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The Boundary of the Turonian and Coniacian of the Northwestern Caucasus

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Abstract—The results of a comprehensive study of the boundaries of the Turonian–Coniacian in the Upper Cretaceous deposits of the Abinskii region of the Northwestern Caucasus, composed of rhythmically constructed carbonate strata of the hemipelagic type, are presented. Biostratigraphic analysis of foraminifera complexes made it possible to identify zones in the section that are comparable to those proposed for the Point of the Global Stratotype of the boundary of the Coniacian in Germany. On the basis of chemostratigraphic (isotope) studies, the levels of abiotic events traced in the section and other territories have been established. The Shapsug section, after further study, can be proposed as a possible Hypostratotype (Limitotype) of the Turonian–Coniacian boundary for the territory of the Russian Federation.

Keywords: Caucasus, stratigraphy, Upper Cretaceous, boundary of the Turonian–Coniacian, foraminifera, isotopes of carbon and oxygen, GSSP

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INTRODUCTION

The studied section is located in the Abinsk area within the territory of the folded allochthonous Anapa-Agoy subzone of the Novorossiisk-Lazarevskaya zone of the Greater Caucasus (Fig. 1) (Korsakov et al., 2013). We note that this section has not been described previously. We studied the deposits of the Natukhayskaya Formation (K_2*nt*, named after Stanitsa Natukhayskaya) exposed in the northwestern wall of a depleted quarry north of Stanitsa Shapsugskaya (Fig. 2). The formation is dated to the Late Turonian–Coniacian (Korsakov et al., 2013, 2021); thus, the boundary between the Turonian and Coniacian stages runs within the section.

The formation is subdivided into the lower (upper Turonian) and upper (Coniacian) subformations. The composition of the subformations differs from section to section, which causes certain difficulties in its stratigraphic breakdown (Korsakov et al., 2013, 2021). The lower part of the formation is mainly terrigenous-carbonate with more frequent interlayers of sandstones and siltstones; the upper Coniacian part is rather carbonate and contains more limestones (Keller, 1947; Afanasyev, 1992). The thickness of the formation in this area reaches 150 m (Korsakov et al., 2013). A characteristic feature of this section is the presence of the so-called red interlayers of limestones and calcareous clays in its lower part. This feature is typical of the Turonian–Coniacian interval in the sections of Dagestan, Alps, Carpathians, and oceanic boreholes (Rengarten, 1965; Neuhuber et al., 2007).

The aim of our work was to determine the integrative characteristics of the Turonian–Coniacian section in the Northwestern Caucasus on the basis of detailed bio- and chemostratigraphic studies.

MATERIALS AND METHODS

Analytical studies were carried out at the Department of Geology of Moscow State University. Twenty-two samples from the 80-m thick section of the Natukhayskaya Formation (sampling interval, 1-5 m) were analyzed by various methods. The material composition of rocks was studied using thin sections.

Data on the age of rocks of the Turonian–Coniacian boundary were obtained by micropaleontological analysis of the foraminifera complexes, which contain

