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A Paleogene sequence in central North Caucasus: A response to paleoenvironmental changes

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The Paleocene-Eocene basin in the south of the former USSR occupied a large area that extended E–W over 3000 km. The northern periphery of the basin (Russian craton) was characterized by essentially terrigenous and biogenic siliceous sedimentation, and the southern (Crimea-Caucasus) region was dominated by carbonate nanno-foraminiferal sediments, giving way in some stratigraphic intervals to carbonate-terrigenous, terrigenous, and biogenic silica-terrigenous sediments.

The proportion of different sediments varied considerably from age to age through the history of the basin; this variation is more clearly pronounced in North Caucasus. The lithostratigraphic subdivision remains roughly identical over the major part of the area. We choose the classical Paleocene-Eocene reference section at Kheu River (Kabardino-Balkaria, central North Caucasus; Fig. 1) to characterize sediment variation through time. This section represents the deepest part of the water area. It is the most complete section of the area and evidently one of the best Paleogene sections of the world. Continuous exposures exist along the Kheu River reaches.

The Paleogene stratigraphic scheme of the area based on foraminifera and nannofossil studies has been evaluated for many years (e.g. Subbotina 1960; Leonov & Alimarina 1964; Shutskaya 1970; Krasheninnikov & Muzylöv 1975; Muzylöv 1981). In this study, we had to use the zonal markers of both nannofossil standard scales (Martini 1971; Okada & Bukry 1980), since neither works very well for the entire succession. Martini's zonal scale is more reliable for the Paleocene and that by Okada & Bukry seems to be more useful for the middle Eocene–Oligocene. For the Danian interval it was in some cases possible to correlate with the high-latitude zonation discussed in Perch-Nielsen (1979, 1985).

Maastrichtian. White limestone with thin marl intercalations (exposed thickness 15 m). Further upsection, an unexposed interval several meters thick.

Elburgan Formation (40 m). CP1–CP2 (NP1–NP3) zonal range is represented by rhythmically alternating greenish gray limestones (10–25 cm) and marls (several cm). The CP3 (NP4) Zone is difficult to establish due to the absence of *Ellipsolithus macellus*, the zonal marker used in both nannofossil standard scales. As was shown by Perch-Nielsen (1979), in high latitudes the first appearance of *Neochiastozygus saepes* (D9 Zone of regional zonation in Denmark) occurs close to that of *E. macellus* and can therefore be used for the lower boundary of the CP3 (NP4) Zone. The lowermost CP3 Zone is composed of soft marl with more calcareous intercalations. The uppermost CP3 Zone is made up of hard limestone.

Nalchik Formation (80 m) overlies the Danian limestone with a sharp boundary (hardground). The range of the stratigraphical hiatus can be only roughly estimated. A sharp turnover in the nannofossil assemblage corresponds to the Formation boundary. At the base of the Nalchik Fm. the first species of *Toweius*, *Ellipsolithus*, and various *Fasciculithus* appear. The absence of *Chiasmolithus bidens* and *Neochiastozygus perfectus* in the uppermost part of the Elburgan Fm. indicates that sediments corresponding to D10 and S1 Zones are lacking, unless their absence is explained by paleoecological conditions at the time of deposition. Nalchik Fm. is composed of bluish and greenish gray calcareous clays with variable carbonate content (maximum c. 50% $CaCO_3$ in the middle CP4 Zone and near the CP7/CP8 Zone boundary). Vague layers with alternating high and low contents of calcareous matter and abundant bioturbation marks (up to 0.5 m in length) are documented. A sapropel horizon (0.45 m) rich in C_{org} (up to 10%) occurs at the CP8a/CP8b Subzone boundary. Abundant and various nannofossils of the calcareous clay of CP8a Subzone sharply disappear within the non-calcareous clay underlying the sapropel bed (Fig. 2) and regain their former frequency in the calcareous clay layer occurring within the sapropel bed, where subzonal marker *Campylosphaera eodela* appears. The foraminifer assemblage shows a similar trend. In the calcareous clay underlying the sapropel benthic foraminifera progressively increase. At the sapropel a major extinction takes place and new assemblages composed dominantly or entirely of planktonic foraminifera reappears (Muzylöv et al. 1996) testifying to the occurrence of anoxic bottom water conditions (Fig. 2). The uppermost 30 m of the Nalchik Fm. (CP8b Subzone) are composed of alternating layers of bluish gray bioturbated slightly calcareous clay and massive cherts (several decimeters thick).

