IDENTIFICAÇÃO DOS LITOTIPOS BÁSICOS DAS ROCHAS EM DEPÓSITOS DE FORMAÇÃO ROCHOSA VIKULOVSKAYA

IDENTIFICATION OF MAIN LITHOTYPES OF ROCKS IN DEPOSITS OF VIKULOV SUITE

ИДЕНТИФИКАЦИЯ ОСНОВНЫХ ЛИТОТИПОВ ПОРОД В ОТЛОЖЕНИЯХ ВИКУЛОВСКОЙ СВИТЫ

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RESUMO

O artigo estuda o potencial de recursos significativos da formação rochosa Vikulovskaya. São descritos os resultados da aplicação de vários métodos de processamento e interpretação dos materiais de análise granulométrica: diagnósticos generalizados do condições de sedimentação segundo G. Füchtbauer e K. Müller, estimativa da gênese de sedimentos pela relação de grau de classificação e características de assimetria (diagrama de K. Bjørlykke), identificação de condições de sedimentação segundo assimetria e excesso (diagrama dínamo-genético de G. F, Rozhkov), a determinação do método de transferência de partículas detríticas no ambiente aquático (diagrama genético R. Passega). Uma análise detalhada dos sedimentos permitiu identificar, dentro do estrato superior VK1, localizado na borda de uma mudança abrupta em ambientes paleofaciais, quatro litotipos principais das rochas, alguns dos quais estão associados ao potencial de petróleo e gás na bacia sedimentar da Sibéria Ocidental.

Palavras-chave: *litotipos de rochas, componentes formadores de rochas, sedimentação, análise granulométrica.*

ABSTRACT

The article explores the significant resource potential of the Vikulov suite. The results of the application of various methods of processing and interpretation of granulometric analysis materials are summarized: the generalized diagnostics of the sedimentation situation according to G. Fühtbauer and K. Müller, the evaluation of the genesis of the deposits by the sorting ratio and the asymmetry features (K. Bjerlkeke diagram), the identification of sedimentation conditions by the correspondence of asymmetry and kurtosis (dynamogenetic diagram of G.F. Rozhkov), establishing the method of transport of detrital particles in an aquatic environment (R. Passage's genetic diagram). A detailed analysis of the sediments made it possible to identify four main rock

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lithotypes within the upper reservoir of VS $_1$, located at the boundary of a sharp change in paleofacial environments, some of which are associated with oil and gas potential in the West Siberian sedimentary-rock basin.

Keywords: *rock lithotypes, rock-forming components, sedimentation, granulometric analysis.*

АННОТАЦИЯ

Статья исследует значительный ресурсный потенциал викуловской свиты. Описываются результаты применения различных методик обработки и интерпретации материалов гранулометрического анализа: обобщенной диагностики обстановки седиментации по Г. Фюхтбауэру и К. Мюллеру, оценки генезиса отложений по соотношению отсортированности и особенностям асимметрии (диаграмма К. Бьерликке), идентификации условий осадконакопления по соответствию асимметрии и эксцесса (динамогенетическая диаграмма Г.Ф. Рожкова), установления способа переноса обломочных частиц в водной среде (генетическая диаграмма Р. Пассеги). Проведенный детальный анализ отложений позволил выделить в пределах верхнего пласта ВК$_1$, располагающегося на границе резкой смены палеофациальных обстановок, четыре основных Литотипа пород, с частью из которых связываются перспективы нефтегазоносности в Западно-Сибирском осадочно-породном бассейне.

Ключевые слова: *литотипы пород, породообразующие компоненты, осадонакопление, гранулометрический анализ.*

INTRODUCTION

Prospects of oil and gas content in the West Siberian sedimentary-rocky basin are connected with four main Lithotype rocks (Alekseev, 2014; Khabakov, 1962):

1. Lithotype I – "sandstones and siltstones with scattered clayiness";
2. Lithotype II – "siltstones and sandstones with textured clay";
3. Lithotype III – "clayey sandstones, siltstones, and mudstones";
4. Lithotype III – "clay sandstones, siltstones, and mudstones".

Deposits of Lithotype 1 are represented by sandstones of fine- and medium-fine-grained, rarely coarse-grained siltstones, predominant in the size of fragments in sandstones 0.12-0.25 mm, in siltstones 0.09-0.10 mm (Figure 1).

The clastic material is medium -graded, the grains are semi-angular and semi-inclined, less often rounded. The clastic part is 90-95%. For the rocks of the first lithotype, oriented and layered microtextures are characteristic, caused by a change in the grain size and interlayers enriched in the micaceous material. In the thin sections, lenticular (spotted) microtextures are sometimes observed, due to the distribution of clay material and carbonate cement.

The composition of rock-forming minerals (V.D. Shutov's (1967) diagram) is arkose: the content of quartz and feldspars is 35-55%, fragments of rocks 10-25%, mica 1-6%. The grains of quartz are light, sometimes with inclusions of pelitic dimension, with uniform or wavy extinction. The grains are regenerated in a weak, rarely medium degree, the regeneration edges are predominantly discontinuous in the form of a cluster of thorns and outgrowths, rarely solid, while the edges restore the faces to crystallographic outlines with a smooth and even surface. In some cases, the regeneration of grains partially or completely absorbs the flakes of film chlorite. Feldspars are represented by plagioclases and fragments of potassium feldspars, incl. and microcline. The feldspars are changed to varying degrees by the processes of pelitization and leaching, which develops in cleavage, with the grains being represented as spiked and partly fragmented to the relict state of forms with a slight presence of small intragranular pores. Separate grains of plagioclases are poorly regenerated; regeneration manifests itself in the form of intermittent cracks. Fragments of rocks are more often represented by effusive, intrusive differences, fragments of sedimentary rocks, crystalline schists. Of micaceous minerals, chloritic and hydrated to a varying degree predominate, rarely fresh biotite, muscovite. The manifestations of quartz regeneration and leaching of feldspars are more pronounced in the sandstones of the distribution channels. Among the accessory minerals, apatite, garnet, zircon, epidote, and titanic grains predominate. Authigenic minerals are mainly represented by leucoxene (less than 1% per rock), pyrite (more often in the form of small crystal aggregates), siderite that develops in micaceous material, calcite fulfilling both individual pores and pore groups (Adams *et al.*, 2014; Conybeare, 1976).

