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REFERENCE SECTION OF THE UPPER KAZANIAN SUBSTAGE: CYCLIC REGULARITIES

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ABSTRACT

In the present paper cyclicity of sedimentary rocks was discussed on the example of so called cycles by Noinskyi discovered in reference section of the Upper Kazanian substage near village Pechishchi (river Volga, near Kazan city, Russia). The analysis is based on layers-thickness distributions and isotope ratios of carbon, oxygen and strontium in carbonate component of section. Cycles by Noinskyi are referred to $1*10^5$ –$4*10^5$ years cycles of Earth eccentricity.

Keywords: upper Kazanian stage, cycles, noinsky, isotope ratios, carbon, oxygen, strontium.

1. INTRODUCTION

The Kazanian stage is the most studied stratigraphic object within Volga and Kama rivers region because of expressed marine component in its composition. It is considered within Middle+Upper Permian sequence called Upper regional cycle [1].

Common regional palaeogeographical history of the Kazanian stage was characterized in [1]. This history was controlled by Hercynian tectonic movements after the fifth global regressive phase of the Late Paleozoic.

Hercynian Ural mountain structures were actively destroyed, and the eastern marginal area of the Russian plate was provided by a huge amount of clastic and chemogenic sedimentary material. Waters of Boreal Permian Sea penetrated from north to Cisuralian foreland basin. Three megacycles corresponding to the Ufimian, Kazanian and Urzhumian+Severodvinian + Vyatkian regional stages occurred inside the supercycle. Maximum transgression associated with the Early Kazanian. Terrigenous and carbonate sediments accumulated in the Kazanian paleosea during the Early Kazanian and beginning of the Late Kazanian. Sedimentation during the Late Kazanian has already occurred in increasing evaporate environments when subsequent invasion of the sea became more transient and less ambitious.

We will consider the cycles of Pechishchi that is well-known reference section of the Upper Kazanian substage on the right bank of Volga River in light of historical interpretation and recent geochemical data.

2. DESCRIPTION OF REFERENCE SECTION

The region of the Volga River near Kazan includes the area along the bank of the Volga River from the village of Pechishchi to the town of Tetyushi. The Upper Permian rocks form the right bank of the river and are accessible for studies in the slope of the bank and in numerous gullies.

The stratotype outcrops are exposed on the right bank of the Volga River opposite the city of Kazan. The succession is exposed in the slope of the bank between the village of Pechishchi and Naberezhnye Morkvashi and in the bottom and in the slopes of the Kamennyi Gully (Figure-1, outcrop 1). The Kazanian–Urzhumian boundary is the best accessible in the Cheremushka (Figure-1, outcrop 2) and Truba (Figure-1, outcrop 3) gullies.

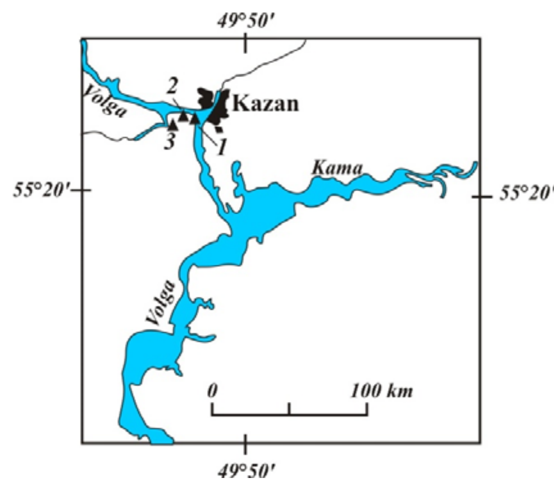

Figure-1. Geographical location of the Upper Permian type sections: 1 - Pechishchi; 2 – Cheremushka Gully; 3 -Truba Gully.

Pechishchi section's stratification was firstly made and developed by M.E.Noinskyi in 1899 and 1924 [2]. Section was divided on 52 layers grouped into series with local names. The groups of series were considered by Noinskyi as three cycles.

The first (lower) cycle includes three series from low to up: "Yadrenyi kamen", "Sloistyi kamen", "Podboi". The second (middle) cycle comprises of series from low to up: "Seryi kamen", "Shikhany", "Opoki" (lower part). The third (upper) cycle includes series from low to up: "Opoki" (upper part), "Podluzhnik" and "Perekhodnaya".