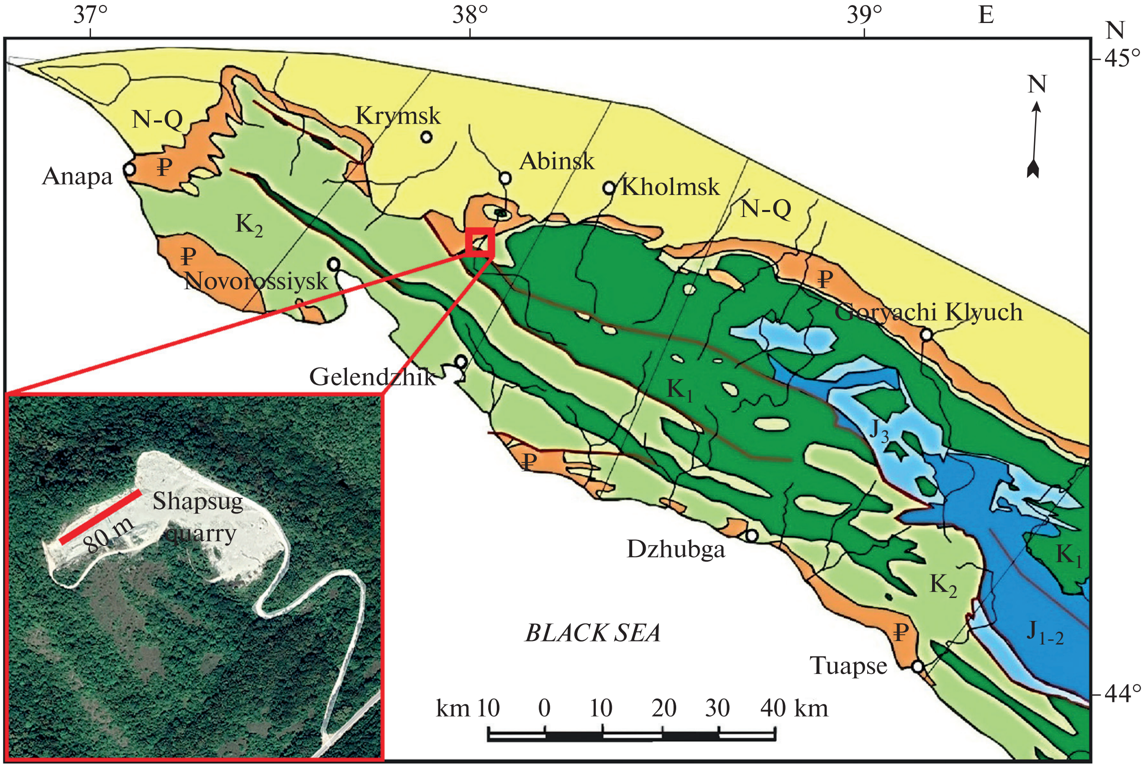

Fig. 1. A geological map of the Northwestern Caucasus, modified after (Rasvetayev et al., 2011). The inset is a satellite image of the Shapsug quarry (Yandex maps). The 80 m line is the sampling interval.

Fig. 2. The boundary of the Turonian and Coniacian in the section of the northwestern wall of the Shapsug quarry. The black dotted line is the boundary of Sequences 6 and 7, the red line is the boundary of the Turonian and Coniacian stages (photo by E.V. Yakovishina).

both planktonic (PF) and benthic (BF) species. Crushed rock was first disintegrated by boiling in a weakly alkaline solution, then washed by hand in flowing water through a 0.063 mm sieve. The images of the taxa that are most important for age determination are given and their stratigraphic distribution is shown. The PF and BF indice species were photographed using a JEOL JSM-6480LV scanning electron microscope.

The oxygen and carbon isotope analysis of the samples was carried out using a Delta V Advantage mass spectrometer. The analysis of the $^{13}C/^{12}C$ and $^{18}O/^{16}O$ isotope ratios was based on the method of CO_2 extraction from carbonate by interaction with phosphoric acid. The reaction products of CO_2 and H_2O were admitted into a vacuum line, where they were separated cryogenically. The purified CO_2 was collected into an ampoule, analyzed using a mass spectrometer, and the deviations of $^{13}C/^{12}C$ and $^{18}O/^{16}O$ values from the respective parameters in the VPDB (δ Vienna Pee Dee Belemnite Standard) were measured. The results are expressed as $\delta^{18}O$ and $\delta^{13}C$ in ‰.

The method of isotope thermometry is based on the distribution of the isotope ^{18}O between water and mineral oxygen, i.e., on the presence of isotope exchange between these two components, expressed by the following reaction, e.g., for carbonates:

$$H_2{}^{18}O + M_2C^{16}O_3 = M_2C^{18}O_3 + H_2{}^{16}O.$$

The paleotemperature values were calculated using the Epstein equation (Epstein et al., 1953) with modified temperature coefficients calculated for laboratory inorganic calcite deposition (Kim et al., 1997). The formula used for recalculation was

$$T = 16.9 - 4.38(\delta) + 0.1(\delta^2), \quad \delta = \delta_c - \delta_w,$$

where T is temperature, °C and δ is the difference between the measured value $\delta^{18}O_c$ normalized using the VPDB standard and the $\delta^{18}O_w$ value (standard average $\delta^{18}O$ value of ocean water for high latitude ice-free conditions in the late Cretaceous interval; equal to 1‰ (Shackleton and Kennett, 1975)), ‰.

