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# Lithological–Geochemical, Petromagnetic, and Paleoecological Characteristics of the Campanian–Selandian Sedimentation Conditions in the Ul'yanovsk–Saratov Basin

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**Abstract**—The results of a complex study of the Upper Cretaceous carbonate section in the quarry of the cement plant of the town of Sengilei (Ul'yanovsk district) are presented. The Lower Paleocene cyclic opoka member is described. The formation conditions of the Upper Cretaceous cyclic and cryptocyclic, as well as Lower Paleocene cyclic, rocks are interpreted for the first time on the basis of lithological, petrographic, petromagnetic, geochemical, and paleoecological methods. The cyclicity was formed due to dilution cycles under climate fluctuation and eustatic variations, which were caused by eccentricity cycles of the Earth's orbit. These cycles are identified in the cryptorhythmic *lanceolata* sequence of the Lower Maastrichtian rocks.

*Keywords:* cyclicity, carbonate and siliceous sequences, Upper Cretaceous and Lower Paleocene rocks, Ul'yanovsk–Saratov basin, dilution cycles, Milankovitch cycles, lithological–geochemical methods, petromagnetism, paleoecology

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## INTRODUCTION

The Upper Cretaceous rhythmic carbonate section in the quarry of the Sengilei cement plant in the vicinity of the town of Sengilei (Ul'yanovsk district) was studied in detail for the first time using a complex of lithological–geochemical, paleoecological, and petromagnetic methods. This approach yielded a surprising result: a macroscopically erratic member of writing chalk was found to be cryptorhythmic, which is evident from the cyclic distribution of the measured parameters.

## METHODS OF STUDY

The boundary Cretaceous–Paleogene rocks of the section in the vicinity of the town of Sengilei were the object of study (Fig. 1). The rocks (151 samples, Fig. 2) were studied with chemical (analysis of the content of organic carbon and $CaCO_3$), petrographic (macroscopic and microscopic description of the section and thin sections, respectively), paleontological (analysis of ichnofossils: identification of an area of bioturbated rocks, the maximum diameter of holes, and ichnotaxons), and petromagnetic (the destructive field of remnant saturation magnetization, natural remnant magnetization, and remnant saturation magnetization) methods. The section has previously been studied with petrographic, chemical, physical, petromagnetic, and paleontological methods; the results have been published in a series of works (Gabdullin et al., 1999a, 1999b; Gabdullin and Ivanov, 2001; Gabdullin, 2002). In this work, we present the results of additional studies of the rocks of the section using another complex of methods.

A complete geochemical analysis of the elements was conducted for the first time for 32 samples, mostly carbonate and, to a lesser extent, terrigenous–carbonate rocks on a MARC GV X-ray fluorescent spectroscan (NPO Spektron, St. Petersburg) at the Department of Geology at Moscow State University (analyst E.N. Samarin). The calculated ratios and contents of

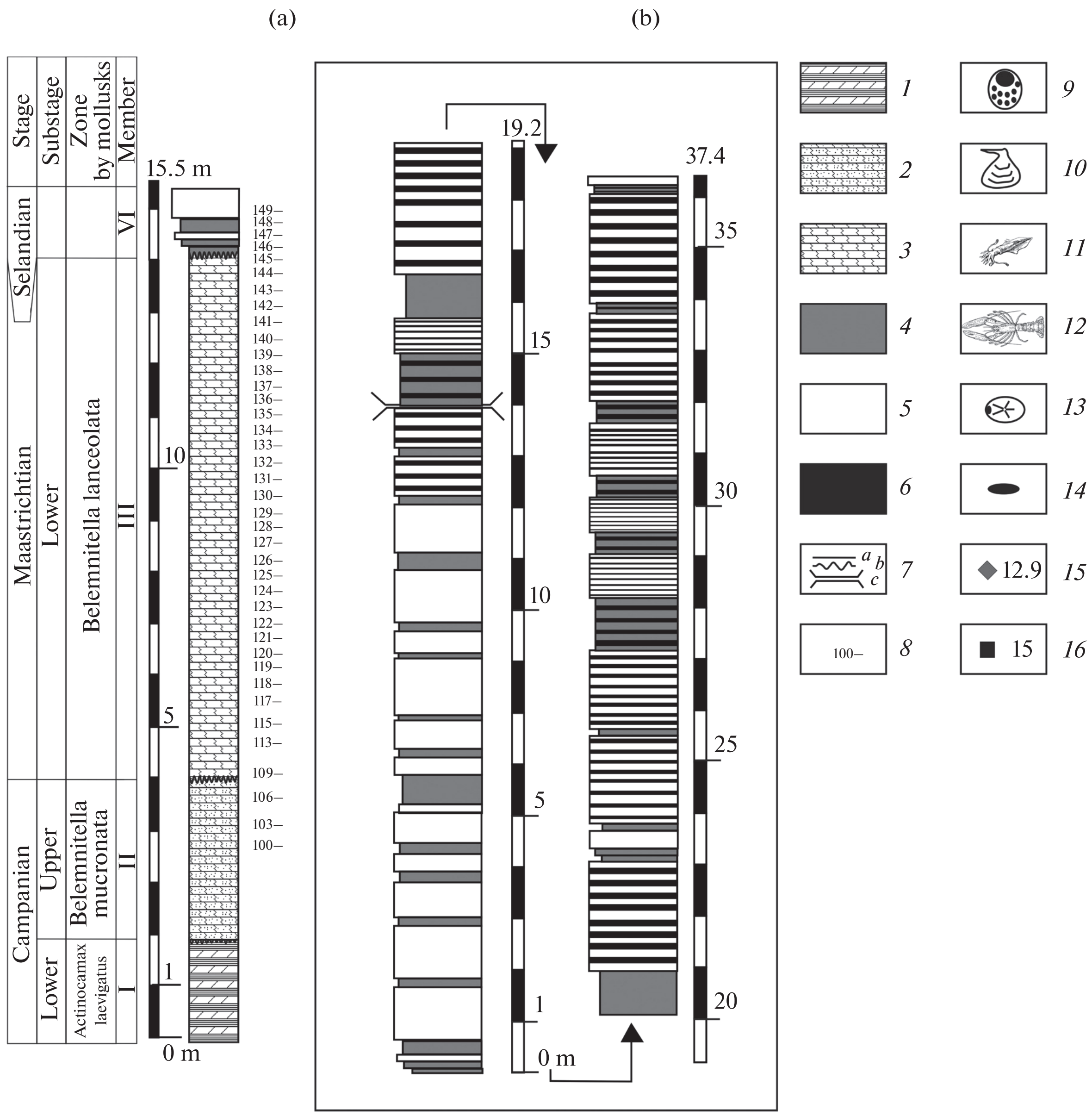

**Fig. 1.** Cross sections of the Campanian–Maastrichtian (a) and Selandian (b) sediments in the area of the town of Sengilei (Ul'yanovsk district). *1*, Intercalation of clay and clayey marl; *2*, sandy chalk; *3*, writing chalk; *4–6*, opoka (color corresponds to the rock color); *7*, geological boundaries: (a) conformable, (b) unconformable, (c) tectonic; *8*, position of sample in the section and sample number; *9*, *Porifera* (sponges); *10, Pteria*; *11, Belemnoidea*; *12, Thallassinoides*; *13, Echinoidea*; *14,* position of fossils in the section; *15–16,* position of samples in the section and position of samples for isotope paleothermometry (*15*, original; *16*, archive).

some chemical elements, which indicate the change of sedimentation conditions (depth of the basin, hydrodynamics, climate, etc.), allowed us to refine the previous ideas on the sedimentation regime.