Cement clay, type of grouting film-pore, porous-film. According to the x-ray diffraction analysis, kaolinite (66%) is the predominant component in clay cement, chlorite is 25% and hydromica is 6%, mixed-layer formations (MCOs) are 3%. Films are thin, intermittent, rarely solid, developed unseemly, in composition chlorite, less often chlorite-hydromica. Intergranular clay cement is patchy and isolated in distribution, with a microgranular structure, one- and two-component: kaolinite, less often chlorite-kaolinite and hydromica composition. In addition to clay cement, an admixture of calcite cement is noted. Calcite cement develops foci and performs a group of pores. Its content in the rock is on average 1-3%.

Deposits of the Lithotype I are identified with the rocks of the barrier-bar complex and the distribution channels associated with it.

Small and coarse-grained aleurolites predominate in the *deposits of Lithotype II*, and fine-grained aleuritic sandstones are less often noted (Figure 2). The predominant size of debris in siltstones is 0.04-0.05 mm and in sandstones 0.10-0.14 mm. The clastic material is medium sorted, the grains are semi-angular and semi-inclined. The fragmental part ranges from 90-95 to 85%.

The main characteristic of lithotype II deposits is the presence of a large number of lenses, interlayers, lenticular interlayers of clayey and silty-clay material. These microtextures are emphasized by the change in the granularity of detrital material, micaceous and carbonaceous deposits. Laminates, lenticular (spotted) microtextures are noted in the examined sections, due to the different packing density of fragments, distribution of clay material and carbonate cement. The mineral and material composition of lithotype II deposits are generally similar to those of Lithotype I, but the degree of quartz regeneration is somewhat smaller, micaceous scales are deformed, hydrated, coalinitic and chloritic (by sites up to complete pseudomorphic substitution) (Biju-Duval, 2002; Reading, 1978).

In contrast to the deposits of Lithotype I, the proportion of the hydromica-chlorite material in the clay cement increases. The average content of kaolinite is – 37%, chlorite – 46%, hydromica – 1 0%, MCO – 6%. Chlorite and the hydromica-chlorite material are developed in the form of narrow and wide, continuous and intermittent films, as well as the execution of mica-chlorite pore material. Part of the pore space is made of finely scaly kaolinite and carbonate minerals (calcite, characterized by the presence of an isomorphous impurity of Fe and Mn). Free pores are small in size, often isolated or interconnected by thin pore channels (Boggs, 2014).

Depositions of Litotype II are rocks of storm shallow water. In essence, these are rocks with textured clayey of storm genesis – "tempestites" (from English "tempest" – a storm). These are event (dicyclic) processes. Such usual from the geological point of view, phenomena lead to the formation of sedimentary deposits with characteristic sedimentological and ecological features:

- the beginning, culmination, and decay of turbulent processes is fixed in the form of well-pronounced erosion and sedimentation textures;
- there is a redistribution of organic and inorganic components in the layer both from the bottom (from the base to the roof) and lateral (from shallow water to deep water);
- the ecological situation for benthic organisms changes as a result of a change in the consistency of the bottom soil and the concentration of nutrients on the bottom.

The concept of the influence of storms was first applied by D.K. Hobday and H.G. Reading (1972) to ancient deposits formed as a result of meteorologically induced processes, especially wind and wave currents and storm surf. The great influence of the energy of storms for the formation of marine shallow-water sandstones was emphasized by N.L. Banks (1973) and R. Anderton (1976). R. Goldring and P. Bridges (1973) determined single storm events and weak currents of calm weather in the ancient seas due to the good preservation of the sediments of these environments. The term "tempestite" was first proposed by D.V. Ager (1974).

Depositions of Lithotype 3 occur in the form of thin interlayers and lenses between sandstones and siltstones. The primary texture of mudstone is layered (often thin-layered), lenticular-thready. Mudstones are usually composed of hydromica and chlorite (with the predominance of hydromica). The amount of detrital impurity (small-aleurite) reaches 25-35%. Often in the form of accumulations, siderite spots, small aggregates of pyrite and leucoxene are noted. To the sediments of this lithotype, also clayey fine-grained siltstones with an increased content of clay material can be classified. Siltstone is characterized by layered and lenticular-layered microstructure due to the presence of clay and siltstone stratums. The prevailing size of the fragments varies within the range 0.02-0.08 mm, the admixture of grains of psammite fractions reaches up to 5-10%. In mudstones, the amount of detrital material, represented mainly by fine silty fractions, is usually 25-30% (Reading, 1978; Pettijohn *et al.*, 1987).

High clayiness in siltstones is associated with both texture and scattered clay. The amount of clay cement distributed unevenly in the rock in such interlayers reaches 15-25%. Hydromica and chlorite predominate in the clay constituent of cement. According to X-ray phase analysis, the ratio of clay minerals in the lithotype deposits is as follows: kaolinite – 29%, chlorite – 47%, hydromica – 17%, MCO – 7%, montmorillonite in some interlayers (Figure 3).

The deposits of Lithotype IV are represented by coarse-grained aleurolites and fine-grained sandstones with a high content of carbonate cement (Figure 4).

The deposits of Lithotype IV form small layers in the strata that are not retentively spread along the strata, and a well-traced interlayer between the VS $_1$ and VS $_2$ layers. According to the composition and features of the rock-forming minerals, the rocks of the Lithotype IV are generally analogous to the deposits of the Lithotypes I and II. Cement – carbonate, less often clay-carbonate, porous and pore-basal type. The clay component is represented by kaolinite, chlorite, and hydromica. Kaolinite makes separate pores. Hydromica-chlorite films are rare and are noted on sites with clay-carbonate cement. The amount of clay material reaches 5-10%. According to the thermal analysis, the carbonate cement material is calcite. Its content varies from 15 to 45%, averaging 25-30% (Hallam, 1981; Allen, 1982).

MATERIALS AND METHODS

In the course of the work, the results of the granulometric analysis of core samples taken from the reservoir of VS $_1$ of the Vikulov suite in six wells were analyzed. K.A. Kostenevich carried out similar works in different years, so did I.V. Fedortsov (2011) and other researchers (Kontorovich *et al.*, 2014). The granulometric composition of the rock was determined by several methods: in transparent petrographic sections; mechanical sieve (up to a fraction of 0.05 mm).

According to the granulometric composition, the described deposits refer to weakly and medium-graded fine-grained sandstones and coarse-grained siltstones.

