Abstract

The paper proposes a new event model of formation of Paleocene-Eocene sands and sandstones of the Southern and South-Eastern Russian Platform and their overlying Eocene bentonite clays. Sands have been considered as sand injectites, which outpouring and intrusion are due to tectonic activity of the Pachelma and Dnieper-Donets aulacogens and the Voronezh mass in the Paleocene-Eocene period. The outpouring of fluidized sand was complicated by the income of acid pyroclastic material to the basin. The influence of the latter explains the layers of camouflage pyroclastics in the sands of Buchakskaya formation. The transformed pyroclastic material is presented by the paragenesis of authigenic minerals - montmorillonite, zeolite, opal-CT, glauconite, and volcanic glass. It has been shown again that the montmorillonite clays of the Kievskaya formation are of volcano-sedimentary origin and were formed by diagenetic transformation of the metastable pyroclastic material. The formation of confluent sandstone is also associated with the diagenesis of overlying ash material, upon which free silica - a quartz grain cementing material - releases. Material composition of sands and sandstones of Buchakskaia formation and clays of Kievskaya formation has been studied with a range of analytical methods (petrographic, X-ray, chemical, and electron microscopy). Consideration of the sand strata under the new perspective requires a review of existing stratigraphic schemes, as a synchronous formation of rocks of both Buchakskaia and Kievskaya formations is very likely.

Keywords: Bentonite Clays, Eocene, Paleocene, Sand Injectites, Sands, Sandstones, The Russian Platform

1. Introduction

The Paleogene deposits, common in the south and southeast of Russian Platform, in the basins of the Dnieper, Don and Volga, in ObshySyrt, in Mugodzhary region and Northern Aral Sea region, have well developed thick (up to 100 m) strata of quartz sand and confluent quartz sandstones shown in Figure 1. The Buchaia formation is common in the interfluve area of the Dnieper and Don Rivers, and represented by white quartz sand with residues of Middle Eocene shellfish (Cardiumsemigranulatum, Venericardiapulchra) and quartzitic sandstones.

The researches have drawn their attention to the Paleogene sand and sandstone due to their suitability for use as mineral raw materials. Despite the high level of geologic certainty, the question of the genesis of these deposits remained elaborated down to recent times.
This paper presents the results of study of the material composition of quartz confluent sandstones of Buchakskaya formation of the Middle Eocene and the overlying marine Lutetian-Barton bentonite clays of Kievskaya formation shown in Figure 2. We have drawn an event-stratigraphic model of the formation of sand injectites covered with ash material, which diagenetic transformations had contributed to the formation of confluent quartz sandstones.

In 2012, we (SZ, NA) analyzed geological and drilling data, generalizing the space-time structure of the Paleogene sand-silica clay strata of Volga region, and studied sands of the Sosnovskaya facie of the Paleogene (Smorodino Quarry, shown in Figure 1)²³. Based on the results of the study, we have suggested a new building mechanism of Paleocene sands of the south-eastern Russian Platform, which considers them as sand injectites.
2. Main Part Geological Structure of the Tarasovskoye Deposit of Quartz Sandstones

The investigation of the quarry of the Tarasovskoye sandstone deposit, located in the right side of the river Glubokaya in Rostov region shown in Figure 1, allowed us to established that the Buchakskaya formation of the Middle Eocene is represented by greenish-light gray, quarzitic, silicified, confluent, concretion-layered sandstones, with giant conchoidal cleavage surface (thickness of 0.2-1.2 m), with lenses of creamy-white, fine-grained, quarzitic, layered sand (thickness of 0.5-0.7 m), and interlayers of highly ferruginized, mudstone-like, concretion-crusted formations (thickness of 0.3-0.6 m) shown in Figure 3A-C.

The sandstone strata of 4.8 m thick was approbated for a set of laboratory tests to study the material composition and genetic characteristics of the formation (petrographic, X-ray, and electron microscopic analysis). All analysis was performed in the laboratories of Kazan Federal University.

The petrographic study of confluent sandstones showed that the ground mass of the rocks is the poorly rounded, comminuted, angular quartz grains of 0.032-0.16 mm shown in Figure 3D, E.

