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CYCLICAL COMPOSITION OF PERMIAN ROCKS

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ABSTRACT

Permian rocks within Volga-Kama rivers region were considered in light of environments and mechanisms of sedimentary cycles during Middle and Late Permian. Cycles are reconstructed on a lot of lithological data series (grain size, carbonates, magnetic susceptibility) in variations along the sections and in statistical models of spectral analysis. It is mathematically showed that coarse grains parameter is important to reconstruct cyclical composition of section consisted of marine and continental facies. Analysis of cycles on other lithological properties should be carried out in parts of sections with no signs of major breaks and scores.

Keywords: permian rocks, sedimentary cycles, spectral analysis

1. INTRODUCTION

Permian basin of the Volga and Kama rivers is known as an interesting stratigraphic and paleogeographic object for study of sedimentary cycles in littoral, transition and continental environments controlled by interaction of tectonic factor, sedimentary influx, accommodation space and eustasy. Duration of such cycles is estimated by ~ 1 million years, which according to modern classifications [1] corresponds to the high-frequency cycles of the 4th and 5th order. Most of these cycles are quite thin (a few meters, a few tens of meters) units sequence. They comprise more large-scale cycles of third order of 1 to 10 million years duration. It is believed that the rate process, generating cyclicity balanced with the rate of carbonates sedimentation, evaluated in the range from 10 to 1000 cm/ky. Thus, quantitative parameters should be fixed in thickness variations of the high frequency cycles, which pointed on processes that can be reconstructed.

We will consider Permian sediments within Middle+Upper Permian sequence named as Upper regional cycle, comprising Ufimian, Kazanian, Urzhumian, Severodvinskian and Vyatskian stages (~272 - 252,5 million years).

Ufimian corresponds to Roadian 272 - 268.5 million years (~ 3.5 Ma). Kazanian is compared with Wordian 268.5 - 265 million years (~ 3.5 Ma). Urzhumian, Severodvinskian and Vyatskian stages correspond to Capitanian + Lopingian in the range 265-252.5 million years (~ 13.5 Ma). Thus, the duration of the formation of the Upper Regional cyclothem is about 20 million years after one of recent estimate in [2].

According to the classification [1] the Upper cycle can be characterized as cycle of second order corresponding to the supercycle or sequence and began his formation after the fifth global regressive phase of the Late Paleozoic. Early Permian uncompensated troughs at south-east of the East European platform, possibly stretched from the northern suburbs of Great Donbass through the Caspian depression to the northeast and on the western margin of Cisuralian foreland [3]. Special conditions for the existence of this system in the Caspian and the Urals region and limitation by reef board determined its first compensation by predominantly evaporite formations of Kungurian age and then terrigenous complex of the upper younger sediments. As a result of this compensation system within the central part of the East European platform it was marked a new rise, the best noted by pre-Ufimian unconformity. This rise, called Kamsko-Donskoy ancient arc [4], largely coincides with the Early Carboniferous rise [5]. Thus, at the beginning of the formation of the Upper cycle most of the East European platform was a geological structure created by paleotectonic processes of Middle Carboniferous - Early Permian due to tectonic movements of the early Hercynian [4].

Hercynian Ural mountain structures actively destroyed, and the eastern marginal area of the Russian plate was providing by a huge amount of clastic and chemogenic sedimentary material. Western boundaries of these formations are traced by marginal uplifts system of Tokmovsky vault. Waters of Boreal Permian Sea penetrated from north to Cisuralian foreland basin. Investigated Permian cycle acts as a foreland basin supercycle history from its opening until closing. Three megacycles corresponding to Ufimian, Kazanian and Urzhumian+Severodvinskian + Vyatskian occurred inside this supercycle. Maximum transgression associated with Early Kazanian, when there was a formation, according to uncompensated trough [3, 6]. Kazanian paleosea formed. Terrigenous and carbonate sediments accumulated in it during Early Kazanian and beginning of Late Kazanian including the time of “yadreny kamen” unit [7]. Sedimentation during next Late Kazanian occured already in increasing evaporite environments when subsequent invasion of the sea became more transient and less ambitious (Figure-1).

Axis of Kazanian paleosea crossed the lower reaches of Mezen river to the upper sites of Vychegda river, then continued to the lower sites of Kama river, then - to the headwaters of Sheshma and Sok rivers and further to south to the town of Busuluk. This line confine most comprehensive marine sediment Kazanian sections with a lot of fossils [8]. To the west and south of the basin axis shallow and then coastal sediments with gypsum and

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salt spread (Samarskaya Luka), and to the east - the strata of marine, lagoon and red-colored siliciclastic sediments are replaced by continental sediments of Belebeevskaya suite.

Expressed evaporate processes in Kazanian paleosea occurred during Late Kazanian. They were revealed in three cycles by Noinsky [7] that can be compared with cycles of Zechstein Sea in Germany and Great Britain. These cycles can be also regarded as cycles described by [9], in which calcareous layers with rich fauna are replaced by dolomite and tidal zones and then - by red or green colored argillaceous rocks. Fisher explained such changes in depth of basin by eustatic fluctuations of ocean level [9]. This interpretation seems more verified than the idea of the necessity of a complex spectrum of local epeirogenic crustal movements, although their influence on sedimentation was not excluded. Fisher suggested that eustatic sea level fluctuations could have amplitude of up to 15 m and characterized by periodic cycles with duration of 20, 000 - 100, 000 years [9].

Similar cycles are characterized by alteration of dolomites with evaporates and mudstones formed in Kazanian paleosea.