Each cycle begins with marine carbonate sediments. Gypsum and dolomite sediments of saline lagoons follow after marine carbonates. The cycle is finished by mud sediments of transition and continental environments.

Main characteristics of section are next:

- dolomites widely spread;
- dolomites altered thinly with limestone and marl;

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ARPN Journal of Engineering and Applied Sciences

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- limestone with rich marine fauna are rare;
- single layer with oolite carbonates (layer 17) is discovered;
- fine grained sediments mostly present in series "perekhodnaya";
- high extent of carbonate rocks weathering.

In [3] the section Pechishchi is described in a grouped form composed of 31 layers with a change in the values of thickness in some layers.

On Figure-2 the distribution of thickness, according to both descriptions, is showed ((by [2, 3])). On thickness plot built using first data (on left) one can see that the thickness (on 52 layers) ranges from 0.04 m (the layer 44 of series «Perekhodnaya ") to 5.48 m (layer 37 of series "podluzhnik "). The thickness of first cycle is 15.6 m (6.8 +5.56 +2.8), second cycle - 11.68 m (5.4 +3.28+3), third cycle - 19.8 (3.27 +9.21+7.32) m. Total thickness is 46.64 m. Mean thickness is 15.69 m. The most thick layers are layers 2 (1.75 m), 9 (2 m), 21 (3 m), 31 (1.57 m), 37 (5.48 m), 38 (3.73m). Second (saline lagoon) component is mostly thick in each cycle. First (marine) and third (lacustrine) components are next. On the Figure-2 bars 9, 21 and 37 point on increasing of continental influence on sedimentation.

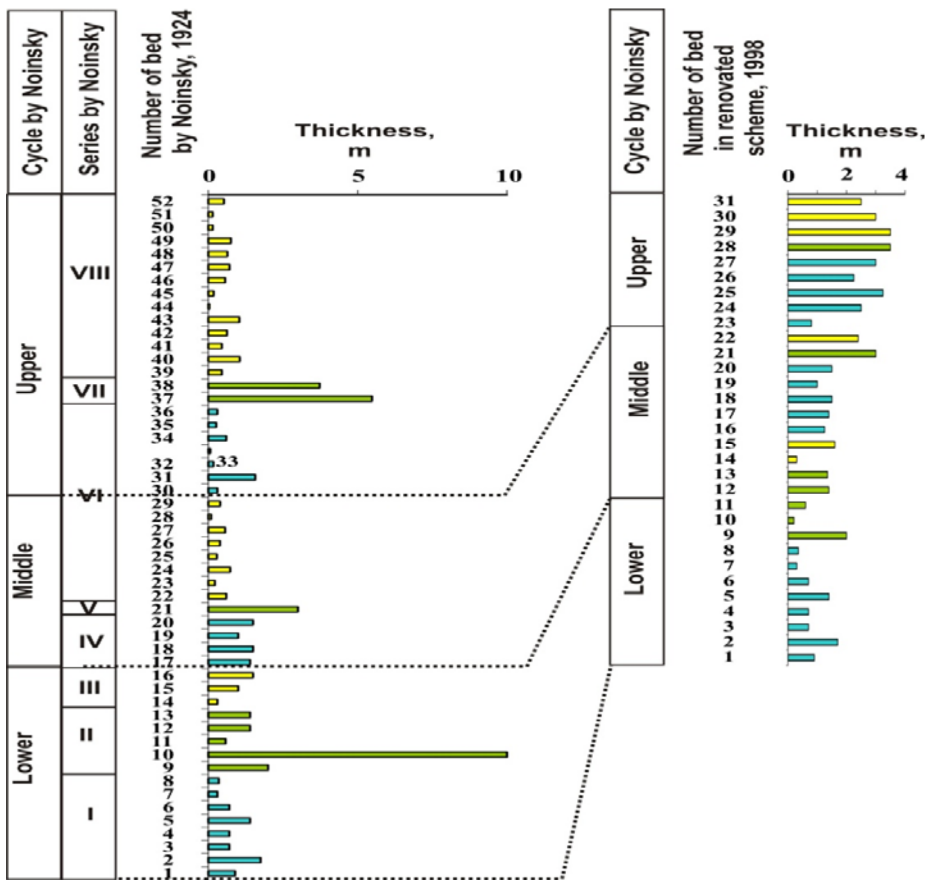

Figure-2. Thickness distribution along reference section. Series by Noinskyi: I- "Yadrenyi kamen", II - "Sloistyi kamen", III - "Podboi"; IV - "Seryi kamen", V - "Shikhany", VI - "Opoki"; VII - "Podluzhnik"; VIII - "Perekhodnaya". Blue - layers with fauna, green - carbonates with hypsum, yellow - clayey-marl sediments.