There are larger, well-rounded grains of quartz of 0.5-1.04 mm among them, making 3-5% of the total mass of the rock. The cement is opaline, locally chalcedonic, crustified, cockade, less often filmy, and makes 5-15% of the total section area.

The crusted mudstone under the microscope is an aggregate of sand grains, bound with clay-glaucanite cement. A clastic part is represented by comminuted, angular, unrounded quartz grains and reniform aggregates of glauconite. Grain size–0.032-0.3 mm. The binder mass consists of glauconite and a clay matrix. The cement content reaches 50%.

Electron microscopic analysis of the sandstones conducted on the scanning electron microscope XL-30 ESEM, has shown that the angular-rounded quartz grains of sandstone are covered with tiny opal-cristobalite globules shown in Figure 3F, which locally “fuse” the grains together. A cementing silicon mass can completely fill all the pore space, making thereby a confluent sandstone shown in Figure 3G.

Figure 2. Stratigraphic scheme of the Paleocene and Eocene deposits of the Central zone of the Voronezh Anticline. 

The crusted mudstone under the microscope is a dense flaky aggregate of montmorillonite, partially impregnated with amorphous silicon mass, with scattered plank crystals of clinoptilolite-heulandite and almost completely decomposed radiolaria shown in Figure 3H.

X-ray phase analysis. The X-ray phase analysis was performed on the diffractometer D2 Phaser (Bruker, Germany) used for measuring the powder products in the Bragg-Brentano geometry, with the use of monochromatic CuKα-radiation (\(\lambda = 1.54178 \, \text{Å}\)), in the step-scan mode. Measuring and recording modes: X-ray tube voltage-30 kV, current-30 mA. Scanning step-0.02°. Speed-1 deg/min. The range of scanning angles in the Bragg-Brentano geometry 3-40°.
We found that the rock-forming mineral is quartz shown in Figure 4A; microcline, albite, and muscovite are present as an impurity terrigenous material. In addition to the above-listed minerals, the crusted mudstone contains zeolite of heulandite-clinoptilolite and montmorillonite groups shown in Figure 4B. Both sandstone and mudstone composition includes a significant content of amorphous phase represented by opal.

For studying the bentonite clays of the Kievskaya formation, we used samples from drill cores drilled in the Tarasovskoye clay deposit. A range of studies included both X-ray phase and electron microscopic analyses.

As the X-ray phase analysis has revealed, the material composition of clay shown in Figure 5 included: smectite, hydromica, X-ray amorphous opal, clinoptilolite, quartz, feldspars, amphibole, calcite and kaolinite. This allows characterizing the studied clays as hydromicaceous-smectite, siliceous, and zeolitic.

Mineral association of the samples studied is quite homogeneous. Their X-ray diffraction patterns are generally identical, except for small-angle region where the difference in the intensity of basal reflex $d_{001}$ of the smectite appears (13.4, 13.9 Å) shown in Figure 5. After saturating the specimen with ethylene glycol, it shifts to 16.8 and 17.0 Å.

Studying the clays under the scanning electron microscope with microprobe analysis showed that the ground mass of the rock is composed of scaly, flaky aggregates of montmorillonite with an abundance of semi-dissolved volcanic glass debris shown in Figure 6A. There are plenty of semi-decomposed skeletons of radiolarians, surrounded by newly formed montmorillonite shown in Figure 6B.

Energy-dispersive spectrum revealed the presence of titanium in the total rock mass (Fig. 6C), which indicates the pyroclastic nature of the original material being in a metastable state.

The conducted research confirms the earlier conclusion about the multi-phase process of acidic pyroclastics conversion into smectite-containing clays of the Kievskaya formation.

### 3. Results and Discussion

The modeling of biological processes shall be started with the nature of the sand strata.

Previously we have justified the most feasible mechanism of their formation as the sand intrusions. While in the south of the Russian Platform the injectites were relieved at the bottom of the sea basin, as evidenced by the findings in the sands of fossil fauna, in the east of the Russian Platform (Volga region) the relief of sand masses could also occur on shore, as there is evidence of the findings of leaf flora of the Eocene sandstones.

