediment–water interface, as suggested by rising $\delta^{13}C_{endobenthic}$ values, supports this interpretation. A transgression, which flooded lowlands, might have caused this development. In the Aktulagay B2 unit (top NP12–NP13; ~52–50 Ma), benthic foraminiferal assemblages dominated by *Epistominella minuta* suggest an oligotrophic environment, with transient pulses of phytodetritus and moderate ventilation.

The Aktulagay B2 unit coincides with the peak temperature interval of the EECO, as indicated by its position close to the base of NP13 and rising $\delta^{13}C_{epibenthic}$ values. Large river plumes, episodically reaching the area, in a monsoonal climatic context, might explain this basin development. Although it is not unlikely that some of the observed patterns are related to long-term climate change, it can currently not be excluded that changing paleogeography and variable connections to the Tethys, Atlantic and the Arctic Ocean were responsible for the long-term period with dysoxia and anoxia during deposition of the sapropel beds at the Peri-Tethyan seafloor.

The evolution of the basin as observed in Aktulagay shows similarities to the evolution of the North Sea Basin as observed in Denmark, suggesting that these basins were connected during the Early Eocene.

1. Introduction

The Eocene was the warmest period in the Cenozoic, characterized by rising temperatures up to the Early Eocene Climatic Optimum (EECO; Zachos et al., 2008). Superimposed on this warming trend, multiple transient warming events, of which the PETM is the most extreme example, can be identified (e.g., Kennett and Stott, 1991; Zachos et al., 2010). Whereas the record of early Eocene global warming towards the EECO, mainly based on geochemical proxies, is becoming well

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established, the biotic response to this long-term trend is poorly known. This study aims at filling this gap through the study of a benthic foraminiferal record of a mid-latitude section in the Northern Peri-Tethys.

The early Eocene northern Peri-Tethys (Fig. 1) was characterized by its position between north–south and east–west trending seaways (Akhmetiev, 2011). From the early Paleocene to the middle Eocene, the northern Peri-Tethys was connected to the Arctic region by a north–south corridor, known as the Turgai Strait (Dercourt et al., 2000; Akhmetiev, 2011; Iakovleva, 2011). The northern and southern parts of the corridor differed in fauna, flora and sedimentation patterns (Dercourt et al., 2000). Recent studies indicate also the existence of a northern Peri-Tethys connection with the North Sea Basin and the Atlantic during the early Eocene (Iakovleva et al., 2004; Knox et al., 2010; Steurbaut, 2011; King et al., 2013). The circulation patterns within these seaways and the exact history of these connections influencing Peri-Tethyan paleoenvironments remain still poorly constrained. In the Peri-Tethys, the PETM is characterized by sapropel (black shale) deposition (e.g. Gavrilov et al., 2003). Interestingly, during the late Ypresian (calcareous nannoplankton zones NP12–13), up to eight organic-rich shale and marl beds, generally denoted as sapropels, were deposited in the northern Peri-Tethys area (Oberhänsli and Beniamovski, 2000; Stupin, 2008). These sapropel beds mark an unusual 500 thousand year period of basin-wide recurrent oxygen deficiency.

The dynamic warm climate, the recurrent deposition of sapropel beds and the paleogeographic setting with connections to the Tethys, Arctic and Atlantic Oceans, provide a unique setting for studying the early Eocene paleoenvironmental development of the northern Peri-Tethys. The stratigraphy of the Aktulagay section (Western Kazakhstan) was recently described in detail, combined with a general interpretation of depositional environments and depositional sequences, based on sedimentology, microfauna, macrofauna, nannofossils and dinocysts (King et al., 2013). This work forms the foundation for an in-depth quantitative and statistical evaluation of the benthic foraminiferal sequence. Together with stable isotopic data of excellently preserved benthic foraminifera this provides a great opportunity to characterize paleoenvironmental and biotic changes during early Eocene long-term global warming in a mid-latitude epicontinental basin.

