A VARIETY OF PETM RECORDS IN DIFFERENT SETTINGS, NORTHEASTERN PERI-TETHYS

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INTRODUCTION

The impact of the Paleocene–Eocene Thermal Maximum (PETM) is clearly observed in the extended area of the northeastern Peri-Tethys basin. Lithological and geochemical features of sediments that correspond to the PETM vary notably in an E-W direction from Central Asia to Crimea and in a S-N direction from Transcaucasia to the central Russian Platform. In the deeper southern part of basin (Crimea, Caucasus and central Asia) it is characterized by calcareous and calcareous-clayey sedimentation, and a sapropel bed (SB) with varying TOC content that accumulated during PETM. In the northern shallower area of the basin, siliceous-clayey sedimentation dominates and the PETM is diffiuclt to recognise, with a turnover in siliceous microfossils being the main tool to identify the PETM (Oreshkina and Oberhänsli 2003). The thickness of the SB ranges from a few decimeters to a few meters in different areas, and the lithology and concentrations of TOC and trace elements vary greatly (Gavrilov *et al.* 1997, 2003; Gavrilov and Shcherbinina 2004). A recent study of new sections in different parts of the basin that span the PETM (Fig. 1) found evidence of erosion below the SB that, once again, confirmed the occurrence of a regressive pulse prior to the PETM and that accumulation of the SB formed during a rapid transgression (Gavrilov *et al.* 1997). Moreover, the combination of results obtained from new sections and a revision of previously studied sections has provided more information regarding the SB architecture.

RESULTS

Lithological and organic matter characteristics

A study of the Dzhengutay section in Dagestan, East Caucasus (Fig. 1), shows a regular fluctuation of TOC content within the SB. At least four 15–20 cm bands of black shale and a lighter, more calcareous layer can be recognized (Fig. 2). While the bottom and top of each band is very prominent, the transition from the lower black to upper pale layers within the band is relatively gradual. Such a regular alternating pattern in lithology suggests a regular variation in sedimentary pattern of the SB formation. In the Kheu section, central Caucasus (Fig. 1), three cycles can be recognized — the most pronounced (lower) cycle is ~25 cm and two additional cycles are ~10 cm in thickness. Two cycles in the SB are also distinguished in the Kurpai section, Tadjikistan.

The cyclic nature of the SB is best defined in sections that contain a high TOC content (e.g. not less than 5%). In sections where TOC is lower (e.g. 2–3%), the variations in TOC content are of a lower magnitude and cyclicity is poorly defined. Only one cycle is present in

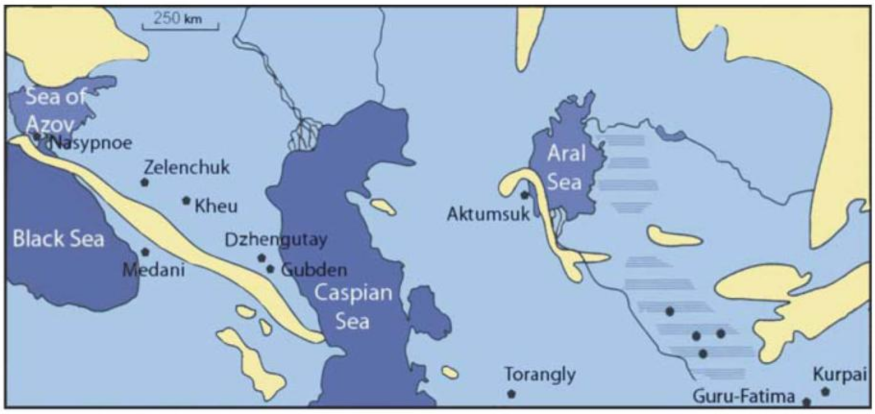

Figure 1 Paleogeographic map showing localities of studied sections that contain the sapropel bed (SB) related to PETM. Blue – Peri-Tethyan basin, yellow – land, dashed area delineates a realm of occurrence of oil-shale coeval to SB.

sections with low TOC content. Fluctuations of TOC within cycles are also accompanied by variations in many trace element concentrations (e.g. V, Ni, Mo, Se, Zn, Cu, U, Au, Ag).