In plot by renovated description (Figure-2, on right), the general character of cycles remained unchanged. There are three levels of continental influence increasing marked by layers 9, 21, 28.

Layers descriptions are similar on thickness in the lower (15.45 m) and middle (10.8 m) cycles. The upper cycle (24.3 m) differs and due to the fact that the layers of third cycle were described by researchers at the close, but different points (gully Truba [2] and gullies Kamennyi, Cheremushka and Truba [3]).

We base our consideration on the modern description by [3] that is presented below.

Prikazanskie layers ($P_2kz_2^1$)

Series Yadrenyi Kamen

Dolomite, clayish, yellowish-brown, soft; with vermiculate cavities. The thickness is 0.9 m.

Light-grey, calcareous, thickly bedded, compact, hard dolomite containing the small foraminifers *Ichtyolaria fallax* (K.M.-Maclay), *Ich. longissima* (K.M.-

ARPN Journal of Engineering and Applied Sciences

Macl.), rare molds and impressions of bivalves and brachiopod shells. The thickness is 1.7 m.

Light-grey, yellowish, compact, moderately hard, solid dolomite. The thickness is 0.7 m.

Light-grey, compact and hard dolomite, sometime cavernous, with *Cancrinella cancrini* (Vern.). The thickness is 0.7 m.

Grey, calcareous, compact dolomite; sometimes it is replaced by thinly porous softer dolomite with numerous inclusions of celestine. This layer contain the foraminifers *Paraglomospira simplicissima* (K.M.-Maclay), *Ammodiscus* sp., *Globivalvulina bulloides* Brady, *Nodosaria suchonensis* K.M.-Maclay, *Pseudonodosaria lata* K.M.-Maclay, *Lingulina semivelata* Tscherd., *Ichtyolaria triangularis* (Gerke), and small shells of *Cancrinella cancrini* (Vern.), *Rhynchopora geinitziana* (Vern.), *Cleiothyridina pectinifera* (Sow.). The thickness is 1.4 m.

Yellowish-grey, fine-grained, porous, sometimes cavernous, relatively soft dolomite. These rocks contain the accumulations of small non-sorted bioclasts. The thickness is 0.7 m.

Yellowish-grey with bluish-grey stains, fine-grained, calcareous, solid dolomite containing numerous molds and impressions of bivalves and brachiopod shells. The dolomite contains inclusions of celestine. The thickness is 0.3 m.

Bluish-grey calcareous crypto-grained, lenticular and bedded dolomite, with impressions of vegetative shoots of charophytes, the brachiopods *Cancrinella cancrini* (Vern.), *Aulosteges fragilis* (Netsch.), *Stenoscisma superstes* (Vern.), *Crurithyris nucella* (Netsch.), and the conodonts *Merrilina* sp. and *Stepanovites* sp. The thickness is 0.35 m.

Series Sloistyi Kamen

Light-grey, calcareous, fine-grained, sometimes bioclastic dolomite. It is clearly subdivided into four layers. Rocks in the upper part contain gypsum nodules and caverns at places where gypsum was leached. The layer contains the bivalves *Nuculana speluncaria* (Gein.), *Lithophaga consobrina* (Eicw.), *Pseudobakewellia ceratophagaeformis* Noin., *Schizodus rossicus* Vern., *Permophorus simplex* (Keys.), *Pseudomonotis* sp., *Solemya (Janeia)* cf. *biarmica* (Vern.), and the brachiopods *Cancrinella cancrini* (Vern.), *Pinegathyris royssiana* (Keys.), *Beecheria* sp., conodonts *Merrillina* sp., and *Stepanovites* sp. The thickness is 2 m.

Yellowish-grey, very compact, moderately hard, finely laminated dolomite, with smooth or uneven fractures. The thickness is 0.2 m.

Light-grey, calcareous, thinly porous, fine-grained, medium bedded dolomite. The layer contains small (up to 2.5 mm) bioclasts oriented along the bedding planes. The thickness is 0.6 m.