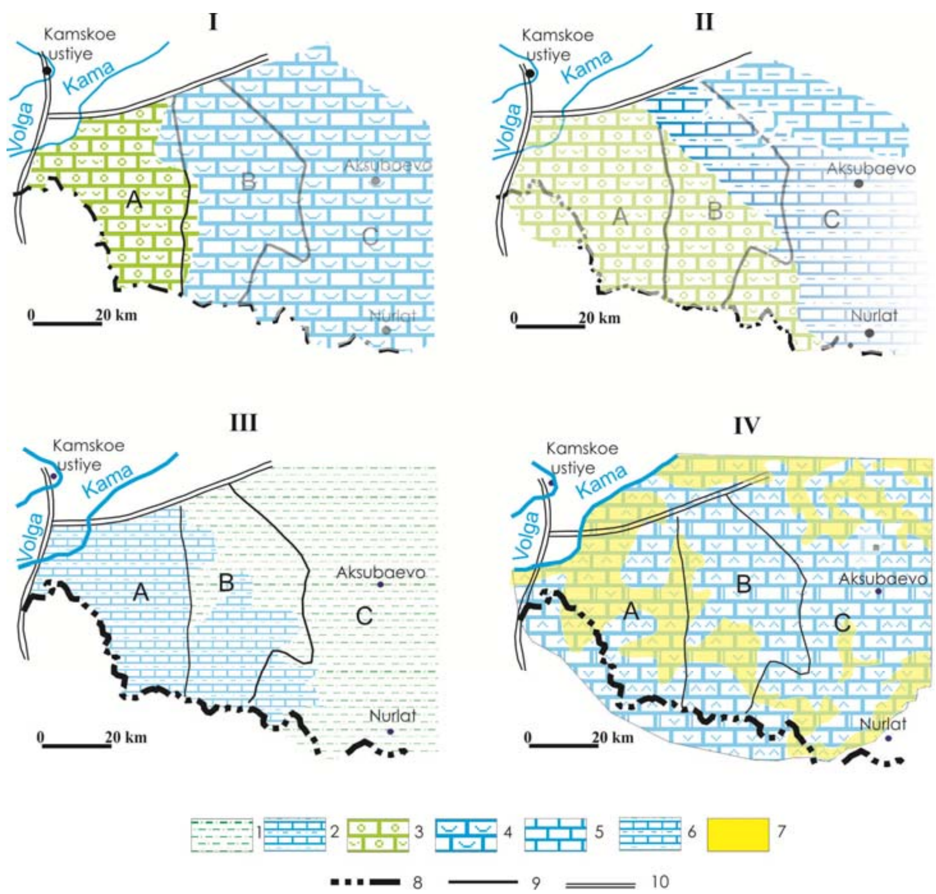

Figure-1. Lithological zones within I - Kamyshlinskian horizon (middle horizon of Lower Kazanian), II - Barbashinskian horizon (upper horizon of Lower Kazanian), III - "yadreniy kamen"+"sloistiy kamen" (bottom horizons of Upper Kazanian), IV - Upper Kazanian.

Legends: **1 -** sandstones and siltstones; **2 -** terrigenous rocks and limestones; **3 -** oolite limestones; **4 -** limestones with marine fauna; **5 -** micrite limestones; **6 -** carbonate and sulphate rocks; **7 -** Neogene incised valleys; **8 -** Southern border of Republic Tatarstan; **9 -** inner borders of western A), central (B); eastern (C) structural zones of Melekess depression; **10 -** outer borders of Melekess depression.

Origin of evaporite components can be explained by partial isolation of lagoon from the open sea because of threshold or shaft that produced the increase of salinity. Otherwise concentrated brines had to flow to the ocean due to the existence of reverse currents. Most researchers suggested a physical barrier, such as organic reef, sand bar or lifting of seabed. However, it is known the basin model [10], suggesting the possible existence of a dynamic barrier, which arises due to friction between water masses of different densities, such as how it is in the Mississippi River. The effect of such a barrier increases with the decrease of the channel connecting lagoon with open sea. This barrier must be in a state of dynamic equilibrium influenced by changes of temperature, pressure, wind, and

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sea level, each of which affects the density of water in the area.

One can find a controversial point of view declining "barrier hypothesis" in because of possible primary high salinity of sea water [11] or vast shallow watered areas with slow circulation and evaporate sedimentation [12].

Relative sea-level change emerges as the most likely mechanism that controlled cycle. This mechanism could also be accompanied by a climate controlled environment. If the atmospheric temperature in the entire basin area increased, evaporation was increased, that lead to a corresponding increase of the compensation flow from the open sea, which prevented an increase of salinity. The result of this process would be to increase the thickness of evaporite layer. If the climate became more humid, fresh water flux increased, which affected the decrease of salinity.

Thickness of investigated cycles of 4th order changes from a few tens of meters to hundreds of meters, and thickness of 4th-5th cycles - from a few meters to a few tens of meters. Areal position of different parts of sections changed during time, therefore complete section of Upper cycle is collected from separate puzzles: Ufimian - on sections of Perm region and Bashkortostan; Kazanian and Urzhumian - on Volga and Kama rivers region; Tatarian - on Volga and Vyatka rivers area and Moscow syncline [13].

We study objects are mostly the second and third of these fragments - Kazanian and Urzhumian, and also Tatarian.

Stratigraphy of these units indicates at least three cycles of 4-5th order in the Lower Kazanian and three or four cycles of 4th order within Upper Kazanian. Two and four cycles of 4th order can be recognised in Urzhumian and Tatarian sections respectively.

2. OBJECTS AND METHODS

We will consider the cycles within three outcropped sections Monastyrskoe, Sheremetevka and Kzyl Bairak on banks of Volga and Kama rivers (Figure-2).

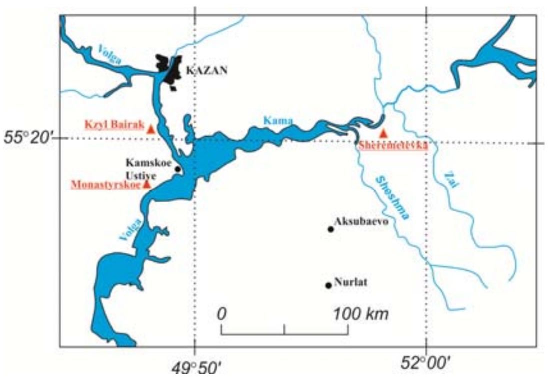

Figure-2. Objects map (investigated sections are marked by red triangles).

To detect cycles we used traditional, nevertheless expressive lithological parameters: grain size content; carbonate component (carbonate content and the ratio $CaCO_3/MgCO_3$); magnetic susceptibility.

Granulometric parameters are useful to determine progradation or retrogradation, the rate of accumulation and boundaries of cycles. Changes of these parameters should be considered in facial association in the light of certain facies hypothesis. If we have a series of limestone - sandstone - siltstone - claystone - limestone - sandstone, so in this association sandstone can be regarded as the beginning of a transgressive cycle and substantial influx of terrigenous material with fresh waters under humid climate. It was preceded most likely a score. Its thickness can point on accommodation space and accumulation of sediment with higher rates. Siltstone and claystone became regular parts of cycle development.

To reveal cycles in sections carbonate, coarse and fine grains content are effective. And coarse grains content was obtained as basic to reconstruct relative sea level changes. Increasing of coarse grains zones can evidence about fall of relative sea level. Strongly magnetized sandstones point on sedimentary material influx. They can be used as event levels of significant changes in region, forming sharp stratigraphic boundaries, expressed by scores and interruptions in sedimentation. This reconstruction is controlled by plots of carbonate and fine grains contents cycles.

