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The reservoir potential of the Bazhenov Formation: regional prediction

M.Yu. Zubkov *

West Siberian Geological Center (ZapSibGC), ul. Surgutskaya 11, korp. 4/9, Tyumen', 625002, Russia

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Abstract

The petroleum potential of the Bazhenov Formation reservoir has been assessed on the regional scale using several criteria inferred from published evidence, available geological and geophysical data, and well logging results from Upper Jurassic reservoirs.

Keywords: Bazhenov Formation; criteria of reservoir potential; regional prediction

Introduction

In the 1950s–1960s, the Bazhenov Formation in the Jurassic–Cretaceous section of the West Siberian basin was universally considered to be the largest oil source (Kontorovich et al., 1967; etc.), as well as a regional-scale screen between the Jurassic and Neocomian reservoirs. However, already in 1962, Gurari hypothesized that it could be also an oil reservoir, which was proved valid in 1970 (Novikov et al., 1970). The Bazhenov Formation turned out to store oil accumulations and to be a unique reservoir rather than only a petroleum source bed (Dobrynin and Martynov, 1979; Dorofeeva et al., 1983; Efremov et al., 1988; Gurari and Gurari, 1974; Gurari et al., 1988; Trofimuk and Karogodin, 1981; Khalimov and Melik-Pashaev 1980; Kontorovich et al., 1986; Melik-Pashaev et al., 1979; Mikulenko, 1974; Nesterov, 1979; Skorobogatov and Krasnov, 1984; Zaripov et al., 1982; Zubkov, 1989, 2014). Therefore the interest of petroleum geologists to the source and reservoir of Bazhenov Formation is understandable as it is characterized by an extremely large territory of $\sim 1 \times 10^6$ km^2.

The most exhaustive and valuable evidence, which remains relevant nowadays, can be found in early reports on the Bazhenov Formation studies by teams from various institutions (*GlavTyumen'geologiya*, SNIIGGiMS, ZapSibNIIGeofiziki, SibNIINP, VNIIneft, VNIGRI, MINKHiGP, IGIRGI, VNIIGAZ, and many others). In this study, we use the classical works of 1970 through early 1990 complemented with data collected for the past three decades to characterize the reservoir potential of the Bazhenov Formation at the regional scale.

Previous assessment of this kind was based on testing results and was made in the context of oil accumulation mechanisms known at that time (Dorofeeva et al., 1979, 1983; Efremov et al., 1988; Gurari and Gurari, 1974; Gurari et al., 1988; Kontorovich et al., 1986; Nesterov, 1979; Skorobogatov and Krasnov, 1984; Trofimuk and Karogodin, 1981; Zaripov et al., 1982; Zubkov, 1989; etc.).

Gurari and Gurai (1974) suggested a model of a shale reservoir formed by hydraulic fracture of laminated sediments by oil generated from kerogen. The model was later used by other researchers (Dobrynin and Martynov, 1979; Dorofeeva et al., 1979, 1983; Efremov et al., 1988; Gurari et al., 1988; Nesterov, 1979; Skorobogatov and Krasnov, 1984; Trofimuk and Karogodin, 1981; Zaripov et al., 1982; Zubkov, 1989). We chose several criteria for assessment of the regional-scale reservoir potential of the Bazhenov Formation using the shale reservoir model, with reference to the cited data.

Criteria for assessment of the regional-scale reservoir potential of the Bazhenov Formation

Reservoir thickness

As follows from the model of the Bazhenov Formation reservoir, the amount of hydrocarbons in it may depend on the reservoir thickness, which was estimated to be at least ~20 m in the producing organic-rich rocks of the Multanovskoe field. This thickness (of no less than 20 m) was assumed to be the first criterion of petroleum potential (Fig. 1*a*).