Dull-grey, fine-grained, medium-grained dolomite, with numerous large cavernous. The rock contains small scattered bioclasts up to 1 mm in size. The thickness is 1.4 m.

Light-grey, fine-grained, thinly wavy laminated very soft, porous, dolomite with numerous celestine nodules and rare gypsum nodules, which are usually leached. The bedding plane at the top of the layer contains desiccation fractures and vermiculate branching perforations. The rock contains rare small bioclasts (up to 0.5 mm in size), in which calcite is replaced by dolomite. The thickness is 1.2-1.5 m.

Pechishchinskie layers ($P_2kz_2^2$)

Series Podboi

Dark-brown and greenish-brown dolomitic, plastic, thinly wavy laminated clays, with numerous differently orientated gliding planes. Clays contain many coaly remains of the plants *Paracalamites kutorgae* Gein., *Sphenophylum stoukenbergi* (Schm.), *Callipteris* sp., *Nucicarpus minutus* Esaul., etc. and scales of the fish *Palaeoniscum* sp. The thickness is 0.25–0.35 m.

Greenish-grey, muddy-marly, fine-grained marl with irregular thin lamination, platy, strongly weathered, loose and soft. Rocks are diagonally fractured, the fractures are filled with calcite. Some interbeds are filled with calcite bioclasts (0.5 mm). The thickness is 1.2–2.0 m.

Series Seryi Kamen

Brownish-grey, muddy, thinly and medium bedded, platy dolomite with rhomboidal fractures. Rocks contain many small (2–3 mm) rounded nodules of dark calcite, the bed is sometimes completely replaced by dark-grey, fine-grained limestone. The thickness is 1.0-1.5 m.

Grey, fine-grained, porous, relatively soft, sandy, thickly bedded, bituminous dolomite, sometimes with oolits. The rock contains the gastropods *Goniasma* sp., *Baylea* sp., bivalves *Schizodus rossicus* Vern., and the brachiopods *Aulosteges wangenheimi* (Vern.), *Cleiothyridina pectinifera* (Sow.), and *Beecheria* sp. The thickness is 1.4 m.

Brownish-grey, muddy, thinly porous dolomite, thickly bedded at the bottom and thinly bedded at the top. The dolomite contains inclusions of calcite, celestine, and gypsum. The inarticulate brachiopods *Orbiculoidea konincki* (Gein.) and the conulariid *Conularia hollebeni* (Gein.) are typical. The bed also contains the bivalves *Pseudomonotis (Trematiconcha) noinsky* (Lich.), *Pseudomonotis (Pseudomonotis) permianus* Masl., *Solemya (Janea) biarmica* (Vern.), *Parallelodon kingi* (Vern.), and the fish scales *Kasanichthys* sp., *and Acropholis* sp. The thickness is 1-2 m.

Grey, thickly bedded, fine-grained dolomite, sometimes stained and with ooids. The bed also contains inclusions of calcite, quartz, and calcedony, more rarely celestine and gypsum. The layer contains the foraminifers *Glomospira* sp., *Ammodiscus* sp., *Globivalvulina bulloides* Brady, *Pseudonodosaria lata* K.M.-Maclay, *Nodosaria suchonensis* K.M.-Maclay, and *Pseudoammodiscus microsphaericus* (K.M.-Maclay), numerous gypseous or siliceous molds of bivalves *Pseudomonotis garforthensis* (King), *Ps.* sp., *Schizodus rossicus* Vern., brachiopods

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Aulostegs wangengeimi (Vern.), and many remains of branching and reticulate bryozoans *Tabulipora ordinata* Moroz., *Fenestella permutula* Moroz. and others, which often form bioherms. The thickness is 1 m.

Grey, fine-grained, thickly bedded, medium hard, compact, sometimes siliceous dolomite. The lower part contains the bivalves *Nuculana kasanensis* (Vern.), *Pseudomonotis (Ps.) permianus* Masl., *Pseudobakewellia ceratophagaeformis* Noin., and the brachiopods *Cancrinella cancrini* (Vern.), *Cleiothyridina pectinifera* (Sow.), *Beecheria netschajewi* Grig. The thickness is 1.5m.

Series Shikhany

Light grey, thinly wavy laminated, porous, soft dolomite with numerous gypsum nodules. The leached rock is cavernous. The top of the layer possesses desiccation fractures. The thickness is 2-4 m.

