# NEW APPROACH TO RANKING OF JURASSIC SEDIMENTARY COMPLEXES OF THE NORTHERN PART OF THE WEST SIBERIAN PETROLEUM BASIN

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**Abstract**. Recent events, such as the commencement of commercial development of the Novoportovskoye, Bovanenkovskoye fields in the Yamal Peninsula, the creation of infrastructure, pipeline and railway transport facilities, and the decision to build an liquified natural gas plant for the Tambey group of fields, – all of it builds a case for increasing the exploration of the resource base of the northern territories of West Siberian petroleum basin and the adjacent Kara Sea offshore. Jurassic hydrocarbon exploration leads/prospects have not been sufficiently studied and require additional exploration.

The resource potential of Jurassic and Cretaceous reservoirs of South Kara region are estimated by various authors from 18,5 to 41,2 billion tons of oil equivalent. The systematization of information was executed from different sources and in the presented work was proposed the methodology for ranking the Jurassic sedimentary complexes.

The ranking of selected fundamental characteristics were divided into three groups depending on their priority. This method allowed to determine the most prospective intervals of the Jurassic section for further study.

The priority targets for further exploration in the Jurassic section based on the ranking results are the Middle Jurassic reservoirs of the Lower Bajocian-Upper Bathonian and Upper Aalenian-Lower Bajocian sedimentary complexes and the Upper Jurassic Callovian-Tithonian reservoirs.

**Key words**: ranking, exploration leads/prospects, Jurassic reservoirs, Western Siberia
**DOI:** https://doi.org/10.18599/grs.19.4.1

**For citation**: Panarin I.A. New Approach to Ranking of Jurassic Sedimentary Complexes of the Northern Part of the West Siberian Petroleum Basin. *Georesursy = Georesources.* 2017. V. 19. No. 4. Part 1. Pp. 302-310. DOI: https://doi.org/10.18599/grs.19.4.1

Despite the high level of production that has been maintained in this region for over 50 years, the West Siberian petroleum basin (PB) has an enormous potential for discovering new fields. The prospects of exploring for large oil and gas fields in West Siberian PB are mainly associated with its northern poorly developed territories of the Yamal and Gydan Peninsulas, and the adjacent Kara Sea offshore with deep sedimentary cover and unconventional structural-lithological hydrocarbon traps.

The low exploration maturity of the Jurassic reservoirs of the Yamal and Gydan petroleum areas (PA) and the adjacent Kara Sea offshore hinders forecasting the conditions for the formation of possible large and unique accumulations of oil and gas. Studies focusing on the architecture of main reservoirs, promising from the point of view of further hydrocarbon (HC) exploration, also remain insufficient. The relevance of research in this area is also supported by the fact that the majority of the fields are a rather complex object of research, and the details of their geological setting are not fully taken into account during exploration planning.

The resource base of the region under study is colossal and, naturally, many oil and gas producing companies strive to increase it through exploration in this region. An example of this is the discovery by Rosneft in 2014 of the Pobeda oil- gas-condensate field on Universitetskaya structure in Kara Sea offshore in Cretaceous and Jurassic deposits. According to preliminary estimates, the in-place volumes of the discovered field are 338 billion cubic meters of gas and more than 100 million tons of oil (www.rosneft.ru).

The gas potential of the entire Yamal region can reach 61-62 trillion $m^3$, and in addition, there are 13.8 trillion $m^3$ of in-place resources in the “marginal” and tight reservoirs (with gas recovery factors of no more than 0.25), including onshore Yamal – 22.5 trillion $m^3$/4.5 trillion $m^3$ (in-place/reserves), offshore – 39.1/9.3 trillion $m^3$ (Skorobogatov, 2013). The resource potential of the Jurassic and Cretaceous complexes of the South Kara PA is estimated at 18.5 to 41.2 billion tons of oil equivalent. The minimum and maximum estimates differ by more than 100%, which confirms the low exploration maturity of the region (Kazanenkov et al., 2014). N.Ya. Kunin estimated the resources of the Jurassic-Cretaceous deposits of the Gydan Peninsula at 40 billion tons of oil equivalent, mainly oil. According to A.R. Kurchikov and others (2012), the initial total hydrocarbon resources (ITR) of the Gydan

PA are more modest and amount to 9772.1 million tons of oil equivalent, including oil – 938.1 million tons, gas – 8181.1 billion $m^3$, and condensate – 652.8 million tons (Kazanenkov et al., 2014).

