Periodites below and above the K/T boundary

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Abstract

Rhythmically bedded sedimentary rocks from the Maastrichtian and Palaeocene deposits of the Russian craton and southern adjacent areas such as SW Crimea and NW Caucasus have been analysed to determine their origin.

The carbonate content, TOC, foraminiferal, petromagnetic analyses and trace fossil distribution from five sections were studied in order to define the nature of 9 types of rhythmicity. Cycles of dilution, solution and bioproductivity are involved in producing the rhythms. Eleven palaeogeographic models are discussed and five are proposed for the studied sections. A bathymetric zonation for the types of periodites and models of their origin was established. Cyclostratigraphic correlation of the investigated sections with sections of Eurasia may be possible. The origin of rhythms can be related to Milankovich Cycles.

Key-words: Russian craton, Crimea, Caucasus, K/T boundary, Maastrichtian, Palaeocene, rhythmicity, palaeogeographic models

Résumé

Des roches sédimentaires à stratification rythmique appartenant aux dépôts maastrichtien et paléocène du craton russe et des régions méridionales voisines telles le sud-ouest de la Crimée et le nord-ouest du Caucase, ont été analysées afin d'en déterminer l'origine. Le contenu carbonaté, TOC, les foraminifères, le pétromagnétisme et la distribution des traces fossiles ont été étudiés afin de caractériser 9 types de rythmicité. Des cycles de dilution, de dissolution et de bioproduction interviennent dans la production des rythmes. Onze modèles paléogéographiques sont discutés et cinq sont proposés pour les sections étudiées. Une zonation bathymétrique pour les types de périodites et des modèles expliquant leur origine sont établis. Une corrélation par cycles sédimentaires des sections étudiées avec des sections d'Eurasie est possible. L'origine des rythmes peut être en relation avec les Cycles de Milankovitch.

Mots-clefs: Craton russe, Crimée, Caucase, limite K/T, Maastrichtien, Paléocène, rythmicité, modèles paléogéographiques.

Резюме

Проанализированы ритмично построенные осадочные породы из Маастрихтских и Палеоценовых отложений Русского кратона и прилегающих южных районов таких, как ЮЗ Крым и СЗ Кавказ, с целью определения их происхождения. Изучено содержание карбоната кальция, органического углерода, петромагнитные анализы и распределение ихнофоссилий в пяти разрезах для определения природы 9 типов ритмичности. Привлечены циклы разбавления, растворения и биопродуктивности, как факторы возникновения ритмов. Обсуждены 11 палеогеографических моделей и пять предлагаются для изученных разрезов. Установлена батиметрическая зональность для типов периодитов и моделей их происхождения. Было предпринято ритмостратиграфическое сопоставление изученных разрезов с разрезами Евразии. Природа ритмичности может быть связана с циклами Миланковича.

Ключевые слова: Русский кратон, Крым, Кавказ, Мел-Палеогеновая граница, Маастрихт, Палеоцен, ритмичность, палеогеографические модели

Introduction

This study focuses on the origin of periodites outcropping on the Russian craton, SW Crimea and NW Caucasus. The K/T boundary in the investigated area was studied by GERASIMOV *et al.* (1962) and more recently by MUSATOV & ERMOKHINA (1997), but the presence, types and the nature of rhythms in these deposits were not given detailed attention. The biostratigraphic subdivision of the Maastrichtian deposits of the Besh-Kosh section was investigated by ALEKSEEV & KOPAEVICH (1997).

The presence and types of rhythmicity below and above the K/T boundary on the Russian craton were already mentioned by GERASIMOV in GERASIMOV *et al.* (1962). Carbonate turbidites on the Caucasus were studied by AFANASIEV (1993), but intervals with periodites were not observed in the succession.

During the last two years a classification of the palaeogeographic models of the origin of carbonate periodites was undertaken (GABDULLIN, 1997) and a new model was proposed (GABDULLIN & BARABOSHKIN, 1997). Space-time laws of the forming of the carbonate rhythmic successions (GABDULLIN, 1998b), the origin of rhythms in the Cretaceous of the Ulyanovsk-Saratov foredeep (GABDULLIN *et al.*, 1998 a, b) and in the Palaeocene of the Crimea and of the Ulyanovsk-Saratov foredeep (GABDULLIN & WIDRIK, 1998) have been presented elsewhere.

Text-fig. 1 — Locality map. Sections: 1-Sengeley, 2-Volsk, 3-Belogrodnya, 4-Besh-Kosh, 5-Betta.

Geological setting

Examples of rhythmically bedded carbonate successions containing a K/T boundary are found (Figure 1) on the Russian platform (Sengeley, Volsk, Belogrodnya sections) and in southern adjacent areas such as the Crimea (Besh-Kosh section) and the Caucasus (Betta section). The Sengeley section (Ulyanovsk region, Russia), the Volsk and Belogrodnya sections (Saratov region, Russia) are situated inside the Ulyanovsk-Saratov foredeep. The Besh-Kosh section (Bakhchisaray region, Ukraine) was described from the slope of Besh-Kosh mountain (second chain of Crimean mountains). The Betta section is situated in the Novorossyisk foredeep on the Black Sea shore.

Materials and methods

In the field, sections were divided into rhythms based on the weathering of the profiles, their colour differences, trace fossil distribution and thickness variation.

Foraminiferal analysis (23 samples), total organic carbon content and calcium carbonate content analysis (159 samples) were used in the analysis. Petromagnetic investigations (169 samples) include measurements of magnetic susceptibility (k), natural remnant magnetization (Jr), remnant saturation magnetization (Jrs), destructive field of remnant saturation magnetization (Hcs) and magnetic susceptibility increase (dk) to determine mineral species with magnetic properties. Differential thermal magnetic analysis (DTMA) was used, JR-4 and IMB-2 machines were used for remnant magnetization and magnetic susceptibility analyses. Increasing magnetic susceptibility is connected with the thermal transformation of iron sulfides into magnetite. Thus the presence of pyrite and pyrrothine in rocks is indicated by the magnetic susceptibility increase. Petromagnetic methods can help scientists to:

- determine low concentrations of sulfide and non-sulfide Fe-magnetics of size of a dust invisible even in the thin section;
- distinguish the composition and volume of the terrestrial input;
- understand the nature of magnetic minerals.

Cyclic distribution of magnetic minerals detected by these methods can be interpreted as cycles of dilution (allotegenious Fe-magnetic minerals) or solution (authigenic sulfide Fe-magnetic minerals).

