Definition of facies conditions by granulometric analysis on the example of horizons JK_{2.5} in Em-Egovskoe field (Western Siberia)

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Abstract. The significance increase of recoverable oil reserves in reservoirs of deep horizons requires more detailed study of their formation conditions. Granulometric and mineralogical investigations of terrigenous sediments allow obtaining the basic ideas on their sedimentation conditions. In this case the combination of the existing methods enables to address some issues of facies analysis. The integrated investigations of the horizons JK_{2.5} of Tumensk formation in Em-Egovskoe area, Krasnoleninskoe field (208 samples) have been performed. Based on granulometric and mineralogical studies, the authors made the conclusion that the sediments studied had been formed within the estuary. The results of the study show that the sedimentation conditions may be different under the same dynamic accumulation conditions and similar particle granulometric distributions. The efficiency of facies prediction can be enhanced only through the integrated analysis.

1. Introduction
In recent years, the hydrocarbon deposits of deep horizons with complicated geological structure and ambiguous reservoir filtration-capacitive properties are the main sources of oil and gas reserves. Improving the efficiency of prospecting, exploration and development of the discussed hydrocarbon deposits requires qualitatively new geological modeling methods.

Economic feasibility of the development of such deposits is based on the reliability of reservoir extension forecast and analysis of formation conditions, affecting the choice of the technological development scheme. One of the methods in predicting structural features and spatial development of oil-bearing formation is facies analysis of its deposits, which enables to study a number of corresponding properties within each facies.

The granulometric studies are of great importance in facies analysis of sedimentary formations. As reported by many researchers, this is due to the fact that the peculiarities of clastic particle distribution to fractions indicate sedimentation environment in the paleogeographic sense (L. Rukhin, R. Folk, G. Friedman and others)\cite{1} or the features of sedimentation dynamic structure (P. Passega and others)\cite{1}.}

2. Methodology of lithofacies analysis
Many researchers, particularly L. Rukhin, B. Sakhu, F. Shepard, B. Greenwood, J. Klovan, R. Young and others, came to the conclusion that certain statistical characteristics of sediment fractional composition, as well as their different pairs cannot identify sedimentation environment \cite{1}. It is necessary to take into account that similar dynamic accumulation conditions and, of course, similar granulometric particle distribution may indicate to different environments. Therefore, the combination...
of granulometric data genetic interpretation techniques is required; it allows predicting more accurately the sedimentation environment.

For preliminary genetic classification of precipitation and granulometric rock characteristics it is recommended to apply the generalizations of Fyuhmbauer and Mueller where the environments are allocated to the level of facies groups – continental, marine, transition [2, 3].

In lithology, there are various ways to divide precipitation based on fractional composition and, also, to distinguish different facies – for example, genetic and dynamogenetic diagrams of L Rukhin, R Passegi, H Friedman, G Rozhkov and others.

One of the relatively simple diagrams has been developed by K Berlikke, which is based on the different sorting ratios and the asymmetry character of sand and silt rock fraction distribution. The study results have shown that coastal marine or lacustrine sand deposits have negative asymmetry, while river and aeolian have positive asymmetry and the mode of distribution is located in fine-grained fraction [4].

The most satisfactory results in determining the genesis of recent sediments were obtained by dynamogenetic diagrams of R Passegi and G Rozhkov. Despite the different approaches to determining sedimentation conditions, the results obtained in these two diagrams for aquatic sedimentation environment were basically similar [5].

The dynamic diagram C–M, developed by R Passegi, specifies transportation of clastic materials by particle rolling, saltation or as homogeneous or graded suspension. Large- and fine-grained fractions are transported independently. The analysis results of various precipitations in the diagram C–M form a complex configuration, which has been divided by points N–S into segments that correspond to certain conditions of sedimentation.

The dynamogenetic diagram of G Rozhkov is based on the principle of mechanical differentiation (different in intensity) of sand and silt particles in different facies. Naturally, this phenomenon is also associated with a variety of ways to transport different sized clastic particles and it is mainly determined by the energy levels of the transportation dynamic forces and sedimentation environment [5].

