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The regularities of the distribution of siliceous mudstones and "coccolith" member of the Bazhenov Formation

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Abstract

Based on results of comprehensive lithological and geochemical analysis, we have established the regularities of the spatial distribution of major rock-forming components of the Bazhenov Formation in the West Siberian Basin (WSB), namely, siliceous, argillaceous, and carbonate material. According to the SiO_2/Al_2O_3 ratio, the most siliceous rocks of the Bazhenov Formation are biomorphic siliceous mudstones (radiolarites) (>20), cryptocrystalline siliceous mudstones (8–20), and the most argillaceous rocks are argillaceous mudstones (<3). Intermediate SiO_2/Al_2O_3 values (3–8) are observed in mudstones of different types. North–south distribution profiles of the SiO_2/Al_2O_3 ratio and CaO content in different areas of the WSB were constructed. The areas of occurrence of radiolarites (potential reservoirs) and a "coccolith" member with the highest content of organic matter have been clarified. The thickest radiolarite bed (3–4 m) has been found in the Salym area. In some sections of the North Surgut area, a "coccolith" member is 2 m thick and is carbonatized. In most of the sections of the North Surgut, South Tomsk, and West Tomsk regions, rocks of this type are observed as 1 cm thick intercalates, and in the Novosibirsk region they are virtually lacking. We have established that a "coccolith" member, localized mostly in the upper part of the Bazhenov Formation, occurs not only in the Salym and Krasnoleninskii regions but also in the North Surgut region. It was also found in the Northern region in the southern and central parts of the South Nadym megamonoclise. Coccolithophorid relics are occasional in the South and West Tomsk regions and are lacking in the Novosibirsk region and in the Northern region of the South Nadym megamonoclise.

Keywords: lithology; Upper Jurassic; Lower Cretaceous; Bazhenov Formation; black shales; biogenic siliceous and carbonate rocks

Introduction

In recent time, researchers and oil companies have focused increasingly more attention on black shales, unconventional sources of oils, because of the reduced hydrocarbon (HC) reserves in the conventional sources. The Bazhenov Formation, regarded as the main oil source strata in West Siberia (Kontorovich et al., 1994, 2014), is developed in most of its territory. The thickness of the formation varies from 10 to 50 m, with the average thickness being ~30 m. According to finds of numerous remains of macro- and microfauna, the Bazhenov Formation covers the upper Lower Volginian–lower Berriasian stratigraphic range (Nesterov, 1976; Gurari, 2004; Shurygin et al., 2000). These oil source strata are composed of fine-grained rocks of multicomponent composition, silicites (siliceous mudstones), and scarcer black and brown massive platy mudstones with marine fauna and carbonate rock intercalates. The content of organic carbon in these deposits varies from 5 to 20%. In some regions (Shaim, Krasnoleninskii, Salym, etc.), oil influx from the Bazhenov Formation was obtained (Alekperov et al., 2013; Alekseev, 2013; Gurari, 1961; Nesterov, 1979; Novikov et al., 1970). In the rest area of oil occurrence, the oil source strata can be exploited by applying methods of intensified HC recovery used for shale strata (hydrofracturing, chemical impact, etc.).

Lithology of the Bazhenov Formation in the Salym region was studied by many researchers (Balushkina et al., 2013; Eder, 2006; Eder et al., 2015a; Nemova et al., 2011; Ushatinskii and Ibragimova, 1982; Zanin et al., 2005; Zubkov and Doronina, 1982). The structure of the formation sections in the southeast of the Ob'–Irtysh interfluve (Tomsk Region) is less covered in literature (Eder, 2006; Gurova and Kazarinov, 1962; Polyakova et al., 2002). There are no publications on the lithologic structure of the Bazhenov Formation in the Novosibirsk Region. In this work we study the occurrence of the formation silicites (the most brittle rocks appropriate for

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hydrofracturing (Zoback, 2010) and potential oil reservoirs (Balushkina et al., 2013; Gurari, 1982; Konysheva and Sakhibgareev, 1976; Korovina, 2004; Nemova, 2015)) and an OM-enriched "coccolith" member in different regions of the WSB. This study is part of the research into geology and geochemistry of the Bazhenov Formation performed by the Federal State Budgetary Institution "All-Russian Research Geological Oil Institute" (VNIGNI), Moscow, and the Institute of Petroleum Geology and Geophysics (IPGG), Novosibirsk, under the guidance of Academician A.E. Kontorovich and M.B. Skvortsov. It will be useful for paleogeographic reconstructions, expansion of the knowledge of black-shale sedimentation in the closed basin, assessment of the petroleum potential of the Bazhenov Formation, and planning of the formation exploitation.

