Microstructural analysis of quartz grains in Vasyugan suite sandstones of layer $U_1^{1-2}$ in Kazanskoe deposit

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Abstract. Microstructural analysis of quartz grains in sandstones revealed preferred directions which define and influence porosity and permeability anisotropy in oil and gas reservoirs. In this research, we investigated the Upper Jurassic sandstone reservoir sediments from 14 wells in Kazanskoe field. The authors studied: the orientation of elongated quartz grains, and intergranular fracture within grains, as well as the pore space in oriented thin sections of sandstones. The analysis of elongated quartz grains in the bedding plane showed three main types of preferred directions in quartz grain orientation along different axes in sandstone reservoirs. Obtained results allow identifying a variability of facies and dynamic depositional environment for Upper Jurassic sandstone formation. Subsequently, these results can be used in field modeling, as well as pattern optimization of injection and production wells.

1. Introduction
Kazanskoe oil and gas field is located in the southeastern part of Tomsk region, were the commercial hydrocarbon potential is associated with Upper Jurassic terrigenous sediments. It is necessary to solve a number of issues for the successful development of this field. First of all, the characteristic features of sandstone bodies - reservoir distribution, as well as, their formation conditions and areas including the reservoir properties should be identified. And secondly, to study the reservoir anisotropy. It should be noted that the anisotropy factor is fundamental in updating the essential geological structural alteration of oil and gas field reservoir rocks. Numerous publications of the last few years have highlighted such a fact as the intrinsic heterogeneity of horizontal permeability [1,2,3,4].

In recent years, an increasing number of geologists use microstructural analysis of rock forming minerals as an optical method for studying sediments, which allows obtaining information about the dynamic mode of their formation [5,6,7].

2. Data Setting
The investigations of the sandstone layer was based on the sediment material from 14 wells of the Kazanskoe oil field. More than 70 meters of core samples were described, 16 rock samples of thin reservoir sandstone sections from $U_1^{1-2}$ layer were studied in details. The core sampling depth embraced 2481.3 –2511.2m. Paleomagnetic oriented core samples and oriented thin sections were used. The results of the sampling examination can be used in field modeling, existing anisotropy in reservoirs benefits the pattern optimization of injection and production wells, as well as, monitoring enhanced oil recovery operations. The sampling examination involved several stages which are described below.
3. Morphological analysis of quartz grains in thin sections

3.1 Instrument and materials. Morphological analysis was performed using north-oriented thin sections. Measurements included MWD dimension of elongated quartz grains in sandstones. These measurements embraced elongated grains to the northern direction. The number of measurements required to describe the characteristics of orientation distribution involved 100-120 grains in thin sections. Besides, these investigations, obtained on the microscope, we measured the orientation distribution was observed on thin section photos, where the minimum number of measurements included 200-300 grains and further data processing in ArcGIS and Grapher 9 programs and charting. This suggested method of measuring and interpreting grain orientation allows to simplify the exceedingly enormous amount of obtained numerical data.

The entire process of measuring and calculation was divided into several stages:
1. taking photos of oriented thin sections in an interval, processing and grouping these photos in CorelDRAWX5 program.
2. plotting preferred directions of elongated quartz grain orientation by ArcMap program.
3. recalculate azimuth directions by a special module for ArcInfo program.
4. plotting rose-diagrams based on azimuth data and further visualization with “StereoSN” and Grapher 9 programs.

3.2 Data processing Statistically processed measurement results are shown on a pie chart. Based on calculations of the linear orientation of quartz grains semicircular arc data was obtained (from 0 to 180˚), which, in its turn, proved the fact that the second semicircular is symmetrical to the first one. For data visualization and comparison of elongated quartz grain orientation with other data, the petrostructural program Grapher 9 was applied on the basis of which rose diagrams were plotted and lines for preferred elongated quartz grains L1, L2, L3 and were drawn (figure 1).

![Figure 1](image)

**Figure 1.** Rose-diagrams plotted according to the orientation of elongated quartz grains in sandstones from U1, U2 layer in well № 14 Kazansko field. L1, L2, L3 - preferred direction of elongated quartz grains in thin sections.

3.3 Types of orientation for elongated quartz grains

Analysis of quartz grains according to their elongation in the bedding plane has revealed three main types of preferred directions for major axis orientation of quartz grains in investigated sandstones. The first orientation type is predominant and is characterized two directions (L1, L2) in elongated quartz grains orientations, the first of which L1 is dominant. The second type can be identified by the presence of one maximum longitudinal orientation of the grains L1 with slightly developed transverse orientations. The third type of orientation is much rarer the first two and is characterized by polymodal distribution (L1, L2, L3).