The authigenic minerals, which are indicators of certain sedimentation environments, are of great importance in genetic interpretation. For example, D Goldsmith and his colleagues defined the phase relations in the system Ca–Mg–Fe–Mn–CO₂, which helps to define the sedimentation conditions. Thus, pH environment influences calcite and dolomite sedimentation; whereas the formation of Fe and Mn carbonates is further dependent on the redox balance of the sedimentation environment. Therefore, they associate the cause of siderite formation with the environment typical to stagnant pools or areas subjected to tides and ebbs, as well as estuaries with high productivity of organic matter [6].

Thus, having analyzed the modern approaches to genesis determination based on particle size and mineralogical analyses, we can conclude that different sedimentation environments may have similar characteristics. The combination of the existing granulometric studies methods resolves some issues of facies analysis. In this paper, the authors propose a complex use of methods according to the following plan.

1. Generalized description of the environment by Furchtbauser and Muller [2, 3];
2. Definition of deposit genesis by sorting ratio and features of asymmetry (K Berlikke diagram);
3. Determination of sedimentation conditions by asymmetry and excess ratio (Rozhkov dynamogenetic diagram);
4. Identification of the way to transfer clastic particles in aqueous environment (R Passegigenetic diagram);
5. Authigenic mineral composition analysis in rocks.

In the case of such complex studies, each subsequent method clarifies the sedimentation conditions and it enables to determining the precipitation formation conditions more accurately.

The proposed method was tested on the upper-middle Jurassic sediments of Em-Egovsk area in Krasnoleninsk field (Western Siberia).
Basic productivity is associated with Tumensk formation horizons where reservoir rocks (horizons JK₂,₅) are represented by sand and silt varieties (variations) with thickness-dependent clay bands. There are fine-grained sandstones, silty with predominant sand (0.12-0.30 mm) and silt (0.05-0.10 mm) dimension.

Low reservoir properties of productive sandstones are defined by several reasons. The main one is probably a high degree of compactness and transformation by epigenetic processes. Wide development of authigenic and epigenetic carbonate minerals, primarily siderite, and their presence in pore space destroy significantly the reservoir properties of sandstones and, especially, of siltstones. High content of clay and fine silt fractions impacts negatively the reservoir properties in the reservoir rocks.

3. Granulometric and mineralogical analyses

The authors analysed the results of granulometric analysis of 208 samples from horizons JK₂,₅ Tumensk formation which were selected from 7 wells of Em-Egovsk field. The paper introduces the 1819 well results as a definite example.

The granulometric composition of the reservoir rock is determined by Ltd. "Sibgeotcentre" through two methods: transparent petrographic thin sections and mechanical sieve (up to 0.05 mm fraction), and decantation (finer fractions). It should be noted that if granulometric analysis of the samples taken from the Jurassic sediments is based on thin section data, it is more reliable than mechanical and decantation methods, as Jurassic sandy-silty rocks are well-sealed and firmly cemented that can be hardly separated by mechanical method.

As an initial step of graphical processing of the results, the authors built histograms of granulometric composition in order to study and to illustrate the changes of rock properties along the cross-section. Then, the cumulative curves were built. They are important both for graphic display of analytical data and determination of a set of parameters characterizing rock structure. The authors calculated the main granulometric characteristics in the following samples: average particle size ($X_{\text{average}}$), standard deviation (sorting coefficient $S_0$), asymmetry parameter (A), excess measure (E), median (Md). Let us consider as an example of the results obtained for samples from well № 1819 of Em-Egovsk field (table 1).

