Changes in composition and pore space of sand rocks in the oil water contact zone (section YU$_1$ $^{3-4}$, Klyuchevskaya area, Tomsk region)

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Changes in composition and pore space of sand rocks in the oil water contact zone (section $YU_1^{3\text{-}4}$, Klyuchevskaya area, Tomsk region)

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Abstract. The article provides an analysis of specific features in changes of rocks in the oil water contact zone. The object of study is the formation $YU_1^{3\text{-}4}$ (J_3o_1) of Klyuchevskaya oil deposit (West Siberian oil-gas province, Tomsk region). The research data allow the authors to determine vertical zoning of the surface structure and identify the following zones: oil saturation (weak alteration), bitumen-content dissolution, non-bitumen-content dissolution, cementation, including rocks not affected by hydrocarbon deposit. The rocks under investigation are characterized by different changes in composition, pore space, as well as reservoir filtration and volumetric parameters. Detection of irregularity in distribution of void-pore space in oil-water contact zones is of great practical importance. It helps to avoid the errors in differential pressure drawdown and explain the origin of low-resistivity collectors.

1. Introduction
The goal of research is to study the main character of changes in void-pore spaces and composition of terrigenous reservoir rocks in the oil water contact zone (OWC zone) on the basis of section $YU_1^{3\text{-}4}$, Upper-Jurassic producing horizon YU_1, Klyuchevskaya area, 207 Well (Tomsk region, West Siberian oil-gas province).

2. Background
The processes connected with rock alteration during their conversion into hydrocarbons in the oil-water contact (OWC) zone was the discussion topic for many researchers, among which were many Russian [4, 5, 9] and foreign [1–3, 7, 10] authors and the author of the paper [6]. Due to mass exchange, the trap at the water – oil contact zone is not completely filled with oil and hydrocarbons are located at the top, while water is displaced to the bottom. Oil-water contact is the intensive alteration zone of oil, porous water and country rock where the reservoir during long – term OWC formation acquires a zonal structure.

3. Research Methods
The research focuses on sandstone rocks in colored thin sections, when studied in transmitted and polarized light. For this purpose, the microscope Polam 213 was used. The researchers applied X-ray

phase analysis to determine mineral composition of the cement. Laboratory data on porosity and permeability were used. The researchers compared the sandstone rocks with the identical median diameters to reduce the influence of sedimentogenic factors.

4. Object

Sandstone rocks in the oil water contact zone, section YU_1^{3-4} (J_3o_1), are located in the low part of the Upper Jurassic producing horizon YU_1, Upper Vasyugan Subsuite (Klyuchevskaya oil deposit, West Siberian oil-gas province, Tomsk region). The formation under study is located above marine clayey deposits of Lower Vasyugan Subsuite (J_3c_3) and related to regressive longshore bars [8]. The formation is in depths ranged from 2693.95 to 2708.3 m based on the analysis data from the Well No. 207 (Figure 1). Sandstones have feldspar-quartz composition with insignificant amount of clastics (cilica rocks, average and acid effusive rocks, pegmatites) and minerals (mica, chlorite). The cement is composed of clay minerals (kaolinite, chlorite, illite), carbonates (calcium, siderite), quartz, and pyrite.
The degree of sandstone conversion is related to average catagenesis.

5. Key findings

The research data allow the authors to determine vertical zoning of the surface structure and identify the following zones: I – oil saturation (weak alteration), II – bitumen-content dissolution, III – non-bitumen-content dissolution, IV – cementation, V – including rocks not affected by hydrocarbon deposit (Fig. 1).
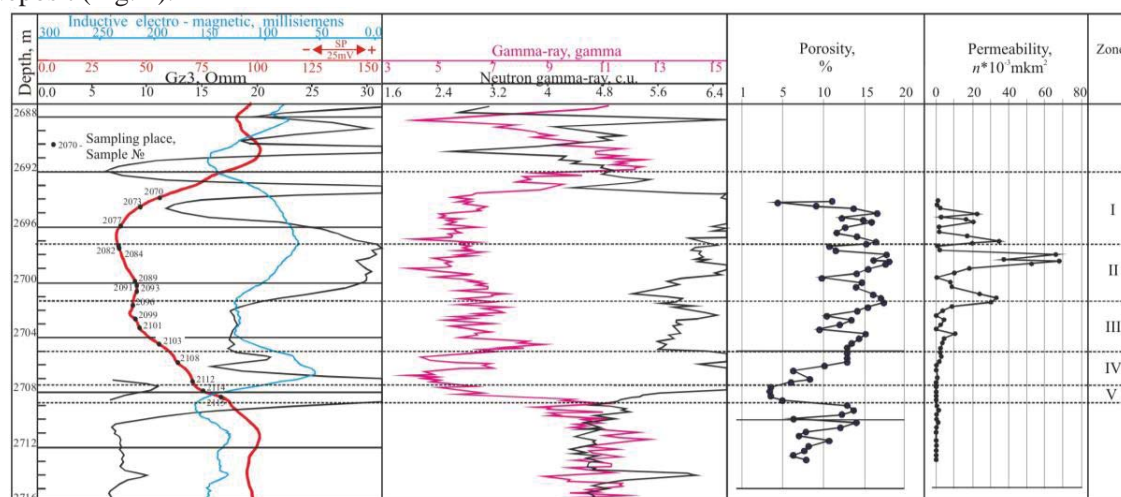
Figure 1. Vertical zoning of section YU_1^{3-4}. Klyuchevskaya area, Well No. 207