The share of hydrocarbon resources of the Jurassic complex is much less than that of the Cretaceous one and accounts for 10-20% of the total volume (Kurchikov et al., 2012). Thus, it is believed that the primary targets for exploration and further development of the discovered fields in this region are mainly associated with the Cretaceous productive horizons of Yamal, Gydan and the Kara Sea offshore, taking into account mainly their shallow depths and better reservoir properties vs. Jurassic prospects. This results in significantly lower exploration, development and commissioning costs. However, the emergence of new technologies that significantly accelerate drilling operations (including offshore) and allow cost savings, is expected to offset this difference in the near future. In addition, it is necessary to account for the rather rich Western (mainly US) experience of hydrocarbon production from rocks, which were traditionally considered non-reservoirs (shales, low permeability rocks).

Thus, it is time to evaluate and plan exploration programs taking into account the discovery potential in the Jurassic complex, which is regionally associated mainly with positive structures, such as swells and uplifts (Panarin, 2012).

In this paper, we propose to rank the Jurassic sedimentary complexes (SC) and identify the most promising of them. In total, according to the data of various researchers, six such complexes are identified: the Hettangian-Lower Pliensbachian, the Upper Pliensbachian, and the Toarcian-Lower Aalenian; the Upper Aalenian-Lower Bajocian; the Lower Bathonian-Upper Bathonian and the Callovian-Tithonian (Figure 1).

## Ranking methodology

To perform the ranking of the Jurassic sedimentary complexes, some basic characteristics were selected, which were then divided into three groups depending on the degree of priority (first, second and third order characteristics – Table 1). The characteristics of the **first order** include five most significant conditions:

- Presence of a high-quality seal – preservation conditions;
- Generation potential of the SC oil source unit – generation conditions;
- Specific productivity of similar complexes in adjacent areas;
- Distribution of SC reservoir rocks (local or regional);
- Number of identified reservoirs in SC.