Verkhneusolnskie layers ($P_2kz_2^3$)

Series Opoki - 'Opoka'

The base of the layer is formed by the band of conglomerates (10–20 cm thick) which irregularly overlies the underlying rocks and consists of marl and clay small pebbles (0.5-1.0 cm in size), cemented by clay-silty material. The conglomerate is overlain by yellowish-grey, thinly wavy laminated siltstone with large cherty nodules, with interlayers of crypto-grained muddy dolomite. The siltstone contains the rare bivalve *Parallelodon kingi* (Vern.). The thickness is 1.6-3.2 m.

Grey, clayish, crypto-grained, micro wavy laminated, sometimes sandy dolomites with rare bioclasts (0.1-0.2 mm). The thickness is 0.8 m.

Alternation of siltstones and clays, yellowish-grey, thinly bedded, with rare interlayers of thinly laminated dolomites. The thickness is 2.2-3.8 m.

Grey, muddy, fine-grained dolomite fractured by the intersection of hair-thin fractures filled with hydroxides of iron. Upward in the section dolomites are replaced by dolomitic clays and yellowish-grey marls, with subdominant interlayers of siltstone and sandstone. Clays and sandstones contain foraminifers *Glomospira* sp., *Ammodiscus* sp., *Pseudoammodiscus megasphaericus* Gerke, bivalves *Pseudobakewellia ceratophagaeformis* Noin., *Pseudomonotis (Ps.) permianus* Masl., *brachiopods Cancrinella cancrini* (Vern.), *Rhynchopora geinitziana* (Vern.), *Cleiothyridina pectinifera* (Sow.), marls contain *Lingula sp*. The thickness is 2.5-4.0 m.

Series Podluzhnik

Light-grey, muddy, fine-grained, thickly bedded dolomite with cherty nodules. The rock contains imprints of the bivalves *Nuculana kasanensis* (Vern.), *N.speluncaria* (Gein.), *Schizodus rossicus* Vern., *Netschajewia globosa* (Netsch.), *Pseudomonotis (Ps.) permianus* Masl., the brachiopods *Cancrinella cancrini* (Vern.), *Beecheria netschajewi* Grig., *Spiriferellina netschajewi* (E. Ivan.), *Odontospirifer subcristatus* (Netsch.), and fish scales of *Platysomys soloduchoi* Minich, *Palaeoniscum kasanense* Gein. *et* Vett., and conodonts *Merrillina* sp. and *Stepanovites* sp. The thickness is 2.3-3.2 m.

Light-grey, fine-grained, medium bedded dolomite. The thickness is 3 m.

Light-grey, muddy, irregularly layered dolomite with numerous thin laminas and nodules of white and pink gypsum. The top of the bed has desiccation fractures. The thickness is 3.5 m.

Morkvashinskie layers ($P_2kz_2^4$)

Series Perekhodnaya

The rocks of this member unconformably overlie the underlying rocks.

Yellowish-grey, dolomitic, stained marl with lenses of conglomerates (10–20 cm) at the base. Conglomerates consist of small pebbles of white dolomite. Upward in the section, marls are occasionally replaced by muddy dolomites. Marls contain non-marine ostracodes *Palaeodarwinula onega* (Bel.), *Prasuchonella belebeica* (Bel.) and others, phyllopodes, fish scales of *Acentrophorus varians* Kirkby, *Kasanichthys viatkensis* Esin, and *Palaeoniscum kasanense* Gein. *et* Vett., and plant fragments. The thickness is 3-4 m.

Light-grey, muddy, fine-grained, thickly bedded dolomite. The rock contains numerous foraminifers *Saccammina* sp., *Ammodiscus* sp., *Haplophragmoides opinabilis* Ucharsk., *Trochammina* sp., *Verneuilinoides* sp., *and Digitina rara* Ucharsk., the gastropod *Loxonema* sp., the bivalves *Paralledon kingi* (Vern.), *Pseudobakewellia ceratophagaeformis* Noin., *Lithophaga (=Modiola) consobrina* (Eichw.), *Schizodus rossicus* Vern., *and Pseudomonotis (Ps.) permianus* Masl., the brachiopods *Cancrinella* sp. and *Beecheria netschajewi* Grig., and the conodonts *Merrillina* sp. and *Stepanovites* sp. Because of the mass occurrences of *Lithophaga (= Modiola) consobrina* (Eichw.), the layer is known as the "Modiolovyi Horizon". The thickness is 2.5-3.5 m.