In *oil saturation (weak alteration) zone* (2692.0–2697.2 m) the sandstones contain significantly high component integrity, with weak corroded quartz grains, sometimes regenerated. Potassium feldspar and plagioclase either remain unchanged or undergo pellitization and sericitization along the cleavage fractures and grain edges. Cement has polymineral chlorite-hydromica-kaolinite composition, sometimes with compound impurities, such as hydromica-montmorillonite, including siderite, pyrite, rare dispersed relict calcite and ferriferous dolomite. Recrystallization of cement components is non-uniform, having selective, spotty features, where pelitomorphic mineral modifications are adjacent to micro-fine crystallized minerals. Kaolinite is pelite (initial cement) non-uniform fine- microcrystallized (in mica) – up to 0.05 mm and uniform microcrystallized (secondary cement) – 0.001mm in voids modifications. Capacity space in oil-containing sandstones include: primary residual sedimentogenic intergranular voids; secondary dissolution voids: micro-cavities on the fragment surfaces; intragranular voids; intercrystalline voids. Intergranular voids formed from several grain contours are predominate in

the sandstones of this zone. Void walls are even or irregular. In regenerated sections with weak dissolved fragments the intergranular void walls show distinct relative even surfaces and vice versa, in sections with the dissolved fragments, the void walls show irregular micro-cavernous surface. Intragranular voids in oil-saturated sandstones are insignificant; they are confined to effusive feldspar fragments. Intragranular porosity includes fracture voids of catagenesis compaction and, besides, the following: in plagioclase – slit-like voids along cleavage and twin seams; in kalifeldspath – regular, often isometric voids along perthite growths; in clastics (silic rocks, effusive) – irregular cavity voids with sinous boundaries, sometimes forming thin cellular patterns. Micro-cavernous dissolution voids form separate areas on the fragment surfaces. Such voids in feldspar are found in the altered grains or on the end-parts of prismatic fragments, where lateral prism face surface shows no traces of dissolution. Combination of surface dissolution in several sections and regeneration in adjacent grain sections or contacting enriched quartz grains are found in quartz grains, as well as, acid effusive and flinty rock fragments. Intercrystalline micro-voids are formed in recrystallization sections during primary cement kaolinitization or muscovite. They are located between kaolinite crystals. Due to confined kaolinitization in saturation zone and weak kaolinite recrystallization, these void types have limited and irregular distribution. Thus, the specific features of void-pore space in oil-saturated zone are the following: intergranular voids predominace, weak dissolution resulting in even void wall surface.

In *bitumen-content dissolution zone* (2697.2–2701.2 m) formed in the environment containing oil and water, the dissolution of grains as well as the feldspar pelitization and sericitization is increased, kaolinite cement is crystallized, the bitumen and pyrite are formed. Void space in sandstones from this zone, as in oil-saturated sandstones include combination of intergranular, intragranular, micro-cavernous voids on the fragment surfaces and intercrystalline voids, however, the relation between different void types and their peculiarities significantly change. Furthermore, secondary dissolution voids as surface and intergranular voids are widely developed. The following factors were determined: intergranular void size and connectivity degree increase due to fragment and primary cement dissolution; most grains in sandstones from this zone show intensive developed surface micro-cavity, which in its turn, significantly complicates not only void wall surface, but also the intergranular void configuration itself; not only does the number of intragranular voids increase, but also their sizes. Often surface voids transform into intragranular voids, and these on their turn, merge together, while remaining relic cellular grains (in this case, feldspar) are practically dissolved; significantly increases the role of intercrystalline voids due to mass kaolinitization [5, 6] of primary kaolinite-chlorite-hydromica cement and formation of monomineral coarse-flaky (0.06–0.1 mm) aggregates from tabular kaolinite grains with complete tricline lattice. Intercrystalline voids (size 0.01–0.02 mm) have relative uniform distribution. Intergranular voids, micro-voids on inside and surface grain and intercrystalline voids form uniform associated void-pore space which is partially or completely filled with oxidized or pyrite bitumen. Bitumen forms films on the rock fragments, fills small voids and micro-voids in kaolinite cement, covers large void walls and completely seals small intergranular voids.