Lithostratigraphy

The investigation of the Maastrichtian and Palaeocene of the Russian craton and southern adjacent areas in the SW Crimea and NW Caucasus (Figure 2) resulted in the establishment of nine types of periodites in carbonate (marl-marl (1); marl-limestone (2); marl-chalk (3) and chalk-chalk (4) cycles), in terrestrial-carbonate (sandstone, sand-calcareous sandstone, sand (5); sandstone, sand-marl (6); clay-marl, limestone (7) cycles) and siliceous-carbonate successions (opoka-marl (8) cycles) and siliceous successions (sandy/marly opoka-opoka (9) cycles). Opoka is a light porous siliceous abiomorphic rock, consisting from more then 50% of opal or opal-cristabolite.

Carbonate turbidites (Caucasus), periodites (mostly Russian craton and the Crimea and Caucasus) and transitional turbidite-periodite successions (Caucasus) were observed. Most of the Maastrichtian and Palaeocene in the Caucasus contains limestone (marl)-marl-sandstone carbonate turbidites (Figure 3) or sandstone-clay, sandstone-clay-sandy clay turbidites (Figure 4). Ichnofossils are represented by *Thallassinoides* sp. , *Teichichnus* sp. , *Chondrites* sp. and *Nereites* sp. Turbidites always consist of two or more rhythm elements with graded bedding. These criteria were used to separate them from the periodites. The thickness of the Maastrichtian in the Caucasus is thought to be up to 1230 m, of the Palaeocene — up to 490 m. That is why the studied parts of the succession are shown out of scale on the Figure 2. Intervals with arrhythmic, chaotic bedding were found in all investigated regions.

Studied sections of the Ulyanovsk-Saratov foredeep are characterized by the presence of Lower Maastrichtian, Danian (only in the Belogrodnya section) and Selandian. The Crimean section contains Lower and Upper Maas-

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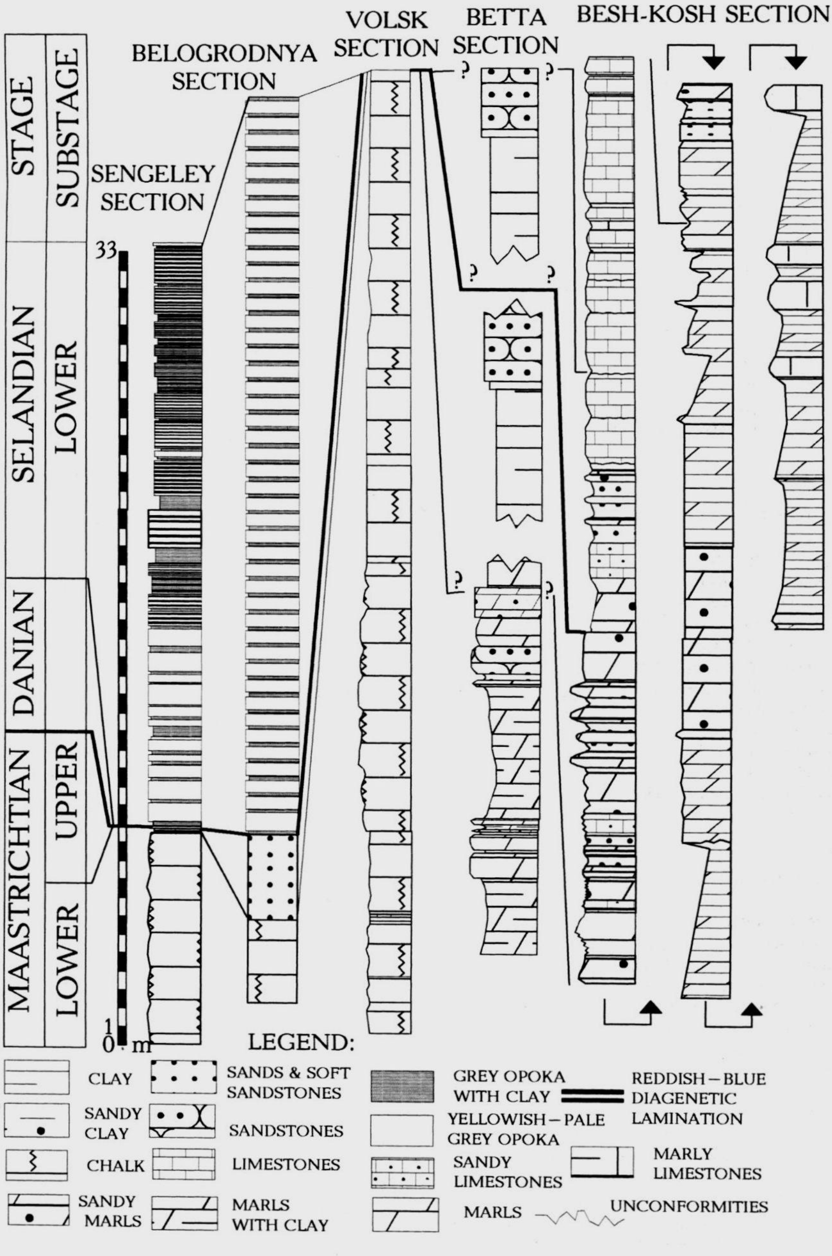
Text-fig. 2 — Correlation sketch of Maastrichtian, Danian and Selandian deposits of Russian craton (Sengeley, Volsk and Belogrodnya sections), SW Crimea (Besh-Kosh section) and NW Caucasus (Betta section).