Methods

We present results of a comprehensive lithological study of well cores. The first stage was their macroscopic description. The thin sections of rock samples were examined using an Olympus BX-59 polarizing microscope and then using a MIRA3 TESCAN scanning electron microscope (SEM) with an INCAEnergy 450 + XMax 80 microanalysis system and a LEO-1430VP SEM with an INCAEnergy 350 microanalysis system (200 samples). These SEMs favored a more detailed (at ×10,000–15,000 magnification) study of the rock structure, the state of minerals in the rocks (crystalline or amorphous), the type of organic matter (OM) distribution, secondary alterations of minerals, and the presence of microfauna (5–10 μm in size). The contents of major rock components (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, MnO, K_2O, Na_2O, P_2O_5, BaO, etc.) were determined by X-ray fluorescence analysis on an ARL-9900-XP (Thermo Electron Corporation) spectrometer. The mineral composition of the clay fraction (<0.002 mm) and bulk rock samples of the Bazhenov Formation were studied by X-ray diffraction analysis on DRON-3 and DRON-4 diffractometers. The contents of sulfur (total, sulfide, and sulfate) and CO_2 were determined by the solution chemistry method. All analyses were carried out in the laboratories of the Analytical Center of the Institute of Geology and Mineralogy, Novosibirsk.

The content of total organic carbon (TOC, % per rock) was measured with an AN-7529 rapid analyzer in the Laboratory of Petroleum Geochemistry at the IPGG, Novosibirsk. Based on results of the analyses, the chemical composition of rocks was recalculated to the mineral one, using the MINLITH software proposed by Rosen et al. (2000). Based on the recalculation data, each sample was given a lithological name according to the adopted classification by Kontorovich et al. (2016) (in Russian) and Lazar et al. (2015) (in English). Following these authors, the rocks with >50% biogenic quartz were called siliceous mudstones, and those with <50% clay material and <50% biogenic quartz, siliceous–argillaceous mudstones. Two types of siliceous mudstones were distinguished according to their structure: biomorphic (radiolarites) and cryptocrystalline.

The ratio of biochemogenic to terrigenous components was evaluated from the SiO_2/Al_2O_3 ratio. The content of fine silt material in the studied deposits is mostly ≤5%. Thus, the siliceous material in the Bazhenov Formation is regarded as predominantly biochemogenic, and the clay material, as predominantly allothigenic.

This work is concerned with a detailed lithological research into the sections of 27 wells that penetrated the Bazhenov Formation (Fig. 1) in different regions of West Siberia (they were conventionally named the Novosibirsk, South Tomsk, West Tomsk, Salym, North Surgut, and Northern regions). The research included a comprehensive analytical study of ~500 samples. North–south distribution profiles of the SiO_2/Al_2O_3 ratio and CaO content have been constructed.

Results and discussion

Siliceous mudstones. Siliceous bio- and biochemogenic material dominates over clastic quartz (few percent) in the Bazhenov Formation. Biogenic silica is found in radiolarian shell relics and lenticles of microcrystalline silica and as micro- and cryptocrystalline structures. Chalcedony is the main mineral in the siliceous mudstones; it formed from opal of organisms with a silicon skeleton (Ushatinskii, 1981). The radiolarians are of different degrees of preservation, from perfectly preserved to strongly deformed ones passing into microlenticular siliceous segregations of nonbiogenic structure (Gurari, 1988; Saraev, 1987).

The SEM examination of rocks has revealed the following secondary alterations in the Bazhenov Formation radiolarites (Fig. 2): (1) total pyritization of radiolarians; (2) partial pyritization (of the outer shell of radiolarian skeleton), dissolution, and filling of the internal cavity of the relic with colloid-like OM or authigenous kaolinite; and (3) replacement of radiolarian relics by quartz and chalcedony.

The SEM data confirm that the radiolarites were more strongly subjected to secondary processes than other rocks of the Bazhenov Formation. The dissolution of organism relics led to an increase in their porosity. Later, the pores were filled with kaolinite or colloid-like OM. During pyritization, replacement of radiolarian relics by quartz and chalcedony, and carbonatization, the porosity significantly decreased. However, the signs of global dissolution of radiolarites that were earlier observed by Balushkina et al. (2013) in the Krasnoleninskii arch are lacking in the studied formation sections. There are different viewpoints of the nature of the Bazhenov reservoir. Some researchers think this reservoir resulted from autohydrofracturing (Dobrynin and Martynov, 1980; Gurari, 1983; Gurari and Gurari, 1974; Kontorovich et al., 1994; Korzh and Filina, 1980; Nesterov, 1979, 1985; Predtechenskaya and Zlobina, 2015; Zaripov et al., 1976). Others relate its origin to secondary transformations of siliceous and carbonate rocks (Balushkina et al., 2013; Gurari, 1982; Konysheva and Sakhibgareev, 1976; Korovina, 2004; Nemova, 2015). A