An isotope analysis of stable isotopes of light elements of five samples of the boundary Cretaceous–Paleogene rocks was carried out on a Delta V Advantage mass spectrometer. The dried and crushed samples were treated with 105% polyphosphorous acid on a Gas Bench II device directly connected to the mass spectrometer. The content of stable carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) of $CO_2$ released after the carbonate–acid reaction was analyzed. The accuracy of the measurement was controlled by the NBS-19 international standard. The isotope values are given per mill relative to VPDB. Each sample was analyzed twice; the standard deviation is less than 0.1%.

The variations of the $^{18}O/^{16}O$ ratio can be measured by mass spectrometer with an error of ±0.01%; however, the methods of sample preparation for the analysis prevent such precision; thus, the ancient tempera-

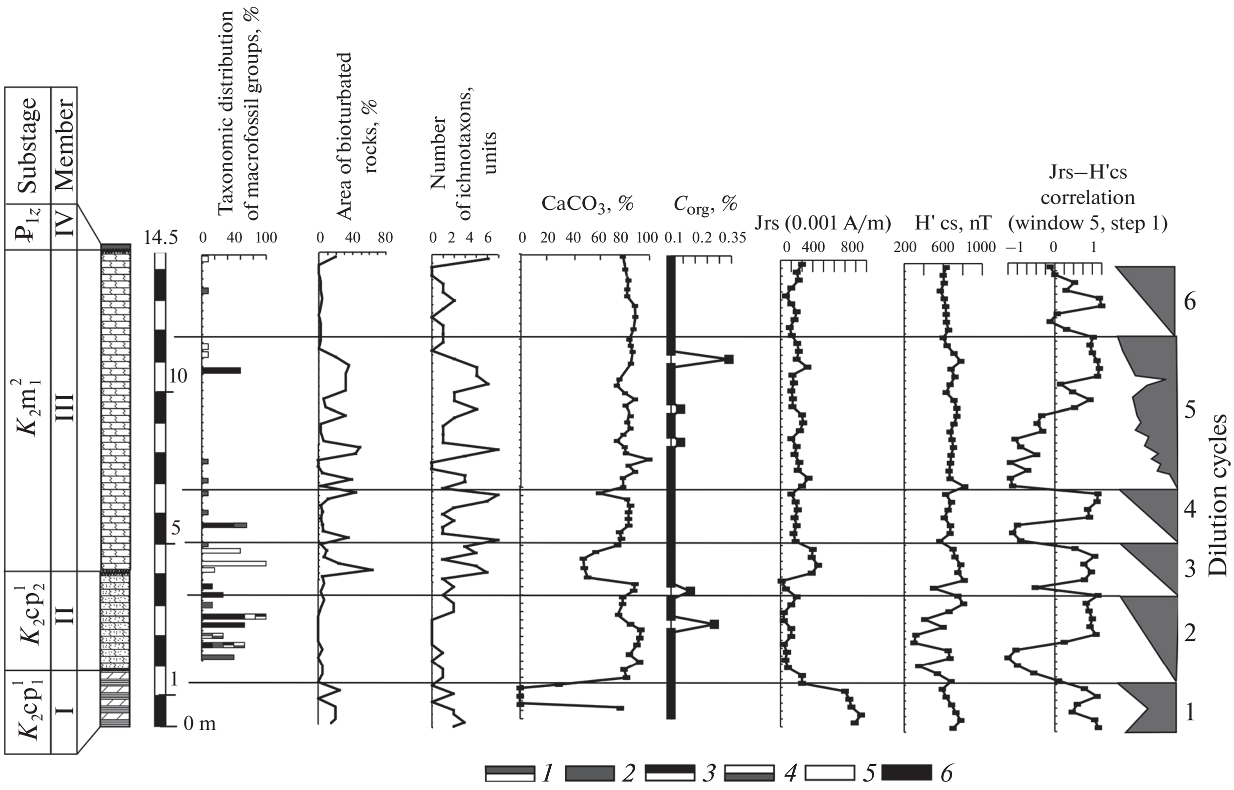


**Fig. 2.** The cyclic distribution of taxonomic groups of microfossils, the area of biturbated rocks, ichnotaxons, contents of $CaCO_3$ and $C_{org}$, remnant saturation magnetization, the destructive field of remnant magnetization and their correlation, mechanism of formation of cryptorhythmic Upper Campanian–Lower Maastrichtian rocks in the quarry of the Sengilei cement plant (town of Sengilei, Ul'yanovsk district). *1*, Gastropods; *2*, bovalvias; *3*, sponges; *4*, brachiopods; *5*, marine urchins; *6*, belemnites. For other captions, see Fig. 1.

tures are determined with an error up to 1°C, rarely up to 0.5°C (Verzilin, 1979; Hoefs, 1983).

If the carbonate skeletons of organisms (or chemogenic carbonate matter) are formed under isotope equilibrium with ambient water, then, at its constant isotope composition, the $^{18}O/^{16}O$ ratio of the carbonate will vary depending on the temperature because of its correlation with the equilibrium constant for the isotope equilibrium system. The correlation between the $^{18}O/^{16}O$ ratio and temperature for chemogenic and organic calcite in some marine invertebrates is determined experimentally. Thus, the following equation of the paleotemperature scale was derived:

$$t\,°C = 16.5 - 4.3(\delta^{18}O_o - \delta^{18}O_w) + 0.14(\delta^{18}O_o - \delta^{18}O_w)^2,$$

where $t$, °C is the temperature of the water where the $CaCO_3$ was formed; $\delta^{18}O_o$ is the oxygen-isotope composition of the $CO_2$ that was released from $CaCO_3$ by its dilution using 105% phosphoric acid and measured relative to the PDB standard, and $\delta^{18}O_w$ is the isotope composition of $CO_2$ equilibrated with the water in which $CaCO_3$ was formed and measured relative to SMOW (Faure, 1989; Kaplin and Yanina, 2010).

The study of marine carbonates, however, requires several important conditions to achieve the necessary precision of paleotemperature determinations. First, we need to know the $\delta^{18}O$ value of the seawater that was in equilibrium with a sample. Second, $CaCO_3$, which is precipitated by some organisms, is not in equilibrium with water; thus, this equation is inappropriate. Third, mineralogy has a significant effect on the fractionation of oxygen isotopes. The correlations are calculated for aragonite, calcite, Mg calcite, and dolomite. We also need to take the changes in the isotope composition after carbonate burial into account: dilution and redeposition.

