

Santonian–Campanian Boundary Position in the Alan-Kyr Section (Central Crimea): New Micropaleontological Data

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Abstract—This work presents the results of determination of foraminifers and nannoplankton from the Upper Cretaceous deposits of the Alan-Kyr section (the central part of the Crimean Mountains). The interpretation of these data, together with previously obtained palynological and paleomagnetic data, allow us to justify the age of country deposits. In the lower part of the section, beds with planktonic foraminifera are correlated with the Santonian part of the *Dicarinella asymetrica* Zone. The benthic foraminiferal assemblages also belong to the Santonian interval and allow us to subdivide this interval in more detail. Based on the nannoplankton data the transitional Zone CC17 was identified, which corresponds to the Upper Santonian–Lower Campanian. The base of a probable analogue of Chron C33r is distinguished within these deposits and is proposed for use as a primary feature to define the lower boundary of the Campanian.

Keywords: Santonian–Campanian boundary, Mountain Crimea, Alan-Kyr section, foraminifera, nannoplankton

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INTRODUCTION

The Upper Cretaceous Alan-Kyr section, which is exposed in a gully at the foothills of Mt. Alan-Kyr near the village of Lechebnoe (Belogorsk District, Republic of Crimea) (Fig. 1), was previously studied by L.G. Bragina et al. (2016); Beniamovsky and Kopaevich (2016), who justified the occurrence of the Coniacian, Santonian, and Campanian deposits in this section. The Alan-Kyr section is composed of pelagic limestones, marls, and calcareous clays with chert nodules. Beds are dipping to the northeast at an angle varying from 10° to 30° (dip azimuth, 40°–60°). In 2017–2018, additional appraisal of this section, including the description and collection (the “sample to sample” system) of paleomagnetic, palynological, and micropaleontological (dinocysts, nannoplankton, and foraminifers) samples was performed (Guzhikov et al., 2020). The goal of this work was to obtain sedimentological and paleomagnetic data and determine dino-

cysts and nannoplankton for the first time. During our work, we intended to restudy benthic and planktonic foraminifers, since only a small number of samples were previously studied. In addition, foraminifer shells were extracted from siliceous nodules and not from enclosing rocks.

Beniamovsky and Kopaevich (2016, p. 12) noted: “Hence, the position of the Santonian–Campanian boundary in the Alan-Kyr section has not been identified as yet. This section should be subject to additional studies involving magnetostratigraphic investigations and detection of the *Dicarinella asymetrica* (Sigal) species, other planktonic forms, and macrofauna.” Given the possibility of inaccurate determination of some event levels and boundaries given in the above work, some works were partially performed and the results are given in the present paper.

As a result of the paleomagnetic and palynological studies (Guzhikov et al., 2020), the stratigraphic char-