STAGE
SUBSTAGE
MAASTRICHTIAN
DANIAN
SELANDIAN
LOWER
UPPER
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SENGELEY SECTION
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VOLSK SECTION
BETTA SECTION
BESH-KOSH SECTION
33
1
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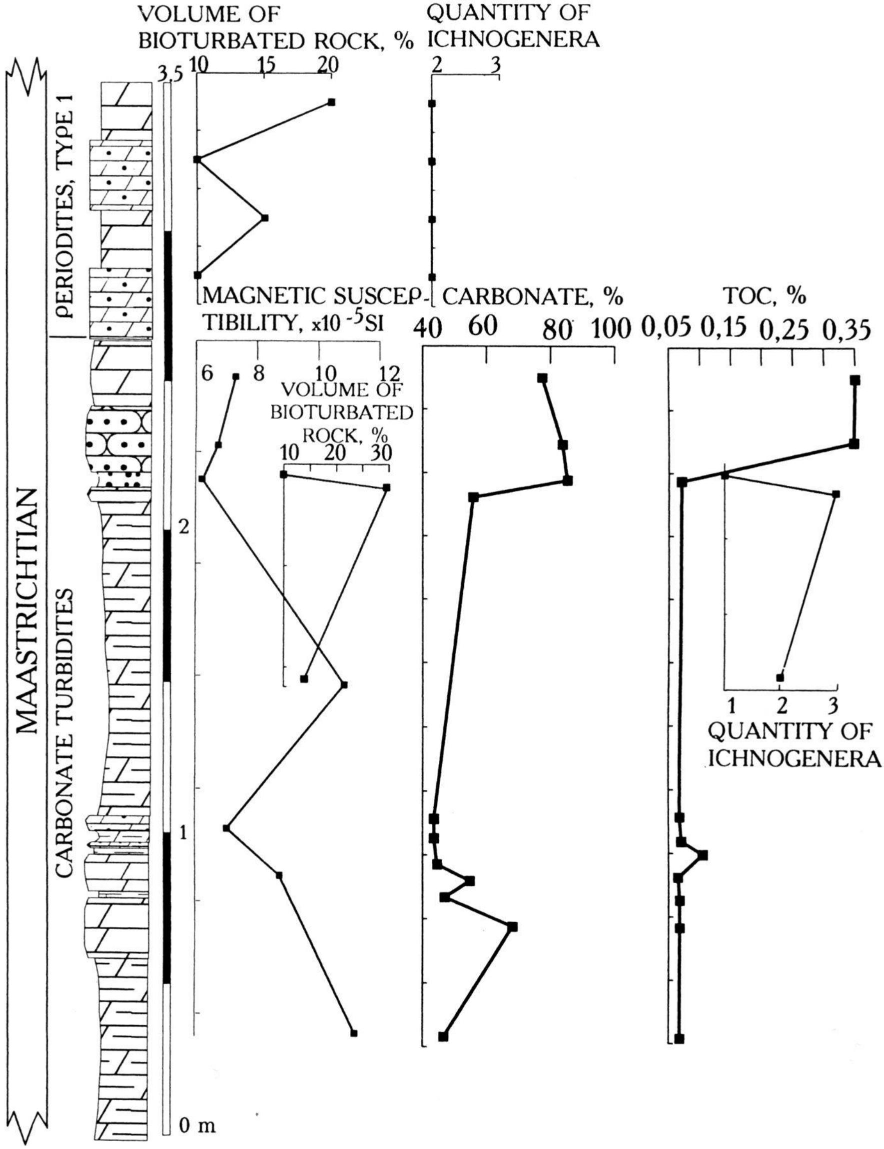
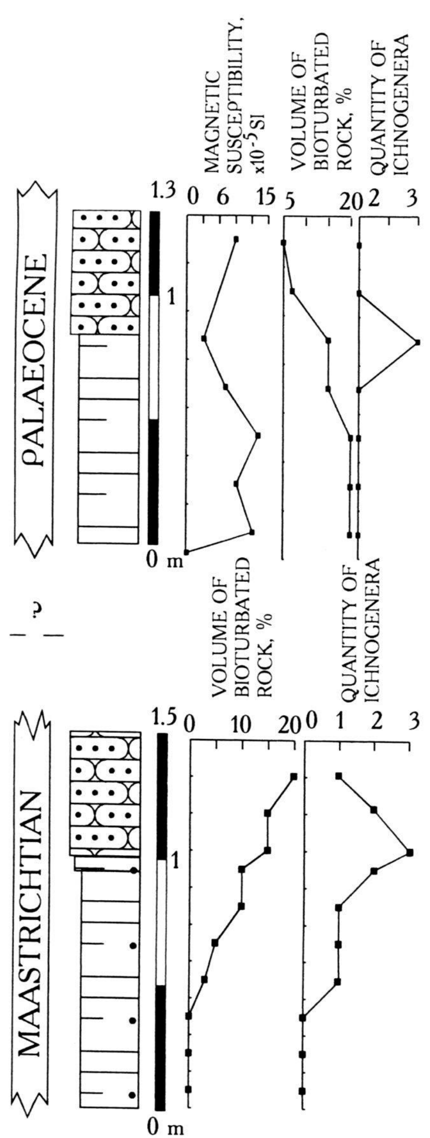
?
LEGEND:
CLAY
SANDY CLAY
CHALK
SANDY MARLS
SANDS & SOFT SANDSTONES
SANDSTONES
LIMESTONES
MARLS WITH CLAY
GREY OPOKA WITH CLAY
YELLOWISH – PALE GREY OPOKA
SANDY LIMESTONES
MARLS
REDDISH – BLUE DIAGENETIC LAMINATION
MARLY LIMESTONES
UNCONFORMITIES



Text-fig. 3 — Maastrichtian transitional turbidite-periodite succession of Betta section, Caucasus. Explanation of signatures used in Text-fig. 2.



Text-fig. 4 — Two types of turbidites below and above K/T boundary (3 rhythm elements in Maastrichtian and 2 rhythm elements in Palaeocene) in Betta section, Caucasus. Explanation of signatures used, in Text-fig. 2.

trichtian, Danian and Selandian deposits. The stratigraphical position of the Betta section is not sufficiently investigated, but it is known that it consists of Maastrichtian (Figures 3 and 4) and Palaeocene (Figure 4) deposits. In the Betta section the K/T boundary does not outcrop. The Sengeley section (Figure 5) contains Lower Maastrichtian chalks (10.5 m) and Selandian opokas (more than 30 m). The Volsk section (Figure 6) consists of Lower Maastrichtian chalks (about 65 m), the Belogrodnya section (Figure 7) is composed of Lower Maastrichtian chalks (5 m), Danian sandstones (10 m) and Selandian, siliceous marls, sandy opokas (37 m) with only a few fossils. The Besh-Kosh section (Figures 8 and 9) includes Maastrichtian marls, sandy marls (total thickness — 140 m for both substages), Danian (Figure 2) bioclastic limestones and carbonate clays (26 m) and Selandian (Figure 2) reddish limestones and marly limestones (more than 6 m).