Newly formed void space structures show significant increase of filter-capacity rock properties, such as: porosity increase up to 15.4–17.6 %, permeability –up to 33.08–52.68·10^{-3} mkm^2.

In non-bitumen-content dissolution zone (2701.2–2705.0 m) the sandstone composition transformation results in further substitution of pelite and sericite by feldspar, kaolinite –mica minerals; disappearance of primary polymineral clay cement and formation of monomineral kaolinite cement in the void spaces. Structure transformations (as in bitumen-content zone) are connected with the intensive fragment and cement dissolution, intergranular void renewal, micro-porosity development on the inside and surface fragments, and occurrence of intercrystalline voids in kaolinite cement. Porosity and permeability in this zone in some samples can be compared to that in the bitumen-content zone.
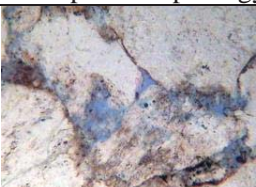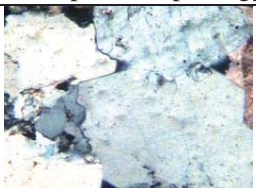
Cementation zone (2705.0–2707.4 m) includes sandstone with the secondary quartz regenerated fragments and calcite corroded cement, substituted by rock fragments and primary cement. Quartz [1, 6, 7, 10], secondary in amount (total mineral content is insignificant and has low percentage), has

incomplete regenerated boundaries with thickness from 0.006 to 0.02 mm. Calcite completely fills in practically all the remaining voids and rocks lose their reservoir properties: rock porosity and permeability decrease.

If there is **no** hydrocarbon *deposit influence* (2707.4–2708.0 m), rocks contain polymineral, weakly recrystallized kaolinite-chlorite-hydromica cement; include thin-dispersed pyrite, pelite-morph and microgranular siderite and porous calcite. Void space is non-uniformly distributed; intergranular voids are of insignificant sizes (0.02–0.1 mm), weakly associated, and often separated by non-permeable compacted cement sections or non-cement combination of several grains.

Specific features of composition and structure sandstone transformation in oil saturation and oil-water contact zones (Tab. 1) can be explained as following.

Table 1. *Geochemical, mineralogical and structural transformation of sandstones under conditions of incomplete oil infilling of trap*

| Zone	Specific features of transformation	Changes of fragments and cement	Porosity types
Oil saturation of weak dissolution	Dissolution of reservoir by oil oxidation products at contact with interstitial water; limited mineral-formation, disrupted oil displacement by interstitial water	Weak dissolution and substitution of fragments, polymineral cement	Intergranular voids of simple morphology, rare – intragranular voids
Bitumen-content dissolution	Oil oxidation, bitumen formation, sulphate restoration, pyrite and kaolinite synthesis, dissolution of fragments and cement produced through oil oxidation.	Dissolved and substituted fragments, kaolinite cement, of bitumen filled	Intragranular, intercrystalline and micro-cavernous voids of complex morphology
Non-bitumen-content dissolution	Dissolution through acid aggressive solutions from bitumen-content zone, kaolinite synthesis	Dissolved interfaces and substitutions of fragments, kaolinite cement	Intragranular, intercrystalline and micro-cavernous voids of complex morphology
Cementation	During acidity decrease quartz and calcite synthesis from solution produced in dissolution zones.	Regeneration of quartz grains	Calcite cement, small isolated residual voids

6. Results and Discussion

In oil saturation zone the oil migrating to the reservoir is in imbalance to void solutions and reservoir mineral phase as a whole. When oil, as any organic substance, interacts with interstitial water it undergoes oxidation due to bacteriological and chemical processes. These oil oxidation products in void solutions stimulate their acidity increase. Previously dissolved elements (silicium, aluminum and others) have precipitated on the newly-formed acid (void-solution) boundary resulting in secondary quartz and kaolinite formations. Unstable minerals, namely, carbonates, aluminum silicates, silicates, etc, at pH decrease are dissolved, forming secondary surface micro-cavernous and intragranular voids. Under conditions of hampering water exchange aluminum silicate and silicate dissolution (feldspar, mica and others) is accompanied by partial displacement of one mineral by another (sericitization and kaolinitization of feldspar, kaolinitization of mica, etc.). As a result of rapid oil displacement from void solutions, mineral and structure transformation processes have a limited nature, while reservoir dissolution is indistinct. Carbonates can be completely dissolved, while their leaching products are carried out beyond the dissolution zone [4]. Transformation processes of oil saturation zones in reservoirs have a limited nature and are, to a certain extent, determined by the amount of interstitial water in sandstones and hydrocarbon infilling velocity in the trap. The composition-structure transformations in the oil saturation part of the reservoir cease during gradual hydrocarbon infilling of the trap and water displacement from void space.