As the initial stage of the graphical processing of the particle size distribution, the grain distribution polygons for the fractions (column diagrams) were constructed to study the change in the nature of the rocks along the section. At the next stage, cumulative (total) curves were plotted according to the method of L.S. Chernova (1980), which are important, both for graphical representation of analytical data and for determining the number of parameters characterizing the rock structure (Figures 5-10) (Chernova, 1976; Chernova, 1984).

In the presented graphs, the size of the fractions was plotted along the abscissa on a logarithmic scale, and the percentage of fractions along the ordinate axis. On the abscissa axis, the grain dimension values for the first quartile (Q_1) are estimated at y = 25%; for the second quartile (Q_2) at y = 50% and for the third quartile (Q_3) at y = 75%, and also the value of C for 1% fractional composition (Bikkenin and Rozhkov, 1982; Borovko and Borovko, 1967; Vakulin and Smirnov, 1971; Griffiths, 1967; Gostintsev, 1989; Krumbein and Sloss, 1963).

Next, the main granulometric characteristics were calculated from the samples: average particle size (Xsr), standard deviation (sorting coefficient S_0), asymmetry parameter (A), kurtosis measure (E), median (Md) (Krumbein and Sloss, 1963; Rukhin, 1947; Rukhin, 1969). The average particle size is determined by Equation 1 (Krumbein and Sloss, 1963; Rukhin, 1947; Rukhin, 1969), where Xsr is the average particle size.

The coefficient of grain sorting is calculated by the formula P.D. Truska (Equation 2) (Krumbein and Sloss, 1963; Rukhin, 1947; Rukhin, 1969), where Q_1 is the grain size for the first quartile at y = 25%; Q_3 – grain size for the third quartile at y = 75%; S_0 is the sorting factor.

According to P. Truska's classification, well-sorted sediments (S_0 = 1.00-1.58), medium sorted (S_0 = 1.58 – 2.12) and poorly sorted (S_0 > 2.12) are distinguished.

The asymmetry (A) is calculated by the R. Folk's formula (Equation 3) (Rukhin, 1947; Rukhin, 1969; Folk and Ward, 1957).

The limits of change in the asymmetry values range from 1.0 to -1.0.

The kurtosis (E) reflects the degree of sorting of the sample at the center of the distribution with respect to its edges and is determined by the R. Folk's formula (Equation 4) [28-30].

The median is the size of the second quartile, which means that half of the grains by mass or indirect count are larger, and the other half is smaller.

As an example, the results obtained for core samples taken from the deposits of the Vikulov suite are given (Table 1).

According to the classification of P.D. Trask, the sediments in the samples studied are medium graded. Particularities of particle size distribution are indicators of the dynamics of sedimentation environment. Analyzing the results obtained, we can conclude that, according to the paleodynamic generalizations of G. Fuchtbauer and K. Muller (described by A.N. Volkova *et al.* (1988)), the investigated deposits were mainly formed in the marine sedimentation environment (marine shallow waters (tidal zones, shelf), because the sorting is average, and the asymmetry is less than one.

RESULTS AND DISCUSSION:

3.1. The results of studies by the method of K. Bjorlykke

According to the method of K. Bjorlykke (1989), according to the ratio of sorting to asymmetry (method), the studied deposits refer to turbidites (Figure 11).

According to the works of many geological scientists, turbidites are sediments deposited by turbidity currents. They represent a rhythmic alternation of sandstones, siltstones with clayey differences. The genesis of turbidites is understood in different ways: either as a result of the shifting of the shoreline and changes in the depth of the sedimentation zone occurring on a relatively shallow (no more than 200m) shelf, or as a result of the deposition of these formations from turbidity streams in the lower part and at the foot of the continental underwater slope in relatively deep-water (1200 m and more) parts of the basin of sedimentation (Bouma, 1962; Mutti, 1992; Pyrcz *et al.*, 2005; Sokolov *et al.*, 2017). Therefore, it is necessary to further refine the genesis of sediments.

3.2. The results of studies using the method of R. Passega

The distribution of the samples in the R. Passega (1957) diagram, constructed in the "C" – "Md" coordinates, the figurative points of all the samples mainly concentrated in the field between the "bottom and gradation suspensions" (Figure 12) (Passega and Byramjee, 1969).

Sediments of SR field – below Cu – sea currents and some rivers with slow current. Sediments of the PQR field, especially in the part lying below C = Cs, falls out of the gradation slurry formed in the lower parts of the fast river streams, directly at the bottom. Sediments of the PO field characterizes mixed transport in suspension and rolling along the bottom, and the field ON is practically only by rolling. These methods of transportation in coastal conditions, on sandy-gravel and pebble shallows, in some parts of the river.

From the analysis of the location of the samples in the diagram of R. Passega (Figure 12), it follows that the samples fell into two genetic regions: part into the deposits protruding from the depth of the bar, the other part into the filling of the upper part of the dying bed with sedimentary deposits.

3.3. The results of research on the methodology of G.F. Rozhkov

On the dynamogenetic diagram "E" – "A" (alpha-gamma) of G.F. Rozhkov (1978a), constructed for the samples of these deposits, the figurative points were concentrated on the right side of the diagram – in the field VII (the lower right part) (Rozhkov, 1978b), which can be characterized as coastal-marine and indicate the development of wave processes in shallow water and in the coastal-marine zone (Figure 13).

3.4. Determination of the genesis of rocks according to the composition of authigenic minerals

The material composition of rock lithotypes was determined by the classification (triangular) diagram of V.D. Shutov (1967) (Figure 14).

According to the rock-forming components, all rocks belong to the polymictic ones. In the diagram, they form a single field. All the allocated lithotypes are assigned to the arkoz group. This group includes actually arkoses and graywacke arkoses. The predominant clastic materials are quartz, less often feldspar, mica, chlorite are present. Arkoses accumulate in shallow water, where there is good water warming, plenty of oxygen, and the hydrodynamic regime is relatively calm. The association of authigenic minerals (kaolinite + chlorite + hydromica) testifies to the transitional conditions of sedimentation. Thus, the predominance of the clay component as kaolinite indicates a continental setting, but it should be noted that there are significant chlorite content and the presence of CCO, which speak of marine conditions (Reineck and Singh, 1980; Selley, 1978).

CONCLUSIONS:

In the course of the complex analysis of the features of the geological structure of sediments, a high degree of lateral and vertical heterogeneity of the rocks studied was established, which is due to the lithologic-facies zonality of the sedimentation basin and the cyclicity of sedimentation processes.

Analyzing the obtained results, it can be concluded that the conditions for the sedimentation of the VS_1 formation are characteristic of the coastal-marine facies complex.