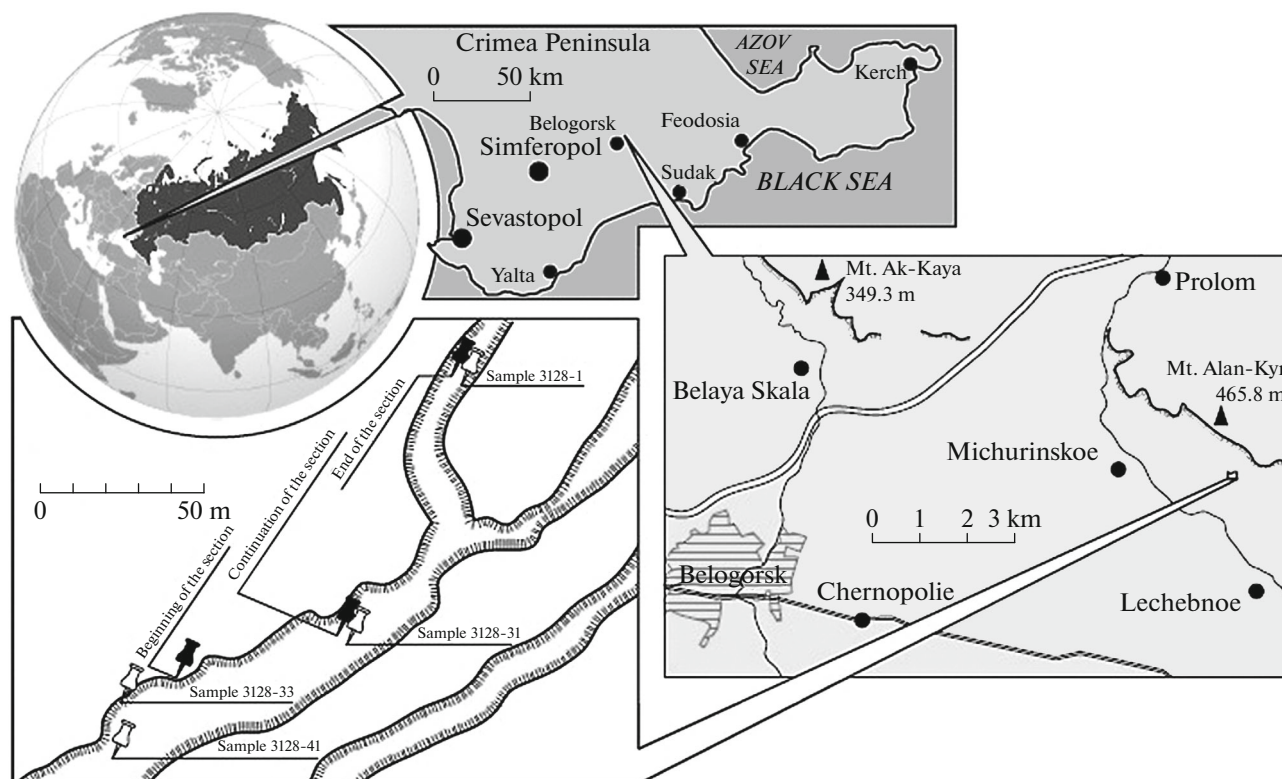


Fig. 1. The location of the Alan-Kyr section in the Crimean Mountains after (Guzhikov et al., 2019).

acteristics of deposits was supplemented. In the lower part of the section, two zones of reversal polarity, separated by a ~35 m hiatus, were recognized. These zones can presumably be correlated with the upper and lower parts of the C33r magnetic Chron (Fig. 2). This hiatus corresponds to the Early and the beginning of the Middle Campanian in the International Stratigraphic Scale (Ogg et al., 2016). Unfortunately, palynomorphs were not found in deposits with reverse polarity, but dinocyst assemblages, which were found upsection, indicate the Campanian age of the enclosing rocks (Aleksandrova and Guzhikov, 2018; Guzhikov et al., 2020).

The present paper provides updated results on the distribution of planktonic (PF) and benthic foraminifera (BF), as well as preliminary data on nannoplankton from the Alan-Kyr section. The analysis of the obtained materials, together with the micropaleontological and paleomagnetic data, made it possible to judge the age of deposits reasonably and the relationship of the stratigraphic boundaries, as justified by the results of various methods (Beniamovsky and Kopae-vich, 2016; Bragina et al., 2016; Guzhikov et al., 2020).

MATERIALS AND METHODS

A layer-by-layer description of the Alan-Kyr section performed by E.Yu. Baraboshkin was given in

(Guzhikov et al., 2020). The treatment of samples for subsequent study of foraminifera was performed in the Laboratory of Micropaleontology of Geological Institute of Russian Academy of Sciences (GIN RAS; analyst P.A. Proshina) and in the Laboratory of Stratigraphy and Paleontology of the Lower Volga Research Institute of Geology and Geophysics (Saratov, analyst I.P. Ryabov). Nannofossil-bearing samples were processed at the Micropaleontological Lab of the Geological Survey of Israel (analyst M.N. Ovechkina). I.P. Ryabov processed 13 samples, 9 of which came from the Unit 1. The other four samples characterize the sequence of units (2 to 5). All samples were treated with glacial acetic acid. Shells were extracted by N.O. Grechikhina and I.P. Ryabov. P.A. Proshina collected nine samples every 5 m and processed them. Samples were melted together with sodium thiosulfate and then washed in an ultrasonic bath. Samples 1, 10, 20, 30, 35, and 40 were washed in accordance with two methods, independently from each other. PF with planispiral and trochospiral shells were studied by L.F. Kopae-vich and N.O. Grechikhina, while biserial planktonic foraminifera were studied by P.A. Proshina; BF were studied by I.P. Ryabov.