Greenish-grey feldspar-quartzite siltstone, with irregular laminas and lenses of clays and dolomites. The rock contains the rare remains of the plants *Signacularia noinskii* Zal., *Paracalamites kutorgae* Gein., *Sphenophyllum stouckenbergii* (Schm.), *Odontopteris rossica* Zal., and *Nucicarpus minutus* Esaul., etc. The thickness is 2–3 m.

These layers are unconformably overlain by the red-layered Urzhumian siltstone and sandstone.

3. CYCLIC REGULARITIES

On isotopic data, received in [4] three cycles on isotopes were detected, correlated with cycles by Noinskyi (Figure-3).

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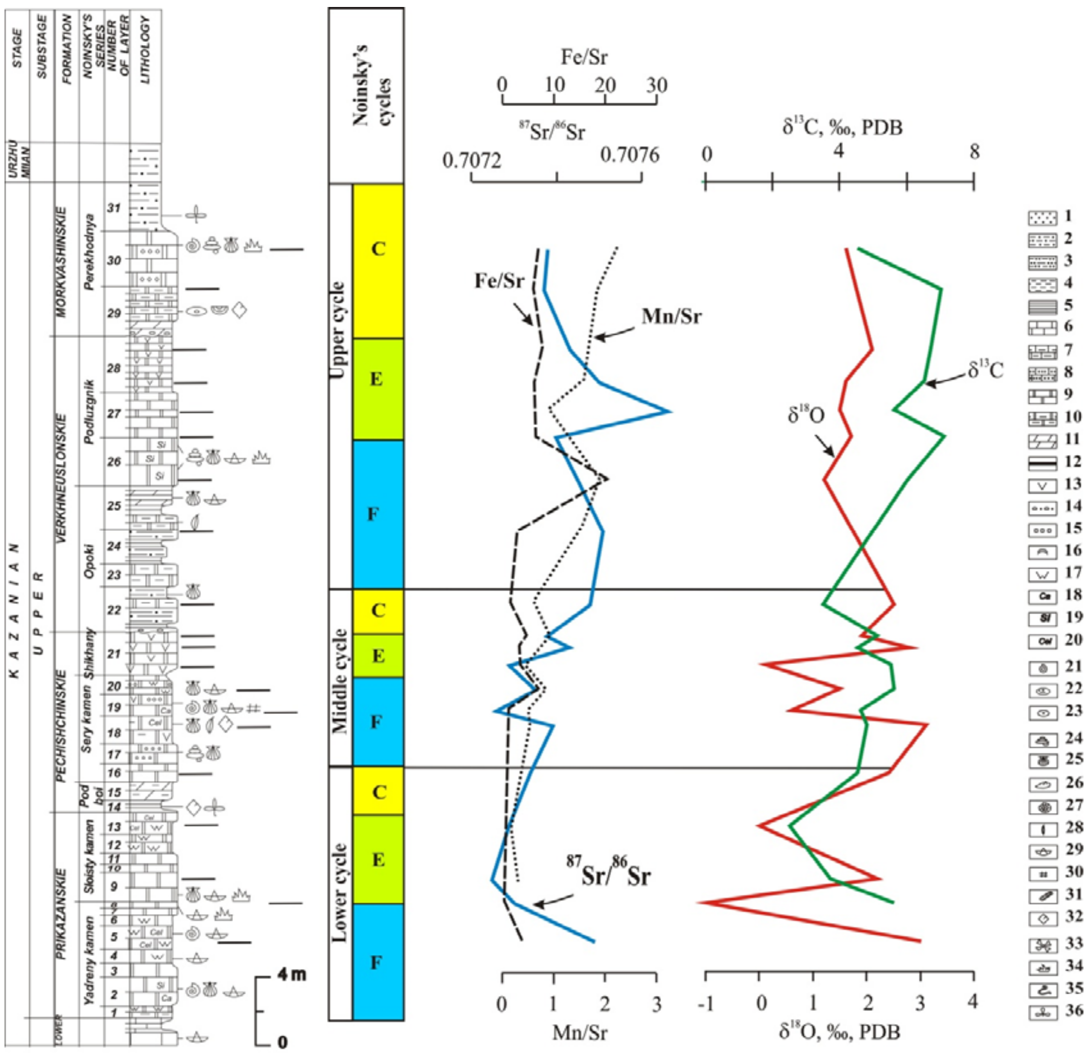

Figure-3. Isotopic variations and cycles along reference section.

