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Research paper

Reconnaissance study of organic geochemistry and petrology of Paleozoic-Cenozoic potential hydrocarbon source rocks from the New Siberian Islands, Arctic Russia

Peter Sobolev [a, *], Dieter Franke [b], Christoph Gaedicke [b], Jolanta Kus [b], Georg Scheeder [b], Karsten Piepjohn [b], Christian Brandes [c], Martin Blumenberg [b], Benoit Mouly [d]

[a] A.P. Karpinsky Russian Geological Research Institute (VSEGEI), Sredny Av. 74, 199106, St. Petersburg, Russia
[b] Federal Institute for Geosciences and Natural Resources (BGR), Stilleweg 2, 30655, Hannover, Germany
[c] Institute of Geology, Leibniz University Hannover, Callinstraße, 30, 30167, Hannover, Germany
[d] TOTAL EXPLO EAC /PN, 2 Place Jean Millier, 92069, Paris La Defense, France

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ABSTRACT

A reconnaissance study of potential hydrocarbon source rocks of Paleozoic to Cenozoic age from the highly remote New Siberian Islands Archipelago (Russian Arctic) was carried out. 101 samples were collected from outcrops representing the principal Paleozoic-Cenozoic units across the entire archipelago. Organic petrological and geochemical analyses (vitrinite reflectance measurements, Rock-Eval pyrolysis, GC-MS) were undertaken in order to screen the maturity, quality and quantity of the organic matter in the outcrop samples. The lithology varies from continental sedimentary rocks with coal particles to shallow marine carbonates and deep marine black shales. Several organic-rich intervals were identified in the Upper Paleozoic to Lower Cenozoic succession. Lower Devonian shales were found to have the highest source rock potential of all Paleozoic units. Middle Carboniferous-Permian and Triassic units appear to have a good potential for natural gas formation. Late Mesozoic (Cretaceous) and Cenozoic low-rank coals, lignites, and coal-bearing sandstones also display a potential for gas generation. Kerogen type III (humic, gas-prone) dominates in most of the samples, and indicates deposition in lacustrine to coastal paleoenvironments. Most of the samples (except some of Cretaceous and Paleogene age) reached oil window maturities, whereas the Devonian to Carboniferous units shared a maturity mainly within the gas window.

1. Introduction

The shelf area around the New Siberian Islands is poorly investigated, even though it is considered as one of the most promising hydrocarbon provinces worldwide (Drachev, 2011). During recent decades, seismic surveys in the East Siberian and Laptev Seas provided first insights into the architecture and tectonic evolution of their sedimentary basins (Drachev et al., 1998; Franke et al., 2000; Franke and Hinz, 2005; Verzhbitsky, 2010; Drachev, 2011; Khoroshilova et al., 2014). However, many important geological questions (timing of basin evolution, paleoenvironments and depositional models), and hydrocarbon resource estimates, have still not been fully clarified. Further complications are that no offshore wells exist, and geophysical data coverage is sparse. In recent decades, studies were carried out to assess the hydrocarbon potential of the region. However, these studies lack geochemical data and are only based on a summary of previous geological and geophysical investigations (Evdokimova et al., 2007; Kim et al., 2007; Malyshev et al., 2011). Onshore studies here can be crucial for a better understanding of the region, as well as the interpretation of offshore data.

The New Siberian Islands are located on the continental shelf between the Laptev Sea and the East Siberian Sea, and allow insights into the geology of both areas. In 2011, a joint Russian-German expedition was carried out in the framework of the CASE (Circum-Arctic Structural Events) program of the Federal Institute for Geosciences and Natural Resources (BGR). The remoteness of the archipelago, the severe climate conditions, the quality of the

* Corresponding author.
E-mail address: peter.sobolev@gmail.com (P. Sobolev).

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exposures with strongly weathered rocks, the large size of the study area, and limited duration of the expedition meant that it was only possible to carry out a reconnaissance study. One of the primary aims of this expedition was to better understand and sample different stratigraphic sections on the New Siberian Islands, and to collect samples of potential hydrocarbon source rocks. The samples were collected by German (BGR) and Russian participants (most of them from the Karpinsky Russian Geological Research Institute, VSEGEI). These samples were then studied separately in German and Russian laboratories.

This study deals with the results of the organic, petrographic and geochemical analysis of potential source rocks in the sampled sedimentary units. With respect to the large study area, a sampling strategy was applied that covers the entire stratigraphic record of the New Siberian Islands and as many potential source rocks as possible. Nevertheless, this study cannot be compared with a detailed petroleum potential assessment for establishing a comprehensive play concept. The results presented here are essentially a first attempt at evaluating the source-rock potential, and may be critical for future in-depth studies of the sedimentary succession of the New Siberian Islands.