The nannofossils from 39 samples were studied; the sample preparation was performed according to the standard technique (Bown and Young, 1998). The

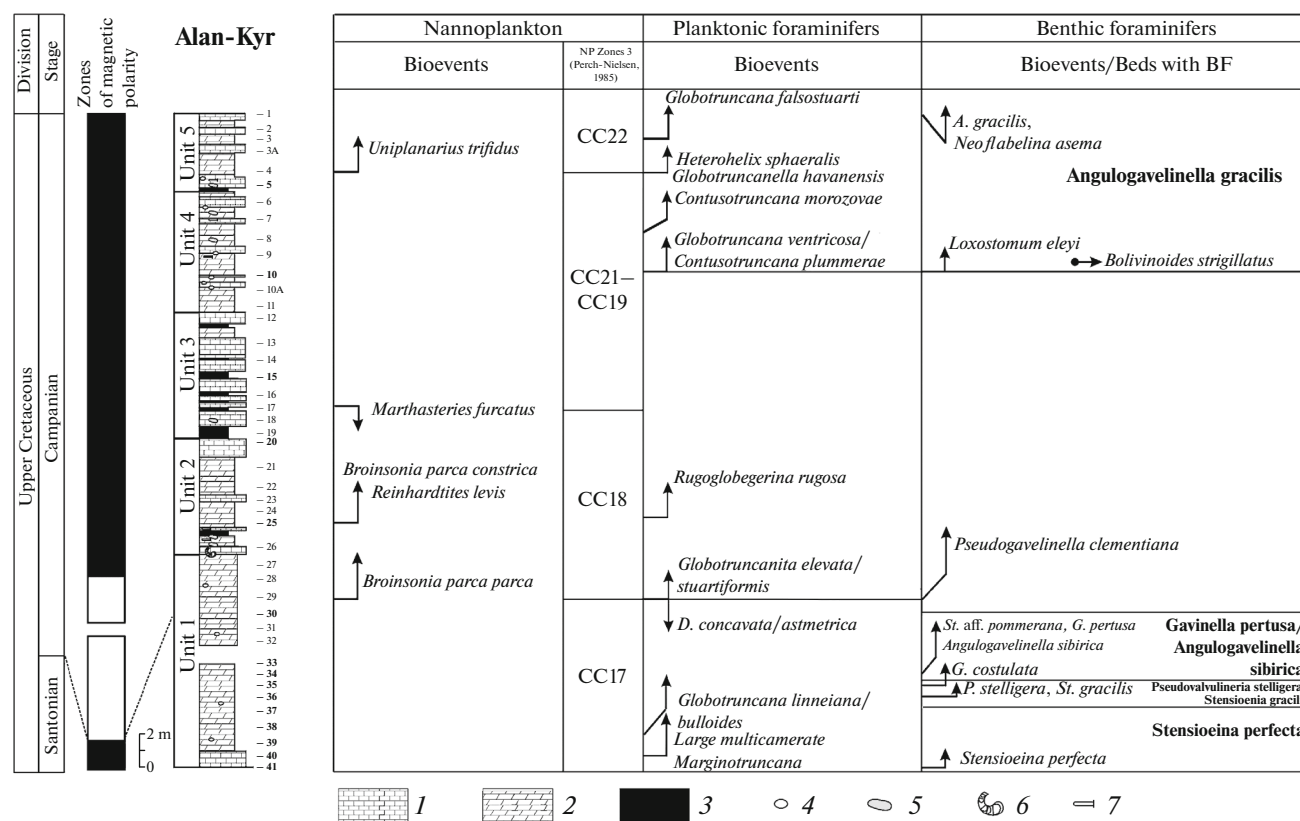


Fig. 2. Subdivision of the Alan-Kyr section based on planktonic and benthic foraminifers, nannoplankton, and major bioevents.

smear-slides were examined under a Zeiss Axiolab light microscope (1200×).

BSE images of PF index species were taken using a Tescan 2300 scanning electron microscope at the GIN RAS, as well as using a JEOL JSM6480LV electron microscope at the Faculty of Petrology of the Department of Geology of Moscow State University. The BF index species were studied and photographed using a MIRA 2 LMU (Tescan) field-emission scanning electron microscope at the Nanomaterials and Structures Diagnostic Laboratory of the Education and Research Institute of Nanostructures and Biosystems of Saratov State University. Images of index species are given in Fig. 3.