It is established that the section of the VS_1 formation is formed by four main lithotypes of rocks. Formation of deposits occurred in the transition zone of shallow water with the influence of wave processes.

The presented materials are the geological base for carrying out more detailed research and geological exploration work.

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$$\mathrm{Xsr} = (\%16 + \%50 + \%84)/3, \quad (1)$$

$$S0 = \sqrt{(Q3/Q1)}\ , \quad (2)$$

$$\mathrm{A} = \frac{\%16+\%84-2*\%50}{2*(\%84+\%16)} + (\%5 + \%95 - 2 * \%50)/(2 * (\%95 - \%5)) \quad (3)$$

$$\mathrm{E} = (\%95 - \%5)\ /\ (2{,}44 * (\%75 - \%25)) \quad (4)$$

***Figure 1**. Sandstone fine-grained with scattered clayeyness*

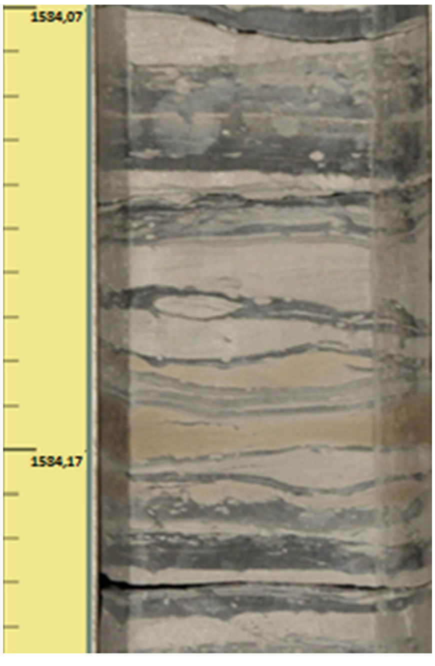

***Figure 2**. Typical interbedding of sandstone and siltstone*

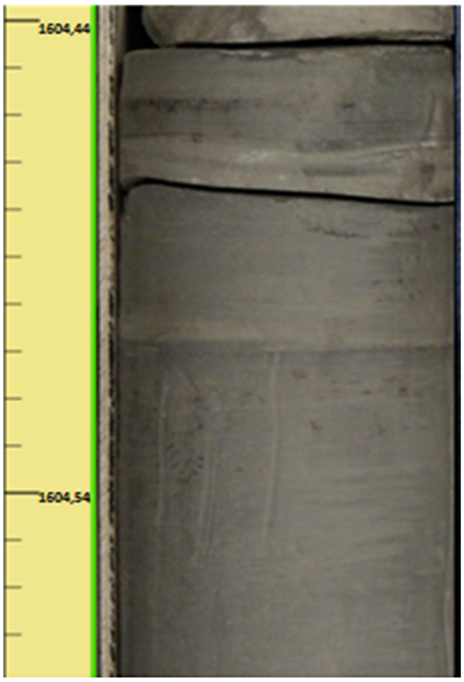

***Figure 3**. Argillite with a thin-layered texture*

***Figure 4**. Sandstone with carbonate cement*

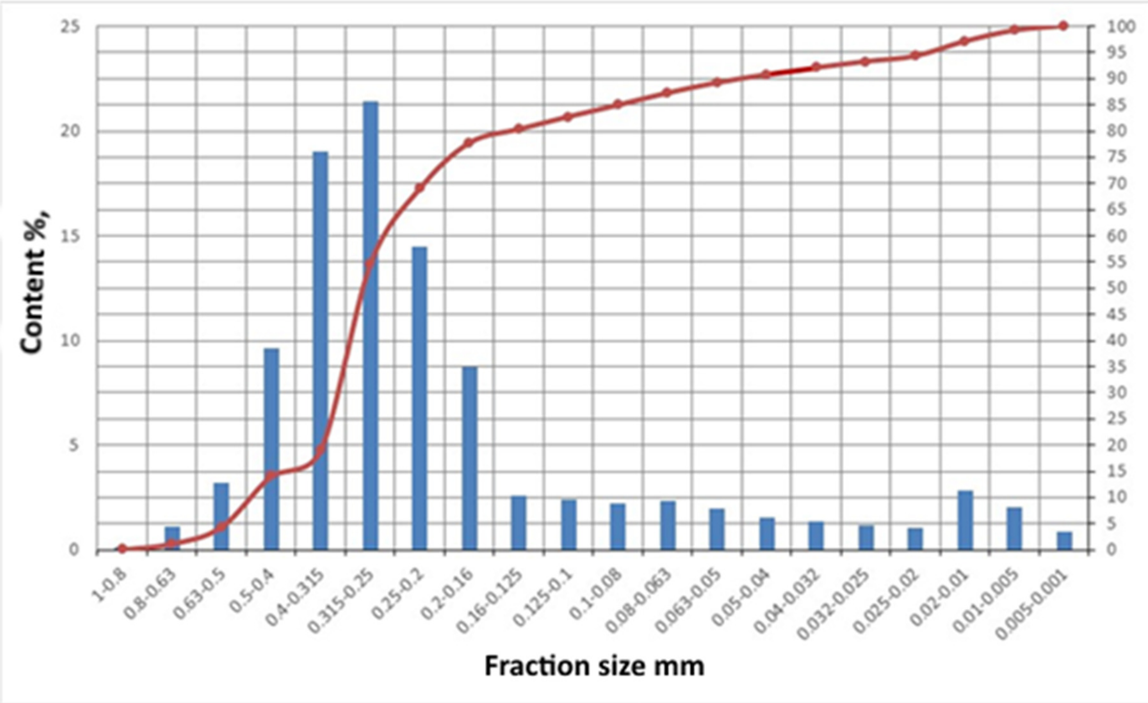

***Figure 5**. Grain distribution range by fractions and cumulative curve (sample no. 7)*

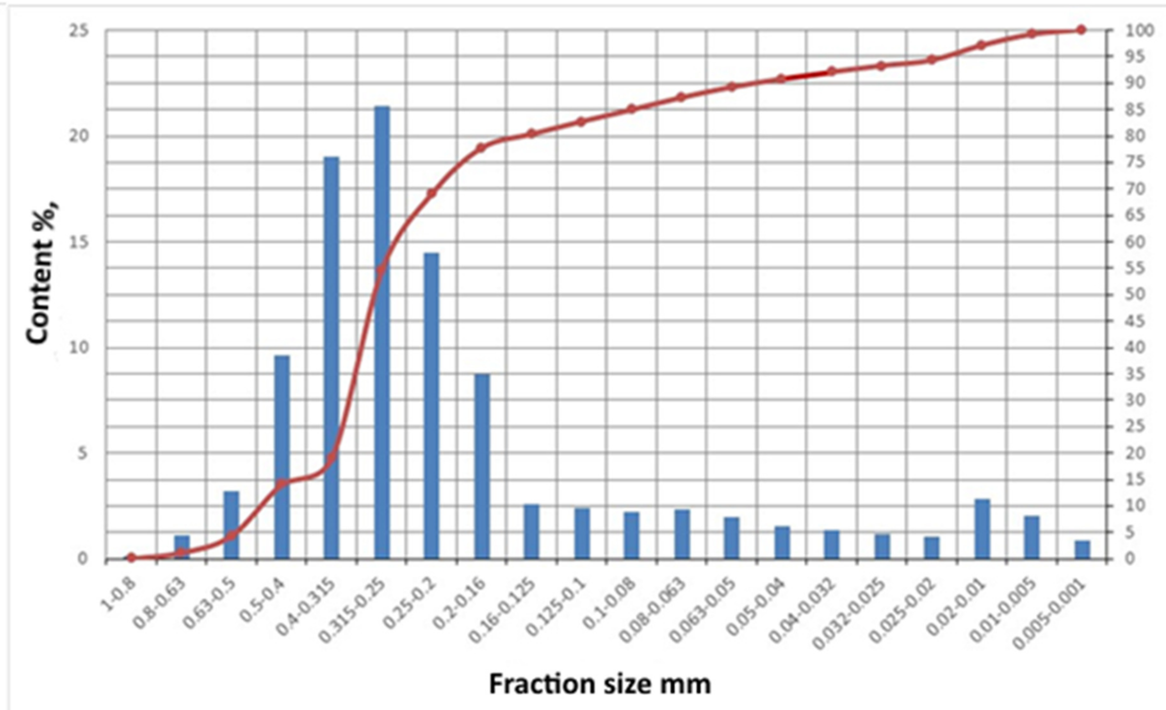

***Figure 6**. The polygon of grain distribution by fractions and the cumulative curve (sample No. 15)*

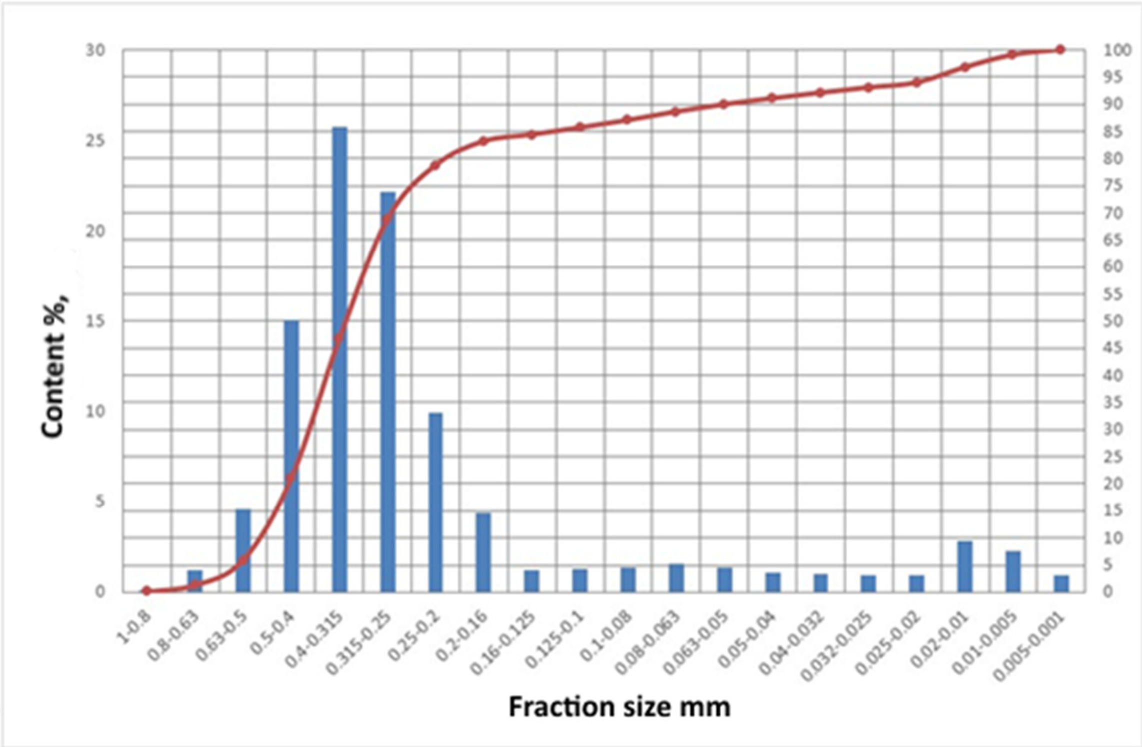