The increase in $\delta^{13}C$ content in the samples indicates the increasing role of organic matter in the paleobasin, since the light isotope ^{12}C was used by living organisms for photosynthesis, while the heavy isotope ^{13}C remained in the water, i.e., the more $\delta^{13}C$ there is, the higher the bioproductivity of the basin is.

RESULTS AND DISCUSSION

Description of the section. The Shapsug quarry section is a steeply dipping southward monocline composed by a rhythmic substantially carbonate sequence. The lower and upper contacts of the Natukhayskaya Formation in the Shapsug quarry have not been established. The thickness of the exposed part of the section is 80 m. The following sediments are exposed in the section from bottom to top (Fig. 2).

Sequence 1. Cyclic alternation of greenish gray limestone, greenish gray calcareous clays, and white chalky limestone. The thickness of greenish-gray limestone is 10 cm, interlayers of clays are 2–3 cm, and white limestone is 30 cm. Stylolite seams are frequent in the white limestones. The sequence is represented by rhythmic cycles, similar to Milankovitch cycles, with a total of 36 cycles. The total thickness of the sequence is 12 m.

Sequence 2. Red and greenish gray limestones with thin interlayers of clays. At the bottom of the sequence there are dense red limestones with iron stains and thin interlayers of clays, greenish-gray limestones, sometimes with inclusions of fragments of red limestones up to 2–3 cm. There are folds of submarine landslide genesis. The thickness of the lower part is up to 1 m. Above, there is a pile of red and greenish-gray limestone (3–10 cm) with thin interlayers of red and greenish-gray clays (2–5 cm). The total thickness of the sequence is 5 m.

Sequence 3. Alternating greenish gray limestone (10–15 cm), clayey limestone (carbonate clays) (5–10 cm) and sandstone. At the top of the pack there is an alternation of greenish gray limestone and clayey limestone and red clay (2-5 cm), as well as a 10 cm-thick layer of limestone with black admixtures. The limestone contains burrows and stylolite seams. Rare interlayers of sandstones, siltstones, and clays are present within the sequence. The thickness of the sandstones is 0.5–3 cm. Sandstones are fine-grained, with carbonate cement. Twenty flichoid rhythms with sandstones were counted. Gradational layering is absent. The boundaries between the layers are well defined. Horizontal burrows up to 20 cm long were observed in the sandstones. The thickness of the sequence is 16 m.

Sequence 4. A 2 m-thick interstratification of white and greenish gray limestone and thinly laminated clayey limestone. The clayey limestone contains calcite veins. Higher up the section there is the interlayering of limestone and calcareous clay. The thickness of limestone layers is 10–15 cm, the thickness of clays varies from 2–3 to 15 cm. The total thickness of the sequence is 7 m.

Sequence 5. Whitish limestones with limonite coating on the layering surfaces and fractures. The thickness of the layers is 15–25 cm. The thickness of the sequence is 2 m. In the roof, there is a slipping plane along a low-amplitude subvertical thrust fault. The amplitude of the uplift is about 4 m. The fault ends in the visible part of the section.

Sequence 6. Rhythmic alternation of light gray and white, very dense limestone (10–15 cm) and clayey dark gray, greenish gray limestone (5–10 cm). The sequence has a cyclic character similar by the type to the cycles of Milankovitch. The clayey greenish-gray limestone contains burrows. The thickness of the sequence is 6 m.

Sequence 7. Rhythmic flichoidal alternation of light gray, whitish limestone (10–15 cm) and clayey limestone of dark gray, greenish gray color (5–10 cm). The thickness of a single cycle of light-dark limestone is about 15–25 cm. There are rare interlayers of fine-grained light gray sandstone (sandy limestone) with oblique stratification; a black admixture of plant detritus can be seen along the stratification. Sandstones are dense, with carbonate cement. Rare small hieroglyphs (traces of currents) are noted in sandstones. Calcite druses are found in clayey limestones. The thickness of the sequence is 25 m.

Sequence 8. Irregular interlayering of dense limestone (20 cm), greenish-gray clayey limestone (10–15 cm), gray limestone, sandy limestone, fine-grained calcareous sandstone, with oblique stratification and traces of flows, with thin (1–2 cm) interlayers of green and black clays. The clays contain thin calcite veins up to 0.5-cm thick and are characterized by numerous horizontal burrows. The thickness of the sequence is 7 m.