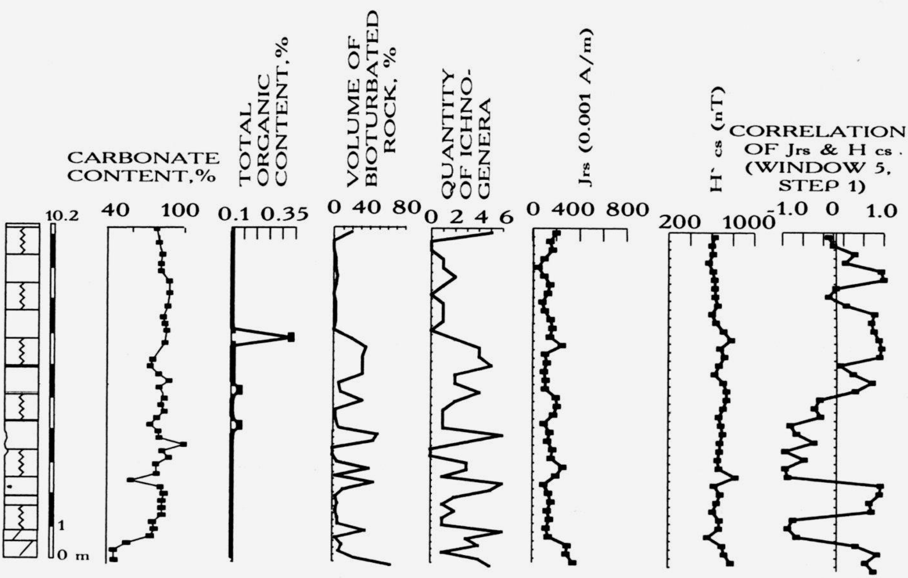
The Maastrichtian stage is characterized by the presence of periodites types 3, 4 and 8 (Russian craton); 1, 2, 5 and 6 (Crimea) and 2 (Caucasus); carbonate turbidites and transitional turbidite-periodite successions (Caucasus). The Belogrodnya section is presented by an arrhythmic interval (5 m) of chalk. It should be noted that the top of the Lower Maastrichtian in the Volsk section is rich in fossils and also arrhythmic, but other parts contain primary rhythms. In the Sengeley section, the succession is a visually arrhythmic and fossil-rich chalk, but the measured parameters demonstrate rhythmic oscillations. The thickness of the Maastrichtian rhythms usually varies from decimeters to meters.

Second order cycles can be distinguished in Maastrichtian rocks of the Russian craton and the Crimea. They contain cyclic variations of rhythmic and arrhythmic levels in the succession (type 4; Lower Maastrichtian, Volsk section) or the possibility of uniting groups of rhythms into new cycles according to their lithologic characteristics and thickness of couplets (all types, Crimea; and type 3; Lower Maastrichtian, Volsk section). This circumstance can demonstrate the connection between the investigated rhythms and Milankovich cycles.

Lower Palaeocene deposits on the Russian craton and SW Crimea are represented by periodites of types 8 and 9. Palaeocene opokas were observed in all sections on the Russian craton. The Belogrodnya section contains Danian deposits presented by arrhythmic, green-blue, glauconitic sandstones. Elements of rhythms in the Besh-Kosh section usually have erosional boundaries. Thickness of Palaeocene rhythms is from a 0.10 m to a few meters.

Discussion

Questions to be answered:
(1) Which models explain the origin of the periodites in pelagic/hemipelagic sedimentary rocks?
(2) What mechanisms (cycles) are responsible for the occurrence of specific types of periodites?



Text-fig. 5 — Lower Maastrichtian of Sengeley section, Ulyanovsk-Saratov foredeep. Explanation of signatures used in Text-fig. 2.

(3) Which palaeogeographical models apply to the studied sections?
(4) What is the connection between specific types of periodites and proposed models?
(5) Is it possible to establish the bathymetrical zonality for the types of periodites and models of their origin?
(6) Is it possible to correlate by cyclostratigraphy between the investigated sections and other sections in Eurasia?

Eleven different models have been suggested for explaining the origin of the periodites. They are briefly described below:

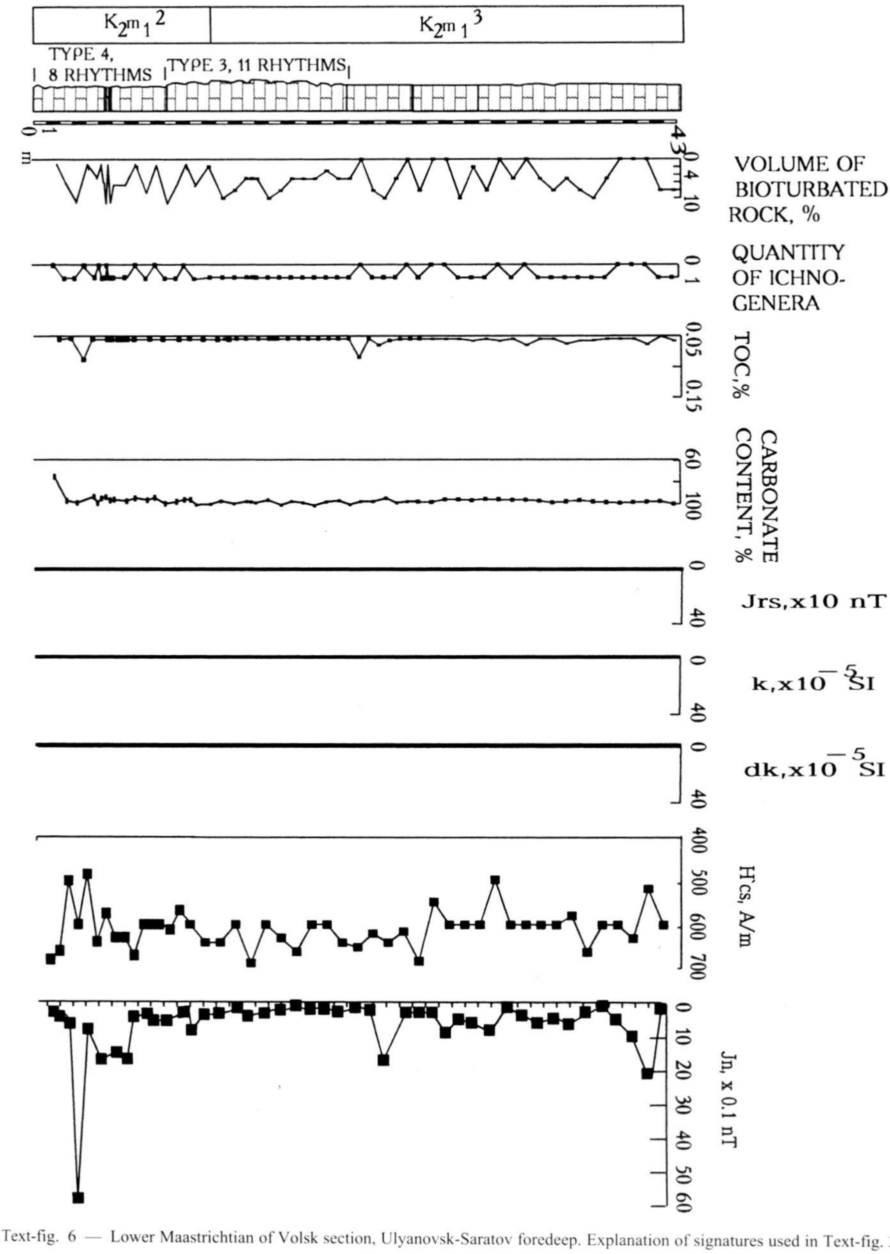
Dilution cycles. Model 1 (EINSELE, 1985). Cyclic changes of moisture, terrestrial input due to climatic variations form rhythmicity in the carbonate sediments. During times of dry climate mainly limestones are deposited. Times of wet climate produce marls, when the dilution of constant carbonate sedimentation by terrestrial material (clay), transported by rivers, takes place.