***Figure 7**. The polygon of grain distribution by fractions and the cumulative curve (sample No. 29)*

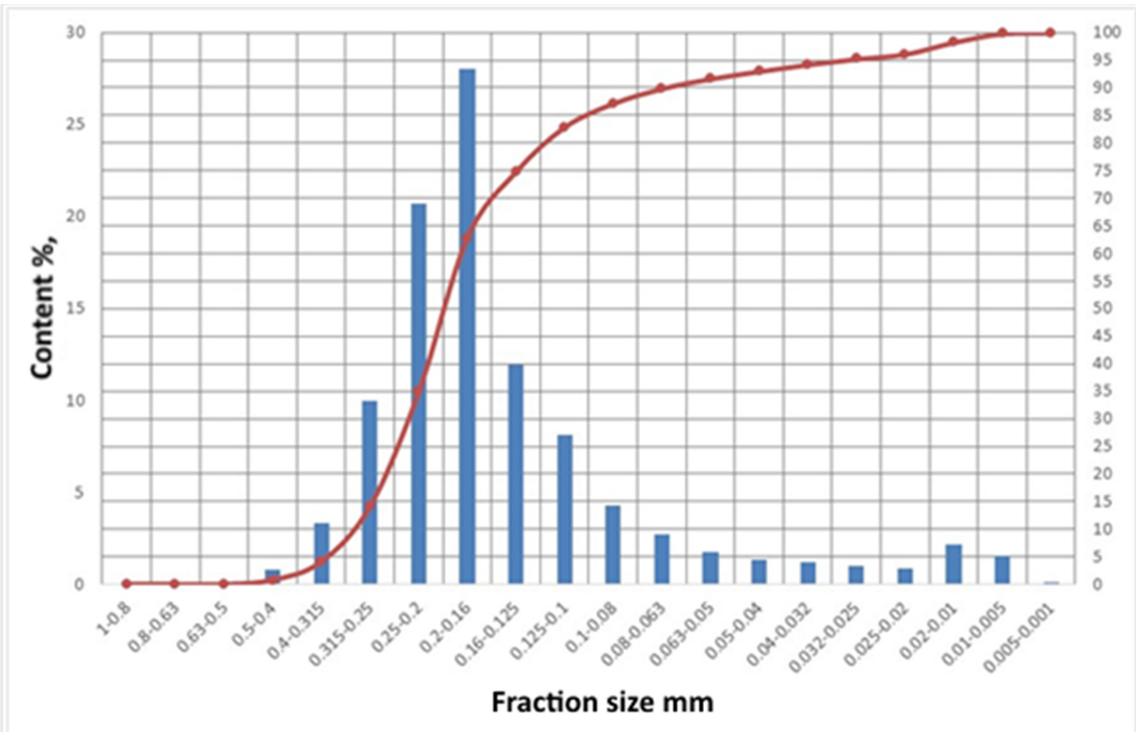

***Figure 8**. The polygon of grain distribution by fractions and the cumulative curve (sample No. 45)*

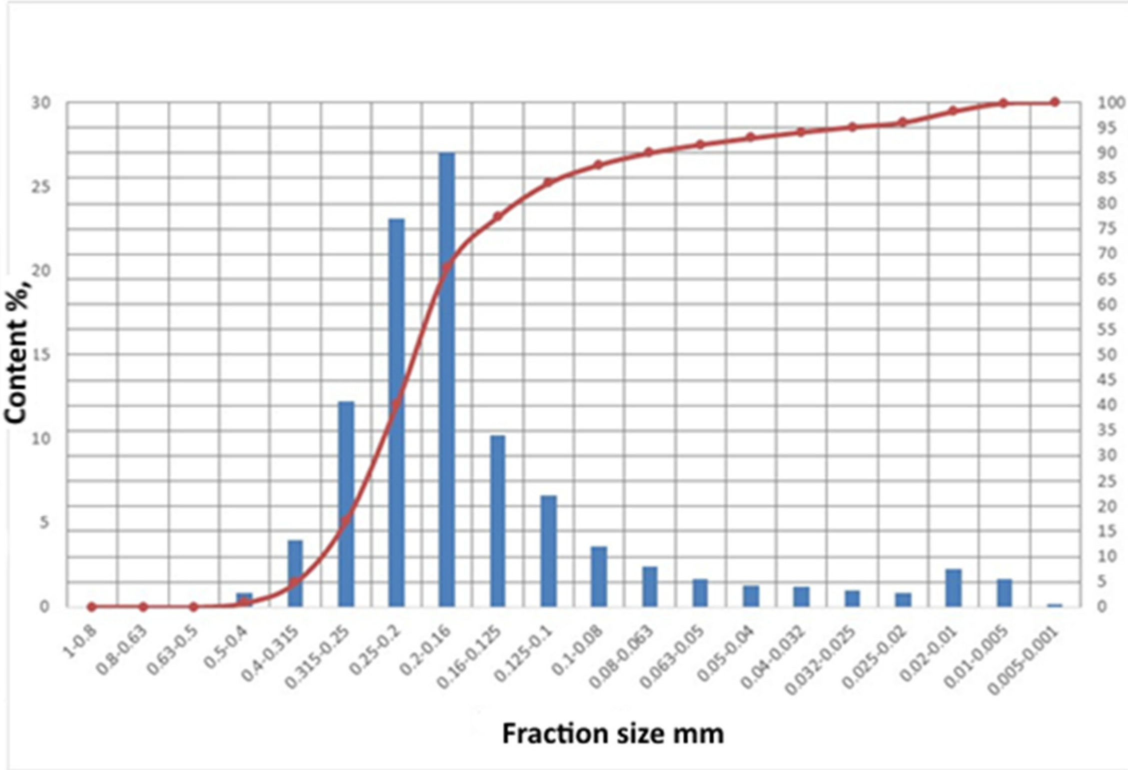

***Figure 9**. The polygon of grain distribution by fractions and the cumulative curve (sample No. 67)*

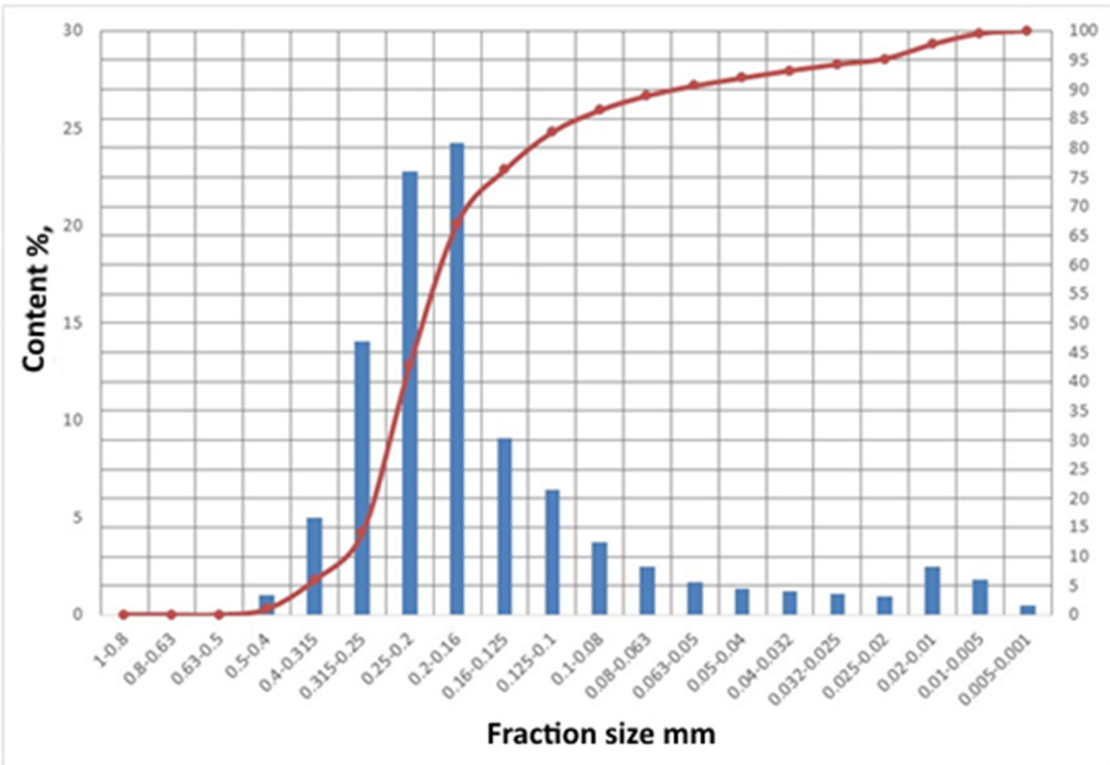

***Figure 10**. The polygon of grain distribution by fractions and the cumulative curve (sample No. 71)*

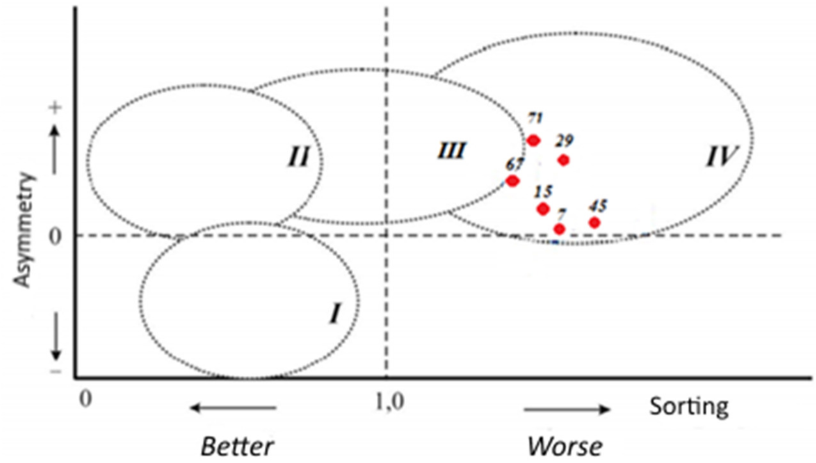