RESULTS AND DISCUSSION

Planktonic Foraminifers (PF)

The assemblage of spiral–conical PF that occur in the lower part of the Alan-Kyr section (samples 40 and 39) is mainly represented by the genus *Marginotruncana* Hofker, 1956. Large forms of multi-chamber taxa *Marginotruncana coronata* (Bolli, 1945) and *M. marginata* (Reuss, 1845) dominate greatly.

Along with these species, there are single specimens of *Globotruncana linneiana* (d'Orbigny, 1839). The first occurrence of this species has been already noted in the Santonian deposits (Coccioni and Pre-

moli Silva, 2015, p. 6; Kopaeovich and Vishnevskaya, 2016; Kopaeovich et al., 2007; Lamolda et al., 2007, 2014; Türk Öz et al., 2016, 2018). Based on this, the lowermost samples 39 and 40 from Unit 1 are ascribed to the Santonian deposits.

Along with the preceding forms, the interval of samples 38–33 includes umbilical–convex shells of *Dicarinella concavata* (Brotzen, 1934); beginning from the sample 37, *D. asymetrica* (Sigal, 1952) and dorsal–convex shells of *Contusotruncana fornicata* (Plummer, 1931) appear. In addition, there are representatives of genera of *Archaeoglobigerina* Pessagno, 1967 and *Whiteinella* Pessagno, 1967. The PF assemblage allows us to ascribe the enclosing deposits to the Santonian interval of Zone *Dicarinella asymetrica* (Coccioni and Premoli Silva, 2015). The occurrence of index species *D. asymetrica* is not typical or highly limited for sections of the Crimea (Maslakova, 1978; Kopaeovich, 2010; Korchagin et al., 2012). However, this species is common (but in single specimens) in samples 38–31 from the Alan–Kyr section. There are single specimens of this species in the Santonian interval of the Shakh-Bogota section in the Mangyshlak Peninsula (Kopaeovich et al., 2007). In addition, this age is confirmed by finds of macrofaunal remains (Marcinowski et al., 1996; Walaszczyk et al., 2015).