* Corresponding author.
E-mail address: ZubkovMYu@mail.ru (M.Yu. Zubkov)

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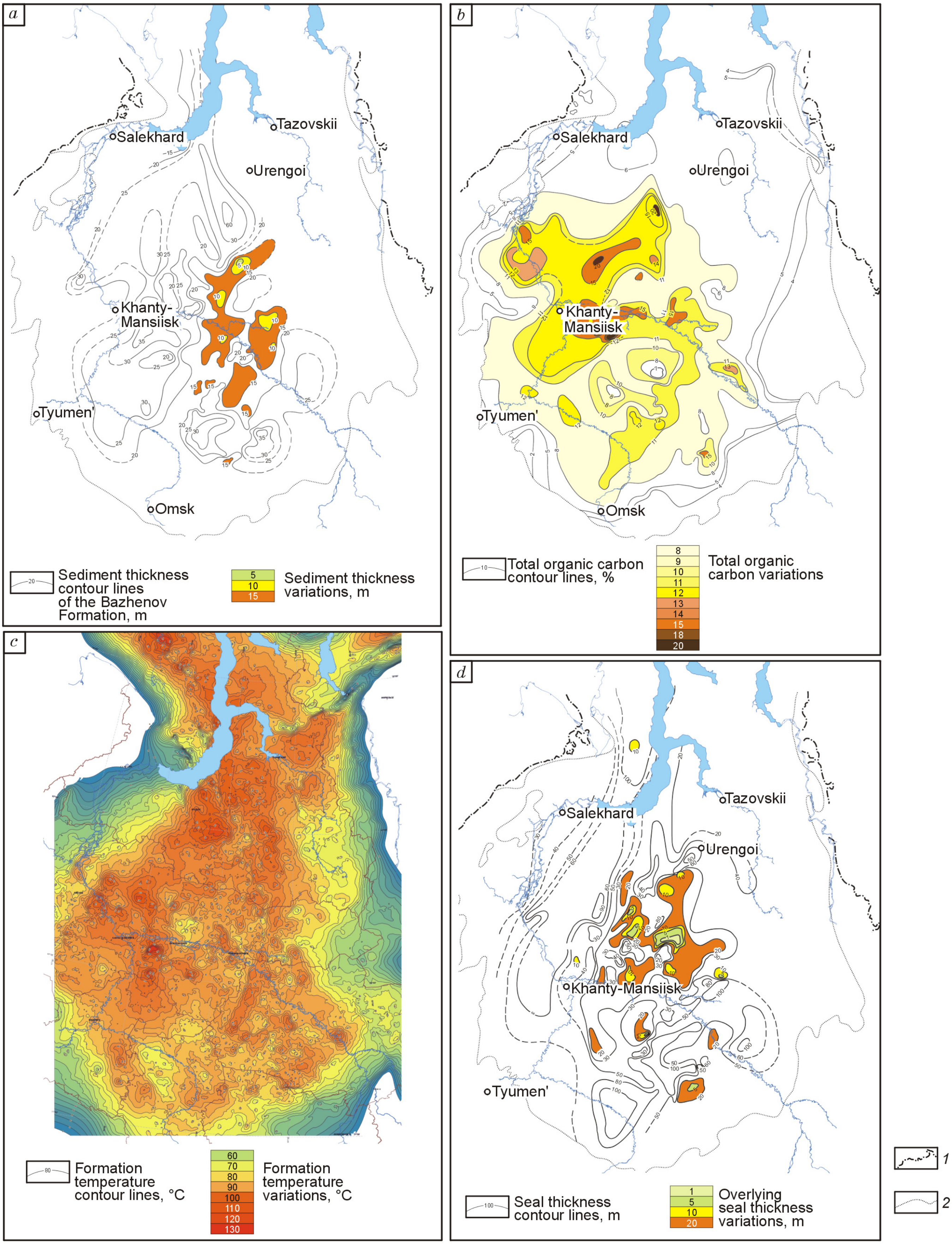


Fig. 1. Criteria for assessment of the regional-scale reservoir potential of the Bazhenov Formation. *a*, Reservoir thickness, after (Zubkov, 1984); *b*, total organic carbon, after (Kontorovich and Fomichev, Pers. Commun.); *c*, formation temperature on the top surface, after (Kurchikov and Plavnik, Pers. Commun.); *d*, thickness of seals, complemented after (Zubkov, 1984). Boundaries of: *1*, Paleozoic framing; *2*, Volgian–Berriasian sediments.

The reservoir thickness exceeds 20 m over most of the West Siberian basin, except for a few small areas in the central and northern Surgut arch, southern and northern Nizhnevartovsk arch, as well as in the central, southern, and northern parts of the basin (Fig. 1*a*). These areas may have been islands in the Late Jurassic (Volgian) Sea unfavorable for oil shale deposition.