Spatial changes in the SB indicate that the concentration and nature of organic matter differs throughout the basin. The eastern part of the NE Peri-Tethys (Central Asia), an area with an arid climate, has the highest TOC concentrations (up to 25% and more) within the SB. Results from pyrolysis suggest the nature of organic matter is primarily from the marine basin, with a minor terrestrial component. In the western sector of the basin (Crimea and Caucasus), the TOC content is significantly lower (varies from <1 to ~10%) and the organic matter appears to have a basinal-terrestrial mix, with the terrestrial fraction locally reaching relatively high concentrations. These findings indicate that sediments with a lower TOC content contain a higher concentration of terrestrial organic matter. This trend is recognised in the SB from different regions and also in individual cycles within the SB — in the lower part of the cycle with enriched TOC content (black shales) the organic matter has a mostly basinal origin (from marine organisms), while the upper pale layers of the cycle primarily contain terrestrial organic matter.

Carbon and oxygen isotope composition

Carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotopes have been studied in most sections in the NE Peri-Tethys. While the $\delta^{13}C$ and $\delta^{18}O$ excursions associated with the PETM are recorded throughout the basin, the magnitude of the excursion varies significantly between different areas. In Crimea and Caucasus (western part of the basin), the $\delta^{13}C_{carb}$ excursion is generally 1.5–3‰. In Central Asia (eastern part of the basin), the magnitude of the $\delta^{13}C_{carb}$ excursion is much larger, reaching 5‰ in the Kurpai (Tadjikistan) and Torangly (Turkmenistan) sections and 8–9‰ in the Guru-Fatima section (Tadjikistan), but only 2.5‰ in the Aktumsuk section (western Aral Sea). It should be noted that in this area the largest negative $\delta^{13}C_{carb}$ excursions are detected in sections that are characterized by higher TOC content (up to 15% and more) and low $CaCO_3$ concentrations. The Aktumsuk section has calcareous-rich sediments (>50% $CaCO_3$) and the TOC content does not exceed 6%.

Significant $\delta^{13}C$ variations occur within the SB that can be linked with variations in TOC content and different parts of the cycle within the SB. For example, in the Kheu section (central Caucasus), the peak of the negative $\delta^{13}C$ excursion (-1.8 ‰) occurs within the lower black shale (Fig. 2), which contains the highest TOC content (up to 10 %), while in the upper (pale) part of the same cycle the TOC drops up to ~1.0% and the magnitude of the $\delta^{13}C$ excursion decreases (-0.6‰). The same trend is detected in the upper cycle. A similar pattern of $\delta^{13}C$ fluctuations is also recognised in different cycles of the SB in the Dzhengutay section.

The rate of onset and recovery of the $\delta^{13}C$ excursion is different between sites. In some sections, a small decrease in $\delta^{13}C$ occurs in sediments underlying the SB, but the most notable negative excursion occurs at the base of SB. Thus, in most sections, the onset of the $\delta^{13}C$ excursion correlates to the base of the SB. The relationship between the top of the SB and $\delta^{13}C$ recovery differs. The upper boundary of the SB is usually gradual, but nevertheless clearly pronounced, because the TOC content decreases rapidly. The negative $\delta^{13}C$ excursion, however, continues for several decimeters or even meters above the horizon where TOC content drops. Hence, the $\delta^{13}C$ excursion extends beyond the thickness of the SB.