Biostratigraphic analysis. The zonal stratigraphy of the Turonian–Coniacian deposits of Western Europe is based primarily on the distribution of inoceramids and ammonites (Walaszczyk et al., 2010, 2021; Wood et al., 2004). No fossil macrofauna was found in the Shapsug quarry; therefore, the age of the host rocks was inferred from the distribution of planktonic and benthic (predominantly planktonic) foraminifera shells (Fig. 3). The bulk of the PF associations are represented by large sculpted shells with a bifacial peripheral margin and a broad umbilical opening. The details of the aperture structure, unfortunately, are not distinguishable, since the preservation of shells is not that good. This group includes representatives of the genus *Marginotruncana*, as well as the very rare *Dicarinella* with convex umbilicus (in the modern classification of some researchers *Concavatotruncana*). They underlie the stratigraphic zone of the Turonian–Coniacian boundary interval (Fig. 3). The remaining part of the complex consists of smaller shells with relatively simple morphology, consisting of globular chambers without a keel, with a simple umbilical or interiomarginal aperture.

The high diversity of species of the genus *Marginotruncana* and the absence of shells of *Helvetoglobotruncana helvetica* (Bolli) (a zonal form of the Lower Turonian) indicate that the section between Samples 1–5 belongs to the *Marginotruncana pseudolinneiana* zone, i.e., to the middle zone of the Turonian. The first *Marginotruncana coronata* (Bolli) specimen was found in Sample 7, which allows the zone of the same name to be distinguished at this level. The zone corresponds to the Upper Turonian in the sections of Central Poland (Walaszczyk and Peryt, 1998), and to Upper Turonian–Lower Coniacian in the sections of Southwestern Crimea and the Northeastern Caucasus (Kopaevich, 2010; Kopaevich and Vishnevskaya, 2016; Vishnevskaya and Kopaevich, 2020). Isolated shells of *Marginotruncana sinuosa* (Porthault) appear in the section starting from sample 14; from sample 18 on there were also isolated convex-umbilicus shells of *Dicarinella concavata* (Brotzen). The occurrence of *M. sinuosa* in the section indicates the presence of the upper part *Marginotruncana coronata* zone of the Crimean–Caucasian zonal scale (Kopaevich, 2010), and the occurrence of the *Dicarinella concavata* morphotype with a strongly convex umbilical side in Sample 18 indicates the definite presence of Lower Coniacian deposits in the section (Coccioni et al., 2015).

BFs are found throughout the section; the number of their shells ranges from 20 to 60%. The taxonomic diversity is low, within 17 species. We note the constant predominance of calcareous-secreting benthos over agglutinated benthos, represented by only six species. Agglutinated forms dominate only in Sample 7. Species of the BF association that are frequent in the Cenomanian–Lower Turonian sediments, but may also appear in the higher intervals of the Turonian, were encountered in the lower part of the section (samples 1–5). The presence of the species *Gavelinella moniliformis* (Reuss) in these deposits, however, indicates the age of the deposits is no older than the Middle Turonian, and the appearance of the first *Protostensioeina* sp. in Sample 7 indicates the Late Turonian age. The index-species *Reusella kelleri* Vasilenko, which usually occurs in the upper part of the Upper Turonian of the East European Platform, was observed in Sample 16 in the upper part of the section, while *Protostensioeina granulata* (Olbertz) was found in Sample 18, indicating the Early Coniacian age of the host deposits (Benyamovsky, 2008; Vishnevskaya et al., 2018). Shells of *Gyroidinoides nitidus* (Reuss) were found throughout the section (samples 4–20). An increase in the content of BF with an agglutinated wall including *Ataxophragmium nautiloides* (Brotzen), which usually appears in the terminal part of the Turonian (Benyamovsky, 2008), was recorded in sample 11.