Dilution cycles. Model 2 (RUFFELL *et al.*, 1996). This model is close to the first. The difference is that in the first case cyclic climatic changes are assumed to result in the cyclic changes in the volume of run off, but here climatic fluctuations cause variations in the nature of weathering and in the composition of terrestrial material transported by rivers. Wet warm seasons are the time of marl sedimentation. Limestones occur during dry cold conditions.

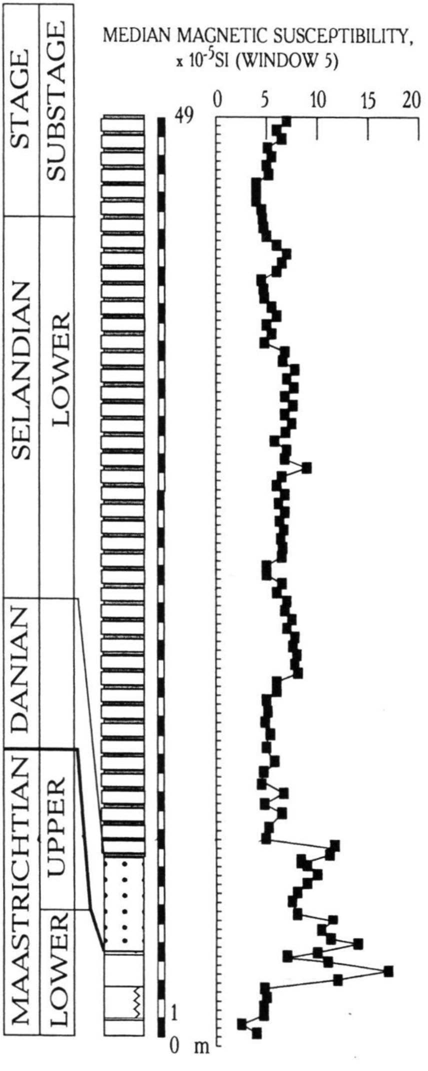
Dilution cycles. Model 3 (MOROZOV, 1952). Sea level rise is a time of transgression (ingression) which washes out accumulated terrestrial material from the shore districts into the basin. So, during transgressions relatively high terrestrial input takes place. Sea level fall is a time of regression and relatively low terrestrial input.

Dilution cycles. Model 4 (GAVRILOV & KOPAEVICH, 1996). During sea level fall coastal regions become swamps and deposition of organic rich sediments takes place. Sea level rise causes transportation of sediments into the basin, with deposition and partial dissolution, increase of bioproductivity, appearance of anaerobic conditions and occurrence of "black shales".

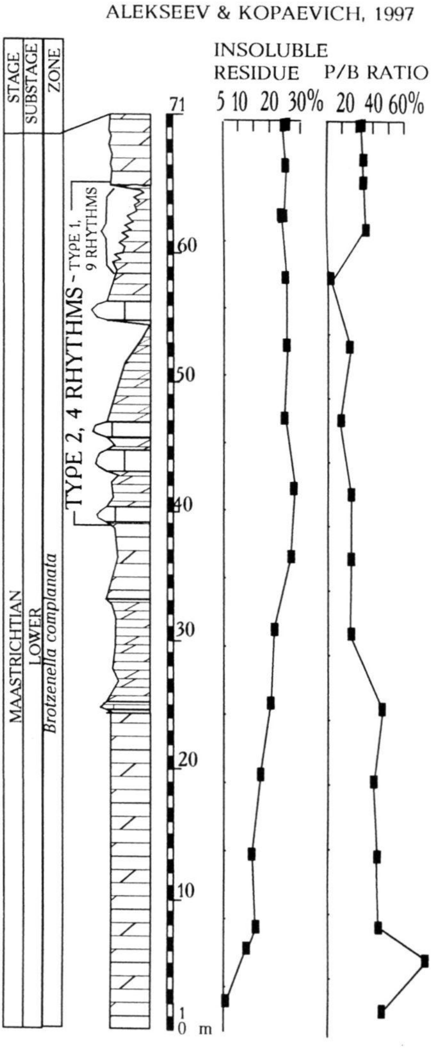
Solution cycles. Model 5 (GABDULLIN & BARABOSHKIN, 1997). Cyclic repetition of condensation and deposition result in the appearance of rhythmic limestone-carbonate clay (marl) sections. Limestones always have an erosional boundary with clays (marls). Limestones represent the sedimentation regime, condensation causes the concentration of carbonate clay, marl (result of limestone dissolution). Erosional surfaces occur due to non-depositional regimes and include soft- and hard-grounds. Con-



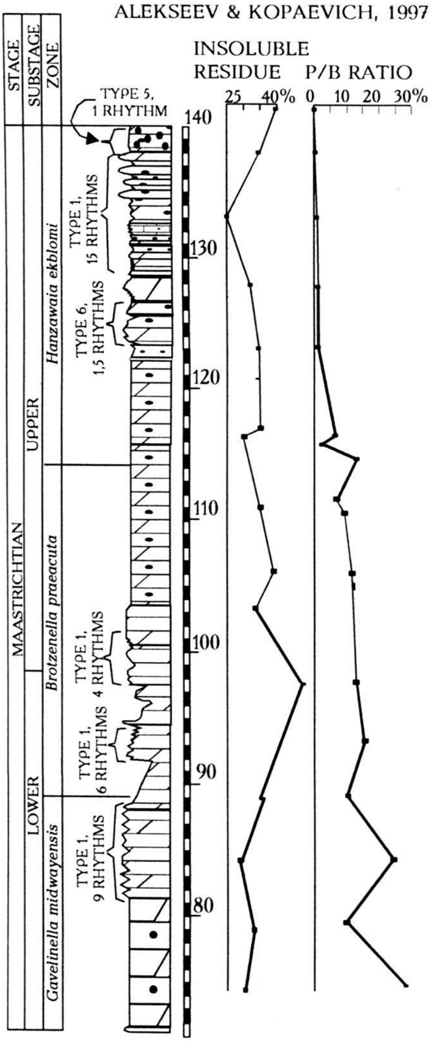
Text-fig. 6 — Lower Maastrichtian of Volsk section, Ulyanovsk-Saratov foredeep. Explanation of signatures used in Text-fig. 2.