The $\delta^{18}O$ excursion in the Crimean and Caucasian sections varies from 1.5–3‰, and in the Kheu section it reaches 5‰ (Fig. 2). In Central Asia, the magnitude of the excursion varies from 3.5‰ (Torangly, Turkmenistan) to 5‰ (Gur-Fatima, Tadjikistan) and 7‰ (Kurpai, Tadjikistan), while it is 2.5‰ in the Aktumsuk section. As with the $\delta^{13}C$ record, in some sections the $\delta^{18}O$ excursion also continues beyond the stratigraphic thickness of the SB.

The magnitude of the $\delta^{13}C$ and $\delta^{18}O$ excursion differs throughout the basin — maximum values are recorded in the Central Asian sections, where sediments are enriched in organic matter and have low $CaCO_3$ content. The Crimea and Caucasus areas were

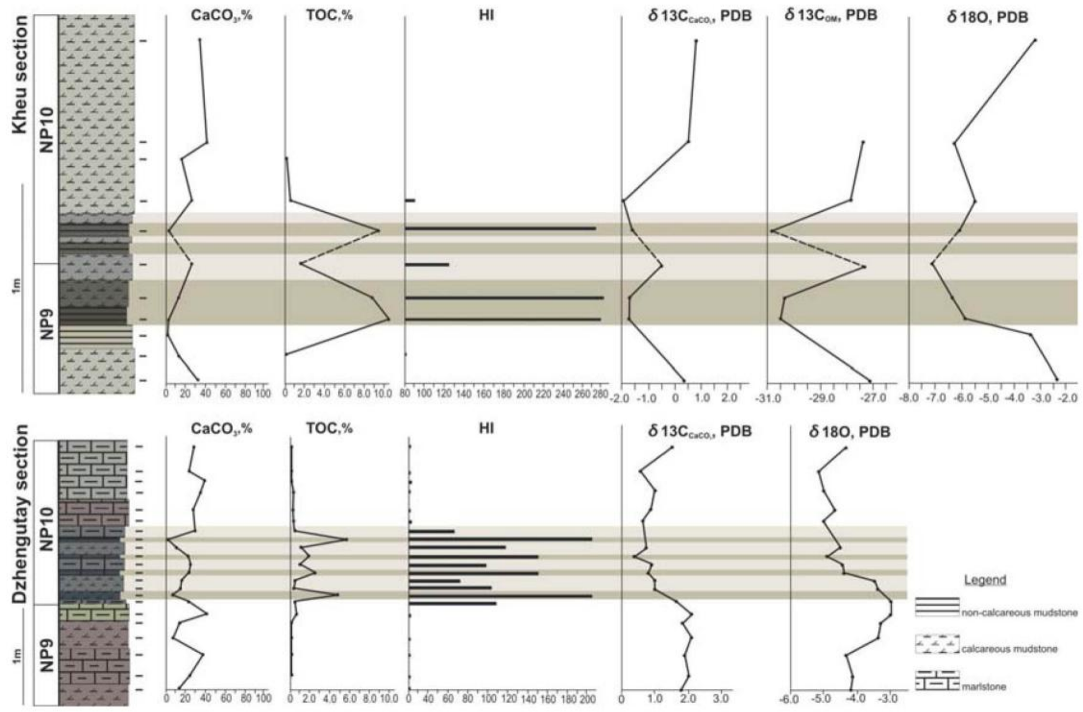

Figure 2 Lithology and contents of $CaCO_3$, total organic carbon (TOC), and hydrogen index obtained from the results of organic matter (OM) pyrolysis (Rock-Eval II), carbon isotope composition from carbonate and OM, and oxygen isotope composition of Kheu (central Caucasus) and Dzhengutay (eastern Caucasus) sections.

characterized by a warm humid climate, whereas Central Asia had a hot arid climate. This may have affected the temperature of the shallow epeiric basin and resulted in the large $\delta^{18}O$ excursion. At the same time, a high enrichment of organic matter in sediments may have enabled a high intensity of diagenetic processes that contributed to the large $\delta^{13}C$ and $\delta^{18}O$ excursions, particularly in calcareous-poor sediments.