Analysis of the taxonomic composition of foraminiferal assemblages from the Turonian–Coniacian deposits in the Shapsug quarry showed that the deposits were formed in an open marine basin with relatively high taxonomic diversity. Species with primitive morphology, relatively shallow, or transient taxa prevail in samples where the taxonomic diversity decreases. These data, as well as fluctuations in the PF/BF ratio, indicate a decrease in depth and the approach to the provenance area. Formation of interlayers of terrigenous sediments found in the Shapsug quarry is associated with these intervals and also indicates short-term periods of lowering of sea level and possible manifestations of tectonic movements. This is also indicated by the rare presence of PFs belonging to the so-called *K-strategists*, which needed a transparent water column to a depth of at least 200 m and a favorable temperature to carry out their life cycle (Kopaevich and

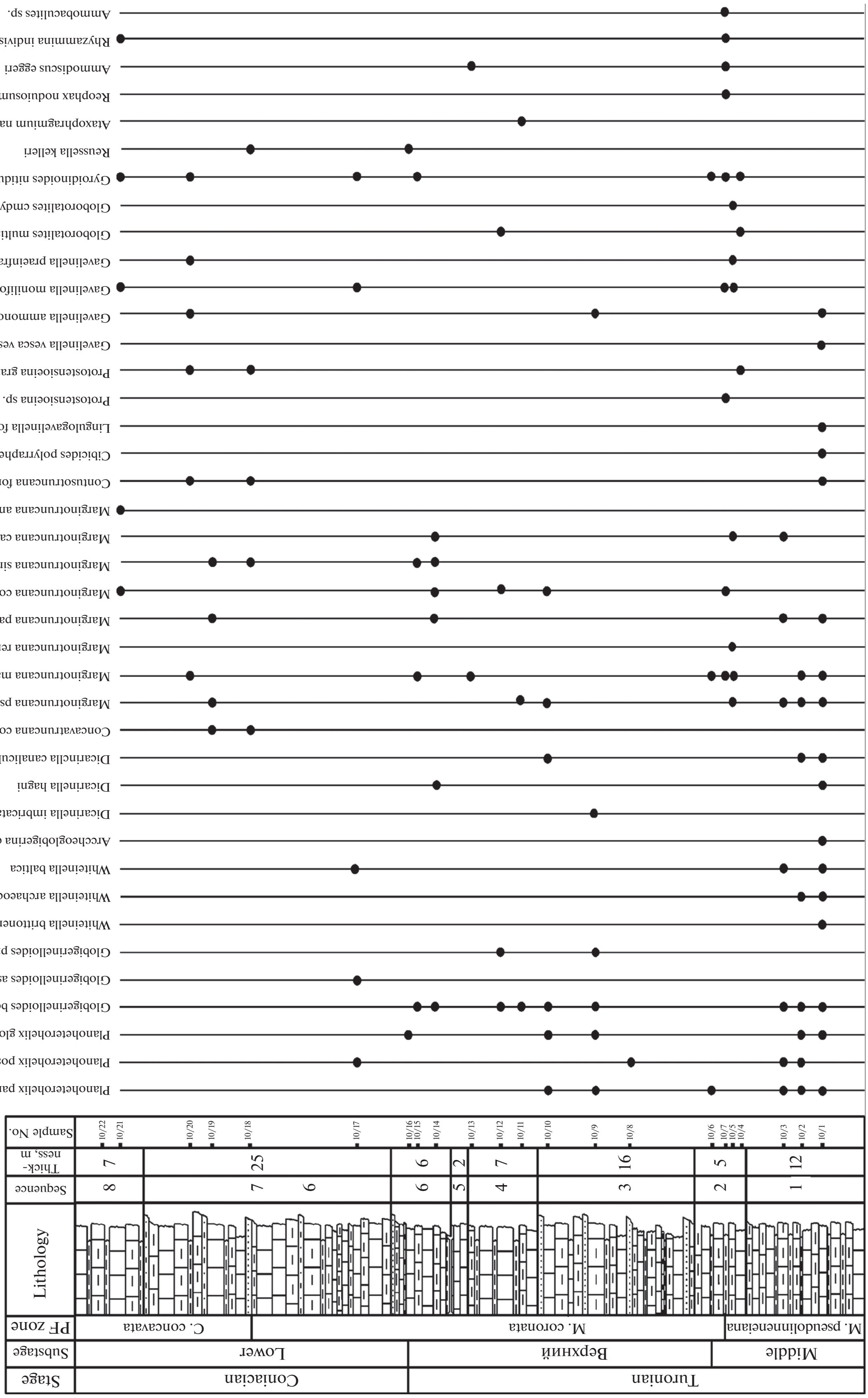

Fig. 3. The stratigraphic distribution of foraminifera in the Turonian–Coniacian deposits of the Shapsug quarry section.