Active substance exchange occurs ***on the oil-water contact zone*** where oil, subjected to bacteriological oxidation, generates organic acids (CnH_2n +1COOH or CnH_2nO_2 type), spirits, aldehydes, ketones and other organic combinations; void solution acidity increases, and, at the same time, their aggressive properties sharply increase; while surrounding (country) rock is subjected to restoration and intensive dissolution. Biochemical and chemical process indicators, occurring in the OWC zone, are mineralogical and structure transformations, reflecting specific processes and their sequence, as well as, fixed space zonality of OWC structure. Rock mineralogical changes at OWC zone include secondary mineral formations, not typical for rocks and structural changes – in the dissolution of rock constituents and secondary porosity formation.

Bitumen-content zone is the zone where oil-water contact immediately occurs, and where oil oxidation takes place, resulting in the formation of solid bitumen, pyrite and other oxidation products (aggressive solvents, such as fatty acid, which in its turn, forms acid environment). Pyrite formation through oxidized bitumen is as following [4, 9]:

$$CaSO_4 + HCO_3 \rightarrow H_2S + CaCO_3 + CO_2;$$
$$Fe + H_2S \rightarrow FeS_2$$
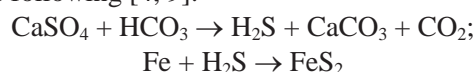
As a result of sulphate reduction the sulphuric and hydrogen boundaries are formed where pyrite precipitation and organic substance pyritization occur in harsh restoration environment. Pyrite formation ceases further from oxidizing oil beyond sulphate reduction. Calcite dissolution in acid environment is as follows:

$$CaCO_3 + CO_2 \leftrightarrows Ca^{2+} + 2HCO_3^-$$
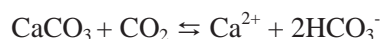
through simple leaching, up to complete mineral dissolution and component removal beyond acid solution reaction. Thus, calcite is not present in the dissolution zone of OWC. During dissolution of aluminum silicate and quartz, component removal is partial as dissolution includes only insignificant mobility of cations, then further formation of new mineral phases: either the replacement of one mineral for another (aluminum silicate) or mineral synthesis from solutions (quartz, kaolinite). During dissolution of feldspar and quartz, cations Na^+ (feldspar kaolinitization) and K^+, Na^+, Fe^{2+}, Fe^{3+}, Mg^{2+}, Ca^{2+} (plagioclase albitization) and anions HCO_3^- pass into void solutions, while Ti^{4+}, Si^{4+} appear during kaolinitization of hydromica, chlorite, montmorillonite and mica. As a result of rock dissolution, the void connectivity degree, rock porosity and permeability are increased. Kaolinite synthesis occurs in acid environments at pH=5–7 from those solutions circulating in the voids.

Geochemical processes *in non-bitumen-content zone* are also connected with rock dissolution under the influence of aggressive solutions which proceed from bitumen-content zone. These processes occur during acidity decrease to the horizon bottom, as acid inflow in this direction decreases, and solutions are enriched by alkalines and alkaline-earth elements. Aluminum loses its mobility, that results in mass synthesis of kaolinite.

The *cementation zone* is formed in the weak acid environment of the lower dissolution zone, where geochemical solution discharge, enriched by chemical elements, occurs. Rearrangement of dissolution products occurs when environment alkalinity increases to the reservoir bottom, resulting in cementation zone that has zonality nature. First, quartz precipitation, then carbonate precipitation (Fe-Ca-Mg carbonates) occurs. Due to these processes, void-space decreases, and the reservoir is sealed.

7. Conclusions

Detection of vertical zonality of sandstone rocks in oil-water contact zones is of great practical importance that allows explaining electrical resistance drop on the diagrams of induction logging of the low resistivity reservoirs. The electrical resistance decrease can be resulted from the presence of pyrite, current-conducting mineral, in sandstone rocks of Bitumen-content zone, from decrease of capillary-adhesive water around pelletized feldspar grains, in micro-voids in both bitumen-content and non-bitumen-content zones of dissolution. High specific surface of micro-cavernous voids on the surfaces of fragments, intergranular and intercrystalline voids provides expanding the film of capillary-adhesive water which forms the network of interconnected channels. The uniform water space formed by the retained capillary water conducts the current well that is reflected by the induction logging curves.

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