The formation mechanism of sand intrusions and extrusions is described in detail in numerous publications. The source for the formation of injectites is
a nonconsolidated sandy material of the source layer, occurring at great depth.

These sources could probably be the glauconite-quarzitic sands of the Aptian, Albian, and Cenomanian age in the south of the Russian Platform, and the Bath and Cenomanian age in the east. It is noteworthy that the Eocene sands of the Buchakskaya formation and the Aptian, Albian, and Cenomanian sand strata of the Russian Platform are intermediate collectors of diamond and have a similar structure of the heavy fraction\textsuperscript{17}.

A “trigger mechanism” for pressing out the sand masses was the formation of sub-vertical cracks in carbonate-clay Jurassic-Cretaceous strata, resulting, apparently, from the activation of the Pachelma and Dnieper-Donets aulacogens in the Paleocene-Eocene age\textsuperscript{18} shown in Figure 1.

It is known that the Laramide era of tectogenesis, falling at the end of the Cretaceous - early Eocene age is characterized by global regime of the Earth crust extension\textsuperscript{6,11,19,20}. This process, probably, affected the East-European Platform too. A striking example of this activation is the outpouring of basaltic lavas dated by 74 million years (Campanian), in the south-east wing of the Voronezh anteclise, adjacent to the Dnieper-Donets aulacogens\textsuperscript{11}.

4. Summary

- An event model of formation of Eocene sands and confluent sandstones of the Buchakskaya formation and the overlying bentonite clays of the Kievskaya formation.
- It is supposed that the activation of the Pachelma and Dnieper-Donets aulacogens in the Paleocene-Eocene age led to the formation of sand injectites on the seabed surface and on shore (Buchakskaya formation in the south and the east of Sosnovskaya facie of the Russian Platform).
• Simultaneously with the formation of injectites, an intense impact of volcanic activity is fixed, expressed in the abundance of camouflage pyroclastics in both the sand strata and the overlying clays of the Kievskaya formation.
• The final process was the formation of confluent sandstones, which siliceous cement was formed by the release of free silica, the sand cementation, and their local transformation into the confluent sandstones.
• Consideration of the sand strata under the new perspective requires a review of existing stratigraphic schemes, as a synchronous formation of rocks of both Buchakskaya and Kievskaya formations is very likely rather than sequential formation.

5. Conclusion

The most important conclusion resulting from the study of the material composition of the Buchakskaya formation sandstones is montmorillonite, amorphous opal, glauconite, zeolite and volcanic glass debris identified in the sand strata of camouflage pyroclastics. The volcanic ash alteration products form the cement of sandstones, penetrating into the pore space of the original sand, enveloping the quartz grains and being partially crystallized around them. Where should one search for the source of a large amount of free silica, which contributed to the formation of the giant lenses of confluent sandstones in the sand
strata? The answer was found when studying the overlying clays of the Kievskaya formation of the Eocene age.

A recent comprehensive study of the material composition of clays of the Kievskaya formation showed that the original material for the formation of swelling montmorillonite clay was dacite-rhyolite volcanic ash, which transformation into the bentonite clay was complex and multistaged. Middle Eocene sources of pyroclastic material could be active explosions of a volcanic arc of the Caucasus Minor in the Eocene age, as well as dacite and andesite-dacite tuffs of up to 2000 m thick formed in Adjara-Trialeti zone Trans-Caucasian region. The outflow of these volcanic rocks, apparently, was accompanied by the release of acid (light) ash, which was transferred by air currents in the stratospheric layer of the Russian Platform.

The relief of ash clouds in the sea basin was originally accompanied by transformation of volcanic glass particles in the metastable zeolite-radiolarian ooze. Then, zeolites and radiolarians were completely decomposing with further formation of smectite and silicon gel. The latter, we think, was the source of free silica, serving as cement for the underlying quartz sandstones of the Buchakskaya formation. While a newly formed smectite both transformed into bentonite-containing clay of the Kievskaya formation, and became a cementing substance for crusted mudstones common to the sand strata. Thus, the lithification of the overlying cap, formed by clays of the Kievskaya formation, contributed to the release of free silica, the silicification of loose sands, and their local transformation into the confluent sandstones.

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