Vishnevskaya, 2016). The depth of the basin most likely did not exceed that of the outer shelf (upper part of the continental slope). This is also confirmed by sedimentological data.

Isotope analysis. Isotope stratigraphy based on the curve of $\delta^{13}C$ is well developed for the entire Late Cretaceous, and isotope events can be traced over considerable distances (Jarvis et al., 2006; Voigt et al., 1997; Wiese, 1999; Wood et al., 2004; Walaszczyk et al., 2010). In the Turonian–Coniacian section of the Shapsug quarry, the isotope curve changes and absolute values of $\delta^{13}C$ determined intervals, which can be compared to a number of isotope events identified in the European sections of the corresponding age (Fig. 4) (Jarvis et al., 2006; Voigt et al., 1997; Wiese, 1999; Walaszczyk et al., 2010). The relative values (‰), their variations, maxima, and minima of the values on the isotope curve were taken into account while characterizing the zones of the studied section.

A local maximum of the $\delta^{13}C$ curve characteristic of the end of the Middle Turonian was established in the upper part of zone 1, (Gale, 1996; Wiese, 1999; Jarvis et al., 2006; Walaszczyk et al., 2010). In the Western European sections this event is distinguished as the Pewsey Event (Voigt et al., 2004; Walaszczyk et al., 2010). The boundary between zones 1 and 2 is drawn by the change in the local maximum for a decrease in the $\delta^{13}C$ values and is correlated with the boundary between the Middle and Upper Turonian. The maximum, corresponding to the lower part of the Upper Turonian, is distinguished at the base of zone 2. The manifested maximum of $\delta^{13}C$ values is called the Upper Turonian Event (Hitch Wood Event or Hyphantoceras Event) (Voigt et al., 2004; Walaszczyk et al., 2010). The changing trends of $\delta^{13}C$ curve values in the upper part of the Upper Turonian are associated with the boundary of the Turonian and Coniacian stages (Wiese, 1999; Jarvis et al., 2006; Walaszczyk et al., 2010). This event at the boundary of the Turonian and Coniacian stages is called the Navigation Event (Jarvis et al., 2006; Walaszczyk et al., 2010, 2021).

The local minimum of $\delta^{13}C$ values corresponds to the top of the Upper Turonian. This event was chosen by the International Union of Geological Sciences as an auxiliary marker when establishing the global stratotype point of the so-called golden nail boundary (GSSP), that is, the lower boundary of the Coniacian Stage (Walaszczyk et al., 2021). Zones 3 and 4 correspond to the Lower Coniacian Stage. The $\delta^{13}C$ maximum recorded in zone 4 correlates with the isotope Light Point Event in the West European sections (Jarvis et al., 2006; Walaszczyk et al., 2010). The $\delta^{13}C$ isotope curve of the Cretaceous sediments in the Shapsug quarry has significant similarity with the $\delta^{13}C$ variation in the European sections (Jarvis et al., 2006; Walaszczyk et al., 2010). The excursions of these values are good markers that can be traced over considerable distances, which allows reliable stratigraphic correlations. Thus, based on the analysis of $\delta^{13}C$ variations and construction of the isotope curve, we managed to detail the stratigraphic partitioning of the Turonian–Coniacian deposits of the section and locate the boundary between the Turonian and Coniacian stages, as well as that between the Middle and Upper Turonian (Fig. 4).

In general, the excursions of $\delta^{13}C$ and $\delta^{18}O$ values agree well with the lithological features of rocks and changes in the composition of microbiota of their host sediments.

Thus, an integrative approach to the study of Upper Cretaceous deposits in the Shapsug quarry based on bio- and chemostratigraphy was the basis for determining the Turonian and Coniacian boundary in this section. It should be noted that on May 1, 2021, the International Union of Geological Sciences ratified the Global Stratotype Section and Point (GSSP), the so-called golden nail of the lower boundary of the Coniacian Stage of the Upper Cretaceous system (Walaszczyk et al., 2021). The lower boundary of the Coniacian Stage was determined as the basement of Bed 46 of the section in the Salzgitter-Salder quarry in northern Germany (Fig. 5). The boundary is defined by the first occurrence of the bivalve inoceramus species *Cremnoceramus deformis erectus* (Meek) and is complemented by a carbon isotope (Navigation) event recorded as a negative $\delta^{13}C$ anomaly. Three auxiliary sections of different facies and differing geographically and biogeographically were also selected to refine the characteristics of the boundary. These are the Słupia Nadbrzeżna section located in Central Poland, the Střeleč section in the Czech Republic, and El Rosario in northeastern Mexico (Walaszczyk et al., 2021).