Legends: 1 – sandstones; 2 – siltstones; 3 - siltstones and sandstones; 4 - siltstones and clays; 5- clays; 6 – limestones; 7 - clayey limestones; 8 - sandy limestones; 9 – dolomites; 10 - clayey dolomites; 11 – marls; 12 – coal; 13 – hypsum; 14 - coarse grains; 15 - oolites; 16 - reefs remains; 17 - caverns; 18 - carbonates inclusions; 19 - SiO2; 20 - celestine; 21- foraminifers; 22 - marine ostracodes; 23 - non-marine ostracodes; 24 - gastropods; 25 - marine bivalves; 26 - non-marine bivalves; 27 - nautiloidei; 28 - inarticulate brachiopods; 29 - articulate brachiopods; 30 - bryozoans; 31 - crinoids; 32 - fish remains; 33 - tetrapods; 34 - conodonts; 35 - fauna textures; 36 – plant remains. Noinskyi's cycles components: F - carbonate layers with fossils (blue), E - evaporates (green), C - clays and marls (yellow).

Thicknesses of cycles correlate with the number of layers in them (Figure-4, A). The lower cycle has most frequent changes of thicknesses (five short cycles). Each of middle and upper cycles has two ones respectively.

Amplitude of thickness oscillation in short cycles does not exceed 3 m, with a maximum in middle cycle. If we assume that paleobasin during the Late Kazanian was a bay with carbonate sedimentation, the observed thickness fluctuations can be interpreted as relative sea level fluctuations due to accommodation space changes. The increase of thickness can be correlated with level rise. Nine short cycles can be revealed (Figure-4, B). Maximum 1 corresponds to "Yadrenyi kamen". Group of maximums 2, 3, 4 is referred as "Soistyi kamen". Maximums 5, 6, 7 and 8 correspond to "Podboi", "Seryi kamen", lower and upper part of "Opoki" respectively. Maximum 9 includes layers 28 and 29 in series "Podluzhnik" and "Perekhodnaya".

The hypothesis of correlation of thickness changes with sea accommodation changes can be proved by correlation of thickness changes with the number of fauna species (Figure-4, C).

The zero line is arbitrary and corresponds to the composition of the poor paleontological complex. The resulting graph shows that in zones of marine component of cycle's thickness maximums 1 and 2, and also 3 (with a

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small time lag) correspond to biotic peaks. In middle cycle, the biotic peak accompanies a maximum 6 and still retains its value in a downturn of thickness. In the upper cycle biotic peaks follow the thickness peaks 8 and 9, respectively. Thus, the increase of species of marine biota correlates with an increase of thickness of the layers (sea accommodation increase), and our hypothesis is acceptable.