Carbonate content in the rocks, in general, increases in main profile of sedimentation area from areas of weathering to sedimentary basin in the "seaward" environments [14]. The ratio of content of Ca and Mg (in our case $CaCO_3/MgCO_3$) carbonates also reflects zonal sedimentation. Carbonates deposited in shallow water, are variable facies that contain unstable minerals (aragonite, calcite with high magnesium content), which make them very sensitive to diagenetic changes. In deeper water environments carbonates usually consist of more stable minerals, such as calcite with low magnesium content, and retain more uniform facies. As indicators of carbonate component in some sections we also used paramagnetic labels - EPR spectra of Mn^{2+} and free radicals of R600 type [15].

Variations of the magnetic susceptibility are caused mainly by changes of allogenic concentrations of paramagnetic and ferromagnetic minerals. They reflect fluctuations in the intensity of terrigenous influx due to tectonic and/or eustatic factors.

Using the specified parameters on sections Monastyrskoe, Sheremetevka and Kzyl Bairak, we made a spectral analysis by the maximum entropy method (MEM) and Fourier analysis.

3. LITHOLOGICAL VARIATIONS

Section monastyrskoe

This section is composed of several outcrops. It includes five suits within Urzhumian (suites I+II), Severodvinskian and Vyatskian stages (suites III+IV+V),

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basically described by Forsh (1938) and Sementovsky (1947) [14]. Section consists of 257 layers with thicknesses from 0.03 m to 4.65 m. Mean thickness is 0.58 m. Thicknesses of first, second, third, forth and fifth suites are 28.67 m, 28.39 m, 32.30 m, 40.31 m and 18.34 m respectively. Mean thickness of suite is 29.60 m. Suites can be considered as cycles of forth order (< 2 Ma). Greater thicknesses are observed in sandstones, claystones and carbonate rocks because of continental character of sedimentation [16]. Sandstones have greater thicknesses up the section. It can indicate on a possible increase of the rate of sedimentation in the Vyatskian time. Sedimentation is characterized by frequent interruptions and scores. If we take the rate of accumulation of fine grains about 0.2 mm/ year, each of the first - fourth suites accumulated about 150-200 thousand years. The rate of accumulation of sandstones may be different, tens, hundreds more than the rate of accumulation of fine grains. If we take the rate of accumulation of sandstone > 1 mm/year, the sedimentation time will be less than ~ 18 -20 thousand years. Total time is ~ 200 * 4 +20 = 820 thousand years, i.e. 820000/7000000 ≈ 12%. This is a rather rough estimate, but it shows that we can see only about ten percent of the geological time. Therefore stratigraphic record is extremely discontinuous.

Integration of carbonate content, coarse and fine grains contents variations allows considering cyclical features of the section (Figure-3). The rapid increase of the sandstone zones number up the section may indicate on a global trend of relative sea level falling, against which short-period oscillation cycles are observed. Strong magnetic sandstones (red zones, in this case there are six and they are revealed in the IV and V suites) are markers of significant tectonic changes in the region. Decrease in the ratio $CaCO_3/MgCO_3$ in the top three suites confirms these changes. Within the second suite this ratio varies slightly, but in the first suite the number of minimums is comparable with the number of cycles allocated on Figure-4. Dolomitic mineralization of marl (by paramagnetic valueα) is characteristic of the first and second suites (aggradation). Concentration of Mn^{2+} correlates with the carbonate content. Signals from organic radical R600 confirms sea level fluctuations have been observed by main parameters (arrows on Figure-3 (increase in the number of radicals R600 - more "seaward" setting, decrease - less "seaward "setting)). Graph of relative sedimentation rate for this section is shown on Figure-4. In general, at least six cycles of fourth order (six zones of strongly magnetic sandstone) are distinguishable. First, second and third cycles correspond approximately to suites I, II and III. Fourth and fifth cycles are within the suite IV and sixth cycle - within the suite V. Each of six cycles includes about two smaller cycles. Thus, about 12 cycles of fifth order can be allocated in the section.

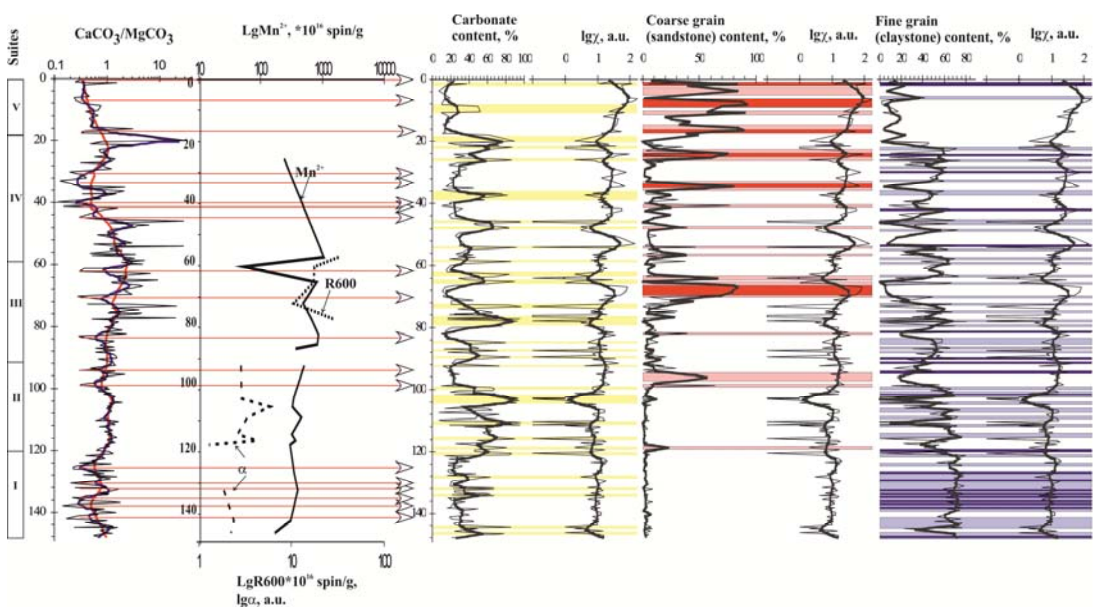

Figure-3. Lithological variations. Section Monastyrskoe. **Yellow -** carbonate zones; **red -** strong magnetic sandstones; **pink -** weak magnetic sandstones; **dark blue -** strong magnetic claystones; **blue -** weak magnetic claystones. Arrows point on sea level falls.