Thus, it should be noted that the $\delta^{18}O$ values of fresh skeletons are caused by both ambient temperature and the isotope composition of water, the mineral composition of shells, and possible metabolic effects. We studied five bulk samples of carbonate–siliceous rocks (siliceous chalk and calcareous opokas).

## MAASTRICHTIAN–SELANDIAN ROCKS OF THE UL'YANOVSK–SARATOV BASIN

The section is located north of the town of Sengilei (Ul'yanovsk district) southeast of Mt. Grannoe Ukho on the right bank of the Volga River downstream from the settlement of Shilovka. It is basically identical to the section on the right bank of the Volga River upstream from the town of Sengilei or the section in the vicinity of the settlement of Shilovka described in (Archangel'skii, 1912; Milanovskii, 1940; Gerasimov et al., 1962; Kamysheva-Elpat'evskaya, 1967; Glazunova, 1972; Ben'yamovskii et al., 1988).

Intercalation of gray silty clays and sandy gray–brown marls (rocks of the member I) is observed in the quarry face (Fig. 1). In stratigraphic position, these rocks of the Ul'yanovsk Volga region with *Hypoxytoma tenuicostata*, *In. lobatus*, and *Actinocamax laevigatus* (Gerasimov et al., 1962) of *Actinocamax laevigatus* zone correspond to the pteric layers of the Saratov Volga region. This interval of the section corresponds to the foraminifera layer XIV with Gavelinella stelligera (Marie) and Bolivinoides strigillatus (Chapman) in the classical section at the right bank of the Volga River, upstream from the town of Sengilei (Ben'yamovskii et al., 1988). The visible thickness of these rocks is 1.8 m. Upward in the section this sequence gives way to Upper Campanian carbonate rocks.

Member II consists of loose writing chalk (microscopically bioclastic limestone), which is sandy in the basement with phosphorites and glauconite. The lower part of the section (Fig. 1) of the member (0.45 m) resembles "surka." The foot and the top of the member contain erosion surfaces. There are *Belemnitella mucronata senior* guards, fragments of sponges, shells of brachiopods, oysters, and gastropods, skeletons of sea urchins, and rare ichnofossils *Teichichnus* and *Zoophycos.* This sequence is similar to layer XIV with Cibicoides temirensis (Vass.) and layer XVIII with Brotzenella monterelensis (Marie) in the section upstream from the town of Sengilei (Ben'yamovskii et al., 1988), which also yielded findings of *Paractinocamax* sp. No rhythmicity is observed in the member. Its thickness is 2.7–3.0 m.

Member III is macroscopically composed of erratic writing chalk 10.5 m thick. A layer of marl limestone 0.5 m thick in its basement lies with erosion on the Upper Campanian rocks. The local guards *B. lanceolata* indicate the presence of the same Lower Maastrichtian zone in the section. There are also skeletons of sponges, shells of brachiopods, oysters, and gastropods, and fragments of skeletons of sea urchins, as well as ichnofossils *Zoophycos, Teichnihnus,* and *Planolites*. The member probably corresponds to the foraminifera layers XXIII and XXIV with Brotzenella complanata (Reuss) and Anomalinoides ukrainicus (Cushm. et. Dead), respectively, in the section near the settlement of Shilovka (Ben'yamovskii et al., 1988). There is a hiatus surface in the top of the member. The member is overlapped with angular unconformity by Lower Paleocene light and dark opokas.

Member IV is a rhythmic variegated siliceous sequence of intercalated yellowish beige opoka with gray and beige clayey opoka (Fig. 1). The rhythms are easily recognized in the outcrop by the contrasting weathering profile, change in the lithology of the rocks, and their color. The opoka layers are characterized by reddish gray banding, which is probably related to the postsedimentation processes. The basal part of the member includes intercalation of relatively more or less sandy opoka. Pure siliceous opokas alternating with clayey varieties are dominant upward in the section.

## THE GEOCHEMISTRY OF THE MAASTRICHTIAN SECTION IN THE QUARRY OF THE SENGILEI CEMENT PLANT

These data allowed us to calculate the concentrations (ppm) of 29 elements and compounds, as well as their ratios (modules), which are necessary to specify the sedimentation conditions and genesis of cyclicity (Figs. 3–5). This method has been described in several works (Sklyarov, 2001; Climate..., 2004; Engalychev and Panova, 2011). At times, our paleogeographic interpretation of some parameters is contradictory and requires additional study. Below, we will briefly characterize the concentration of some elements, compounds, and their ratios.

The variable parameters of the depth of the basin include Fe/Mn, Ti/Mn, and Mn/Ni ratios and Ti (TM), Na (SM), and K (PM) modules, as well as the Zn, Pb, Al, Mn, Cu, Sr, and Ba contents, which indicate the facial bias (Fig. 3).

The Ti/Mn ratio is an indicator of shallow sedimentation conditions: it decreases with increasing distance from the run-off area and increases toward land. For continental conditions, this ratio is 110–150. Because Ti minerals are poorly weathered, they accumulate in alluvial and coastal marine conditions. In a normally saline basin, the Ti content is lower because of the absence of its real solutions (Yudovich and Ketris, 2011).

PM ($K_2O/Al_2O_3$) is caused by the intensity of chemical weathering in the erosion area. Potassium is a constituent of feldspars and accumulates during their erosion in the continental sediments under a dry climate. In a wet climate, it is transferred as solutions and suspensions and is concentrated in marine and lacustrine sediments. Aluminum is related to the clayey part of the rocks and its content in sediments increases toward the open basin. The low PM values are typical of the continental sediments, whereas they increase in the coastal marine and pelagic sediments (Engalychev and Panova, 2011).

The increase in Sr contents indicates the remote terrigenous run-off source, whereas the increase in the Ba contents, vice versa, is indicative of a proximal source. With an increase in the depth of the basin, Ba is diluted much more strongly; however, at a depth of 4–5 km its concentration may reach maximums,