Nannofossil assemblage changes

Nannofossil assemblage charactersistics of the SB, and recognised in different parts of the basin, include a dramatic decrease in the total nannofossil abundance, a wide occurrence of the short-lived species *Discoster anartios*, *D. mahmoudii* and rhomboasters (so-called "excursion taxa"), the elimination of cool-water chiasmoliths, an increase in warm-water discoasters and high-fertility *Toweius*, along with a decrease in *Coccolithus* spp.. *Fasciculithus* displays irregular behaviour in different areas. In some sections they distinctly increase in abundance (Torangly, Kurpai, Maly Zelenchuk, Dzhengutay), while in other sections they slightly decrease.

Generally, nannofossil assemblages from the SB are more abundant and diverse in shallower areas (Nasypnoe, Maly Zelenchuk, Torangly, Aktumsuk), characterized by lower TOC content, and the first occurrence of "excursion taxa" are coeval with the base of the SB. In the deeper parts of basin (Kheu, Dzhengutay) and eastern areas (Kurpai, Guru-Fatima), where the SB is more enriched in organic matter, nannofossils are more stressed and show rhythmical fluctuations in abundance that are coherent with the lithological cyclicity. In these sections, the lower parts of the SB (enriched in organic matter) contain extremely poor nannofossil assemblages and the lowest occurrence of "excursion taxa" is recorded in the middle or even upper part of the SB. This results in a minor diachroneity of the base of nannofossil Zone NP10 throughout the basin.

Nannofossils in the SB from the eastern part of the basin are sparse and often form oligotaxonic assemblages largely dominated by *Braarudosphaera bigelowii* (Guru-Fatima section), or *Fasciculithus* spp. (Kurpai section), or *Fasciculithus* and *Toweius* spp. (Torangly section). Nannofossil assemblages appear to recover when accumulation of the

SB ceases, and this recovery is independent of the continuation of the $\delta^{13}C$ and $\delta^{18}O$ excursion above the SB layer.

DISCUSSION AND CONCLUSIONS

Negative $\delta^{13}C$ and $\delta^{18}O$ excursions are documented in all studied sections, where they correspond to accumulation of the SB and substantial changes in nannofossil assemblages. However, the magnitude of the $\delta^{13}C$ and $\delta^{18}O$ excursion differs considerably throughout the basin, with the largest excursions recognised in Central Asia. The cyclic nature of the $\delta^{13}C$ excursion within the SB horizon appears to co-vary with organic matter content. The magnitude of the isotope excursions was probably influenced by early diagenesis processes.

Studies of several new sections from the NE Peri-Tethys reveal the cyclic architecture of the SB corresponds to the PETM, with accumulation of the SB occurring during the PETM (Gavrilov *et al.* 1997, 2003; Gavrilov and Shcherbinina 2004). This implies a rapid flooding of wide shoreland marshes, which enhanced the influx of biophile elements into the basin and resulted in unusual blooms of dinoflagellates, algae and bacteriaplankton (a kind of "red-tide") that led to increased accumulation of organic matter on the basin floor. Recent studies of the cyclic nature of the SB (1–4 cycles and more) concluded that the transgression may have been interrupted by periodic short-lived still-stands, or even regressions, which reduced nutrient supply and led to productivity decay and accumulation of sediments with low amounts of organic matter. A number of cycles within the SB appear to have been controlled by local geomorphological features of the coastal landscapes. A wide low-gradient coastal area is the most likely landscape for formation of the cyclic SB. Alternatively, a coast with a steep slope (e.g. cliff) may have lowered the nutrient supply and resulted in reduced productivity, lower TOC in sediments and poorly-defined sedimentary cycles. Periodic interruptions of the transgression, which led to the cyclic nature of the SB formation, were more likely controlled by short Milankovich cycles.

Examination of the PETM in the NE Peri-Thetys demonstrates this area was influenced by a mix of global (biotic and abiotic) and regional trends.

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