2. Geological setting and previous work

The New Siberian Islands archipelago is located north of eastern Siberia, and divides the Laptev Sea to the west from the East Siberian Sea to the east. The archipelago is subdivided into three groups (Dorofeev et al., 1999): the Lyakhovsky Islands in the south; the Anjou Islands in the centre; and the De Long Islands in the northeast (Fig. 1). The Lyakhovsky and Anjou Islands are interpreted as a fold-and-thrust belt that evolved during Jurassic-Cretaceous time (Kos'ko and Trufanov, 2002; Bondarenko et al., 2003; Kos'ko and Korago, 2009). The eastern islands are mostly composed of sedimentary rocks of Cambrian–Cenozoic age; some magmatic rocks are present on the Bennett, Zhokhov and Henrietta islands. A continuous, weakly deformed marine Cambrian section was described on Bennett Island (Danukalova et al., 2014). Ordovician rocks on Kotelny Island most likely consist of shallow-water carbonates. Furthermore, Ordovician deep-water clastics crop out on the Bennett and Henrietta islands. Devonian-Carboniferous shales dominate on Belkovsky Island and the SW part of Kotelny Island. In the central part of Kotelny Island, Triassic–Cretaceous rocks are exposed. They are interpreted as marine to continental deposits. Cretaceous rocks are generally widespread on the New Siberian Islands. They vary from deep-water clastics on the Bolshoy Lyakhovsky and Stolbovoy islands, to coastal sandstones on central Kotelny Island, and to terrestrial sands and coals on Novaya Sibir Island.

The tectonic structure of the archipelago is inhomogeneous and poorly investigated. The onshore geology of the New Siberian Islands was the subject of different studies dealing with the structural geology of Bolshoy Lyakhovsky Island, the nature of the South Anyui suture zone (Kuzmichev, 2009; Kuzmichev et al., 2009) and the paleostress evolution of the area (Brandes et al., 2015). It is discussed that the large western islands of the archipelago (the Anjou Islands and almost all the Lyakhovsky Islands) represent the southern passive margin of the Alaska-Chukotka Terrane (Kuzmichev and Pease, 2007; Miller et al., 2008). This terrane existed during the Palaeozoic-Mesozoic collision of the Arctic Alaska-Chukotka microplate with Eurasia along the South Anyui Zone, which is exposed in the southeast of Bolshoy Lyakhovsky Island (Franke et al., 2008). However, there is another interpretation that the islands formed a part of Siberia during the Palaeozoic (Cocks and Torsvik, 2007).

The rocks of the east Russian Arctic shelf are exposed on these islands and allow insights into the petroleum systems of the large province. An initial screening of the oil and gas prone sequences in the New Siberian Islands was obtained during geological surveys in the early 1970s. Numerous bitumen occurrences were revealed in strata of different ages, and a few basic laboratory studies (total organic carbon, quantity and composition of bitumen) were performed as well (Ivanov and Nepomiluev, 1975; Gramberg et al., 1976). According to their results, Ordovician and Silurian marine carbonate rocks have low total organic carbon (TOC) values (0.02–0.6%); they are described as at high levels of maturity, and overmaturity is common. Carbonate and siliciclastic rocks of Lower and Middle Devonian age were reported to have higher TOC contents, but with a large scatter. They are considered as a potential oil-prone source rock interval, even though parts of the samples are petroleum-impregnated. Upper Devonian-Carboniferous-Permian carbonate-siliciclastic shallow marine and coastal deposits were found to be characterized by a low TOC content. Increased TOC values, however, appear to be typical of many Triassic shales on the New Siberian Islands, and this interval is considered to be a gas-prone source rock. Few samples with a high TOC were reported from Cretaceous and Paleogene intervals. Visible bitumens occur in Ordovician to Cretaceous sedimentary rocks from Kotelny Island and Belkovsky Island. Black marly limestones of Lower-Middle Devonian age often contain bitumens along fractures and veinlets, and these rocks are also depicted to usually have a strong petroleum smell. Triassic shales also often contain black bitumens in numerous voids.

Two groups of promising source rock intervals were identified based on the measurement of TOC contents in seven hundred samples (Gramberg et al., 1976). The first one is Lower-Middle Devonian marine carbonates. Their organic matter is mainly sapropelic, and TOC reaches 1–1.5 wt%. These rocks often contain solid bitumens (disseminated or along fractures and fissures). Another potential source rock interval is Lower-Middle Triassic marine shales. Their TOC content was observed to be about 2–2.5%, and organic matter is classified as mixed humic–sapropelic. Traces of migrated petroleum were discovered in these rocks as well (Ivanov and Nepomiluev, 1975).

Some direct indications of subsurface gas accumulations were discovered during hydrogeological studies in shallow wells penetrating Cenozoic sediments (Neizvestnov et al., 1976). Free methane occurrences are commonly linked to fractures in the permafrost; there are elevated hydrocarbon concentrations in groundwater collected from the wells.

A few coal petrography studies of sedimentary rocks from the New Siberian Islands also exist. These include Cretaceous coal-bearing units on Novaya Sibir Island (Klubov et al., 1976). Lignite samples showed a vitrinite reflectance of Ro = 0.3–0.39% (12 samples). TOC varies from 0.5 to 4.3% in clays from this formation. Bitumens were described as probably syngenetic, and related to humic matter according to their chemical composition. Further, detailed palaeobotanical investigations of the mid-Cretaceous floras from Kotelny Island (Balyktakh River in the central part of the island) and Novaya Sibir Island (at a locality named “Derevyannye Gory”, i.e. “Wood Mountains”) were recently carried out by the Geological Institute, Russian Academy of Sciences, Moscow (Herman and Spicer, 2010).

3. Materials and methods

3.1. Sampling

Potential hydrocarbon source rocks were sampled on the Anjou Islands and Bennett Island during the CASE-13 expedition in September 2011 (Fig. 1). The total set of samples for organic studies