Text-fig. 7 — Lower Maastrichtian, Danian and Selandian of Belogrodnya Volsk section, Ulyanovsk-Saratov foredeep. Explanation of signatures used in Text-fig. 2.



Text-fig. 8 — Lower Maastrichtian of Besh-Kosh, Crimea. Explanation of signatures used in Text-fig. 2.



Text-fig. 9 — Lower and Upper Maastrichtian of Besh-Kosh, Crimea. Explanation of signatires used in Text-fig. 2.

densation and sedimentation are assumed to be cyclic processes.

Solution cycles. Model 6 (EINSELE, 1985). SLC (sea level change) causes variation of the critical carbonate solution depth. Periodically, the volume of the constantly deposited carbonate that is dissolved changes.

Solution cycles. Model 7 (RICKEN, 1994). SLC causes cyclic variation in depth of the basin. This results in periodic occurrence of stratified waters with anoxic or nearly anoxic conditions and solution of the constantly deposited carbonates. Sea level up — marl, sea level down — limestone.

Solution cycles. Model 8 (SAVDRRA & BOTTJER, 1994). Climatic variations result in fluctuations of winds and water current direction, which cause changes in the dissolved oxygen content of the bottom waters. Because of new current directions and some specific bottom relief, stagnant, stratified water masses can occur. Cyclic changes of aerobic — dysaerobic — anaerobic conditions result in periodic solution of constantly deposited carbonates.

Dilution and solution cycles. Model 9 (HAY, 1996). Periodical volcanic input into the basin with mostly carbonate sedimentation causes cyclic appearance of bentonite couplets inside chalk or marl layers. Eruptions produce both ash clouds and acid rain. Acid rain enriches water of the basin in acids, dissolving the carbonate.

Cycles of bioproductivity, dilution, solution. Model 10 (FISCHER & ARTHUR, 1977). The history of the organic world can be divided into polytaxic and oligotaxic intervals (FISCHER-ARTHUR cycles), which occur due to climatic variations, SLC.

Solution cycles. Model 11 (EINSELE, 1985). Global cycles of carbon are responsible for changing the carbon/oxygen relation in the atmo- and hydrospheres. This relation depends on the volume of vegetation. The greater the quantity of plants, the lower the content of carbon dioxide.

To determine the mechanisms responsible for producing the periodites and the palaeogeography implied by them established types of periodites were investigated by different analyses. The Palaeocene periodites were less thoroughly investigated. Here is the interpretation of the origin of the studied types of periodites.

A **first type** of periodites was observed in the Maastrichtian of the Besh-Kosh section (Figure 8 and 9). Periodites, consisting both of three elements (Table 1) and two elements (Tables 2 and 3) were observed. Rhythms included marls and chalky marls (Table 1), marls and sandy marls (Table 2), sandy marls and hard sandy siliceous or siliceous marls (Table 3). Rhythmicity in the Maastrichtian of the Besh-Kosh section reflects the distribution of:

- calcium carbonate, carbon dioxide and organic carbon concentration;
- volume of bioturbated rocks;
- P/B relation;
- the weathering profile;

Table 1 – The compossition of 9 marl-marl-chalky marl rhythms in the Besh-Kosh section (type 1, Lower Maastrichtian).

Lithology	Marl	Marl	Chalky marl
Thickness, m	0,05 - 0,2	0,1 - 0,35	0,15 - 0,4
Colour	greyish-yellow	greyish-green	white
Bioturbation	weak or absent	strong	weak
Planktonic forams, %[1]	4,3	0,8	4
Secretional benthic forams, %[1]	7,3	3,2	11
Agglutinated benthic forams, %[1]	88,4	96	85
Quantity of samples	9	9	9

[1] Zayeka O.V., pers. commun.

Table 2 – The composition of 15 calcareous sandstone-sandy marl rhythms in the Besh-Kosh section (type 1, Upper Maastrichtian).

Lithology	Sandy marl	Marl
Thickness, m	0,05 - 1	0,2-1
Colour	grey	yellowish-grey
$CaCO_3$, %	63,56	68,1 - 72,64
TOC, %	0,25	0,1 - 0,17
Insoluble residue, % [2]	29	35
Planktonic/Benthic forams, % [2]	5	10-13
Volume of bioturbated rocks, %	5	10
Quantity of samples	2	4

[2] ALEKSEEV & KOPAEVICH, 1997

— thickness distribution.

Origin of 9 marl-marl-chalky marl rhythms in the Lower Maastrichtian deposits of the Besh-Kosh section is connected with solution cycles and sea level change (model **7**). Fluctuation of the sea level is indicated by oscillations in the relation of planktonic and benthic forams. Dark rock colour correlates with weak bioturbation and sea level rise (relatively high content of the planktonic forams).

The same criteria plus a relatively high content of TOC in the dark couplets are typical for the same model proposed for the origin of 15 calcareous sandstone-sandy marl rhythms in the Upper Maastrichtian of the Besh-Kosh section. At the same time the «sandy» lithology of the rocks is a result of dilution cycles in the basin with fluctuation of sea level (model **3**). In summary, models **3** and **7** are suggested to explain periodites of the first type. These two models and the same interpretation of the data are proposed for the appearance of the 15 sandy marl-hard sandy siliceous marl rhythms of the Lower Maastrichtian and four soft sandy marl-hard siliceous marl rhythms of the Upper Maastrichtian of the Besh-Kosh section.

Another example of periodites of this type is the Cenomanian of the Gamba Zong Shan section, Tibet (LAMOLDA & WAN, 1996).