The importance of this decision is clear for stratigraphers of any country dealing with the Cretaceous system. From the practical point of view, it will serve as an occasion to bring the state of the regional stratigraphic scales into accord with the stratotype, which will allow more reliable comparisons of stratigraphic scales and interregional correlations.

The establishment of the global stratotype of the boundary and the point of the basement of the Coniacian Stage raises the question of isolating the hypostratotype (limitation) of this boundary in the territory of the Russian Federation. The authors believe that the Upper Cretaceous section of the Shapsug quarry in the Abinsk district of the Northwestern Caucasus may serve as a possible hypostratotype (limitotype) of the lower boundary of the Coniacian Stage for the territory of the Russian Federation in accordance with the Russian Stratigraphic Code, as the stratotype is beyond its borders (*Stratigraficheskii*..., 2019). Such a decision would be even more logical, since the sediments in the Shapsug quarry have similar lithological composition to the sediments of the boundary stratotype in northern Germany and

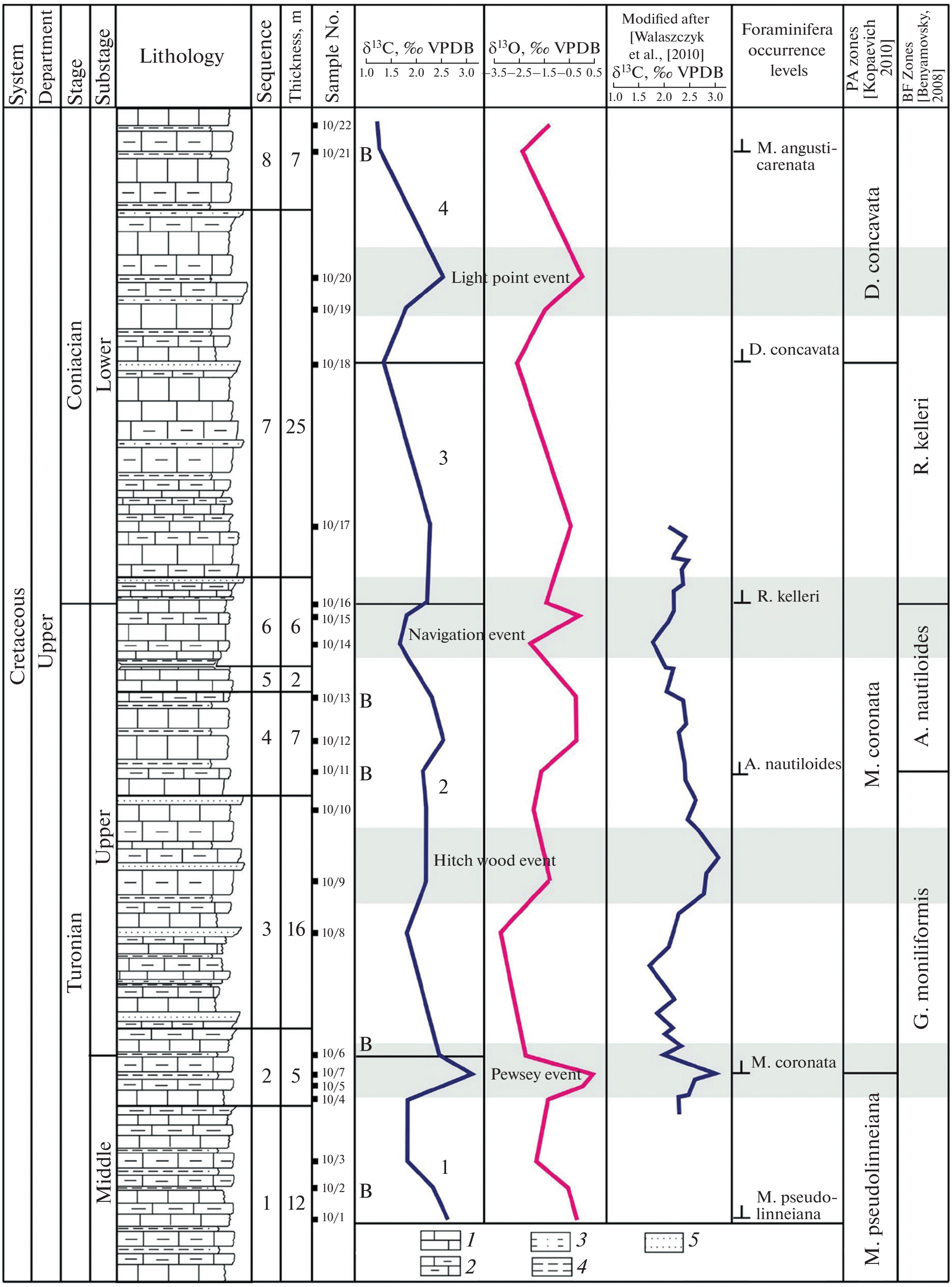

Fig. 4. The ^{13}C and ^{18}O isotope curves and foraminifera zones: 1–4 are ^{13}C isotope zones. The names of isotope events established in the western European sections: Pewsey Event; Hitchwood (Hyphantoceras) Event; Navigation Event; Light Point Event; B, bentonite clay interbeds.

Fig. 5. A paleogeographic map of Europe (90 Ma) with the location of the stratotype and parastratotypes of the GSSP basement of the Coniacian Stage, as well as the proposed hypostratotype in the Shapsug quarry, modified after (Blakey, 2021).

are actually represented by the same or very similar facies.

The boundary of the Turonian and Coniacian stages runs within Sequence 6, as represented by rhythmic alternation of limestones and clayey limestones, which confirms the existing continuity of the stratigraphic sequence and the absence of significant interruptions. The planktonic and benthic foraminifera assemblages are very similar to the stratotype. The $\delta^{13}C$ isotope curve for the sediments in the Shapsug section largely coincides with that in the sediments of the stratotype of the Turonian–Coniacian boundary (Walaszczyk et al., 2010, 2021). Inoceramid and ammonite shells have not yet been found in this section for a more