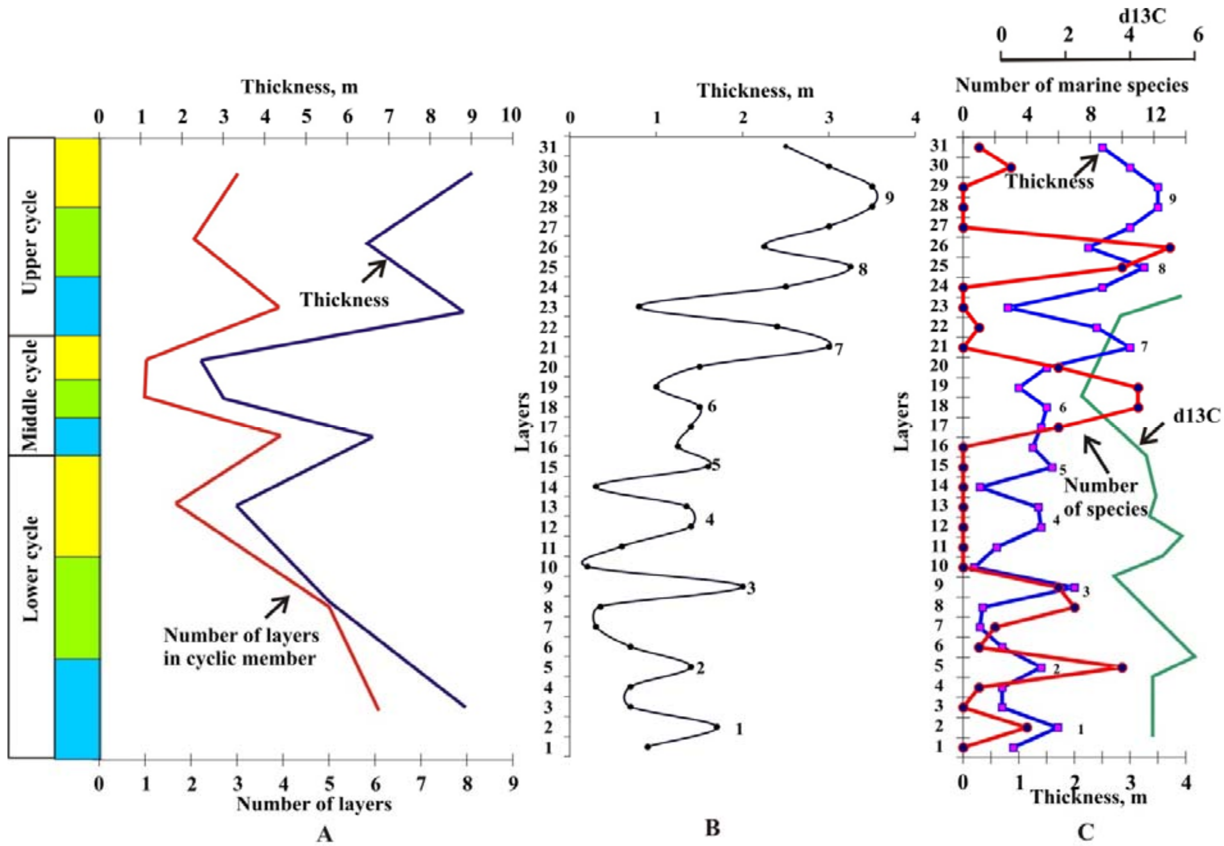

Figure-4. Cycles in Pechischi. A - correlation of layers number and thicknesses:long periods. Composition of each cycle: blue - carbonates with fauna, green - carbonates with hypsum without fauna, yellow - carbonate and mud sediments. B - short thickness cycles with maximums 1-9. C - thickness and biota in cycles.

Also reversal correlation was observed between $\delta^{13}C$ and the number of marine biota species (Figure-4, C), confirmed by cycles of biota activity in dependence on sea level rise or fall ($\delta^{13}C$ increase or decrease respectively).

Three cycles along Pechishchi section correspond to cycles with mean thickness 17 m of fifth order (duration of Late Kazanian is ~1-1.5 Ma by ISS, and one cycle duration is ~0.5-0.6 Ma)

Estimation of the rate of the sedimentation obtained by simple dividing of thickness on the time, gives a value of about 0.02-0.04 m/ka for large-scale stratigraphic records. The smaller cycle corresponds to the increased rate of sedimentation. According to [5], the rate of accumulation of "lingula clays" (base layer of Lower Kazanian) is estimated by value of about 0.5-1 mm/year, supposing that the probability of interruption increases with sediment thickness [6] . This estimation is close to the estimated 0.23 - 0.24 m/ka given for the Permian of Australia in [7]. It can be correlated with one or two 100 thousand year cycles of eccentricity.

Supposing a fifth-order cycles were taken in a simplified visual version comparable to 100 thousand year cycles of eccentricity, then on the table [8] we obtain the following simulation model (Table-1).

Table-1.

Milankovitch cycle [Berger and Loutre, 1994]	**Cycle duration, m** [Berger and Loutre, 1994]	**Ratio** [Berger and Loutre, 1994]	**Pechishchi**	
			Thickness, m	**Sedimentation rate m/ka**
Precession	17638	1:5.7	3.0	
Precession	21034	1:4.8	3.5	
Obliquity	35145	1:2.8	6.1	
Obliquity	44284	1:2.3	7.4	
Eccentricity	100000	1:1	17	0.17
Eccentricity	123000	1.2:1	20.4	
	200000	2:1	34	
Eccentricity	400000	4:1	68	

5. CONCLUSIONS

Cycles, determined by M. E. Noinskyi, were considered as effective terms to reconstruct the Upper Kazanian substage history in Volga-Kama rivers region. They can be used for stratigraphic estimations and correlation in regional and global scale.

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