Organic carbon contents

The general idea of oil generation implies that the source potential of rocks correlates with the amount of organic matter (kerogen) they store, other conditions being equal. According to field experience that oil flows were obtained from sediments with no less than 10% of average total organic carbon (TOC), this value was assumed to be the critical for source rocks. The sediments of the West Siberian basin contain more than 10% TOC on the larger part of the territory (Fig. 1*b*), except for the basin margins and its northern areas where clastic inputs were high from the continental masses flanking the Volgian Sea. Organic carbon is also notably lower than elsewhere within the high-temperature parts of the Salymskoe field and some areas of the Krasnoleninskii district where voluminous oil generation occurred by thermal decomposition of organic matter (Zubkov et al., 1984).

Temperature of the top surface

The temperature on the top surface of the Bazhenov Formation (formation temperature, T_{fm}) is another criterion of reservoir potential, which has been commonly assumed to be at least 100 ℃. The 100 ℃ isotherm contours mainly the western and central parts of the West Siberian basin, as well as some local areas in the central Nizhnevartovsk arch and Alexandrovskoe swell and in the northern Parabel' and North Vasyugan swells (Fig. 1*c*).

Thickness of seals

The degree of fluid dynamic insulation from reservoir rocks above and below is likewise important for the reservoir potential of the formation. The critical thickness of the upper and lower seals has been assumed to be 10 m by most of authors, proceeding from geochemical data.

The cap that separates the Bazhenov Formation from the overlying sand and silt reservoir rocks is mainly no thinner than 10 m (Fig. 1*d*) and is within 5–10 m only in some small areas. There are several such areas in the central and northern Surgut arch, in the northern half of the Nizhnevartovsk arch, in the Alexandrovskoe swell, the Kaimysov arch, etc. (Fig. 1*d*); some of them fall within the zones of smaller Bazhenov Formation thickness (Fig. 1*a*, *d*).

However, the lower seal is thinner than 10 m over almost all of the central and southeastern West Siberian plate (Fig. 2*a*), except for the southern Alexandrovskoe swell with the adjacent part of the Koltogory trough and the northern Middle Vasyugan swell, the northern Kaimysov arch, and the southern Upper Dem'yanka swell with its surroundings (Fig. 2*a*). There are a few areas where the Bazhenov Formation lies directly on the Vasyugan sandstone, the largest in the southern and southeastern parts of the basin (Upper Dem'yanka swell, Kaimysov arch and its adjacent areas, the southeastern Nizhnevartovsk arch, the central Alexandrovskoe swell and further eastward as far as the Pyl'-Karamin swell). The thickness of the lower seal is above the critical value in the western, northern, and marginal parts of the basin (Fig. 2*a*). The boundary between zones of thick and thin lower seals extends in the N–S direction along the western slope of the Surgut arch and coincides with the limits of the J_1 zone.

