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Geochemical methods for prediction and assessment of shale oil resources (*case study of the Bazhenov Formation*)

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Abstract

The paper presents approaches to characterization of shale source rocks using geochemical data for the case of the Bazhenov petroleum system in West Siberia. Regional patterns of oil distribution in the Bazhenov shale are shown to depend on their original total organic carbon (TOC) content and thermal maturity. The existing thermal maturity model for the Bazhenov Formation based on vitrinite reflectance (R^{o}_{vt}) of nearby beds has been updated using parameters measured by Rock-Eval pyrolysis (T_{max}, HI, PC, and RC) for the shale itself. The results were used to quantify hydrocarbon resources in different maturity zones. The relationship between TOC and the presence of para-autochthonous oil found for logged zones in the Bazhenov section allows allocating and quantifying oil resources in unlogged beds.

Keywords: shale oil; Bazhenov Formation; source and reservoir potential; evaluation of resources

Introduction

Although the potential resources of shale petroleum systems (called domanik-type deposits in Russia) have been studied for decades, some key issues remain open to discussion. Namely, it is urgent to find the optimal strategy for allocation of pay zones and assessment of shale oil resources.

Unconventional plays such as shales have a complex structure and require joint use of various methods for their characterization. This study addresses the Bazhenov Formation, the largest and one of best documented source and reservoir shale systems in Russia, with a special focus on the role of organic geochemistry in evaluation of oil and gas resources.

Studies of shale source rocks worldwide have demonstrated that they share much similarity though being somewhat different in structure and influence of nearby beds above and below on their potential (open or close systems of oil generation, storage and retention). However, the regional regularities in distribution of oil within the formations are controlled by same factors: the initial concentration (prior to the start of active processes of oil and gas generation) of organic matter (OM) in rocks and its thermal maturity.

Thermal maturity and total organic carbon (TOC) contents influence both the extent of HC generation and storage capacity properties of shales, as it was recognized for the Bazhenov Formation in the early 1980s (Dorofeeva et al., 1983; Krasnov et al., 1980), while maturation has been crucial for the formation of efficient reservoirs. The reservoir rocks formed simultaneously with oil generation (Dorofeeva et al., 1983).

The effect of OM maturity evolution on porosity in such formations was discussed in a number of publications (Jarvie, 2012; Jarvie et al., 2007; Loucks et al., 2009; Romero-Sarmiento et al., 2013). For instance, Loucks et al. (2009) showed that most of nanopores in the Barnett Shale are associated with grains of organic matter. Pores not associated with organic matter are far less common.

Therefore, organic geochemistry studies are expected to be especially important for characterization of shale formations.

We report geochemical data for the Bazhenov Formation and the Lower Tutleim Subformation, its stratigraphic equivalent, obtained at the Russian Research Institute of Petroleum Geology (VNIGNI, Moscow), and suggest criteria for evaluation of shale oil resources.

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Thermal maturity and distribution of organic matter in Bazhenov shale

The study is based on analyses of about 2000 core samples of the Bazhenov Formation and Lower Tutleim Subformation rocks from more than 80 wells in different areas of the West Siberian basin (Fig. 1).

Organic matter was analyzed on a Vinci Technologies Rock-Eval "Standard" apparatus. Repeated Rock-Eval analysis was applied to 309 chloroform-extracted samples to estimate the amount of free hydrocarbons that formed part of S_2 peak.

Total organic carbon (TOC) content in the Bazhenov and Lower Tutleim rocks exceeds 5–7% over a large area of West Siberia. Content of organic carbon is the highest (>10%) in the Frolov, Nadym, and Yugan basins, the Koltogory trough, and in the surrounding uplifts (Kontorovich, 1975).

Taking into consideration that thermal maturity of OM is the principal agent in both the HC generation and organic porosity creation in the Bazhenov and other shale formations, division of the territory according to thermal maturity is the first step in the resource potential assessment.

The most exhaustive thermal maturity model for the Upper Jurassic top of West Siberia that covers the whole territory of the Bazhenov Formation and the Lower Tutleim Subformation was suggested by Fomin (2011). It is based mostly on reflectance (R^{o}_{vt}) of vitrinite which is absent from the Bazhenov rocks but is present in next beds above and below.

In order to update the model, we used parameters of OM evolution with increasing maturity of the Bazhenov Formation itself measured by Rock-Eval analysis, in addition to vitrinite reflectance data. These parameters include: the temperature measured at the top of the S_2 peak (T_{max}), hydrogen index of kerogen (HI), and the contents of pyrolyzed (PC) and residual (RC) organic carbon.