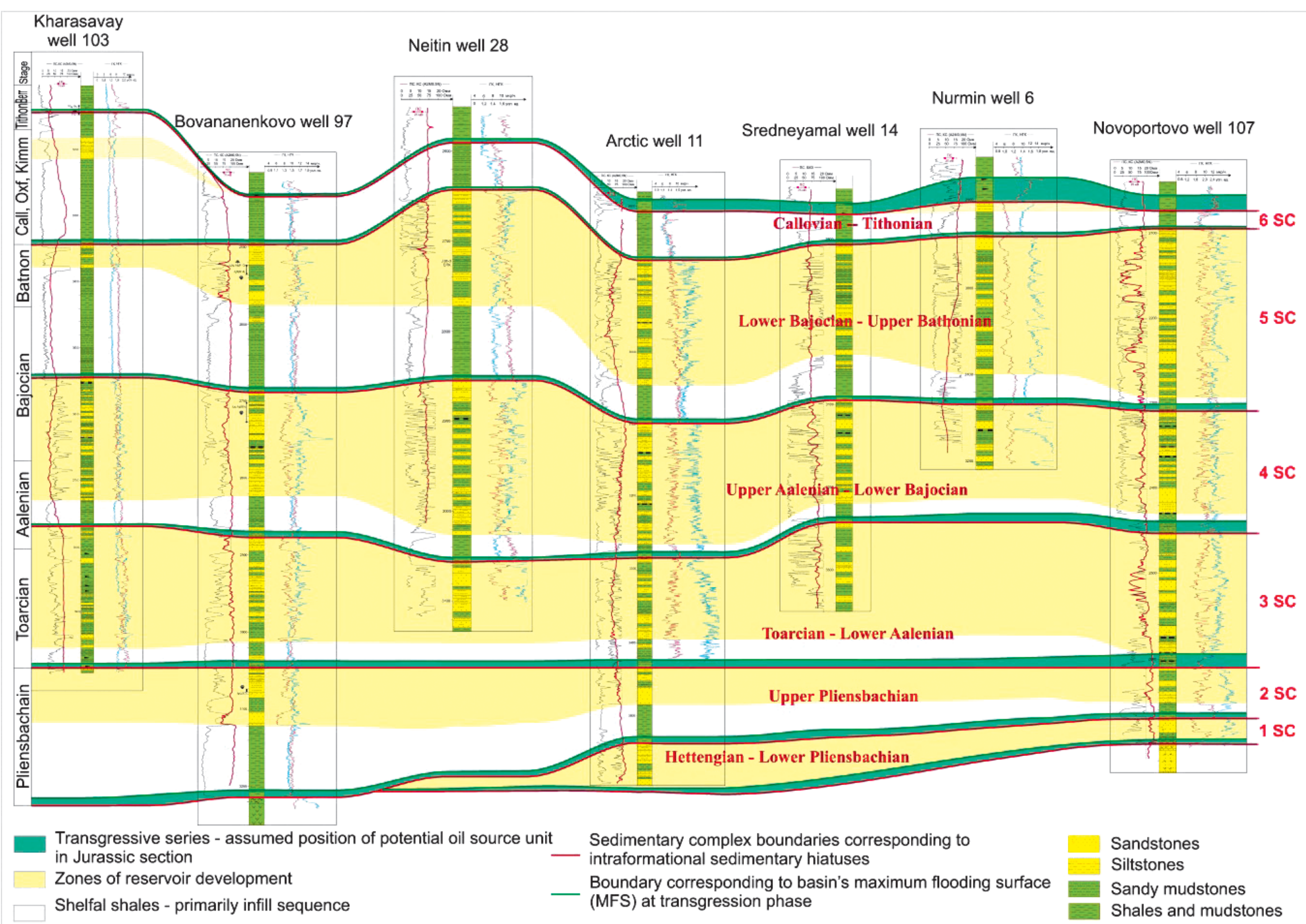


*Figure 1. Jurassic sedimentary complexes of the Northern part of Western Siberia PB*

| Field | Type | Productive zone (reservoir) | Productive horizon | Choke diameter, min/max, mm | Oil rate, min/max, $m^3/d$ | Gas rate, min/max, k $m^3/d$ | Condensate rate, min/max, $m^3/d$ |
|---|---|---|---|---|---|---|---|
| Bovanenkovo | G-C | $Yu_{12}$ | Zimny | 12 | - | 76,9 | 14,57 |
| Novoportovskoye | G-C | Yu11 | Sharapov | 5/16 | - | G+C 25.7/175.62 | |
| Bovanenkovo | G-C | Yu10 | Nadoyakha | | - | 111,01 | 41 |
| West Tambei | G-C | Yu6-7 | Vymsk | 10 | - | 44,98 | no data |
| Malygin | G-C | Yu6-7 | Vymsk | 10,5/20,3 | - | 28.7/544.5 | 6.8/34.9 |
| Nurmin (non-commercial flow) | O | Yu8 | Vymsk | no data | 0,1 | no data | - |
| Novoportovskoye | O | Yu2-3 | Malyshev | no data | 288 | 176 | 38 |
| Tazov | G-C | Yu2-3 | Malyshev | no data | - | 519 | no data |
| Kharasavay | G-C | Yu2-3 | Malyshev | 14/19 | - | 149/283 | no data |
| Maloyamal | G-C | Yu2-3 | Malyshev | 5,4 | - | 14,3 | no data |
| Maloyamal | G-C | Yu4 | Malyshev | 14,5 | - | 164,4 | no data |
| Yubilei | O | Yu2 | Malyshev | 9 | 13,2 | 13,7 | no data |
| Urngoi (Pestsov area) | G-C | Yu2 | Malyshev | 5 | - | 126 | 65 |
| Geophysics field | G-C | Yu2 | Malyshev | 15 | - | 68 | no data |
| Beregovoye | O | Yu2-3 | Malyshev | 5/8 | 9.6/15 | - | - |
| North Tambei | G-C | Yu2 | Malyshev | 20 | - | 77 | no data |
| Lenzit | O | Yu2 | Malyshev | no data | 0.225-5 | - | - |
| Urengoi (S.Pestsov area) | G-C | Yu3 | Malyshev | 5 | - | 35 | 7 |
| Russko-Rechensk | G-C | Yu1 | Vasyugan | 8/17 | - | 168/740 | 109/180 |
| Mangazei | O | Yu1 | Vasyugan | no data | 5.4/14.2 | - | - |
| Limbayakha | O | Yu1 | Vasyugan | 4 | 6.2/26.2 | - | - |
| Yarovoye | O-G-C | Yu1 | Vasyugan | 8 | 14.1/64.4 | 52/170 | 18.1/19.5 |
| Naumov | G-C | Yu1 | Vasyugan | 4/8 | - | 11/116 | 4/63 |

*Table 1. Productivity of Jurassic targets (Skorobogatov et al., 2003)*

**Second-order** characteristics:
- Total SC in-place volumes in the study region;
- Average reservoir rock porosity;
- Average reservoir rock permeability;
- Average SC net sand;
- Depth of occurence;
- Vertical zone heterogeneity (average NTG).