Cherkessk Formation (55 m), CP9–CP12 (NP10–NP14) Zones. Greenish gray non-laminated marls with vague bioturbation marks. In the middle part (CP10–lowermost CP11 Zones), a sequence (15 m) with eight sapropel interlayers (10–25 cm) occurs. C_{org} content reaches 2–3.5% (Gavrilov & Muzylöv 1992).

Keresta Formation (20 m), CP13 Zone. Alternating massive limestones (up to 1 m at the base, 0.1–0.3 m further upsection) and softer marls (0.05–0.15 m).

Kuma Formation (40 m), CP14 Zone. Coffee- to dark-brown calcareous sediments (limestone in the lowermost part, marl in the uppermost part) rich in organic matter (OM). C_{org} varies from 2 to 9% in the lowermost part, and is less variable in the uppermost part (2.5–4.5%). Fine (millimeter-scale) lamination and numerous fish remains are recorded, and bioturbation is absent. Twenty bentonite interlayers (several millimeters to 10 cm) occur in the lowermost part (CP14a Subzone).

Belaya Glina Formation (100 m), CP15 Zone. Greenish gray vaguely laminated sediments with alternating high and low contents of calcareous matter (generally marls).

Maykop Formation, Oligocene–early Miocene. A thick clay sequence rich in OM, which formed in an environment that differed drastically from the Paleocene–Eocene environment.

The sediments are characterized by the most common clay association: hydromica, smectite, mixed-layer mica/smectite minerals, and chlorite, which vary in proportion through the section. In the sapropel sequence of the Cherkessk Fm., kaolinite appears. Smectite makes up bentonitic interlayers in the Kuma