The first type with bimodal orientation L1 and L2 is typical for most of the investigated thin sections. In sample 14 / 1 (figure 1) there are two preferred directions of elongation for grains, one of which is in the subordinate position. The intensity of statistical maximum is 13-16% or even more.
The angle between the peaks varies from 40° to 80°. Such orientation may be related to the coastal (internal) zone of a water basin, which is characterized by constant sea wave action. Waves lapping on the shore at an angle transport sandy material obliquely to the shoreline, while the reverse flushing movement is perpendicular to the coast. Longitudinal orientation is typical for grains with flat and elongated shapes, while cylindrical and spindle grains due to their mobile dislocation by rolling occupy cross position in the water flow. This is reflected in the diagrams as a minor peak (figure 1).

A distinctive feature of the second type is one or two single-order elongation directions - L₁ which can be seen in sample 14/15 (Figure 1). The intensity of statistical maximum is quite high - 15-17%. Angle between the principal maximum is fixed within the limits of 40°. In this case we can conclude that preferred arrangement of quartz grains is consistent to the direction of fast water flow - the sharp grain end is oriented to the flow direction. A similar pattern of distribution is possible when moderate or strong driving environment influences the sediments, for example, longshore currents. It should be noted that an important factor is that the orientation path has different flow heterogeneity. In case of superimposed factors there could be a more complicated orientation image. However, the grain arrangement is still regular.

The third type of grain orientations in sandstones is characterized by spindly located elongated quartz grains in thin sections - L₁, L₂, L₃, which can be seen in sample 14/8 (figure 1). It is impossible to identify the predominant direction. Accordingly, we can assume that sediment resuspension has influenced the formation of such a grain distribution pattern. Such processes form turbidites. In this case, it is possible after transportation and transformation of clastics into sediments have not been lithified yet, because of a large number of plastic clay material.

3.4 Subderivations Rose-diagram analysis of preferred distribution for elongated quartz grains in investigated rocks showed the predominance of two distinct sub-orthogonal directions in quartz grain orientation, i.e. north-east and north-west. Each type of sediment environment can be characterized by a specific type of quartz grain orientation in sandstones. Obtained data in combination with other characteristics of sedimentary rocks (textural and structural features, particle size distribution) can be used to determine depositional facies. As a result of our further investigation – study of microstructural quartz patterns - previously supposed and above-described mechanisms in the formation of linear orientation in elongated grains was proved.

4. Microstructural analysis of optical axes in quartz grains

4.1 Methodology and methods Microstructural analysis is based on the measurement of the optical axes in quartz grains, which describes the internal structure of the rocks in geometrical terms. The research method included determining the optical axis coordinates in quartz grains. To find the spatial orientation of the optical axis it is necessary to make two measurements in Stolik Fedorova (special attachment on the microscope determining the position of the crystallographic axes in minerals): strike azimuth and angle of the optical axis. The selection included 100-150 measurements of quartz grains in thin sections. After statistical processing by applying “StereoSN” orientation elements had the form of a pie chart, by which the geological interpretation was given. By analyzing the pattern diagram of the optical axis we can indicate the presence of orientation in the grains or its absence. Quartz optical axis are located at a higher position in the grain elongation. During the investigation it was noted that a significant part of the optical axes projections in quartz grains are located in the rock bedding plane with deviations in the range of 5-25°.

Types of optical axes orientation. Petrostructural analysis of quartz grains in sandstones allows identifying three types of optical axes orientations (figure 2).

Type 1 is characterized by the presence of two concentration zones: most of the optical axes are scattered conically in the zone around linearity L₁ with a radius of 35-40°; the maximum of density in the belt up to 8%. This type of optical axes orientation is typical for tidal zone at the seaside (figure 2 – sample 14/10).
Type 2 is characterized by two maxima in the outputs of the optical axes, which clearly has one circular zone concentration of a small circle and linearity L₂, located subnormal to L₁. Maximum of density reaches 11%. A similar pattern orientation can be formed in the case of coeffect of tidal and longshore currents (figure 2 – sample 14/1).