2. Geologic setting and stratigraphy

2.1. The Aktulagay section

The Aktulagay section (47°32′31.47″ N, 55°09′13.75″ E; Fig. 1), located about 100 km NE of the town of Kulsary, is exposed in a steep slope on the western flank of the Aktulagay hills (Steurbaut, 2011). The section was logged and sampled for a stratigraphic study between 2000 and 2003 (King et al., 2013). Based on a study of this and other outcrops in the Pre-Caspian area, these authors proposed to subdivide the Eocene part into the Alashen Formation (0–13.45 m), composed of marl and calcareous clay, the Aktulagay Formation (13.45–23.57 m), containing marl, clay and sapropelitic clay, and the more silty overlying Tolagaysor Formation (23.57–56.20 m; King et al., 2013; Fig. 2). This study focuses on the Alashen and Aktulagay Formations for which a total of 24 samples were analyzed (Fig. 3, lowermost sample 0–0.10 m was not studied because of strong reworking). The sampling was carried out initially for stratigraphic purposes, and some of the material was already exhausted during the previous study by King et al. (2013), consequently, a higher resolution study of parts of the sequence was not possible.

2.2. Biostratigraphy

A detailed overview of the biostratigraphy of the Aktulagay section can be found in King et al. (2013). The most important findings are reported here. Since most of the nannofossil units identified in the North Sea Basin can be recognized in the Aktulagay section, the nannofossil subzonation of the North Sea Basin is applied here (Steurbaut, 1998), as a subzonation of the zonal scheme of Martini (1971) (Fig. 3). Ages in this paper are based on the Geologic Time Scale of the Paleogene (Vandenberghe et al., 2012), with corrections on the ages of the nannoplankton zones by Pirkenseer et al. (2013). Ages are inferred from bio- and chemostratigraphic correlation (Fig. 4). The lowest part of the section, unit A1 (0–0.20 m) belongs to nannoplankton subzone NP10b. It is separated by a hiatus from the overlying unit A2 (0.20–10.80 m; ~54–52.75 Ma; NP11–lowest NP12), which is thought to include 13 omission surfaces. Unit A2 is separated from unit A3 (10.80–13.45 m; ~52.75–52.5 Ma; lower NP12) by another omission surface. A further omission surface is detected at 12.80 m. The boundary between zones NP11 and NP12 is found at 9.0 m (in unit A2), identified by the first (rare) occurrence of *Discoaster lodoensis*.

At the base of unit B1 (13.45–16.22 m; ~52.5–52 Ma; mid NP12) a hiatus may be present, indicated by the absence of calcareous nannoplankton subzone IV of the North Sea Basin succession. The base of unit B2 (16.22–23.57 m; ~52–50 Ma; top NP12–NP13) is characterized by a hiatus with a duration of at least ca. 55 kyr, based on the absence of nannofossil subzone VII (King et al., 2013). The top of Zone NP12 (defined by the last occurrence of *Tribrachiatus orthostylus*) is identified at 18.50 m.

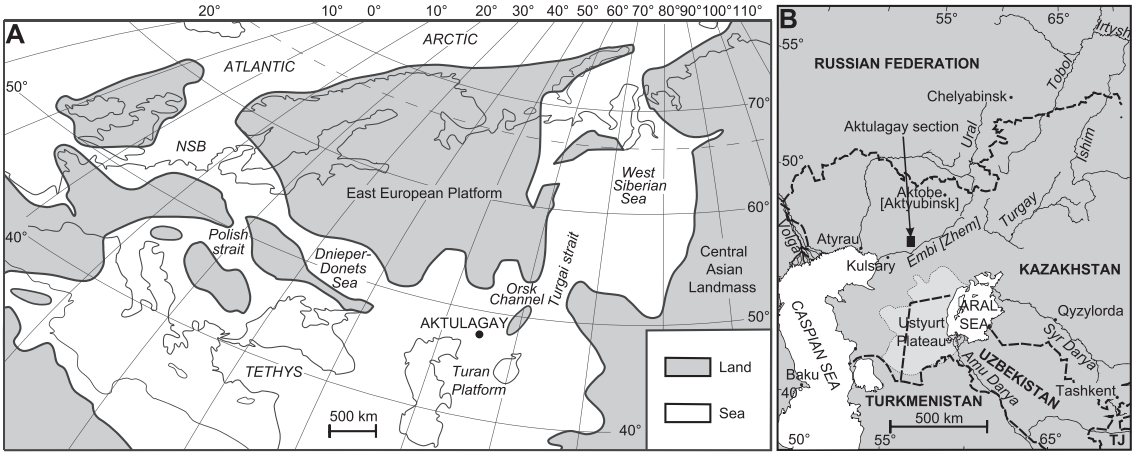

Fig. 1. Location of the Aktulagay section. (A) Early Eocene paleogeography after Steurbaut (2011). The Peri-Tethys is in this reconstruction connected to the Tethyan, Arctic and Atlantic ocean. NSB = North Sea Basin (B) Present-day location (modified from King et al., 2013).