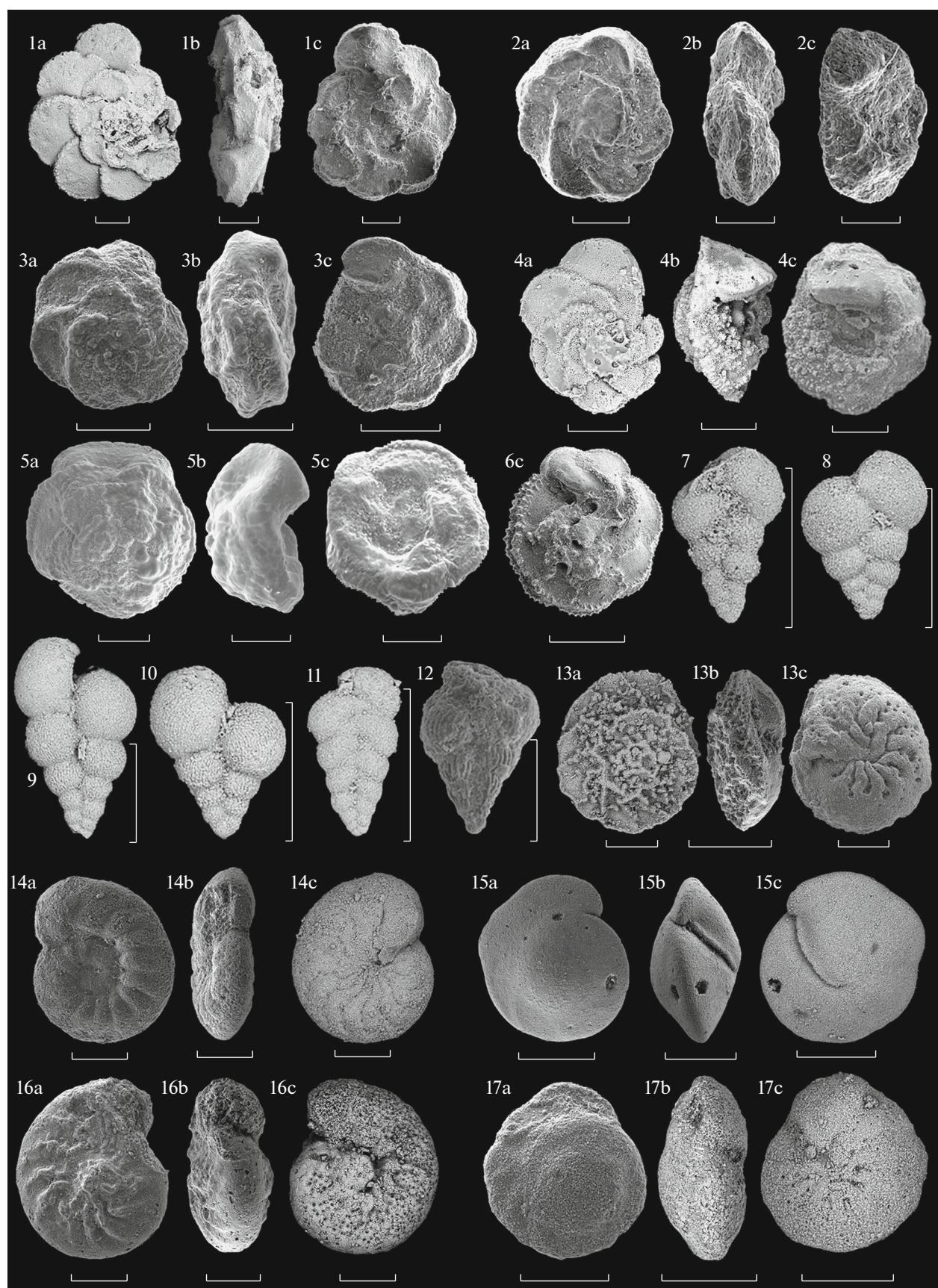


Fig. 3. Planktonic and benthic foraminifers from the Alan-Kyr section. General parameters of all specimens: (a) dorsal side, where all whorls are visible; (b) lateral side; (c) umbilical side, where the last whorl of a shell and the structure of aperture are visible. Scale bar, 200 μ m. Planktonic foraminifers: (1a–1c) *Marginotruncana coronata* (Bolli), sample 40; (2a–2c) *Dicarinella concavata* (Brotzen), sample 38; (3a–3c) *Globotruncana linneiana* (d'Orbigny), sample 38; (4a–4c) *Globotruncanella elevata* (Brotzen), sample 30; (5a–5c) *Contusotruncana plummerae* (Gandolfi), sample 10; (6c) *Globotruncana falsostuarti* (Sigal), sample 1; (7) *Heterohelix directa* (Aliyulla), sample 37; (8) *H. striata* (Cushman), sample 34; (9) *H. plummerae* (Sandidge), sample 33; (10) *H. reussi* (Cushman), sample 33; (11) *H. planata* (Cushman), sample 35; (12) *H. sphaeralis* (Georgescu), sample 5. Benthic foraminifers: (13a–13c) *Stensioeina perfecta* Koch, sample 35; (14a–14c) *Pseudovalvulineria stelligera* (Marie), sample 35; (15a–15c) *Angulogavelinella sibirica*, sample 34; (16a–16c) *Pseudogavelinella clementiana* (d'Orbigny), sample 30; (17a–17c) *Angulogavelinella gracilis* (Marsson), sample 3a.

Unfortunately, specimens from Crimea are characterized by very poor preservation; they are brittle and are broken upon being touched by a brush.

The first very poorly preserved specimens of *Globotruncanella elevata* (Brotzen, 1934) and *G. stuartiformis* (Dalbiez, 1955) and the first representatives of *Globotruncana arca* (Cushman, 1926) were found in sample 30. There are no specimens of *Dicarinella concavata* and *D. asymetrica*. This allows us to establish the Santonian–Campanian boundary, as it coincides with the level of the disappearance of the indicated species from sections (Caron, 1985; Coccioni and Premoli Silva, 2015; Kopaevich and Vishnevskaya, 2016; Maslakova, 1978; Petrizzo, 2003; Petrizzo et al., 2011; Premoli Silva and Sliter, 1995; Robaszynski and Caron, 1995).

The first rare specimens of species *Globotruncana ventricosa* (White, 1928) and *Contusotruncana plummerae* (Gandolfi, 1955) were recognized in sample 10. In general, the PF assemblage changes insignificantly. However the gradual decrease in a number of specimens of *Marginotruncana marginata* up to complete disappearance in sample 5 should be noted. The interval between samples 10 and 5 contains a foraminifera assemblage that corresponds to the *Globotruncana ventricosa* Zone, which is usually distinguished in the middle part of the Campanian deposits (Caron, 1985; Coccioni and Premoli Silva, 2015; Petrizzo et al., 2011; Premoli Silva and Sliter, 1995).