| № sample | Depth, m | Lithology | $X_{\text{average}}$ | $S_0$ | Md, mm | A   | E         | Effective porosity in cores, Kp, % | Bulk density, g/cm³ |
|----------|---------|-----------|---------------------|------|--------|-----|-----------|-----------------------------------|---------------------|
| 27       | 2259.65 | Silty clay| 0.08                | 1.85 | 0.088  | 0.024| 0.733    | 5.88                              | 2.585               |
| 38       | 2266.25 | Sandy siltstone | 0.11                | 1.40 | 0.110  | 0.165| 1.004    | 8.30                              | 2.503               |
| 39       | 2266.95 | Argillaceous siltstone | 0.10                | 1.46 | 0.093  | -0.102| 0.997    | 8.69                              | 2.468               |
| 40       | 2267.20 | Argillaceous siltstone | 0.09                | 1.53 | 0.095  | 0.143| 0.856    | 9.81                              | 2.470               |
| 41       | 2267.95 | Argillaceous siltstone | 0.09                | 1.53 | 0.098  | 0.193| 0.820    | 7.99                              | 2.521               |
| 42       | 2268.07 | Argillaceous siltstone | 0.08                | 1.58 | 0.090  | -0.001| 0.961    | 7.55                              | 2.553               |
| 43       | 2268.86 | Argillaceous siltstone | 0.09                | 1.55 | 0.090  | -0.007| 0.985    | 6.85                              | 2.550               |
| 45       | 2270.90 | Siderite-silty clay | -                   | -    | -      | -    | -        | 5.38                              | 2.651               |
Sorting coefficient ($S_0$) is determined by P. Trask formula – the ratio of the third quartile to the first [4]. According to the Trask classification, precipitations in the studied samples are mostly well-sorted. Asymmetry and excess were determined by Falk formula, using grain size with a certain percentage taken from the cumulative curves [5].

The next step is the data analysis obtained by the method described above. According to Furchtbauer and Muller generalizations, the studied rocks were mainly formed in river sedimentation environment (channel and riverine shallows) because sorting was mostly $> 1.2$ and asymmetry $< 1$.

The studied rocks refer to turbidities according to sorting and asymmetry ratio (by K. Berlikke).

At the same time, when speaking about turbidities, the method of their accumulation is understood in different ways: either as a result of shoreline moving and sedimentation depth changing occurred at relatively shelf shallow (less than 200 m) or as a result of sedimentation from turbidity currents in the bottom part and at the foot of continental underwater slope at a relative depth (1200 m or more) of the sedimentation basin [7]. Therefore, it is necessary to clarify precipitation genesis.

The next step is to build and analyze the dynamogenetic Rozhkov and Passegi diagrams (Figures 1, 2).

It follows from the analysis of point location on the diagram of G.F. Rozhkov that some samples are classified as marginal-marine facies (field VII, lower part), and other samples are classified as coastal facies of vast open areas (field VIII). In Passegi diagram the samples are classified within the area of river sediments (secondary channel).

Association of authigenic (kaolinite + siderite + pyrite) says for sedimentation environment transition. Thus, the predominance of clay component as kaolinite indicates the formation of the continental environment, but significant content of chlorite and mixed layered formations indicate the marine environment and this should be noted, as well. Significant content of siderite is an indicator of continental or coastal marine environment.

It is also necessary to draw attention to the presence of not only debris timber, leaf prints, root prints, plant prints, identifying continental sedimentation regime, but also oolitic limestone typical for shallow coastal areas with high flow turbulence [3], and rostrum of belemnite, the presence of which may be associated with their resedimentation under sea condition. This proves that transitional environment of sedimentation in which the complex of tidal plains and deltaic systems are singled out. Based on the structural features, the deltas are divided into tidal (estuarine), wave (blade) and river (retractable).

4. Conclusions

According to the proposed method, the sedimentation environment can be fully referred to the conditions typical for estuaries. It is the estuary that can explain such ambiguous results typical for different facies.

In general, estuary is a portion of the joint influence of the river and the sea, where the clastic material, on the one hand, is transported by the river and, on the other hand, it is transported from the sea by tidal currents and partly by rough sea currents. This is proved by coastal marine environment presented in Rozhkov diagram. Owing to this fact both plant roots and transported debris of belemnites are observed in sediments. It should be also noted that pelitic deposits (primarily clay) and sand, depending on the conditions, [8] mainly precipitate in estuaries. As shown in table 1, the interval studied is folded by siltstone.