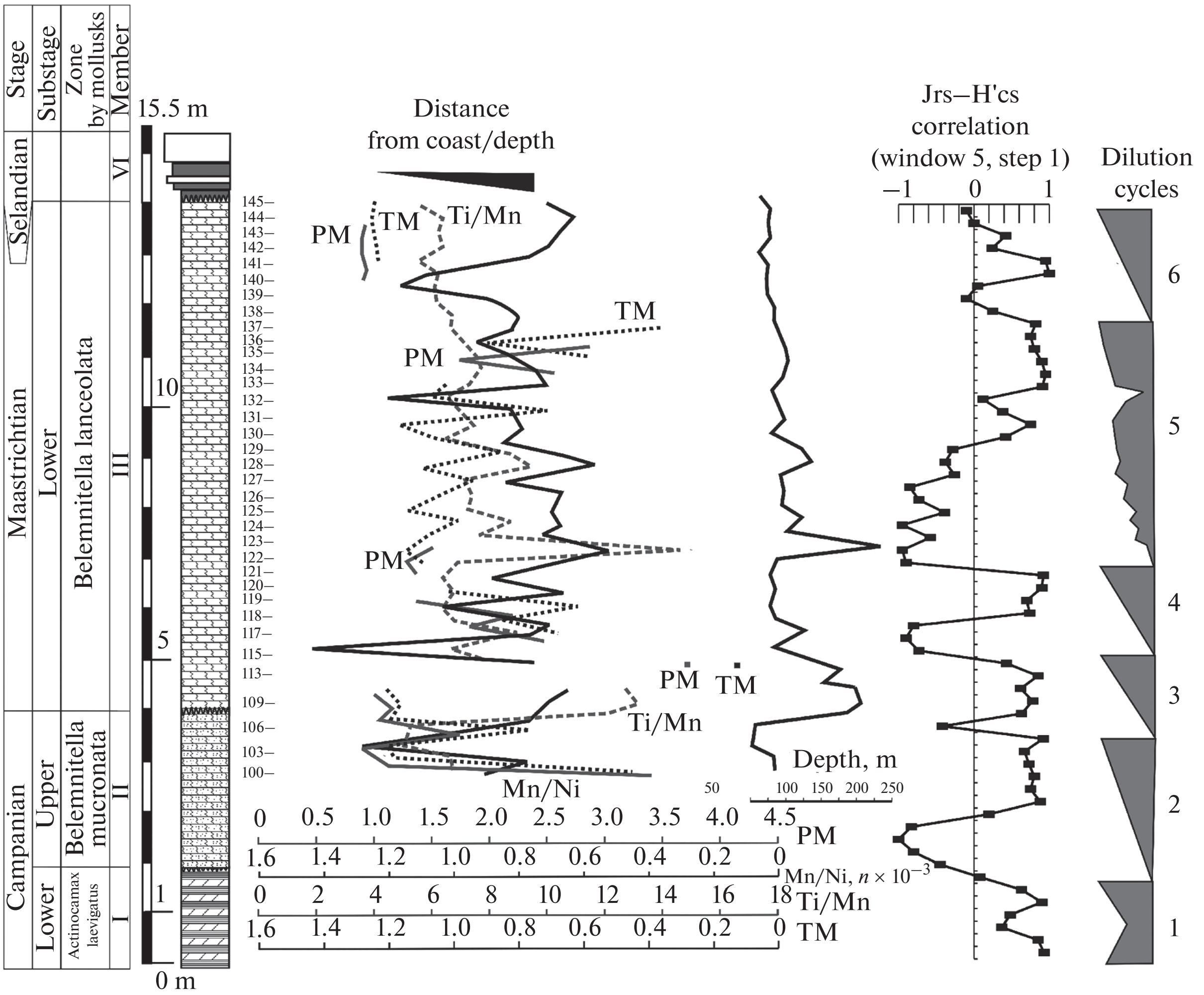


**Fig. 3.** The lithological, petromagnetic, and geochemical characteristic of variations of depth for the section in the area of the town of Sengilei. For captions, see Fig. 1.

because it rarely reacts with ambient seawater and precipitates.

The increase in the concentration of Pb and Zn is caused by the decrease in the distance from the run-off source and/or increase in the salinity of the basin.

The following concentrations of elements and their ratios are used for the analysis of paleotemperature variation (Fig. 4): V, Ca, Ni, Ca/Sr, TM, Mn, and Si/Al. The temperature variations can be estimated using the Ca/Mg, Sr/Ba, Zn/Nb, and (Ce, Nd, La, Ba)/Yb(Y, Zr) ratios.

The increase in the Ca, Sr, and Mg contents may indicate arid climate, whereas the increase in the Sc, Ni, Zn, Y, W, U, Cu, V, and REEs points to humid sedimentation conditions.

The TM ($TiO_2/Al_2O_3$ ratio) depends on both the dynamic sedimentation facies and Ti content of the rocks, thus, if we fix the facial factor, the TM is the best indicator of mafic or felsic rocks. The various TM values indicate different climate conditions. The humid sandy–silty rocks are characterized by higher TM values in comparison with arid rocks. The same is typical of clayey rocks. The use of this module for climate reconstructions is possible only under a constant run-off source. In some cases, the dynamic sorting of the material and the composition of the rocks influence the TM value much more strongly than climate. Generally, its value increases from arid to humid zone and, within the latter, from deep-water zones to coastal and continental zones (Engalychev and Panova, 2011).

The Sr/Ba and Ca/Sr ratios are used for the analysis of the salinity variation (Fig. 5). When the physicochemical equilibrium of a saline solution is violated because of its burial, some minerals in this system are dissolved (e.g., calcite), whereas other minerals are formed (dolomite); this results in deep transformation of the brine composition. The solution selectively concentrates chemical elements, including Ca, Sr, and Ba. This is also evident from supersaline solutions,