A **second type** of periodites was found in the Betta section (NW Caucasus). Rhythmicity is represented by a limestone-marl succession with a cyclic distribution of magnetic susceptibility, volume of bioturbated rocks (Figure 3) and distinct colour differentiation (Table 4). Dilution cycles are indicated by oscillations in the terrestrial input of Fe-magnetic minerals (variations in magnetic susceptibility). Solution cycles are indicated by cyclic distribution of the volume of bioturbated rocks and the trace fossil *Chondrites* sp., which is extremely sensitive to variations of the concentration of oxygen, dissolved in the bottom waters. The presence of *Teichichnus* sp. in both rhythm elements indicates the absence of eustatic fluctuations. The origin of the second type of periodites in the Betta section is considered to be connected with models **1** and **8**.

In the Lower Maastrichtian of the Besh-Kosh section a second type of periodites is represented by thick rhythms (Figure 8). Thickness of the marl layers varies from 1 to 9,5 m. Inside one of these marl units rhythmicity of the

Table 3 – The composition of marl-marl rhythms in the Besh-Kosh section (type 1, Maastrichtian).

	K_2m_1,	K_2m_2,	K_2m_1,	K_2m_2,
Lithology	Sandy marl	Soft sandy marl	Hard sandy siliceous marl	Hard siliceous marl
Thickness, m	0,1-0,32	0,1 - 0,17	0,45 - 1,05	1 - 3,7
Colour	light grey	grey, yellowish grey	dark grey	grey
CO_2, %		25 - 27		29 - 33
$CaCO_3$, %		56,75 - 61,25		65,83 - 74,91
TOC, %		<0,08		<0,08
Volume of bioturbated rocks, %		5		10
Planktonic forams, %[1]	4		7	
Secretional benthic forams, %[1]	11		2	
Agglutinated benthic forams, %[1]	85		91	
Quantity of samples	1	5	1	4
Quantity of rhythms	15	4	15	4

first type was found. Limestones are usually 1-1,5 meters thick. Rhythmicity reflects the distribution of:
— volume of bioturbated rocks;
— insoluble residue concentration;
— P/B relation;
— the weathering profile;
— thickness distribution.

Fluctuation of the sea level is indicated by oscillations in the relation of planktonic and benthic forams, thickness distribution of the marl couplets and weak oscillations in the volume of bioturbated rock. The constant upward increase of the thickness of marls correlates with sea level fall (relatively high content of the benthic forams and relatively low volume of bioturbated rock) and corresponds to dilution cycles. The decrease of the carbonate content in the succession correlates with the shallowing of the basin. The nature of the second type of periodites in the Besh-Kosh section is considered to be explained by model **1**.

It should be noted that this rhythmic succession is similar to many rhythmic Upper Cretaceous sections in Eurasia and North America (RICKEN, 1994).

The Selandian marble-marbled marl rhythms (Figure 2) of the Besh-Kosh section (GABDULLIN & WIDRIK, 1998), which are diagenetically cemented limestones and marls (Table 5) and the top of the underlying (Danian) deposits of the Besh-Kosh section represented by two limestone-marl rhythms (Figure 2), can be referred to the second type of periodites, but there are not sufficient data available to propose a comprehensive model of the origin of this type of periodites.

A **third type** of periodites was found in the Volsk section. It is represented by extremely thin greenish-white couplets inside of thick white chalk layers. In the field these layers are termed ''marls'', but according to laboratory analyses they are chalks (Figure 6). Rhythms are characterized by oscillations of the natural remnant magnetization and destructive field of remnant saturation magnetization, of the volume of bioturbated rocks, calcium carbonate and organic carbon content, and differences of colour and thickness (GABDULLIN *et al.*, 1998a). No periodic fluctuations in the magnetic susceptibility, remnant saturation magnetization, and magnetic susceptibility increase were found in examined samples. Model **8** is proposed as their cause.

Other examples of periodites of this type are the Cenomanian and Turonian of the Anglo-Paris basin (GALE, 1995), Campanian of the Gulf of Mexico (KAUFFMAN,

Table 4 – The composition of 5 rhythms in the Betta section (type 2, Maastrichtian).

Lithology	Marl	Limestone
Thickness, m	0,01-1,04	0,02-0,2
Colour	dark grey	white
Ichnogenera	*Teichichnus* sp.	*Teichichnus* sp., *Chondrites* sp.

Table 5 – The composition of 3 marble-marbled marl rhythms in the Besh-Kosk section (type 2, Selandian)

Lithology	Marbled marl (transformed marl)	Marble (transformed limestone)
Thickness, m	0,1	1-6
Colour	pinky-green	pink

Table 6 – The composition of 6 sandstone-calcareous sandstone rhythms in the Besh-Kosh section (type 5, Upper Maastrichtian).

Lithology	Sandstone	Calcareous sandstone
Thickness, m	0,13 - 0,32	2,13 -0,5
Colour	dirty grey	grey
Volume of bioturbated rocks, %	5	5 - 15

Table 7 – The composition of calcareous sandstone-sandy marls rhythms in the Besh-Kosh section (type 6, Upper Maastrichtian).

Lithology	Calcareous sandstone	Sandy marl
Thickness, m	1,1-1,6	3,6
Colour	dirty grey	dirty yellow
Volume of bioturbated rocks, %	15-40	10-50
CO_2, %	26	20-28
$CaCO_3$, %	59,02	45,4 - 63,56
TOC, %	0,1	0,2 - 0,23
Quantity of samples	1	2

1985), and Campanian and Maastrichtian of the Exmouth Plateau, NW Australia (BOYD *et al.*, 1994).

Rhythmicity of the **fourth type** is presented by chalk-chalk rhythms in the Volsk section and hidden rhythmicity in the Sengeley section. The Volsk section is characterized by weak petromagnetic rhythmicity and low value of petromagnetic parameters (Figure 6). In the Sengeley section visual rhythmicity was not observed, but the distribution of the measured parameters shows periodic variations (Figure 5). Another difference between these two sections is the high value of the petromagnetic parameters in the Sengeley section. Rhythmicity in the Maastrichtian of the Sengeley section is established by distribution of: the volume of bioturbated rocks, the quantity of trace fossils, the remnant saturated magnetization (Jrs), destructive field of remnant saturated magnetization (H'cs), the Jrs-Hcs correlation, and the taxonomic diversity of macrofossils. Rhythms in the Maastrichtian of the Volsk section are defined by the same distribution of characteristics as in the Sengeley section plus cyclic oscillations in organic carbon content, colour differentiation and weathering profile.