There are single specimens of *Globotruncanella havanensis* (Voorwijk, 1937) and *Globotruncana falsostuarti* Sigal, 1952 in sample 5; the number of specimens of *Rugoglobigerina rugosa* (Plummer, 1927) and planar–spiral species of the genus *Globigerinelloides* (Cushman and Ten Dam, 1948) increases. Species of the preceded assemblage are traced to this interval; only variations in quantitative ratios from sample to sample are observed. The PF taxonomic composition allows us to distinguish deposits of the *Globotruncanella havanensis* Zone in the interval of samples 3–5.

Among the studied species, well-preserved biserial representatives of the family Heterohelidae Cushman, 1927 substantially prevail among the PFs throughout the section, while they were absent in the material studied in 2015. However, the Heterohelidae assemblage shows a low diversity of taxa and is represented exclusively by biserial forms of the genus *Heterohelix* Ehrenberg, 1843. The applied taxonomy

(Georgescu, 2016) was used to recognize these species. In the lower part of the section (samples 41 and 40), abundant small *Heterohelix reussi* (Cushman, 1938) and *H. striata* (Cushman, 1938) were found; along with the latter, there are large taxa of *H. papula* (Belford, 1960). *Heterohelix directa* (Aliyulla, 1965), *H. planata* (Cushman, 1938) and *H. plummerae* (Sandidge, 1932) were recognized in the interval of samples 36–38. Throughout the studied stratigraphic interval the taxonomic composition of Heterohelidae species varies slightly; all the forms described above have a wide stratigraphic distribution (from the Turonian to the Maastrichtian inclusive). Apart from them, at the level of sample 5, specimens of the Middle Campanian (at the three-member division of the stage)—Maastrichtian species of *H. sphaeralis* (Georgescu, 2014) occur with poor preservation.

Benthic foraminifers

Within the Alan-Kyr section, the following BF-based subdivisions were established in the rank of beds (Fig. 2): *Stensioeina incondita/perfecta* Beds (the Lower–Middle Santonian); *Pseudovalvulineria stelligera*/*Stensioeina gracilis* Beds (the Middle–Upper Santonian); *Gavelinella pertusa*/*Angulogavelinella sibirica* Beds (the Upper Santonian); *Pseudogavelinella clementiana* Beds (the Lower Campanian); and *Angulogavelinella gracilis* Beds (the Upper Campanian).

Stensioeina incondita/perfecta Beds were established on the basis of the occurrence of the index species in the interval of samples 37–41. The assemblage is taxonomically diverse and is represented mainly by well-preserved calcareous BF. The species *Stensioeina perfecta* Koch, 1977, which was first recognized in the northwestern part of Germany in the Middle Santonian (Koch, 1977), where the eponymous zone was established (Schönfeld, 1990), is of the greatest stratigraphic importance. A similar zone was distinguished in the Lower Santonian of Western Ukraine (Dubicka and Peryt, 2014). According to this, the interval of *Stensioeina perfecta* Beds can be ascribed to the Lower–Middle Santonian.

Pseudovalvulineria stelligera/*Stensioeina gracilis* Beds were recognized in the interval of samples 35–36 on the basis of the first occurrence of index species. The most stratigraphically important species (*Pseudovalvulineria stelligera* (Marie, 1941) and *Stensioeina gracilis* (1945)) are used as zonal index species in some schemes (Beniamovsky, 2008; Walaszczyk et al.,

2016). According to these publications, these deposits can be ascribed to the Middle–Upper Santonian.

Gavelinella pertusa/*Angulogavelinella sibirica* Beds were recognized on the basis of the first occurrence of index species, which are used as zonal in some biostratigraphic schemes (Beniamovsky, 2008; Dubicka and Peryt, 2014; Vishnevskaya et al., 2018; Walaszczyk et al., 2016). This allows us to ascribe the interval of samples 34–40 to the Upper Santonian.

Pseudogavelinella clementiana Beds were recognized on the basis of the first occurrence of index species in the interval of samples 10–30. The first specimens of the zonal species were found in the upper part of Unit 1 (sample 30). The Santonian–Campanian boundary in the East European Platform was drawn on the basis of its first appearance (Vishnevskaya et al., 2018).