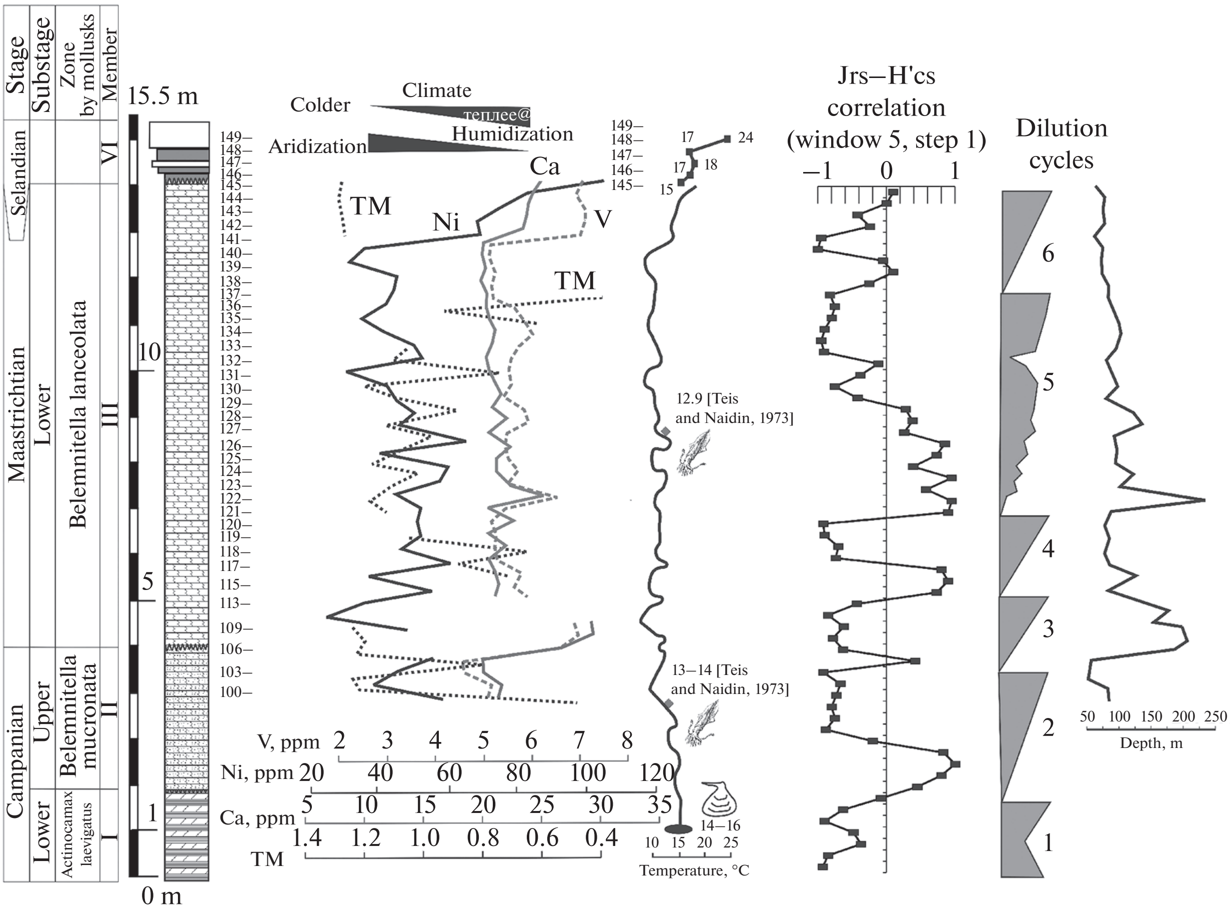


**Fig. 4.** The lithological, petromagnetic, and geochemical characteristics of climate variations for the section in the area of the town of Sengilei. For captions, see Fig. 1.

where the Ca content is almost zero because during the increase in salinity Ca is replaced by Mg from the sediment. Thus, the increase in the Sr/Ba and Ca/Sr values indicates the increase in salinity of the solution.

The B, Ba, S, Cr, Cu, Ga, Ni, and V contents of marine sediments are higher relative to the fresh-water sediments. Zinc and Cu also indicate that the salinity and their mobility directly depends on salinity. In rivers, the Cu content is almost always constant; thus, when river water is mixed with seawater, the rate of Cu precipitation decreases with an increase in the salinity of the solution. The Zn mobility also decreases with the increase in salinity.

## DISCUSSION

The huge array of the previous data (Gabdullin et al., 1999; Gabdullin and Ivanov, 2001; Gabdullin, 2002) allows interpretation of the Campanian–Maastrichtian paleogeographic conditions. These geochemical data allowed us to specify the sedimentation conditions in the Ul'yanovsk–Saratov basin in Maastrichtian and the beginning of Paleocene.

### *Early Campanian*

**Composition of paleocenosis.** Plankton with Si and Ca skeletons. Benthic and nekton forms are pelecypods (two genera, two species) and belemnites (two genera, two species), respectively.

**Depth.** The presence of pterias indicates a depth of 6–60 m. The deepest modern pterias are known from the depth of ~374 m, whereas inocerams prefer relatively deep conditions. According to (Bondarenko, 1990), these sediments were formed in the sublittoral area. Thus, the approximate depth of the basin was 60 m or more. No geochemical data are known for this depth.

**Temperature.** The modern pterias tend to waters with temperatures of 14–16 or 25–32°C. The presence of siliceous–carbonate rocks (with dominant siliceous rocks) in the section supports relatively lower temperatures (i.e., 14–16°C). The determination of temperature by belemnite guards most likely indicate ~14°C (Teis and Naidin, 1973).

**Hydrodynamics.** Pterias avoid areas with currents and breaking waves. Thus, we can suggest calm hydrodynamic conditions in the sedimentation basin.

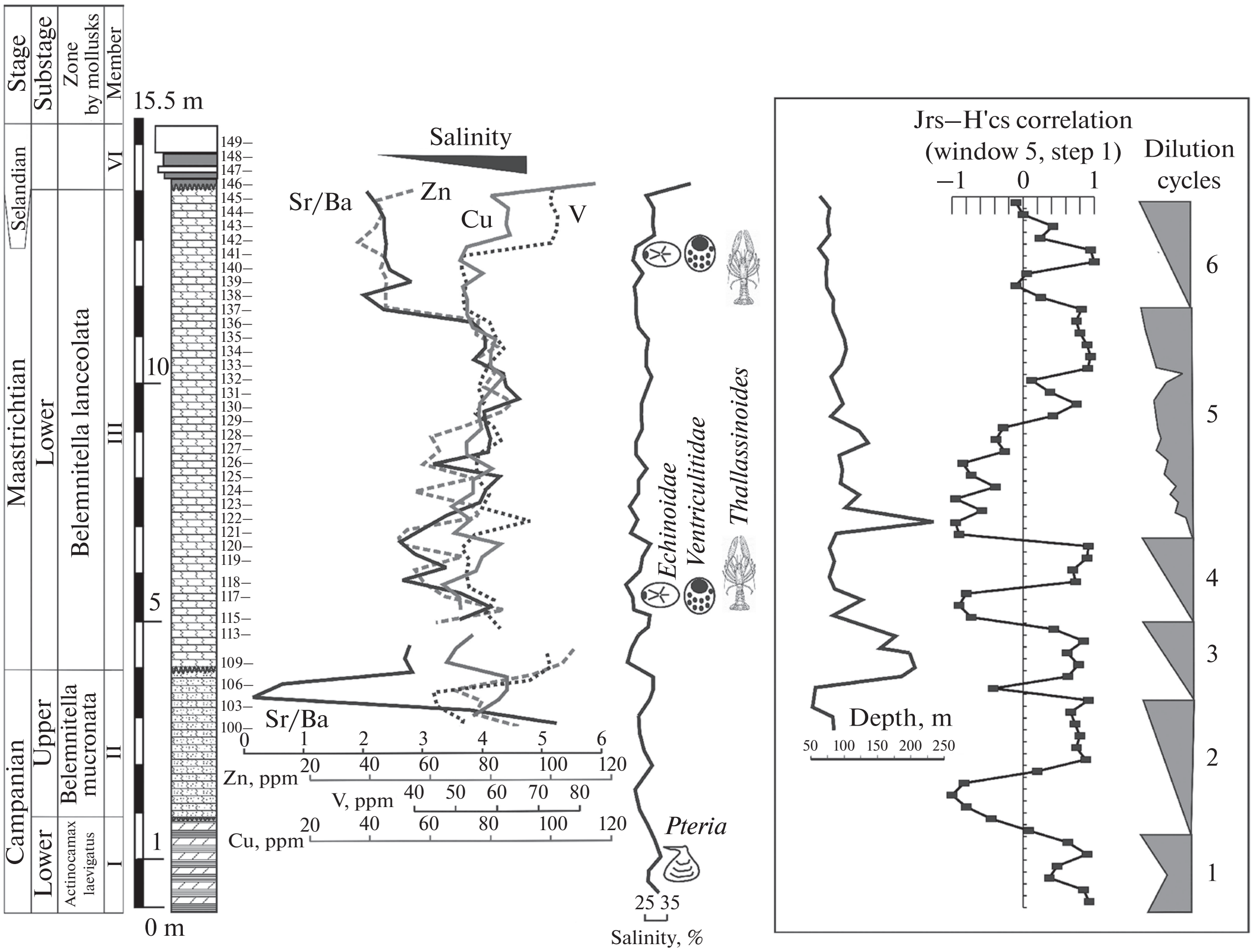


**Fig. 5.** The lithological, petromagnetic, and geochemical characteristics of salinity variations for the section in the area of the town of Sengilei. For captions, see Fig. 1.