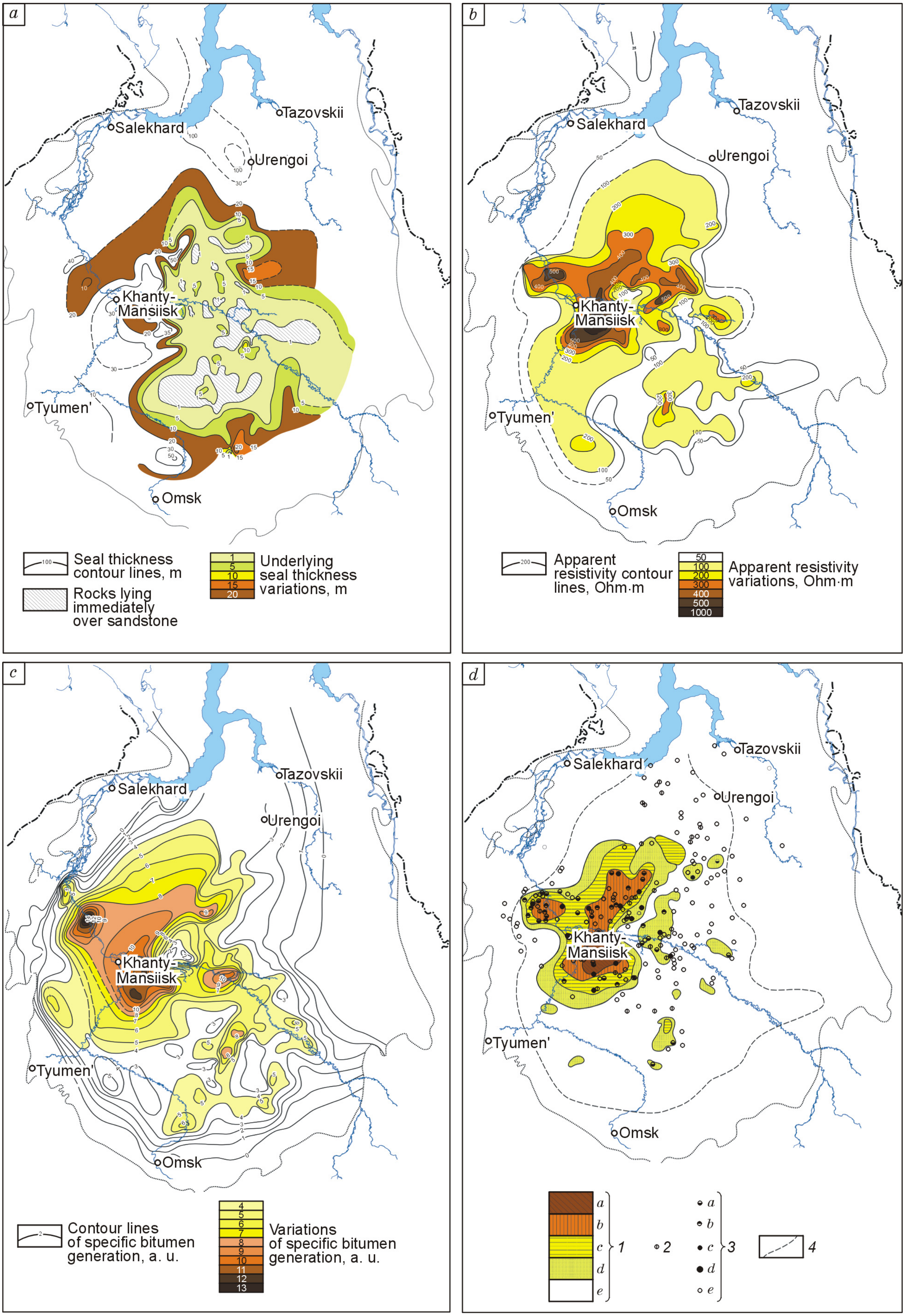
Apparent resistivity

Apparent resistivity, another criterion of reservoir potential, depends on lithology and on the contents of bitumen and residual water. The contour lines of 0.8–1.0% bitumen contents generally agree with those of 100–150 Ohm·m (Efremov et al., 1988). This correlation even allows the respective petroleum zoning of the territory on the basis of resistivity data (Fig. 2*b*). The apparent resistivity is about 200–250 Ohm·m or higher within proven reservoir zones (Dorofeeva et al., 1979; Efremov et al., 1988; Gurari et al., 1988; Zaripov et al., 1982) and increases, for instance, from 250 to 500–1000 Ohm·m in the Bolshoi Salym field where the bitumen content increases from 1.5 to 3.0%, respectively (Zubkov et al., 1984).

Formation temperature

Apparent resistivity also correlates with the formation temperature (Figs. 1*c*, 2*b*). Namely, the resistive zone coincides with the temperature anomaly in the Krasnoleninskii arch; the Bol'shoi Salym field falls within the 100 ℃ contour line and highest apparent resistivity; the zone of low resistivity (<200 Ohm·m) in the adjacent Surgut area coincides with the 80 ℃ isotherm. The two parameters (formation temperature and apparent resistivity) correlate because both depend on bitumen contents, while temperature controls the generation of hydrocarbons from kerogen (Dorofeeva et al., 1983; Gurari et al., 1988; Skorobogatov and Krasnov, 1984; Zubkov et al., 1984).