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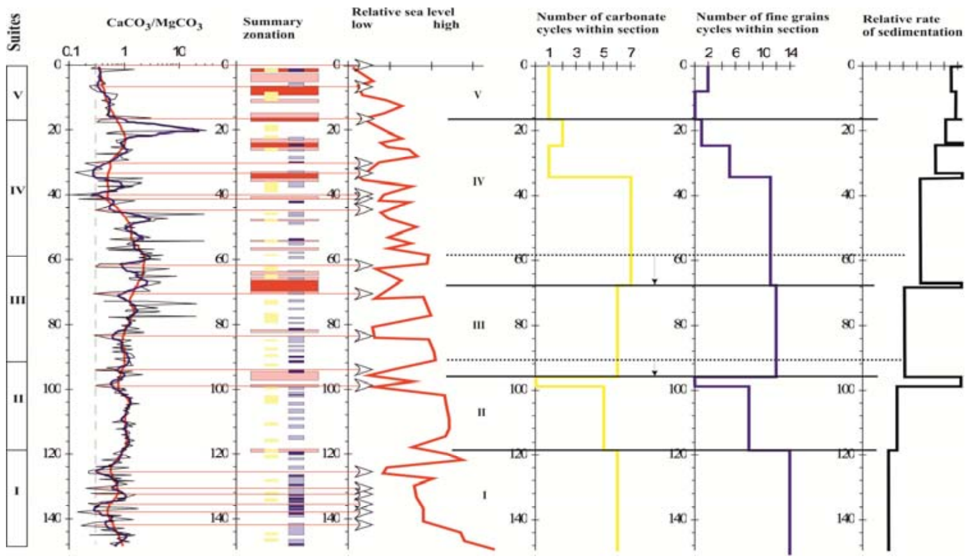

Figure-4. Section Monastyrskoe. Graph of cyclicity. Suits are marked by roman numbers. Solid doundaries between suits are justified. Dotted boundaries are taken from primary description. Solid and dotted lines coincide between I and II, IV and V.

Section sheremetevka

This section consists of 215 layers with thicknesses from 0.03 to 3.00 m. Mean thickness is 0.41 m. Total thickness is almost 82 m, including Prikazanskie, Pechischinskie, Verkhneuslonskie and Morkvashinskie layers of Upper Kazanian with about 20, 18, 28 and 2 m respectively, and Urzhumian rocks - 19 m.

The greater thicknesses associate with different types of rocks and less thicknesses - with fine-grained sediments.

By analogy with the section Monastyrskoe it can be roughly estimated the part of recorded time as 400ky/2my ≈ 20%, i.e. The stratigraphic record is interrupted.

Lithological variations are shown on Figure-5. On variations of coarse grains content one can distinguish 33 sandstone zones including 6 strongly magnetic zones. Frequency of sandstone zones increases up the section.

Section has 56 zones of claystones (fine grains content) including 8 strongly magnetic zones. 23 zones are revealed on carbonate parameters (carbonate content, $CaCO_3/MgCO_3$ ratio, Mn^{2+} and R600 EPR parameters) and magnetic susceptibility.

6 cycles of fifth order can be discussed. They are marked by strongly magnetic sandstones pointing on activation of continental sedimentary supply mobilization. These cycles are referred to Prikazanskie layers (one cycle), Verkhneuslonskie layers (two cycles) and Urzhumian (three cycles) rocks. The cycles are also emphasized by carbonate and fine grains contents. Cycle's boundaries correspond most closely to boundaries between Pechischinskie and Verkhneuslonskie layers, and also between layers of Kazanian and Urzhumian (Figure-6).

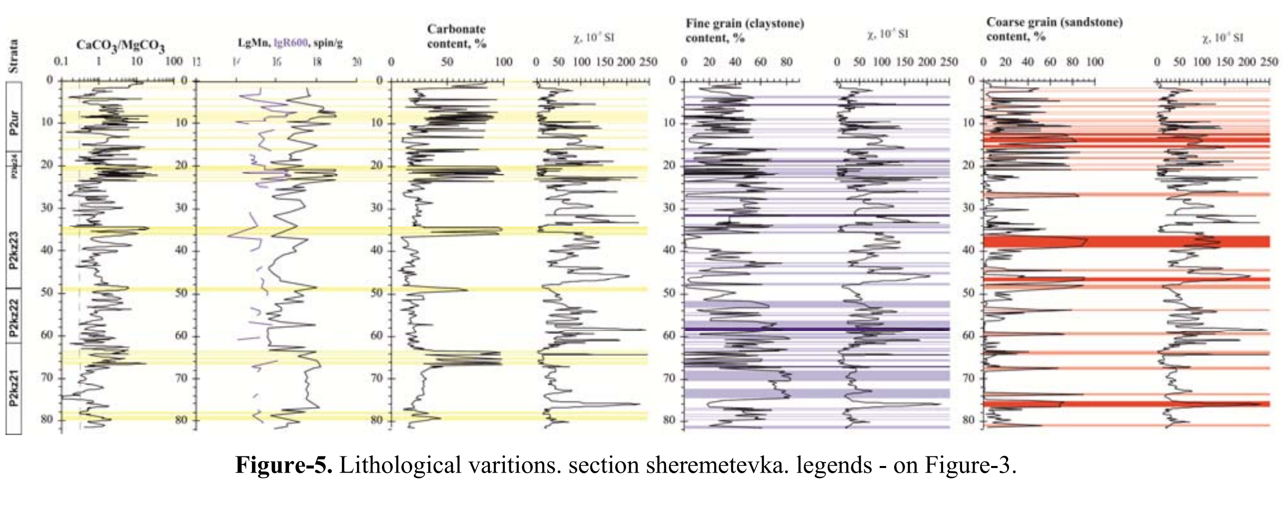

Figure-5. Lithological varitions. section sheremetevka. legends - on Figure-3.