**Gas regime.** Waters with normal content of dissolved oxygen are suggested.

**Salinity.** Pterias are stenohaline organisms, which cannot tolerate desalination, thus, they indicate normal conditions of the basin.

**Type of substrate.** Pterias prefer to settle the solid substrate, whereas inocerams populate various substrates. Thus, the loose bottom of the basin was characterized by the rocky ledges or the whole substrate was solid.

**Formation of cyclicity.** The rhythmicity of the section is expressed in intercalated terrigenous rocks, which were formed in a shallow basin with terrigenous sedimentation and which most likely indicate dilution cycles (DC). For an interpretation of the origin of the rhythmicity, we suggest the model of Einsel and Seilacher (1985), which postulates DCs (Fig. 2). Cyclic variations of climate (wet/dry) lead to cyclic fluctuations in the volume of silicate clastic material (more/less, respectively), which is contributed with river run-off from the land to the sedimentation basin. More and less carbonate rhythmic elements are formed in a dry and a wet climate, respectively. This model can be applied to sedimentation in one of the Chilean regions (Lamy et al., 1998).

**Late Campanian. Belemnitella mucronata phase.** The data from complex laboratory studies showed cyclic distribution of the parameters measured in macroscopically erratic Upper Campanian and Lower Maastrichtian carbonate section, which indicates cryptorhythmicity. Below, we show a possible interpretation of the origin of this cryptorhythmic sequence.

**Composition of paleocenosis.** Plankton with carbonate skeletons and a poor macrofossil complex including benthic forms (several species of echinoderms, pelecypods (inocerams), belemnites).

**Depth.** According to Bondarenko (1990), the sediments accumulated in the pelagic zone. The analysis of the geochemical data (Fig. 3) showed similar variations of the CM and TM modules and Ti/Mn and Mn/Ni ratios. The Ti/Mn curve, which was chosen as

**Table 1.** The comparative scheme of the geochronological charts

| Stage | Authors, years | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | V. Hinte, 1975 | Harland 1982 | Palmer, 1983 | Haq, 1987 | Harland, 1989 | Cowie, 1989 | Odin, 1990 | Obrado-vich, 1993 | Gradstein & Ogg, 1994 | Hardenbol et al.,1998 |
| | Duration, Ma | | | | | | | | | |
| m | 5 | 8 | 8.5 | 7 | 9 | 10 | 7 | 6 | 6.3 | 6.3 |
| cp | 8 | 10 | 9.5 | 10 | 9 | 8 | 10 | 12 | 12.2 | 12.2 |
| st | 4 | 5 | 3 | 4 | 4 | 3 | 5 | 3 | 2.3 | 2.3 |
| cn | 4 | 1 | 2 | 1 | 2 | 2 | 1 | 3 | 3.2 | 4.5 |
| t | 6 | 2 | 3 | 3 | 3 | 3 | 3 | 4 | 4.5 | 4.5 |
| cm | 8 | 6 | 6 | 4 | 5.5 | 4 | 5 | 5 | 5.4 | 5.4 |

a paleobathymetric curve, is most representative and correlates well with petromagnetic parameters (Jrs—H'cs correlation).

**Gas regime.** Insignificant variations in the content of water-dissolved oxygen follow from cyclic distribution of $C_{org}$ content, bioturbation volume, and the presence of pyrite nodules in the section, which correspond to the epochs of relatively low dissolved oxygen contents.

**Type of substrate.** Benthic organisms include spatangus urchins, which prefer silt, and inocerams, which inhabit all bottom types. Thus, the bottom was most likely soft and silty.

**Temperature.** The belemnite guards (Teis and Naidin, 1973) indicate a temperature of 13–14°C. The analysis of geochemical data (Fig. 4) demonstrates a correlation of the fluctuation trends of the Ni, Ca, and V contents, as well as TM. The Ca content curve is most representative and correlates well with data of other methods (e.g., with Jrs—H'cs correlation curve) and is the basis for the paleotemperature curve taking the paleoecological data on sediments of member I into account and the published and original paleotermometric data. Two cycles of temperature variations within a range of 10–15°C occurred during the *mucronata* phase.

**Salinity.** The analysis of the geochemical data (Fig. 5) showed similar fluctuations of the Zn, Cu, and V contents and the Sr/Ba ratio. The Cu content curve, which was the basis for the paleohalinometric curve, was most representative and correlates well with the data of other methods (e.g., with Jrs—H'cs correlation curve). During the *mucronata* phase, salinity constantly varied within a range of 25–35‰. No data on the hydrodynamics of the basin are known.

**Formation of cryptorhythmicity.** The complex of the studied parameters is shown in Fig. 2. The DCs (Gabdullin et al., 1999) included variations of the volume of the terrigenous material (which underwent petromagnetic studies) contributed mostly carbonate sedimentation to the basin. The origin of the macroscopically erratic sequence of the writing chalk can be explained by the above-described model (DC) caused by climate variations. The formation of this sequence can be related to two DCs, which are clearly recognized on the Jrs—H'cs correlation curve (Fig. 1).

*Early Maastrichtian. Belemnella lanceolata phase*

**Composition of paleocenosis.** Plankton with a carbonate skeleton and benthic macrofossil forms are dominant over nekton macrofossils. Traces of *Planolites* can belong to pelecypods, gastropods, and echinoderms. Traces of *Thallassinoides* indicate the presence of crustaceans.

**Salinity.** The sediments are hosts to sponges (*Ventriculitidae*), echinoderms (urchins *Echinocorys,* cydaroids), brachiopods, and crustaceans (*Thallassinoides*), which live under normal salinity. The geochemical data (Fig. 5) showed that salinity permanently varied within a range of 25–35‰ in the beginning and end of the *lanceolata* phase and was almost stable during most of the phase.

**Gas regime.** The presence of pyrite nodules, on the one hand, indicates reducing conditions; on the other hand, the poor biocenosis contains stenoxic sponges and euryoxyc oysters. Possible weak variations of gas regime are supported by the rhythmic distribution of ichnofossils (bioturbation volume) and $C_{org}$ content.

