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Classification of rocks of the Bazhenov Formation

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Abstract

In this study, we propose a new classification of rocks of the Bazhenov Formation based on the proportions of four principal components (siliceous, clay, and carbonate minerals and organic matter (kerogen)) of mostly biochemogenic and, to a lesser extent, allothigenic origin. The classification is based on the results of mineralogical and chemical analyses of more than 400 core samples from 15 wells drilled within the Bazhenov Formation, West Siberian petroleum basin. Four major classes of rocks, divided into 16 subclasses, have been recognized. The terms mixtite and kerogen-rich rock are introduced. Mixtites (biochemogenic mixtites) are defined as a class of rocks containing less than 50% of each component, including kerogen. It was shown that the most common rocks of the Bazhenov Formation are siliceous-argillaceous, kerogen-siliceous, and kerogen-argillaceous-siliceous mixtites and kerogen silicites, which together account for ~65% of all samples analyzed. The proposed approach can be used to study organic-rich black shales in different sedimentary basins worldwide.

Keywords: petroleum source rocks; rock classification; Bazhenov Formation; West Siberia

Background and problem statement

The Bazhenov Formation has long been considered to consist of thick strata of mudstones that are exceptionally rich in organic matter. For example, I.I. Nesterov, F.K. Salmanov, G.R. Novikov, A.V. Tyan, and I.N. Ushatinskii wrote back in 1970 that the Bazhenov Formation "is ubiquitously composed of black, very fine-grained dense mudstones" (Nesterov, 1970, p. 228). However, a more detailed study showed that the Bazhenov Formation has a very complex lithology and is, at least in the deepest parts of the Bazhenov basin (Gurari et al., 1963; Kontorovich et al., 1971, 2013; Nesterov, 1976; Vinogradov, 1968; Zakharov and Saks, 1983), a product of biogenic sedimentation. Despite the apparent homogeneity of the Bazhenov Formation, recent analytical data revealed the extreme lithological variations within the formation.

Many classification schemes have been proposed by different researchers (Dorofeeva and Blinkova, 1983; Eder, 2002; Filina et al., 1984; Gavrilov et al., 2015; Gurari, 1988; Gurova and Kazarinov, 1962; Saraev, 1987; Ushatinskii, 1981, 1989; Zanin et al., 1999, 2005; Zubkov, 2016; Zubkov and Mormyshev, 1987).

Ushatinskii (1981) recognized four rock types in the Bazhenov Formation: silicites, shales, marls, and limestones, whereas Filina et al. (1984) described three main rock types in the section of the formation: mudstones, including various subtypes of argillaceous rocks, variably silicified and carbonated, radiolarites, and limestones. Zubkov and Mormyshev (1987) identified eight types of the Bazhenov rocks within the area of the Salym field using the ternary diagrams for their lithological classification: argillaceous, carbonate, argillaceous-carbonate, siliceous-carbonate-argillaceous, argillaceous-siliceous-carbonate, argillaceous-carbonate-siliceous, argillaceous-siliceous, and pyritic. This classification was further elaborated by Zubkov (2016).

The classification of G.N. Perozio (Gurari, 1988) is also based on the relative proportions of the major rock-forming components, such as silica, clay minerals, and carbonates, as well as chemogenic and biogenic silica. Saraev (1987) identified the Bazhenov rocks as silicites and subsilicites using discrimination diagrams of Neelov (1980). Zanin et al. (1999) identified two main rock types in the Bazhenov Formation: (1) argillaceous-siliceous rocks and silicites; and (2) mudstones. Eder (2002) used cluster analysis to recognize two main groups and eleven subgroups of the Bazhenov rocks based on the proportions of rock-forming components.

The classification and appropriate terminology for sedimentary formations composed of fine-grained rocks enriched in

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aqueous organic matter (algal, archaeal, bacterial) and minerals that are the products of physical breakdown of catchment rocks or chemogenic and biogenic sedimentation has been successively elaborated in a number of papers published in the USA and Europe (Adams and Carr, 2010; Bohacs et al., 2005; Dawson and Almon, 2010; Könitzer et al., 2014; Lazar et al., 2010, 2015; Tyson, 1995; Tyson et al., 1979).