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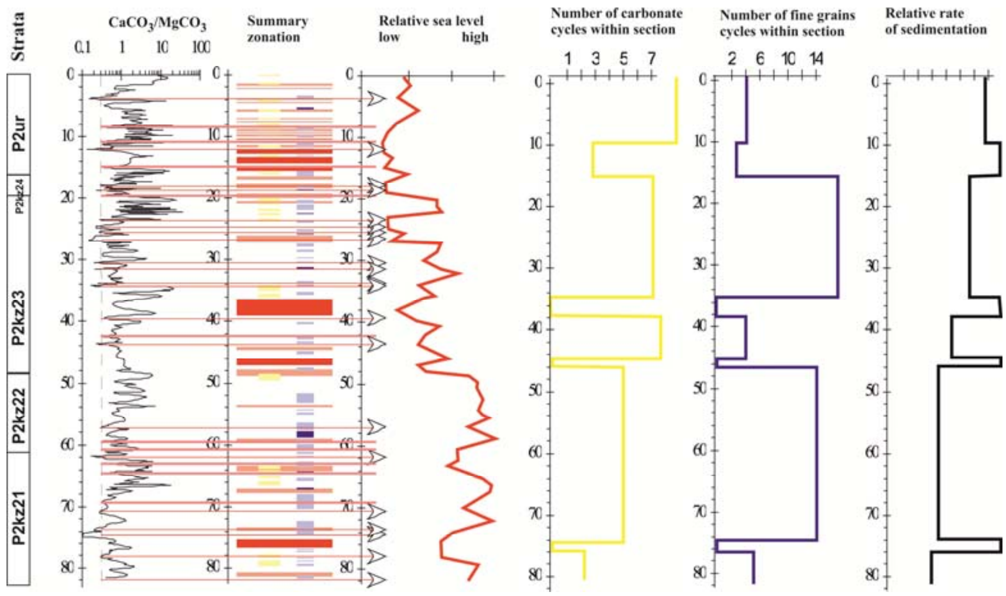

Figure-6. Section Sheremetevka. Graph of cyclicity.

Section kzyl bairak

This section consists of 95 layers with thicknesses from 0.08 to 5.45 m. Mean thickness is 0.69 m. Total thickness is almost 66 m, including upper part ("perekhodnya") of Kazanian (1.4 m) and thickness of both suites (I+II) of Urzhumian (40.5 + 23.8 m).

The predominant thicknesses do not exceed 2 m. Increasing of thickness to 5.5 m is due by comprising of thin layers into a single layer. Increased thicknesses tend to sandy-silty and carbonate rocks. By analogy with the section Monastyrskoe stratigraphic record can be estimated as interrupted with 10 % of time recorded in rocks (300 ky/3 my).

$CaCO_3/MgCO_3$ ratio was the basic to reveal cycles because magnetic susceptibility variation in marl-clay-carbonate sediments of Urzhumian did not permit differing strongly and weakly magnetic zones.

Suites I and II (Urzhumian) can be considered as cycles of 4th order including three and two cycles of 5th order respectively (Figure-7, Figure-8).

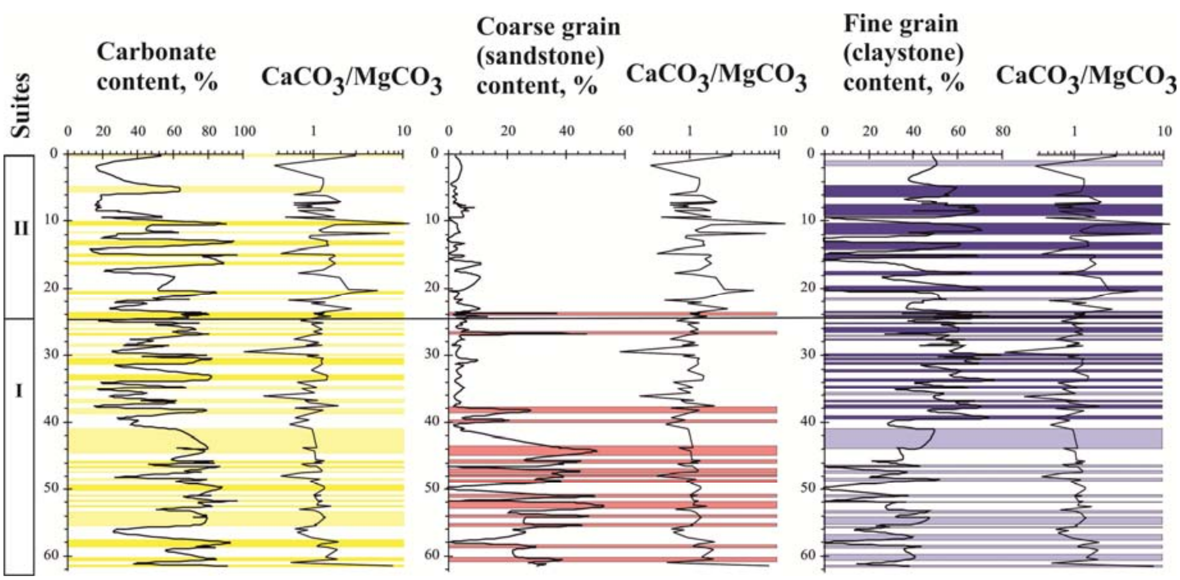

Figure-7. Lithological variations. Section Kzyl Bairak. 33 carbonate zones (among them 18 - bright-yellow – correlation with increasing of $CaCO_3/MgCO_3$) 15 sandstone zones, 37 claystone zones (among them 21 bright-blue - correlation with increasing of $CaCO_3/MgCO_3$).

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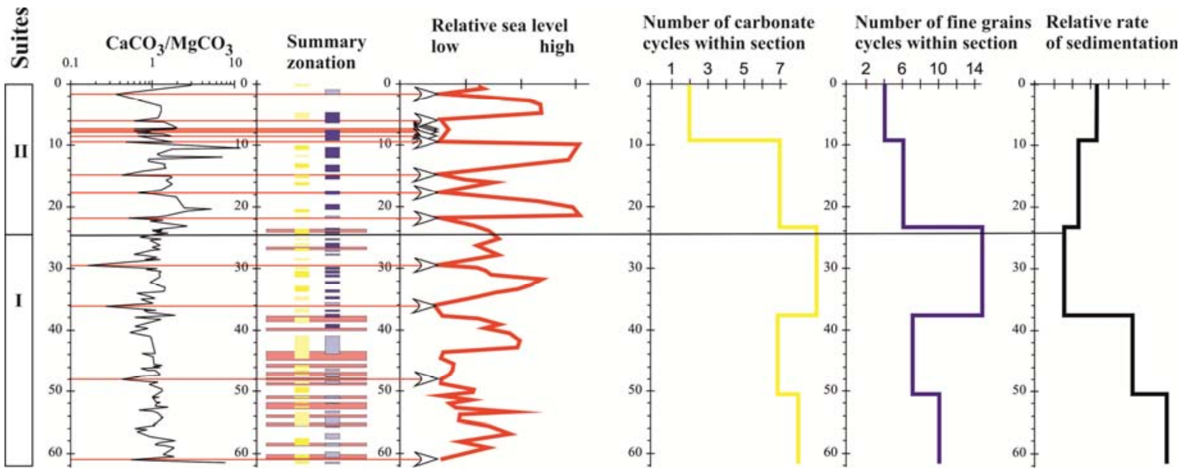

Figure-8. Section Kzyl Bairak . Graph of cyclicity.