Angulogavelinella gracilis Beds were recognized on the basis of the occurrence of the index species in the interval of samples 1–10. The eponymous beds were also described in previous works (Beniamovsky and Kopaevich, 2016; Bragina et al., 2016) and the BF assemblage was characterized. A similar assemblage was recognized based on our data. The appearance of the stratigraphically important species *Angulogavelinella gracilis* (Marsson, 1878) allows us to attribute this interval to the Upper Campanian.

Nannoplankton

Sissingh's standard zonation (1977) with supplements (Perch-Nielsen, 1985) was applied for the biostratigraphic subdivision of the Alan-Kyr section. The studied nannoplankton assemblage contains nannofossils of poor and moderate preservation (about 60 species).

In the lower part of the section (Unit 1, sample 30–41) the transitional Upper Santonian–Lower Campanian Zone CC17 occurs. This zone is determined as the interval from the first occurrence of *Calculites obscurus* Deflandre, 1959 to the first occurrence of *Broinsonia parca parca* (Stradner, 1963).

Higher in the section (Units 1–3, sample 17–29) the Lower Campanian CC18 Zone is distinguished as the interval from the first occurrence of *Broinsonia parca parca* to the disappearance of *Marthasterites furcatus* (Deflandre in (Deflandre and Fert, 1954)). The subdivision of Zone CC18 is impossible due to the absence of zonal markers. In sample 25, slightly above a hiatus in sedimentation, the appearance of *Br. parca constricta* Hattner et al., 1980 is noted. The appearance of the latter immediately above the appearance of *Br. parca parca* in the section is typical and defines the lower boundary of the CC18b Subzone, which has been recognized by many authors. However, the appearance of *Reinhardtites levis* Prins & Sissingh in Sissingh, 1977, which, according to (Perch-Nielsen, 1985), should be much higher, i.e., already in the

Upper Campanian interval, was also noted at the level of sample 25. Nevertheless, as was noted in (Burnett, 1998), the appearance of *R. levis* can be also recorded in the Lower Campanian.

It is most likely that the interval of samples 25–27 corresponds to a significant hiatus in sedimentation. Due to this, we cannot trace the sequence of appearance of species here with confidence. The interval of samples 5–16 (Units 1–3) corresponds to the undivided CC19–21 Zones, which are distinguished at the level of the Lower–Upper Campanian at the two-member division. A more accurate division into zones is difficult due to the lack of zonal index species. The upper part of the section (Unit 1) corresponds to the Upper Campanian CC22 Zone, whose the lower boundary is established on the basis of the appearance of *Uniplanarius trifidus* (Stradner in Stradner and Papp, 1961) in sample 4.

Based on the distribution of foraminifers and nannofossils in the Alan-Kyr section, several levels of bioevents have been distinguished (Fig. 3).

CONCLUSIONS

(1) The major bioevents are confined to the level of sample 30, i.e., the boundary between the Santonian and the Campanian stages, dated on the basis of PF and BF index species. This is in agreement with the available nannoplankton data, since the appearance of the species *Broinsonia parca parca* (Stradner) was established in sample 29, which confidently indicates the Campanian age of the deposits.

(2) The CC17 Zone recognized below contains the Santonian–Campanian transition nannofossil assemblage. At the same time, the presence of *Dicarinella concavata* (Brotzen) and *D. asymetrica* (Sigal) indicates the Late Santonian age of this interval.

(3) BF assemblages made it possible to date the interval of samples 30–39 as the Lower, Lower–Middle, and Upper Santonian (Fig. 2).

(4) The boundaries of the C34n and C33r magnetic Chrons extend at the level of sample 39, i.e., within the Santonian–Campanian interval based on nannoplankton and within the Santonian based on planktonic and benthic foraminifers (Guzhikov et al., 2019a, 2019b). At the same time, in the classical section at Gubbio (Italy), it coincides with the boundary between the *Dicarinella asymetrica* Zone and *Globotruncanites elevata* Zone (Coccioni and Premoli Silva, 2015) and therefore coincides with the Santonian–Campanian boundary.

(5) The bioevent levels identified in the overlying deposits made it possible to establish the presence of the Lower, Middle, and Upper Campanian deposits (Fig. 2, as well as Fig. 3 with PF and BF images). In addition, a hiatus in sedimentation, as established on the basis of the study of nannoplankton and BP, is assumed in the Alan-Kyr section.

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