correct correlation with the stratotypic section, which is a significant drawback. Inoceramids, however, have been found in neighboring sections of the area. Thus, *Inoceramus lamarcki* Park. was determined in the lower Natukhayskaya Formation (Korsakov et al., 2013). *Cremnoceramus* ex gr. *inconstans* Woods, and *C. schloenbachi* (Boehm) were found in the Shapsug syncline (Korsakov et al., 2021). This may indicate the possibility of their occurrence in the Shapsug section as well, which is a clear reason for its further study and collection of fossil fauna.

The Turonian–Coniacian boundary lies within the C33n normal polarity magnetozone of the Cretaceous magnetostratigraphic scale (Guzhikov et al., 2007; Wendler, 2013). Therefore, this method cannot be applied to refine it. Additional advantages of the Shapsug section are the presence of representative complexes of pelagic and benthic foraminifera, as well as the absence of clear evidence of discontinuities, condensed horizons, levels of unaccumulated sediments, and traces of erosion. It is also important that the location of the section is convenient to access and there is well-developed infrastructure in the area. The solution of the problem of the boundary between the Turonian and Coniacian stages is very relevant to the domestic Upper Cretaceous stratigraphy.

CONCLUSIONS

1. Sedimentation at the Turonian–Coniacian boundary took place in a relatively deep open marine basin. The sand- and siltstone interlayers record brief moments of shoreline retreat toward the basin, which is confirmed by micropaleontological data.

2. Events recorded by $\delta^{13}C$ and $\delta^{18}O$ values on the isotope curves reflect climate and bioproductivity fluctuations of the paleobasin. The intervals between isotope events are highlighted as isotope zones.

3. The excursions of δ^{13} C values can be compared with a number of isotope events established in the sections of Western and Eastern Europe of the corresponding age.

4. The boundary between the Turonian and Coniacian stages was established in the section on the basis of complex chemo- and biostratigraphic data. The

boundary between the Middle and Upper Turonian was also determined.

5. The Upper Cretaceous section of the Shapsug quarry is proposed as a possible hypostratotype (limitotype) of the lower boundary of the Coniacian Stage for the territory of the Russian Federation.

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