Figure 11. Dynamogenetic diagram of K. Bjorlykke: I – "beach sand"; II – "eolian"; III – "river sand"; IV – "turbidites"

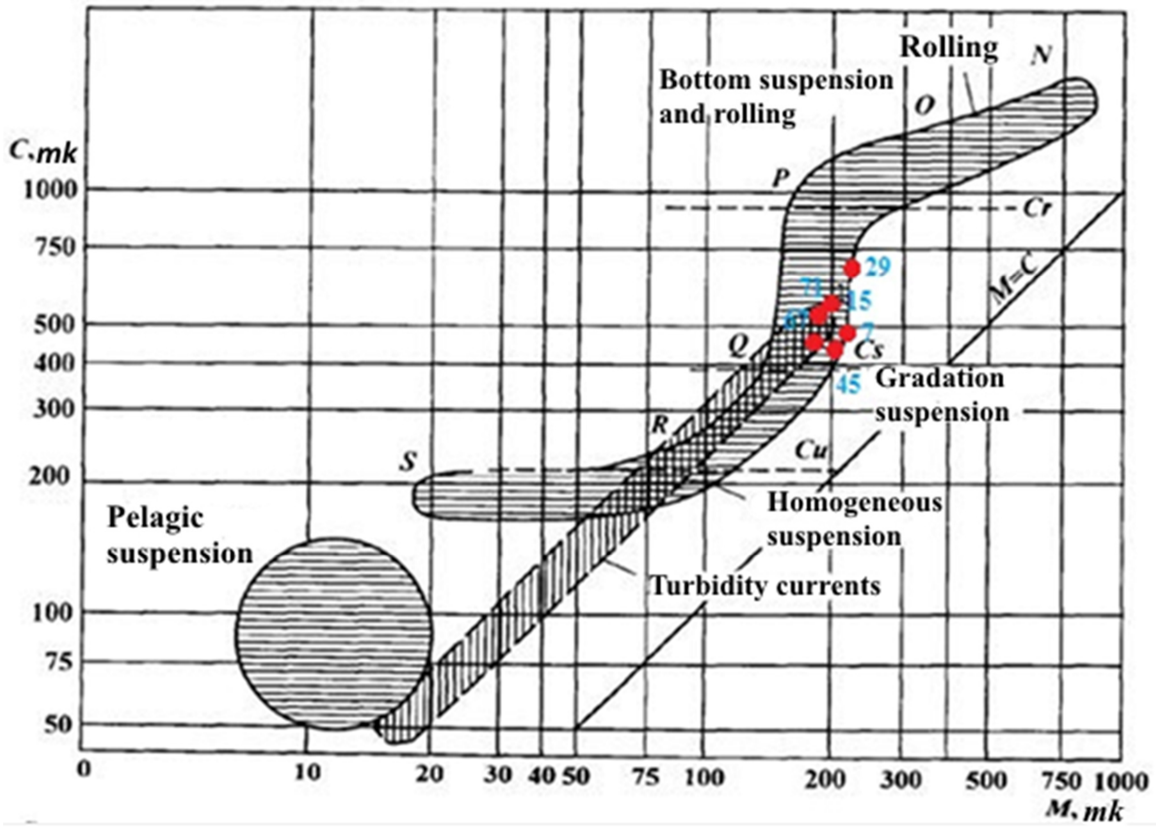

Figure 12. Diagram R.R. Passega for determining the ways of transporting detrital particles in an aquatic environment: S – floodplain far from the main channel; SR – secondary channel with low and medium flow; R – bank shaft; RQ is a secondary channel with a slow current; Q – protruding from the depth of the bar; PQ – filling the upper part of the dying bed; P – filling the bottom of the dying bed; PO – active filling the channel.