Type 3 is difficult for interpretation; however, we can note the pattern of a small circle for optical axes - belt type chart. Such a pattern appears in a mobile depositional environment with typical currents, which have alternating direction, whereby there is no preferred direction in grains orientation. Perhaps, postsedimentary (diagenesis, katagenesis) processes, which occur in sediments after their lithification, had a significant influence on the formation of this pattern (figure 2 - sample 14/9).

Figure 2. Diagrams with quartz optical emergences of axes (top row) and rose-diagrams with orientation of elongated quartz grains (bottom row) in sandstones from Kazanskoe deposit.

5. Accompanying investigations
5.1 The spatial orientation of the fractures and pores in sandstones Fractures in quartz grains and location (orientation) of pores in sandstones have also been studied in oriented thin sections in which orientation of elongated quartz grains and the optical emergences of axes in quartz have already been defined.

5.2 Comparison of petrostructural and petrophysical data Directions of preferred orientation for elongated grain material coincide with the directions of cataclase fractures in quartz grains in combination with the main axis of the magnetic anisotropy ellipsoid. The main direction of the orientation elements in the rocks is defined as north-east with a subordinate north-western direction (figure 3).
Figure 3. Rose-diagrams showing comparison of magnetic anisotropy ellipsoid and main directions of orientation elements in sandstones.

6. Interpretation of the results
Dynamic and facies conditions of reservoir U₁₁-2 formation in Kazanskoe field depend on sand-clastic sediment with numerous pore spaces, which was formed from medium-grained clastic material at the early stage of sediment accumulation process.

Shelf aqueous medium promoted the preferred orientations pattern process which is defined wave-cut character and longshore currents. At the time of sedimentation wave flow velocity can be defined as moderately strong and according to the morphological and microstructural analysis tracked north-easterly to the shoreline. Extension of pores and pore channels in sandstones coincides with the direction of elongation in quartz grains. In the same direction the largest number of fractures in the terrigenous cataclase material of sandstones was recorded, showing simultaneous development of additional directions of grains fragmentation.

7. Conclusion
Integrated petrophysical and petrostructural studies revealed that sand layer has a spatial anisotropy of reservoir properties. Direction of spatial orientation in elongated quartz is well-matched with the anisotropy magnetic properties of rocks and orientation of cracks and pores in the sandstones.

Spatial orientation of grains associated with the hydrodynamic features of the clastic reservoirs formation determines the structure of the porous matrix and the anisotropy of its filtration characteristics.

According to the microstructural analysis they have a north-east direction to the coastline, which is consistent with the proposed model of Kazanskoe deposit where there are facies with bar sedimentary structure.

Methodology developed by the authors included lithological and petrophysical investigations to predict: anisotropy in sediment rocks with high permeability and reservoir properties. It can also be used to study sedimentary rocks and for the modeling of hydrocarbon deposits.

References

[1] Du J and Wong R 2002 Stress-induced Permeability Anisotropy in Fractured Reservoir paper SPE 79019 presented at the SPE International Thermal Operations and Heavy Oil Symposium and International Horizontal Well Technology Conference, Calgary, Alberta, Canada, 4-7 November

[2] Sahin A, Menouar, Ali A and Saner S 2003 Patterns of Variation of Permeability Anisotropy in a Carbonate Reservoir paper SPE 81472 presented at the Middle East Oil Show (Bahrain 9-12 June) p 12
[3] Hansen C E and Fanchi J R 2002 Producer/Injector Ratio: The Key to Understanding Pattern Flow Performance and Optimizing Waterflood Design *SPE 75140 presented at the SPE/DOE Improved Oil Recovery Symposium, Tulsa, Oklahoma*, 13-17 April, p 12

[4] Schönh J H, Georgi D T and Fanini O 2003 Imparting Directional Dependence on Log-Derived Permeability *SPE Reservoir Evaluation & Engineering* 6/1 48 – 86

[5] Baas J H, Hailwood E A, McCaffrey W D, Kay M and Jones R 2007 Directional petrological characterisation of deep-marine sandstones using grain fabric and permeability anisotropy: Methodologies, theory, application and suggestions for integration *Earth-Science Reviews* 82 (1–2) 101–142

[6] Ketcham R 2005 Three-dimensional grain fabric measurements using high-resolution X-ray computed tomography *Journal of Structural Geology* 27 1217–1228

[7] Merkulov V and Krasnoshchekova L 2014 Estimation of influence oil and gas reservoirs filtration anisotropy in the modeling field *J. Gas industry* 3/703 22–27