Fig. 2. Criteria for assessment of the regional-scale reservoir potential of the Bazhenov Formation. *a*, Thickness of seals; *b*, apparent resistivity; *c*, specific oil generation; *d*, map of regional-scale reservoir potential, complemented after (Zubkov, 1984): *1*, areas of different reservoir potential categories, with respective possible flow rates: category 1, >10 m^3/day (*a*), category 2, 3–10 m^3/day (*b*), category 3, 1–3 m^3/day (*c*), category 4, 0.1–0.5 m^3/day (*d*), dry rocks, <0.1 m^3/day (*e*); *2*, low-quality data and testing of the Bazhenov Formation jointly with other formations; *3*, wells with different flow rates: up to 2 m^3/day (*a*), from 2 to 5 m^3/day (*b*), from 5 to 10 m^3/day (*c*), >10 m^3/day (*d*), dry wells (*e*); *4*, boundaries of oil shales of the Bazhenov Formation and its equivalents. Other symbols same as in Fig. 1.


a
Salekhard
Tazovskii
Urengoi
Khanty-Mansiisk
Tyumen'
Omsk
Seal thickness contour lines, m
Rocks lying immediately over sandstone
1
5
10
15
20
Underlying seal thickness variations, m
b
Salekhard
Tazovskii
Urengoi
Khanty-Mansiisk
Tyumen'
Omsk
Apparent resistivity contour lines, Ohm·m
50
100
200
300
400
500
1000
Apparent resistivity variations, Ohm·m
c
Salekhard
Tazovskii
Urengoi
Khanty-Mansiisk
Tyumen'
Omsk
Contour lines of specific bitumen generation, a. u.
4
5
6
7
8
9
10
11
12
13
Variations of specific bitumen generation, a. u.
d
Salekhard
Tazovskii
Urengoi
Khanty-Mansiisk
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a
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Specific generation rate of hydrocarbons

The revealed correlation of the present formation temperature T_{fm} with the degree of kerogen conversion to hydrocarbons allowed mapping the specific HC generation rate based on OM distribution and T_{fm} (Fig. 2*c*) (Kontorovich et al., 1967; Zubkov et al., 1984). The critical value of this parameter is 4 arbitrary units and more. Generation of hydrocarbons has been the most active in the western part of the West Siberian basin, especially in the Krasnoleninskii arch and the Nazym and Galyan areas east of it; in the western slope of the Surgut arch; in the area of the Bol'shoi Salym field and its surroundings, including the Severodem'yanskoe (in the south), Priobskoe, Prirazlomnoe fields and further northward (Tortasin claim, Kamynskoe and Ai-Pimskoe fields.

Regional-scale reservoir potential

The patterns of the chosen criteria were superposed to compile an integrate map (Fig. 2*d*) of the regional reservoir potential (Efremov et al., 1988). The territory of the West Siberian basin was divided into four categories of economic potential, with nonreservoir rocks outside of them.

Category 1, highest reservoir potential: all parameters chosen as criteria are no less than the critical values. The zone generally coincides with the Bol'shoi Salym field. Wells within this zone are expected to give the highest flow rates from the Upper Jurassic reservoir.

Category 2, high reservoir potential: one parameter is below the critical value. The areas of this category surround the category 1 zone, cover the northern part of the basin, and the Krasnoleninskii arch (Fig. 2*d*). The expected flow rates from the reservoir are high or medium.

Category 3, medium reservoir potential: two parameters are below the critical values. The areas of this category surround the zones of category 1 and 2.

Category 4, low reservoir potential: three parameters are below the critical values. The areas of this category form a narrow belt around the zones of higher categories. Small areas of category 4 occur in the central, southern, and eastern parts of the basin, of which the largest are in the Tanlov basin and in the western Nizhnevartovsk arch and on its slopes.

All other territories have no economic petroleum potential (Fig. 2*d*).

It is worth noting in conclusion that some authors (Khalimov and Melik-Pashaev, 1980; Melik-Pashaev et al., 1979; Mikulenko, 1974; Tereshchenko, 1972) suggested that reservoirs of oil and gas within the Bazhenov Formation can form as a result of tectonic fracturing, in addition to hydraulic fracture. However, the cited authors did not specify how the fractured reservoirs can be found. Therefore, the presence of these reservoirs appears to be more a theoretical idea rather than a practically useful prediction.

Conclusions

1. The regional-scale oil reservoir potential of the Bazhenov Formation has been assessed and mapped proceeding from field testing, with reference to the known mechanisms of oil and gas accumulation. The assessment was based on several parameters chosen as reservoir potential criteria, with the following critical values: formation thickness ≤20 m; TOC ≤10%; formation temperature on the top surface ≤100 °C; thickness of seals above and below ≤10 m; average apparent resistivity ≤200 Ohm·m; specific oil generation rate ≤4 a.u.

2. On this basis, the territory of the West Siberian basin was divided into four categories of economic reservoir potential, with nonreservoir rocks outside of them.

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