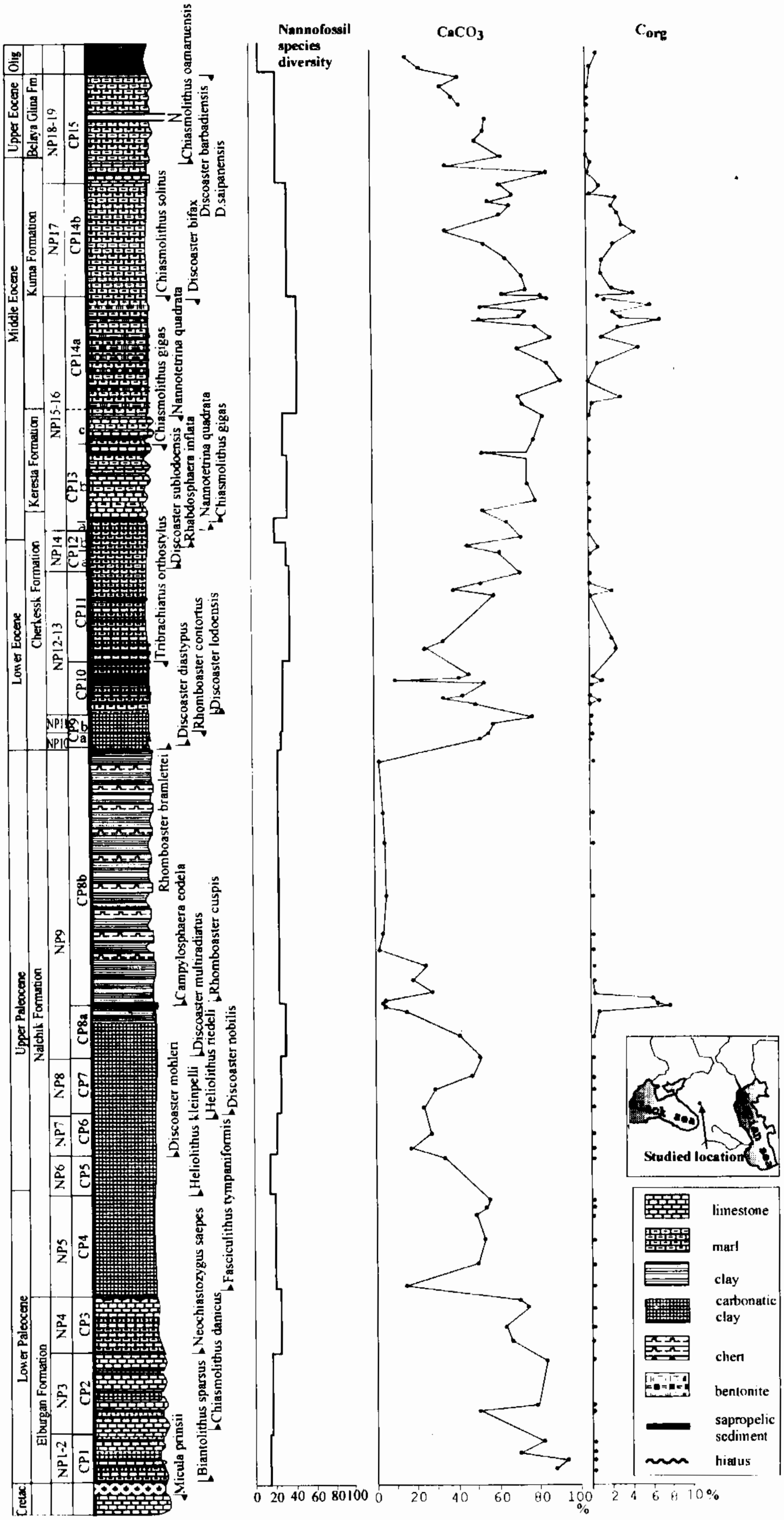

Fig. 1. The Paleogene succession of Kheu River section with major nannofossil zonal markers.

Fm., and is present in the Keresta Fm. along with clinoptilolite.

Throughout the section OM is low, although initially it was higher, judging from sulfide nodules. Certain horizons, however, are considerably enriched in OM (sapropels of the Nalchik and Cherkessk Fms., limestones and marls of the Kuma Fm., Fig. 1). Accordingly, OM-rich sediments are high in P, V, Ni, Co, Cr, Mo, etc. Significant biotic changes (involving a decline of nannofossil and planktonic foraminifera and disappearance of benthic foraminifera) accompanied OM accumulation (Muzylöv et al. 1996).

The generally high carbonate content, resulting from high calcareous microplankton (mainly nannofossil) productivity, changed significantly through time. The $CaCO_3$ curve reflects two stages in the Paleocene–Eocene sedimentation:

(1) The Paleocene stage, with a clear trend in the content of carbonate matter. From the limestone-dominated Danian sequence through marls and carbonate-rich clays to upper Thanetian (CP8b Subzone) low-carbonate clays and cherts. Accordingly, nannofossils, very abundant in the Danian–lower Thanetian, become rather diverse but not abundant in the upper Thanetian chert sequence. Similar changes in carbonate matter from the Danian to Thanetian have been shown for coeval sediments in western Europe. Considering that similar trends of sediment changes characterize basins that are situated great distances apart, these trends might be related to eustatic sea-level changes, rather than to regional factors.

The general Paleocene trend of changes in sedimentation is complicated by smaller-scale fluctuations in $CaCO_3$ content. The middle Paleocene sequence (CP4–CP8a Zones, "pre-sapropel" stage) displays two positive $CaCO_3$ shifts separated by reduced carbonate accumulation in CP6–lowermost CP7 Zones. In the terminal Paleocene (CP8b Subzone), clays with the lowest $CaCO_3$ content in pre-Oligocene sedimentation accumulated, evidently due to (i) reduced calcareous microplankton productivity coincident with siliceous microplankton productivity outburst, and (ii) a relative decrease in carbonate content owing to increased terrigenous input, resulting in a thick sequence accumulated over a short time interval (CP8b Subzone).

(2) The terminal Paleocene–Ypresian transition involved a dramatic warm marine transgression (Leonov & Alimarina 1964) and a drastic increase in biogenic