4. SPECTRAL ANALYSIS OF THE DATA SERIES FOR THE SECTIONS: RESULTS AND DISCUSSIONS

Spectral analysis by the maximum entropy method (MEM) and Fourier analysis allow us to quantify the oscillation periods marked above on a qualitative level.

On Figure-9 the spectra of MEM series of lithological parameters (magnetic susceptibility, content of coarse and fine grains, ratio Ca/Mg and total carbonate content) are shown for samples collected from sections Monastyrskoe, Sheremetevka, and Kzyl Bayrak. Tables 1-3 demonstrate these spectra harmonics.

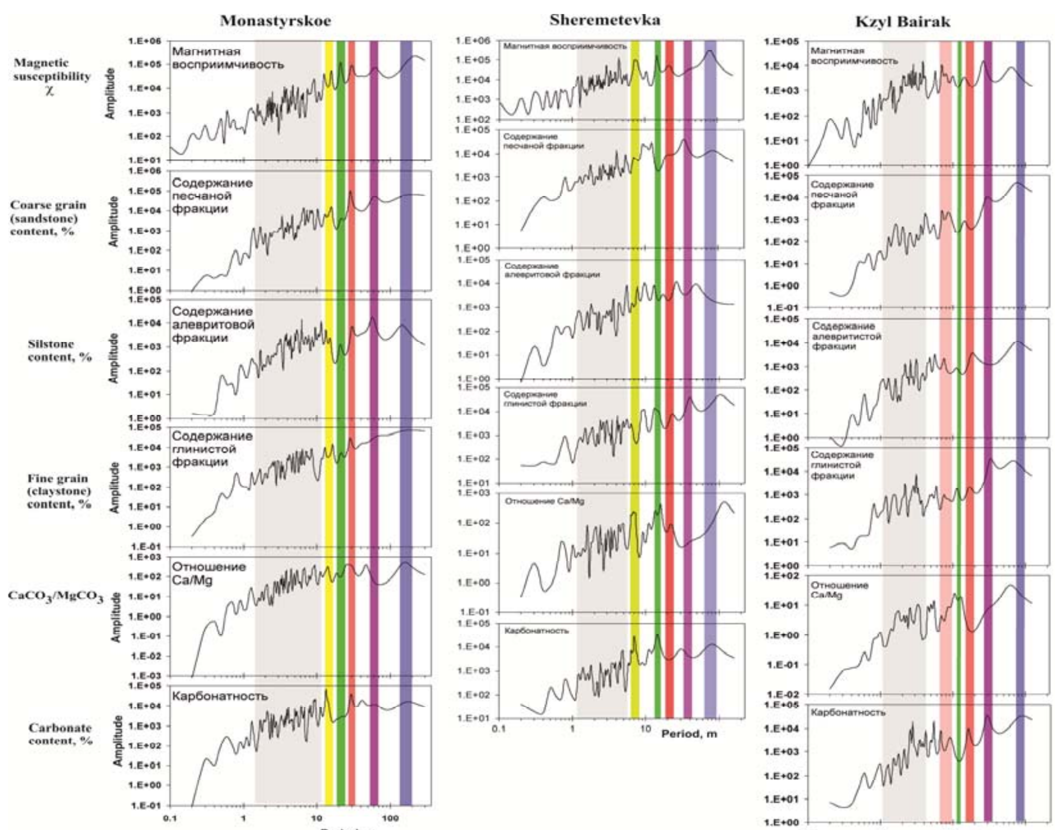

Figure-9. MEM spectra of lithological data series. Colored bands correspond to periods of different length. Gray band corresponds to strong variation with a lot of peaks.

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Table-1. Lithological parameters periods. Monastyrskoe.

Parameters	T ≤ 11 м	11 м ≤ T ≤ 25 м	26 м ≤ T ≤ 42 м	T ≥ 50 м
Magnetic susceptibility	9.1	12.4; 15.6; 20.8;	29.1;	58.2; 206;
Coarse grains content (sand)	6.6; 8.0; 10.2;	12.7; 15.5; 21.1;	28.2;	58.2; 178;
Silt content	6.2; 9.5;	11.5; 13.4; 14.9; 20.5;	29.7;	55.0; 136;
Ratio Ca/Mg	6.6; 9.2;	11.1;13.8; 18.3;	26.0;	46; 150
Fine grains content (mud)	8.5;	12.8; 16.3; 20.9;	28.0;	66.1; 185;
Carbonate content	8.2; 9.1;	13.3;	29; 39.6;	57.2; 169;

Table-2. Lithological parameters periods. Sheremetevka.

Parameters	T ≤ 11 м	11 м ≤ T ≤ 25 м	26 м ≤ T ≤ 42 м	T ≥ 50 м
Magnetic susceptibility	7.2; 10.3;	14.5; 20.2;	38.0;	74.0;
Coarse grains content (sand)	6.9;	9.3-12.2; 19.1;	32.5;	79.6;
Silt content	5.5; 7.6; 9.5;	12.8; 16.7; 25.4;	45.5;	-
Ratio Ca/Mg	6.7; 9.1; 10.9;	13.3; 15.7; 21.5;	41.3;	109.5;
Fine grains content (mud)	8.9;	13.0; 22.4;	38.5;	98.3;
Carbonate content	7.0; 10.9	14.2;	28.7;	75.0;

Table-3. Lithological parameters periods. Kzyl Bairak.

Parameters	T ≤ 11 м	11 м ≤ T ≤ 25 м	26 м ≤ T ≤ 42 м	T ≥ 50 м
Magnetic susceptibility	5.6; 7.0;	13.7;	25.7;	60;
Coarse grains content (sand)	7.1-8.5;	14.8;	28.5;	72.7;
Silt content	4.8; 5.6; 7.3;	10.7; 17.8;	-	72.7;
Ratio Ca/Mg	4.5-5.5;	10.4-12.4;	29	58.4;
Fine grains content (mud)	5.9; 7.4;	11.1; 16.6;	32;	68;
Carbonate content	5.5; 6.8; 8.8;	16.1;	29.0;	85.7;

We observed MEM spectra and noted next general features for them:

a) Energy spectra increase with the period of detected harmonics. This indicates that in all series long-period oscillations have higher amplitude than the short-period. Quantitative features of this property are defined by the Fourier spectra we use below.
b) All spectra have band in their central parts, where the number of peaks per unit reaches the maximum. MEM spectra display all periods of regular and irregular harmonics (even single), therefore we can say that this band (usually wavelengths with a period of 1 to 5 m) reflects most frequent thicknesses of enough homogeneous layers.
c) In the low-frequency part of the spectra one can see peaks, which in most cases are detected visually on the graphs of variations of lithological properties of sections. However the accuracy of their determination remains very low, which does not allow identifying them reliably in different spectra. In the low-frequency band the longest periods allocate. They are longer than the length of series and they are most clearly distinguished by variations of coarse grain component of the magnetic susceptibility.