As with all previous attempts to establish a terminology for rocks of the Bazhenov Formations and other black shales, it has not been possible to account for one of its distinctive features, the presence of organic matter (kerogen) as a major rock-forming component. The need for identification, measurement, and assessment of sedimentary organic matter in the description and classification of sedimentary rocks was first highlighted in earlier studies (Kontorovich, 1976; Kontorovich and Savitskii, 1975; Savitskii et al., 1972; Vassoevich, 1973). These researchers developed their own classification schemes on the basis of this approach. In our classification scheme, the term "kerogen" is used as a qualifier in the rock name: kerogen silicite, kerogen-argillaceous mixtite, etc.

The recent study by Lazar et al. (2015) also noted the need to take account of the amount of organic matter (kerogen), although the proposed classification did not include the term "kerogen" as a rock-forming component in a rock name.

A specialized classification of the Bazhenov rocks is required for the general description of the Bazhenov Formation, its detailed subdivision and correlation, the establishment of a statistical relationship between the mineral composition of the rocks and log data and a better understanding of the evolution of the Volgian sedimentary basin. It is apparent that a similar situation would arise in a study of other black shale suites. This study attempts to create a more specific classification scheme that would contain some important differences to the previous widely accepted schemes and reflect the amount of organic matter (kerogen) as a major rock-forming component. A statistical analysis was carried out to determine the frequency distribution of specific rock types in the Bazhenov Formation.

Analytical techniques

The major mineral constituents of the Bazhenov rocks were evaluated by X-ray diffraction, electron microscopy, infrared spectroscopy of the clay-sized fraction. The other methods used include determination of major element contents by X-ray fluorescence (XRF), iron and sulfur speciation, concentrations of C_{org} in rocks, and elemental composition of kerogen. The quantitative mineral composition of the Bazhenov rocks was calculated from chemical analyses following the methods described in previous studies (Bogorodskaya et al., 2005; Florenskii et al., 1964; Rosen, 1981; Rosen and Nistratov, 1984; Strakhov and Zalmanzon, 1955). It should be kept in mind, however, that the values reported were organic matter concentrations and not organic carbon concentrations. As a result, the following rock-forming minerals were calculated: silica, clay minerals, including the specific clay mineral groups, albite, kerogen, calcite, dolomite, apatite, pyrite, and barite. The results of the calculation were confirmed by petrographic examination and X-ray diffraction analysis. Moreover, elemental sulfur was found in relatively large amounts in the bitumen extracts, but the concentration of sulfur in the rocks of the Bazhenov Formation was not determined in this study.

Principles of classification and factual material

The proposed classification of the Bazhenov rocks is based on the composition of the main groups of minerals and mineraloids (kerogen). Mineralogical geochemical, and petrographic analysis reveals that most rocks of the Bazhenov Formation consist of the following minerals and mineraloids:

– minerals formed by biochemical processes (calcite, silica);

– planktonic and benthic (algae, archaea, bacteria, eukaryotes) organic matter (kerogen) preserved in rocks during diagenesis and cataganesis;

– dispersed products of chemical weathering of source rocks in catchment areas (allothigenic clay minerals);

– authigenic minerals precipitated during late diagenesis and catagenesis.

In building the classification scheme, it should be kept in mind that mineral phases with similar chemical composition could have formed by biochemical and chemical processes at different stages of formation and transformation of the Bazhenov rocks. The products of early lithification may serve a likely source for late-stage minerals. For this reason, the proposed classification is not wholly genetic.

The database used in classification comprise more than 400 core samples of Bazhenov rocks recovered from 14 wells drilled in the central part of the West Siberian geosyneclise (Khanty-Mansi Autonomous District, western Tomsk and northern Novosibirsk regions). The majority of core samples were collected from wells drilled to the deepest parts of the Volgian paleobasin (Kontorovich et al., 2013).

Classification of rocks. Characterization of rock classes

All the studied samples are characterized by the following variations in the amounts of the principal minerals (%): 0.8–88.6 (average 37.1) for siliceous minerals; 1.1–51.6 (average 22.3) for clay minerals; 0–23.9 (average 8.4) for albite; 0–92.3 (average 14.3) for carbonate minerals; 0.2–27.8 (average 10.8) for organic matter (kerogen); 0–23.5 (average 6.2) for pyrite; 0.1–17.5 (average 0.8) for apatite (Fig. 1).

Therefore, the principal minerals and mineraloids of the Bazhenov rocks are silica, clay, and carbonate minerals and kerogen, which may comprise more than 75 wt.% of the rocks, whereas pyrite, apatite, barite, elemental sulfur, etc. compose the remaining portion of the rock.

The authors first attempted to classify Bazhenov rocks on the basis of the amount of principal minerals and constituents, including kerogen. The types of rocks were identified using