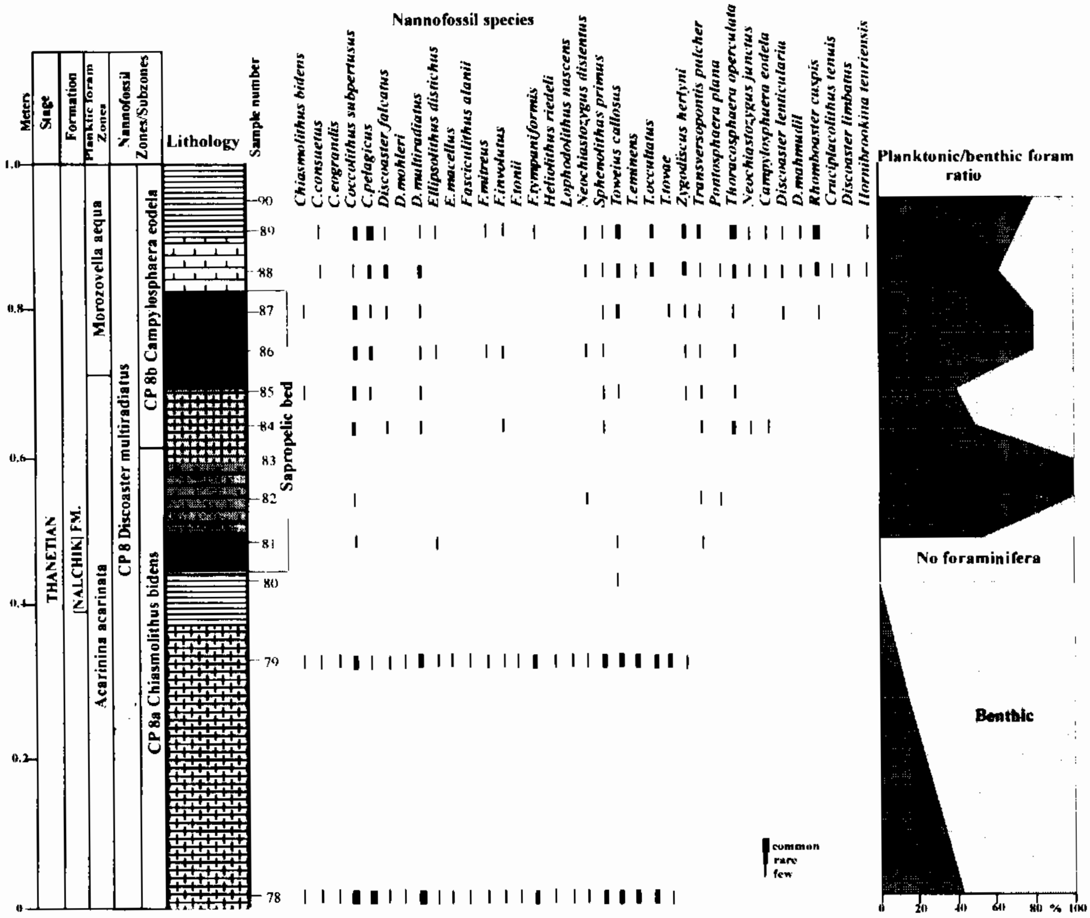

Fig. 2. Sapropel bed of Kheu River section. Foraminiferal data are taken from Muzylöv et al. (1996).

carbonate sedimentation. In the Ypresian, two $CaCO_3$ maxima are recorded, separated by a minimum during sapropel accumulation. The lower Ypresian (CP9–CP11 Zones) likely corresponds to a climatic optimum, judging from nannofossil assemblages dominated by warm-water species. Species diversity, however, is not very high.

The middle Eocene shows a great increase in nannofossil productivity and species diversity (with a maximum in CP14a Subzone), which caused constantly high $CaCO_3$ contents (accompanied by regional aridization, as established by paleofloristic studies), dropping only in the late Eocene.

This section is clearly rhythmic, consisting of strata several centimeters to tens of centimeters thick alternately higher or lower in calcareous matter (Milankovich cyclicity). This rhythmicity is better pronounced in the Maastrichtian, Danian, and Lutetian (CP13 Zone), and becomes vague to visually absent in the anoxic Kuma Fm. (CP14 Zone).

In summary, in the basinal evolution two stages with distinctive depositional, geochemical, and biotic features stand out sharply against the general carbonate-terrigenous sedimentation: (i) upper Thanetian, beginning with a dramatic decrease in $CaCO_3$ just before the accumulation of the sapropel bed (terminal CP8a Subzone), followed by sapropel formation (CP8a–CP8b Subzone boundary) and accumulation of siliceous-terrigenous sediments (CP8b Subzone), and (ii) Bartonian (CP14 Zone), characterized by OM-rich sediments accumulated in a dysoxic to anoxic environment. The main changes in the depositional environment were evidently related to eustatic sea-level changes, anoxic episodes, climatic variations, and terrigenous input.

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