Each spectrum has a number of significant features (Tables 1-3):

a. In all sections significant peak (harmonica) in periods (thickness)
cycles from 10 to 15 m is observed:

- In section Monastyrskoe this peak is at ~ 11.5-13.8 m. It is reflected in the spectra of all the studied parameters. At ~ 15.5-16.3 m the peak is observed in the spectra of magnetic susceptibility, coarse and fine grains content;

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- In section Sheremetevka this peak is at ~ 12-14.5 m. It is reflected in the spectra of all the studied parameters;
- In section Kzyl Bairak this peak is split into two peaks at ~ 10.4-11.1 m (observed in the spectra of silty grains, Ca / Mg ratio and fine grains) and at ~ 13.7-14.8 m (observed in the spectra of magnetic susceptibility and coarse grains content). Also here it is allocated peak at ~ 16.1-17.8 m (in the spectra silty and fine grains and carbonate component).

b. In all sections significant harmonics are observed in the band from ~ 20 to ~ 30 m:

- In section Monastyrskoe in this band two peaks are also revealed: - ~ 20.5 - 21.1 m (in the spectra of magnetic susceptibility, coarse and fine grains content, Ca/Mg ratio) and ~ 26-29.7 m (all spectra);
- In section Sheremetevka in this band two groups of peaks appear: ~ 19.0 - 22.4 m (in the spectra of magnetic susceptibility, coarse and fine grains content, Ca/Mg ratio) and ~ 29-33 m (in the spectra of coarse grains and carbonate content);
- In section Kzyl Bairak on the spectra of all lithological parameters (except silty grains content) peaks are observed at ~ 25.7 - 32 m.

c. In the periods of more than ~ 35 m one can indicate the following sustainable harmonics:

- In section Monastyrskoe in this band two peaks are also revealed: ~ 55-58.2 m (in the spectra of magnetic susceptibility , coarse and silty grains and carbonate content) and ~ 178-185 m (coarse and fine grains content);
- In section Sheremetevka in this band two groups of peaks appear: ~ 38-45.5 m (in the spectra of magnetic susceptibility, silty and fine grains, Ca/Mg ratio) and ~ 74-80 m (in the spectra of magnetic susceptibility, coarse grains and carbonate content);
- In section Kzyl Bairak in the long period band two peaks are also detected: ~ 58.4-60 m (in the spectra of magnetic susceptibility, coarse grains content and Ca/Mg ratio) and ~ 68-72.7 m (all grains content).

Peaks of such parameters as magnetic susceptibility and coarse grains content occurred pair wise in one group of cycles more frequently. High frequency is also observed for pair of coarse and fine grains contents. Pairs of magnetic susceptibility and silty grains content; coarse and silty grains contents; Ca/Mg ratio and silty grains content; and also pairs of parameters with carbonate content are rare (excepting pair of carbonate content and coarse grains content).

Thus variations of coarse grains content can be considered as main cycle factor. On the other hand, the magnetic susceptibility contains information about the variations of most lithologic properties and it is an additional integral parameter, which can be used in the analysis of lithologic data.

In section Monastyrskoe pairs of magnetic susceptibility-coarse grains content; coarse and fine grains contents are typical as soon as pairs of fine grains - carbonate contents and Ca/Mg ratio and carbonate content are rare.

In section Sheremetevka pairs of magnetic susceptibility-coarse grains content; magnetic susceptibility-fine grains content; magnetic susceptibility - Ca/Mg ratio; coarse grains content - carbonate content and fine grains content-Ca/Mg ratio are most frequent. Pairs of coarse and silty grains contents; silty grains and carbonate contents; fine grains - carbonate contents; Ca/Mg ratio and carbonate content are most rare.

In section Kzyl Bairak close periods are observed for pair of silty and fine grains contents. Other combinations are rare.

Besides of MEM spectra we obtained Fourier spectra that we used additionaly to the results of MEM analysis to clarify cycles and to identify new statistical parameters for the evaluation of the nature and characteristics of the spectra of different lithological parameters in sections. Fourier spectra were approximated by a function:

$$E(f) = a*f^{\beta},$$

where f - frequency of oscillation (in this case, as cycles per decimeter), a - the spectrum amplitude at the highest frequency, β - index showing the degree of relationship between the signals at the low and high frequencies.

Fourier spectra are shown in Figure-10. Table-4 lists all parameters of function, which spectra were approximated. If we estimate the value of β along the entire spectrum, it varies from almost zero to values much higher than shown in Table-4. It is not only due to non-stationary properties of the data series, but limited length of series. As soon as we need to assess the statistical properties of the whole series, we consider the approximation for the whole series. These parameters, in particular the exponent β allows us to evaluate the type of signal and to make an assumption about the nature of the variability of parameters in sections.

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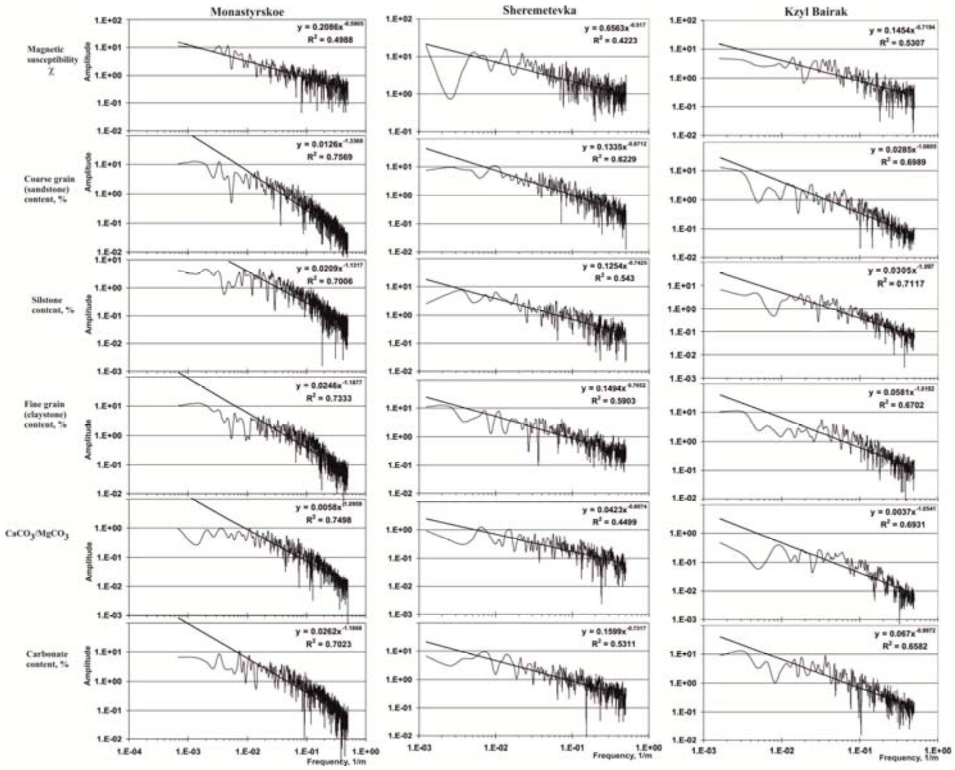

Figure-10. Fourier spectra of lithological data series.