**Type of substrate.** Spatangoids (*Echinocorys*), cydaroids, and crustaceans (traces of *Thallassinoides*) inhabit loose and soft ground. The solid substrate is favorable for sponges and terebratulids. Brachiopods are indifferent to the substrate type. Thus, the bottom was most likely silty with rocky outcrops.

**Hydrodynamics.** The presence of oysters and sponges indicates active hydrodynamic processes (currents).

**Depth.** According to Bondarenko (1990), the sediments accumulated in the pelagic zone (deeper than 130–200 m). The ventriculidea sponges are known at depth from several hundreds of meters to 6 km. The oysters of the *Ostrea* species typically occur at a depth

**Table 2.** The results of calculation of the duration (T) of the suggested astronomical–climatic cycles for the Lower Maastrichtian sediments (*lanceolata* zone) in the quarry of the Sengilei cement plant according to ten scales

| Scale number | Duration of Early Maastrichtian, Ma | Duration of the *lanceolata* zone, years | $T_{cycle} = T_{zone}/11$ oscillations | $T_{cycle} = T_{zone}/4$ oscillations of the Jrs–H'cs correlation curve |
|---|---|---|---|---|
| 1 | 2.5 | 825000 | 75757 | 206250 |
| 2 | 4 | 1320000 | 121212 | 330000 |
| 3 | 4.25 | 1402500 | 128788 | 350625 |
| 4 | 3.5 | 1155000 | **100060 (cycles $E_1$)** | 288750 |
| 5 | 4.5 | 1485000 | 136363 | 371250 |
| 6 | 5 | 1650000 | 151515 | **412500 (cycles $E_2$)** |
| 7 | 4.5 | 1485000 | 136363 | 371250 |
| 8 | 3 | 990000 | **90909 (cycles $E_1$)** | 247500 |
| 9 | 3.150 | 1039500 | **95454 (cycles $E_1$)** | 259875 |
| 10 | 2 | 660000 | 60000 | 165000 |

The eccentricity cycles of the first and second orders are in bold.

of 40–100 m. The urchins–cydaroids inhabit the depths of 75–100 m (locally, up to 4 km), where they consume sponges. Thus, urchins–cydaroids and sponges most likely coexisted. In our opinion, the depth of the basin could be more than 100 m (the lower sublittoral–bathyal zone). Relatively shallow forms (e.g., pectinaceans) were most likely allochthonous. The geochemical data (Fig. 3) showed that constant variation in the paleodepth of 50–250 m and two transgressive–regressive cycles with an amplitude of the epicontinental sea level of 150 m occurred during the *lanceolata* phase.

**Temperature.** The temperature in the vicinity of the town of Khvalynsk (Teis and Naidin, 1973) is estimated at 12.9°C. According to the geochemical data (Fig. 4), the temperature weakly varied from 10 to 15°C, tending to warm conditions to the end of the phase.

**The composition of the paleocenosis and depth of the basin.** A rich paleocenosis includes plankton with carbonate skeletons, benthic forms (sponges, brachiopods, gastropods, pelecypods, and urchins) and rare nekton forms (belemnites). There are also *Zoophycos, Planolites,* and *Teichnihnus* ichnofossils. The relatively small amount of nekton forms and plentiful benthic forms are evidence of relatively more shallow conditions (the littoral zone of sedimentation conditions).

**Formation of cryptorhythmicity.** DCs (Gabdullin and Vydrik, 1998; Gabdullin et al., 1991) are supported by the results of petromagnetic studies (Fig. 3). The contribution of terrigenous material was cyclic and four DCs are suggested. A hypothetical hidden more carbonate element of the rhythm (ER) can be distinguished in the basement in contrast to a less carbonate ER in the top, which corresponds to the period of the maximum contribution of terrigenous material. Such a conclusion is based on variation of the positive and negative values of remnant saturation magnetization and the destructive field of remnant saturation magnetization on the correlation curve and is supported by the results of a microscope study of thin sections of rocks with two varieties of writing chalk.

The less carbonate ER in the section of the Sengilei cement plant quarry is microscopically bioclastic writing chalk with 20% bioclasts (15% foraminifers and calcisphaerulides, 4% fragments of prismatic layer of bivalves, 1% fragments of echinoderm skeleton) and 15% crystal clasts of ore minerals, including magnetite emplaced in the matrix (65% micritic calcite).

The more carbonate ER is composed of bioclastic writing chalk, which includes 20% bioclasts (16% foraminifers and calcisphaerulides, 2% fragments of the prismatic layer of bivalves, and 2% fragments of the echinoderm skeleton) and 10% crystal clasts of ore minerals, including magnetite emplaced in the matrix (70% micritic calcite).

These hypothetical rhythms correlate with the peaks of some parameters on the distribution curves (Fig. 2). No bioproductivity cycles are established. Study of thin sections taken from the suggested ERs showed an approximately equal amount of bioclasts of foraminifers and calcisphers. No DC signatures were found. This model, which is related to climate variations, is offered for interpretation of the formation conditions of this macroscopically erratic sequence of writing chalk.

We also studied repeated variations of the parameters of the section and determined the period of the formation of rhythms via calculation of the average number of oscillation of parameters along the section with further division of the duration of the interval by the number of peaks. Ten temporal scales were used, whose comparative scheme is shown in Table 1. It is seen from the table that the duration of periods,