The use of Rock-Eval parameters for studying thermal maturity is valid for the Bazhenov shale due to homogeneity of its organic matter type and to relatively low maturity in the area (till secondary thermal cracking of oil to late gas).

Variations of Rock-Eval parameters and their ratios as a function of thermal maturity (T_{max}) were plotted (Fig. 2) using average values for the Bazhenov shale in 77 wells, without oil-saturated interbeds detectable from anomalies of S_1 relative

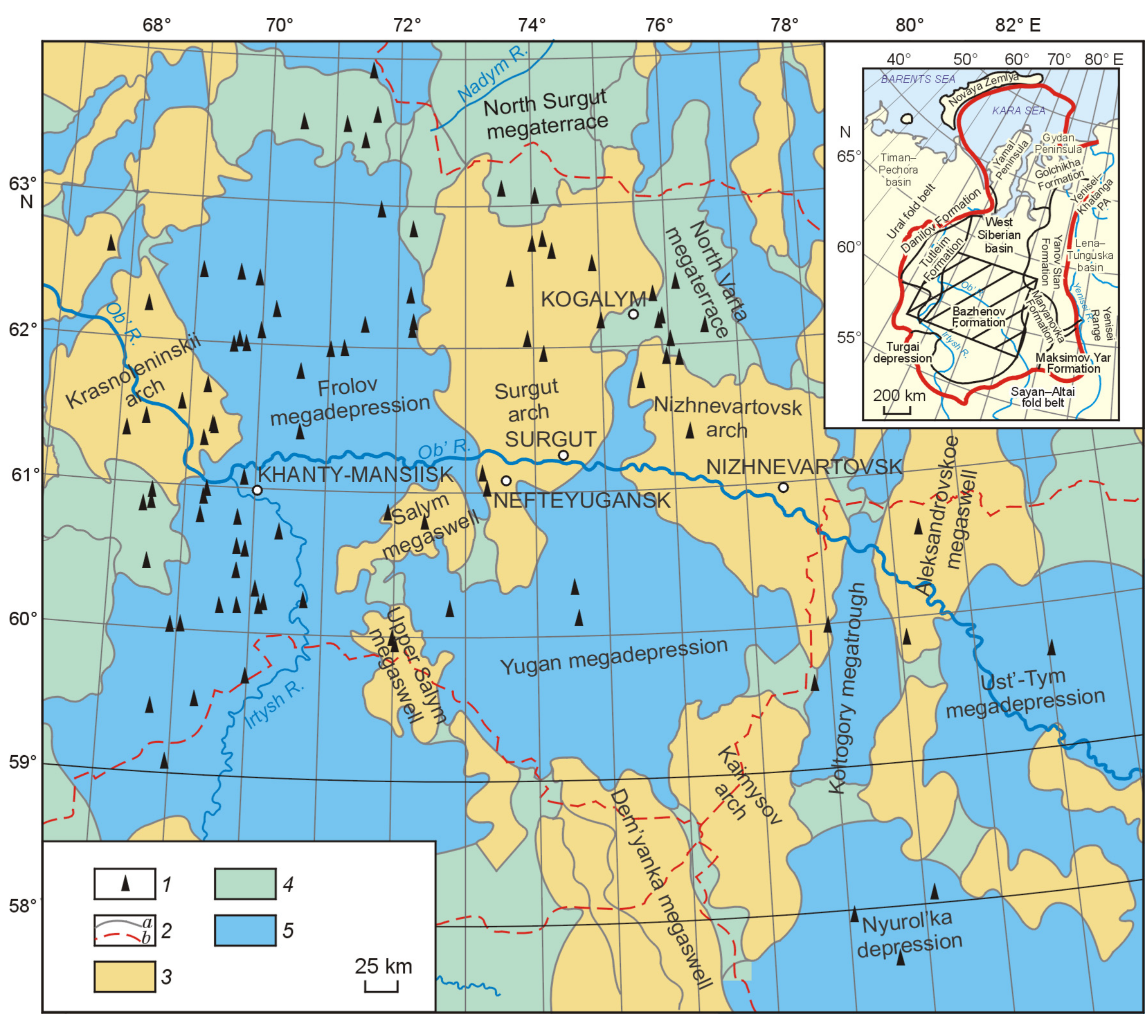

Fig. 1. Location map of wells. *1*, logged wells; *2*, boundaries of tectonic (*a*) and administration (*b*) units; *3–5*, positive (*3*), intermediate (*4*), and negative (*5*) tectonic structures. Inset shows location of West Siberian basin and study area (hatched).