Tidal and deltaic channels within tidal plains and estuaries form sedimentation environment similar to those in river channel conditions [8], which may explain the result obtained by Furchtbauer and Mueller generalizations as well as the availability of samples in the field of secondary channels in the genetic Passegi diagram.
Figure 1. Rozhkov dynamogenetic diagram (well № 1819 of Em-Egovsk field).

Figure 2. Passega genetic diagram to determine transportation ways of clastic particles in aqueous environment (well № 1819 of Em-Egovsk field).
Surface water often contains dissolved substances in the form of colloids. When penetrating marine basins, such colloids are destroyed with sea water which is electrolyte. Colloids are coagulated, and then they fall to the bottom, giving rise to marine sediments. Fe, Al, Mn hydroxides may be accumulated in the form of such colloidal chemogenic precipitation. Thus, iron hydroxide colloids are the most unstable. They are coagulated just at the river confluence into the sea [9]. This explains the presence of siderite in the samples.

Another data analysis result is the classification of rocks as turbidities according to Berlikke diagram. Considering the fact that material sedimentation in the estuary is strongly influenced by tides, the currents associated with the tides can be characterized by different velocities. In general, tidal current velocity decreases from output to the top of estuary. Typically, the power of flows associated with ebb is higher than the power of tidal currents. The tidies form periodically varying sedimentation conditions [8]. In the case of two different water masses contact, the water mass of higher density tends to flow and to spread below the less dense one. Such density flows are well known in the ocean, where they are caused by the difference in temperature and salinity. In a similar way, turbid and suspended-enriched layers of high density can descend and move below pure water with lower density [3]. Therefore, lateral and vertical mixing of water occurs in estuaries [10], i.e. the collision of two divergent dynamic flows and precipitations, which are close to turbidity characteristics.

Thus, based on the analysis results obtained by determining the origin according to granulometric and mineralogical studies, it is possible to conclude that the deposits studied were formed within the estuary.

It should be noted that all the described methods in determining precipitation origin do not provide a clear description of facies sedimentation environment. They allow dividing precipitation into those formed in the saltwater pool, in the continent or in the transition zone. For more accurate definition of facies, it is necessary to carry out a complex study of the area by selecting appropriate sedimentation model based on not only on granulometric analysis, but also on the additional data obtained by core sampling (faunal, petrographic, texture and etc.), well logging (facies electrometric analysis) and well testing (filtration-capacitive).

5. References

[1] Romanovsky S I 1977 Sedimentological basis of lithology (Leningrad: Nedra) p 408
[2] Krasheninnikov G F, Volkova A N and Ivanova N V 1988 Facies lithology with the basics: guide to laboratory studies (Moscow: Moscow State University Press) p 214
[3] Reineck H-E and Singh I B 1981 Depositional sedimentary environments (with reference to terrigenous clastics) (Moscow: Nedra) p 439
[4] Kuznetsov V G 2007 Lithology. Sedimentary rocks and their study: textbook for universities (Moscow: Nedra-Business Centers) p 511
[5] Grossgeim V A, Beskrovnaya O V, Gerashchenko I L and other 1984 Methods of paleogeographic reconstructions (in the search for oil and gas) (Leningrad: Nedra) p 271
[6] Pettidzhon F, Potter M and Seaver R 1976 Sands and sandstones (Moscow: Mir) p 536
[7] Markiewicz P V 2004 "Turbidities" and "flysch" without explanation – the dangerous terms Bulletin of the Far Eastern Branch of the Russian Academy of Sciences 4 95–105
[8] Gradzinsky R, Kostetskaya A, Radomski A and Unrug P 1980 Sedimentology (Moscow: Nedra) p 640
[9] Bakumenko I T 2001 Mineralizing processes: textbook (Novosibirsk: Novosibirsk State University Press) p 80
[10] Leeder M R 1986 Sedimentology. Processes and Products (Moscow: Mir) p 439