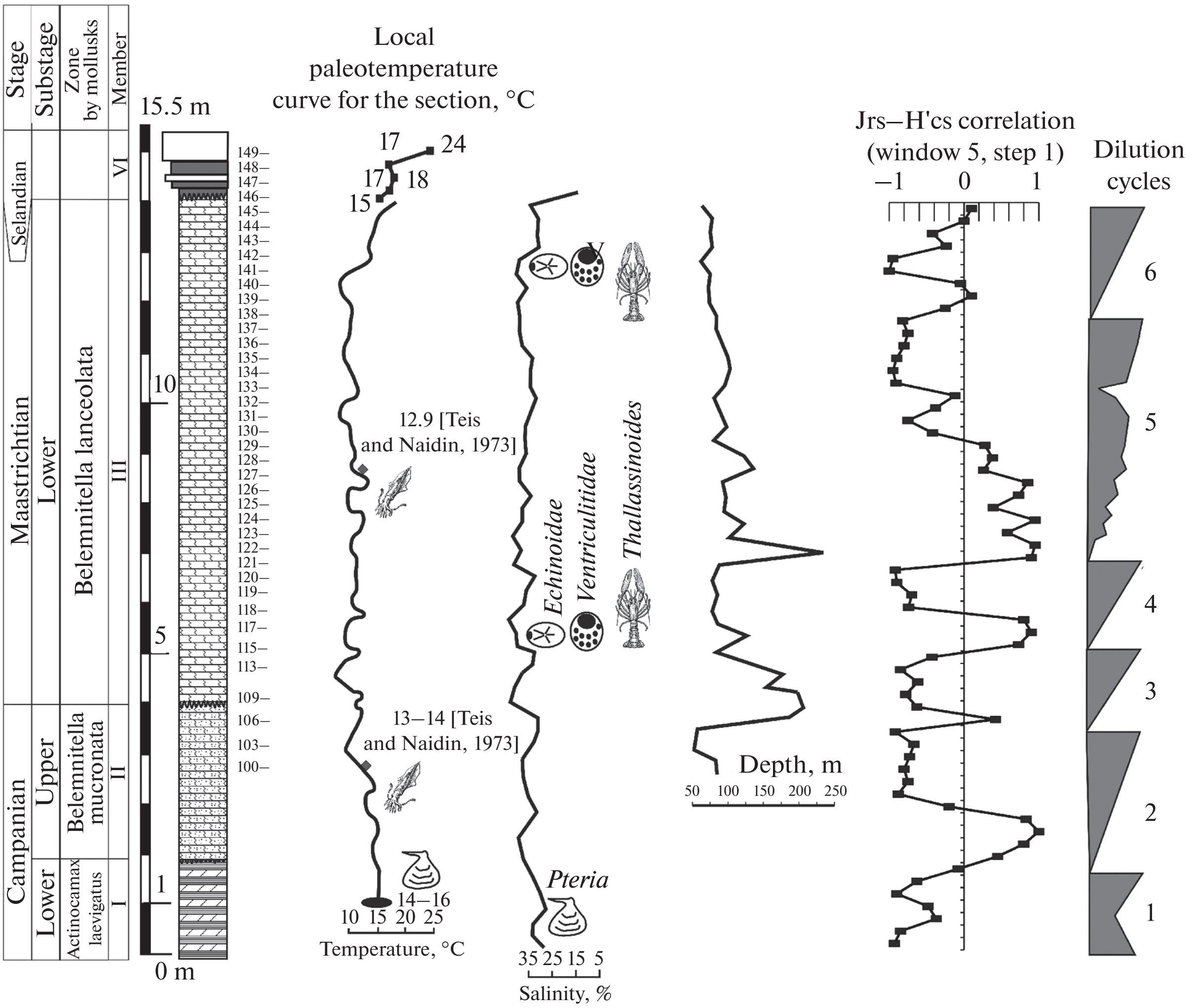


**Fig. 6.** Variations of temperature, salinity, and depth, petromagnetic characteristic, and dilution cycles in the Campanian–Selandian of the Ul'yanovsk–Saratov basin. For captions, see Fig. 1.

according to various authors, can vary by two times or/and by one order of magnitude (as well as Milankovitch cycles).

The duration of the *lanceolata* zone (Table 2) is estimated as one-third of the Early Maastrichtian. The duration of the rhythms was calculated by division of the duration of the *lanceolata* zone by the average number of oscillations (11) on the plots of the measured parameters. As a result, three scales yielded values that are close to the duration of the eccentricity $E_1$ cycles (~100000 years). The durations of the rhythms according to seven other scales do not coincide with known astronomical–climatic Milankovitch cycles. The variations of positive or negative values on the correlation curve of the remnant saturation magnetization and destructive field of remnant saturation magnetization interpreted on the DC basis are probably related to the eccentricity cycles $E_2$ (~400000 years). The dispersion of the estimated duration of the rhythms indicates the presence of eccentricity cycles in the studied section. Another interpretation of these results cannot be excluded: the section is composed of eccentricity cycles of various orders and the lower-order cycles are included in the higher-order cycles.

**Selandian.** Due to the reconnaissance study of the Lower Paleocene part of the section, the conclusion on the origin of its rhythms is preliminary. Because of the absence of the data of instrumental studies for this part of the section, the sedimentation conditions can be interpreted on the basis of the lithology of rocks. The DCs formed intercalation of relatively more or less sandy opoka in the basal part of the member and, most likely, led to the formation of intercalated pure siliceous and clayey opoka varieties. In the very lower part of the section, the Selandian rocks contain isotopically characterized carbonate-bearing (calcareous) opoka (or siliceous limestones). The paleotemperatures vary from 15 to 24°C (17–18°C, on average) with a tendency to warming (Figs. 4, 6). The paleotemperature for the cyclic sediments of the lowermost part of the Selandian Stage was 15–24°C. Further studies will allow a more precise interpretation of sedimentation conditions.

## CONCLUSIONS

1. One of the most significant conclusions from the method point of view is that the complex of lithological, petrographic, petromagnetic, geochemical, and paleoecological methods, which was conducted for the first time, allowed estimation of the paleogeographic sedimentation conditions for a particular geological section.

2. The cryptorhythmic sequence was characterized by a macroscopically erratic structure with cyclic distribution of the measured parameters.

3. As a result of a complex analysis, most parameters varied in the macroscopically erratic sequence of the writing chalk. The variations are clearly seen on the parametric paleobathymetric (Fig. 3), paleotemperature (paleoclimate, Fig. 4), and paleohalinometric (Fig. 5) curves and their derivatives. The curves were the basis for estimations of the paleogeographic formation conditions of sediments and the geological evolution of the Ul'yanvsk–Saratov basin at the end of Cretaceous–beginning of Paleogene (Fig. 6).

4. The cryptorhythmic carbonate and rhythmic terrigenous–carbonate and siliceous sequences were formed during dilution cycles according to the paleogeographic model of Einsele and Seilacher (1985). The origin of the cryptorhythmic sequence is related to periodic climate variations, which follow the eccentricity cycles of the Earth's orbit.

5. According to the geochemical and paleoecological data, the relative increase in salinity correlates with the increase in temperature and decrease in the depth of the epicontinental basin (Fig. 6). The latter was 50 to 225 m, while the eustasy amplitude during transgressive–regressive cycles could be 150 m. One dilution cycle and two cycles of salinity variations (which, at this period and later, are estimated at 35–25‰; salinity was 30‰, on average) were distinguished for the Early Campanian (member I, *laevigatus* phase). Two cycles of salinity and temperature variations, dilution cycle, and transgressive–regressive cycle (in the second part of the phase) were identified for the Late Campanian (member II, *mucronata* phase). Eight cycles of salinity and temperature variations, four dilution cycle, and two transgressive–regressive cycle (in the second part of the phase) were established for the Early Maastrichtian (member III, *lanceolata* phase).

6. Previous paleotemperature data (Teis and Naidin, 1973) correlate well with our data. The paleotemperature in the Campanian–Maastrichtian was 13–16°C (~14°C, on average). In the Campanian and at the end of the Early Maastrichtian, the climate was slightly (by 1–2°C) warmer than in most of the Early Masstrichtian. In the Selandian, the temperature was 15–24°C.

7. Our paleogeographic data for the epicontinental basin of the Ul'yanovsk–Saratov basin allow a detailed description of the paleogeography and geological evolution of the peripheral parts of the Tethys paleoocean (Peritethys).

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