Rhythmicity in the Maastrichtian of Sengeley section (GABDULLIN *et al.*, 1998b) was formed by solution cycles proved by the cyclic distribution of the calcium carbonate and organic carbon content, the volume of bioturbated rocks, the quantity of ichnocoenoses. Dilution cycles are indicated by cyclic fluctuations in the input of terrestrial Fe-magnetic minerals which produce oscillations in the distribution of the remnant saturated magnetization (Jrs), destructive field of remnant saturated magnetization (H'cs) and Jrs-Hcs correlation. Negative correlation we interpreted as the absence of the terrestrial input,

Table 8 – The composition of 5 clay-limestone rhythms in the Besh-Kosh section (type 7, Danian).

Lithology	Clay	Limestone
Thickness, m	0,01-0,05	1-3
Colour	greyish-green	greyish-white

Table 9 – The composition of rhythms in the Belogrodnya section (type 8, Selandian).

Lithology	Marl	Opoka
Thickness, m	0,3	0,2
Colour	yellowish pale grey	brownish grey
Magnetic susceptibility ($x10^{-5}$ standard units)	4-6	6-10
Quantity of samples	60	56

Table 10 – The composition of rhythms in the Sengeley section (type 9, Selandian).

Lithology	Soft sandy opoka	Hard opoka
Thickness, m	0,1-1	0,2-1,5
Colour	grey	yellowish pale grey
Remnant saturation magnetization, $x10^{-3}$ nT	670	650
Destructive field of remnant saturation magnetization, A/m	770	700
Quantity of samples	1	1

positive — as a presence of the terrestrial input. The dilution and solution cycles are described by models **1** and **8**. Rhythms in the Maastrichtian of the Volsk section (GABDULLIN *et al*, 1998a) are defined by the same distribution of characteristics as in the Sengeley section plus differences in colour and in the weathering profile. The same models are proposed to explain the periodicity of the Volsk section.

A **fifth type** of periodite was studied in the Besh-Kosh section, near the K/T boundary (Figure 2). Preliminary results of the investigation are shown on Table 6. Periodite of this succession have distinct weathering profile, colour differentiation, volumes of bioturbated rock and thickness variation. The origin of this periodite is connected with dilution cycles (sandstone-calcareous sandstone succession). Model **1** is proposed for this type of rhythm.

A **sixth type** of periodite was observed in the Upper Maastrichtian of the Besh-Kosh section near the K/T boundary. Here (Table 7) the rhythmic distribution of the colour of the rocks, volume of bioturbated rocks, carbon dioxide, calcium carbonate and organic carbon content are nearly equal not direct, or sometimes inverse of those in the other parts of the section (Table 6). The lithology of the rhythms (calcareous sandstones and sandy marls) indicates that there are dilution cycles. It is interesting that the character of distribution of calcium carbonate and organic carbon content and volume of the bioturbated rocks is more complicated, than in most of the periodites studied: the TOC content in the sandy marl is higher, and the calcium carbonate content can be higher or lower than in the sandstone. At the same time the volume of the bioturbated rocks is nearly equal in both rhythm elements, but a darker colour is typical for the sandstones. Thus, the influence of the solution agent could be constant or periodic, but the duration (amplitude) of this periodicity was different (probably longer) from the duration of dilution cycles. Models **1** and **8** may account for these periodites.

Other examples of this type of periodites are the Lower Shale member of the Niobrara formation, Santonian of the Western Interior Basin, USA (RICKEN, 1994).

A **seventh type** was found in the Danian deposits of the Besh-Kosh section (Figure 2). The preliminary results of research are shown on Table 8. These periodites (GABDULLIN & WIDRIK, 1998) are distinctly identified by their weathering profiles and thickness distributions. The Danian clay couplets are thought to be the result of dissolution and condensation of limestone beds (solution cycles). The origin of the cyclic repetition of limestone beds, erosional surfaces and clay couplets with glauconite can be described by model **5**.

An **eighth type** of periodite is typical for the Selandian of the Belogrodnya section (Table 9), where rhythms can be detected by the weathering profile and fluctuations of the magnetic susceptibility (Figure 7). Dilution cycles are indicated by the variation of the petromagnetic parameters and lithology (marl-opoka) (GABDULLIN & WIDRIK, 1998). Model **1** is suggested as the cause.

A **ninth type** of periodite was observed in the Selandian of the Sengeley section (Figure 5). This type differs slightly from the previous one in the criteria of the establishment of the rhythms (Table 10). Model **1** is proposed for its origin.

From this analysis it is evident that different models could be proposed for the same types of periodites. In some cases a model can produce different types of rhythms.

It is possible to establish a bathymetric zonation for the different types of periodites and models of their origin. The shallowest periodites (littoral-sublittoral) are the terrestrial-carbonate [sandstone, sand-calcareous sandstone, sand (5); sandstone, sand-marl (6); clay-marl, limestone (7) cycles) and siliceous deposits (sandy opoka-opoka (9) cycles]. The middle position in the bathymetric zonation are sublittoral-hemipelagic carbonates [marl-marl (1); marl-limestone (2); marl-chalk (3) rhythms] and siliceous-carbonate successions [opoka-marl (8) cycles]. The deepest periodites (hemipelagic-pelagic) are the carbonate chalk-chalk (4) and siliceous-carbonate marly opoka-opoka (9) successions.

The bathymetric distribution of palaeogeographic models is more complicated than the distribution of types of periodites. It seems possible to establish a littoral-sublittoral group of models (1-5) and hemipelagic-pelagic group (6-8, 10). Models 9 and 11 reflect more global influences upon the sedimentary system, than the other models.

The Volsk, Belogrodnya and Sengeley sections are neither typically Boreal nor Tethyan; their position is transitional. The Besh-Kosh is an example of a typical Tethyan section. It is very similar to the Agost and Zumaya sections (NE Spain) (TEN KATE & SPRENGER, 1992). All of these sections have the same type of rhythms (lithology, thickness). A few groups of couplets (below and above K/T boundary) have the same thickness and the same stratigraphic position in these sections, indicating the climatic-orbital control of deposition of these rocks and probably reflect Milankovich Cycles.

The origin of periodites is a result of cycles of dilution, solution and bioproductivity described by the 10 palaeogeographic models. The climatic variations caused by Milankovich Cycles probably resulted in the appearance of different kinds of rhythmicity in Maastrichtian and Lower Palaeocene rocks of the Russian craton, SW Crimea and NW Caucasus.

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