Table-4. Fourier spectra parameters.

Sections		Magnetic susceptibility	Sand	Silt	Mud	Ratio Ca/Mg	Carbonate content
Sheremetevka	a	0.6563	0.1335	0.1254	0.1494	0.0423	0.1599
	β	-0.517	-0.8712	-0.7425	-0.7652	-0.6074	-0.7317
	R^2	0.42	0.62	0.54	0.59	0.45	0.53
Kzyl Bairak	a	0.1454	0.0285	0.0305	0.0581	0.0037	0.067
	β	-0.7194	-1.0805	-1.097	-1.0192	-1.0541	-0.9972
	R^2	0.53	0.70	0.71	0.67	0.69	0.66
Monastyrskoe	a	0.02086	0.0126	0.0209	0.0246	0.0058	0.0262
	β	-0.5905	-1.3368	-1.1317	-1.1877	-1.0958	-1.1868
	R^2	0.50	0.76	0.70	0.73	0.75	0.70

Analysis of the data shown in Table-4 reveals the following patterns:

- for the approximation of all series by power function values of exponent $\beta < 0$ were obtained;
- the worst approximation of spectra is obtained for the series of section Sheremetevka (R^2 varies from 0.42 to 0.62);
- for each of the sections the worst approximation is obtained for a series of magnetic susceptibility;
- for each of the sections the best approximation is obtained for variations of coarse grains content;
- the quality of the approximation is controlled by the exponent β, which increase is accompanied by R^2 increasing;
- the smallest absolute value of the exponent β is obtained for section Sheremetevka;
- the greatest absolute value of the exponent β is obtained for section Monastyrskoe;
- for each of the sections the greatest absolute value of the exponent β is obtained for coarse grains content;
- for each of the sections the smallest absolute value of the exponent β is obtained for magnetic susceptibility;

- usually the absolute values of the exponent β increase in raw magnetic susceptibility - (Ca/Mg) - carbonate content - fine grains content - coarse grains content.

Obtained results permit to interpret the nature of the exponent β variations in the spectra of various lithological parameters in studied sections:

a) There is a substantial variability in the magnitude of the exponent β in the spectra of various lithological parameters for a separate section. It indicates on the presence of real statistical information in the exponentβ. It is also confirmed by the fact that there is ordering of this value depending on the type of lithology parameter;
b) The length of the row weakly influences on the values of the exponent β that is proved by the absence of relationship between the value of β and thickness (Sheremetevka - 82 m, Kzyl Bairak - 64 m, Monastyrskoe - 148 m).

In common, an important result we obtained from the spectral analysis of series of lithological parameters consists in detecting major scale periods in the studied sections (Table-5).

Table-5. Cycles thicknesses on spectral analysis data.

Sections	Thickness, m	T_1, m	T_2, m	T_3, m	T_4, m	T_5, m	T_6, m
Sheremetevka	82	~12.6	-	~20.7	~34.5	~87.3	-
Monastyrskoe	148	~12.8	~15.9	~21	~28.1	~62.0	~182
Kzyl Bairak	64	~10.9	~16.5	-	~31.2	~72.7	-

The values of β indicate that data sets represent something between white noise (β = 0) and the Brownian noise (β = -2). In order to appreciate what we have actually - Brownian noise mixed with white noise, or vice versa - white noise with traces of Brownian signal, we built elementary regressions between | β | and R^2, that points on the processes close to Brownian noise.

After that we can propose the following scheme of the data interpretation:

a) Rows of the magnetic susceptibility variations of rocks in studied sections are extremely complicated by effects of various factors on this value (carbonate content; content of magnetic and non-magnetic coarse grains, fine grains content as a pointer of paramagnetic material). In the spectra of magnetic susceptibility various combinations of these influences are possible, making them close to the spectra of white noise (β ≥ -0.72). Therefore harmonics, marked only on the spectra of magnetic susceptibilty variations can not be directly used to study cyclic composition of sections.
b) Spectra of Ca/Mg ratio, carbonate and silty grains contents variations, also have a smaller absolute value of the exponent β in comparing with the spectra of coarse and fine grains contents.
c) Spectra of coarse and fine grains contents have higher absolute values of the exponentβ. They can be considered as parameters to distinguish cycles in sections.

These considerations are based on the fact that the enormous geological processes have greater energy. They are pronounced in natural records in higher extent. Spectra of ideal records of such processes should have values of β >> 0, i.e. the amplitude (energy) of the low-frequency harmonics should prevail over the energy of high frequency oscillations. How these processes are recorded in the stratigraphic record it depends on the properties of the "recording system". If the spectrum of stratigraphic record is similar to the spectrum of white noise, this means most likely that the record was made with a lot of breaks and scores. One can give a simple example. Let suppose, that there is an ideal system of sedimentation, in which a thin carbonate layer regularly is formed. If we had a complete record of the signal (complete thickness of the sediments), then we would get on the carbonate content spectrum a single peak. But if the system randomly interrupts sedimentation, than spectrum will be different. The distance between carbonate layers can be random (white noise).

5. CONCLUSIONS

Coarse grains content is exclusive parameter. It increases when the surface of sedimentation situates in high energy zone (mostly in low sea level environments). Usually coarse grains point on unconformity. It is used to distinguish cycles in Permian rocks within Volga-Kama region for many years [17-20]. However in our consideration it is mathematically showed that coarse grains parameter is important to reconstruct cyclical composition of section consisted of marine and continental facies.

Thus, the results of spectral analysis of lithological data series in sections Monastyrskoe, Sheremetevka, and Kzyl Bairak allow us to state that the variation of coarse grains content in the sediments is the most important and significant factor to reveal cycles. Analysis of cycles on other lithological properties should be carried out in parts of sections with no signs of major breaks and scores.

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