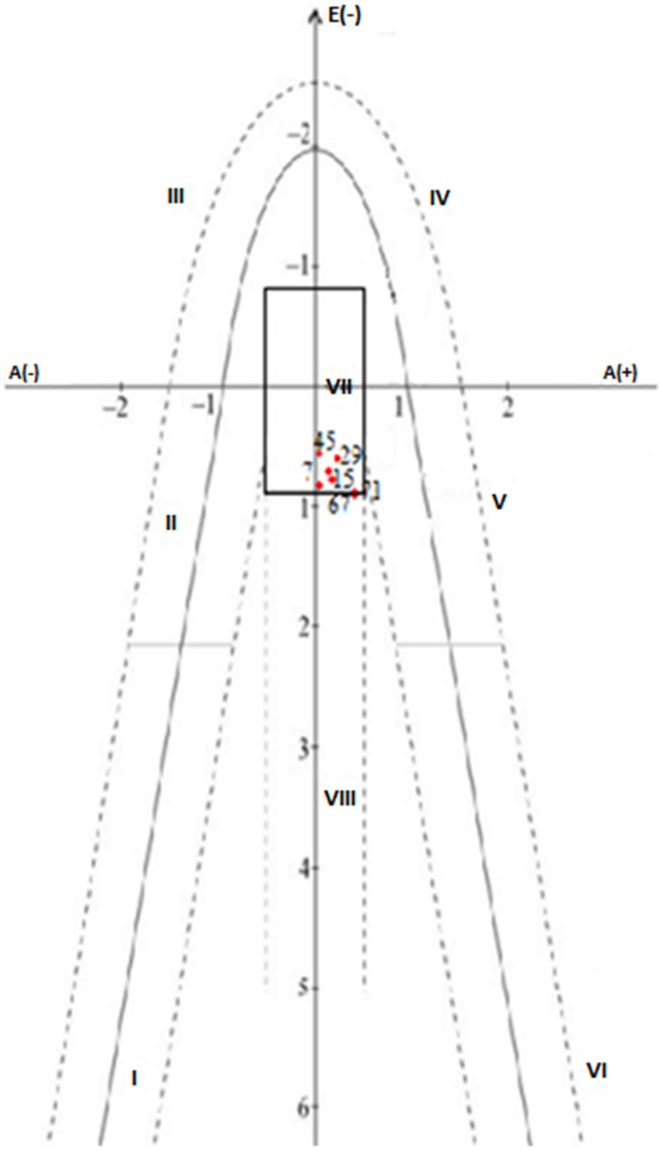

***Figure 13**. Dynamogenetic diagram of G.F. Rozhkov : I – stagnant conditions of sedimentation at the bottom of water areas of various depths (sea facies); II – bottom currents or turbidity currents (sea facies); III – weak mainly river currents (continental river facies); IV – strong river or coastal currents (continental, river or coastal-marine facies); V – wave output in shallow water, strong alongshore currents, rolling waves (coastal-marine facies, continental microfacies of the beaches of large flat rivers); VI – wave output in shallow water, strong wave rolling – the upper half of the site, eolian processing of sand of sea beaches – the lower half of the site (microfacies of coastal dunes).In general, the facies of the coast of the water areas near the coastline; VII – eolian processing of marine river sediments – the upper half of the rectangle. Continental facies of deserts (continental dunes). The lower right quarter of the rectangle is the wave processes in shallow water, the neutral coastline (coastal-marine facies); VIII – wave output in shallow water, a powerful nakat-surf. The speed of the dynamic rearrangement exceeds the speed of the introduction of detrital material (the coastal facies of huge open water areas).*

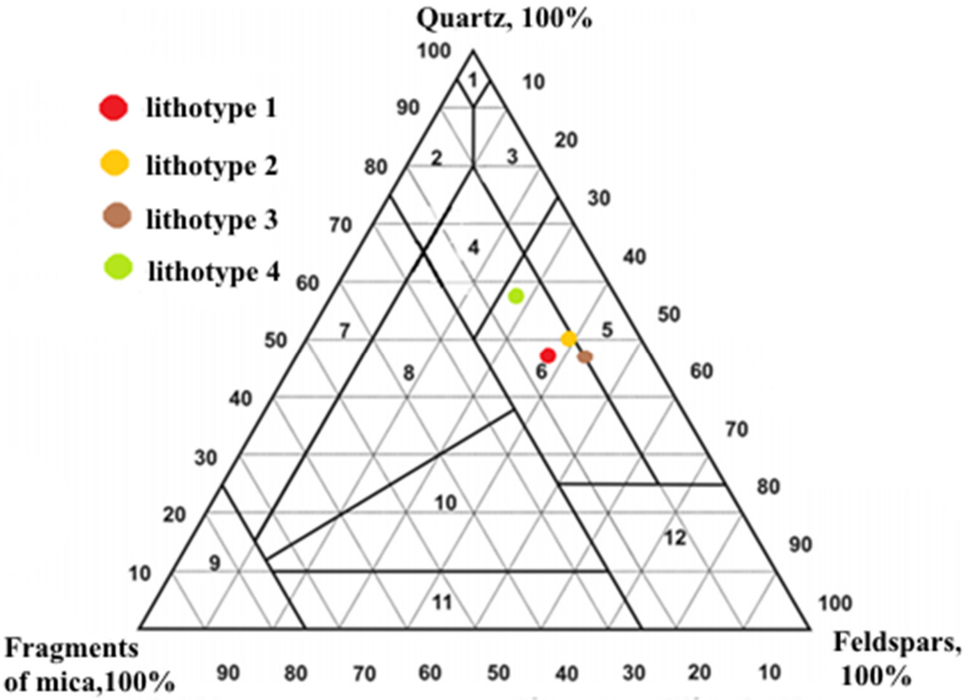

***Figure 14**. Classification diagram of V.D. Shutov with figurative points of the composition of the identified lithotypes of rocks [3]. Quartz group: 1. monomictic quartz sandstones; 2. silica-quartz sandstones; 3. feldspar-quartz sandstones; 3. Mesomictic quartz sandstones. Arkoz group: 5. actually arkoze; Greywacke arkoz. Greywack group: 7. Caucasian greywackes; 8. feldspar-quartz greywackes; 9. proper greywackes; 10. quartz in feldspar greywackes.12. The field is not of terrigenous origin.*

***Table 1**. The main granulometric characteristics of samples of core sampled from the deposits of the Vikulov suite*

Sample No.	Sampling depth, m	Lithological description	Xsr	S_0	Md, mm	A	E
7	1594.82	sandstone fine-grained	0.24	1.71	0.198	0.01	1.005
15	1600.52	sandstone fine-grained	0.27	1.7	0.197	0.191	0.811
29	1603.06	sandstone fine-grained	0.34	1.72	0.203	0.294	0.992
45	1607.54	sandstone fine-grained	0.21	1.83	0.201	0.09	0.945
67	1610.07	sandstone fine-grained	0.21	1.84	0.185	0.254	0.767
71	1611.27	sandstone fine-grained	0.21	1.87	0.178	0.592	1.090