**Third-order** characteristics include:
- Environments of deposition (EODs);
- The predominant composition of the reservoir rock cement;
- Percentage of cement in inter-pore space.

The above characteristics did not include important properties complicating further development of reservoirs, for example, such fluid properties as viscosity, density, content of harmful components (hydrogen sulphide, carbon dioxide) or overpressure. This is due to the fact that oil or condensate of discovered reservoirs in Jurassic SCs have similar features – they are light or very light and have low viscosity, and also contain practically no harmful components. And almost all the reservoirs of the complexes have characteristic overpressure conditions. So in this particular case, these items were excluded from ranking.

To determine the priority level of each six SCs, the scoring system was used from 1 to 6. One point corresponds to the lowest priority, the six points to the highest priority.

Thus, all sedimentary complexes received their own score for each of the characteristics (Table 2). But for the final ranking, each score should be multiplied by a factor depending on the priority level of each characteristic – the first order parameters must be multiplied by the maximum coefficient of 3, the second order by the coefficient of 2 and the third order by the coefficient of 1 (Table 3). The sum of all points, with the weighting factor and the ranking results, is presented in Table 4.

## First-order characteristics

### Presence of quality seal

The maximum score (6) is assigned to the Malyshev Horizon, since the quality of the overlying Bazhenov and Abalak seals is probably beyond doubt. The second highest score (5) is Vymsky Horizon, considering the thick predominantly shale unit (up to 200 meters) of the Lower Bajocian-Upper Bathonian SC. Four (4) points were awarded to the Vasyugan Horizon, since the lower part of the Cretaceous complex contain shales of the Akhsky

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| Era | System | Subsystem | Stage (International scale) | Suite (Regional scale) |
|---|---|---|---|---|
| Mesozoic (Mz) | Jurassic (J) | Upper (J3) | Volgian (J3v) | Bazhenov (K1-J3bg) |
| | | | Kimmeridgean(J3rm) | Danilov (J2-3dn): Abalakov (J2-3ab) |
| | | | Oxfordian (J3o) | Danilov (J2-3dn): Abalakov (J2-3ab) |
| | | Middle (J2) | Callovian (J2k) | Danilov (J2-3dn): Abalakov (J2-3ab) |
| | | | Bathonian(J2bt) | Tyumen (J2tm): Malyshev (J2ml) |
| | | | Bajocian (J2b) | Tyumen (J2tm): Leontiev (J2ln) |
| | | | Aalenian (J2a) | Tyumen (J2tm): Vymsk (J2vm); Laidin (J1-J2ld) |
| | | Lower (J1) | Toarcian (J1t) | Jangod (J1dg) |
| | | | Pliensbachian(J1p) | Levin (J1lv) |
| | | | Sinemurian-Hettangian (J1s-g) | Zimny (J1zm) |

| Petroleum Area (PA) | Petroleum District (PD) | Field | Abalakov (J2-3ab) | Malyshev (J2ml) | Leontiev (J2ln) | Vymsk (J2vm) | Jangod (J1dg) | Levin (J1lv) | Zimny (J1zm) |
|---|---|---|---|---|---|---|---|---|---|
| Gydan PA (Petroleum Area) | Messov PD (Petroleum District) | North Parusov | | Gas-condensate Yu2 | | | | | |
| | | Minkhov | Assumed productivity Yu1 | | | | | | |
| | | East Messoyakha | Gas (potentially productive) Yu1 | | | | | | |
| | | East Minkhov | Assumed productivity Yu1 | | | | | | |
| | | Semakov | Assumed productivity Yu1 | | | | | | |
| | Napalkov PD | Geophysics field | | Gas-condensate Yu2 | | | | | |
| Yamal PA | Nurmin PD | Bovanenkovo | | Gas-condensate Yu2-3 | Gas-condensate Yu6 | Gas-condensate Yu7 | Gas-condensate Yu10 | | Gas-condensate Yu12 |
| | | Neitin | Oil (potentially productive) Yu1 | | | | | | |
| | | Kharasavay | | Gas-condensate Yu2-3 | | | | | |
| | Malygin PD | Malygin | | Gas-condensate Yu2-3 | Gas-condensate Yu6 | Gas-condensate Yu7 | | | |
| | Tambei PD | North Tambei | | Gas-condensate Yu2 | | | | | |
| | | West Tambei | | | Gas-condensate Yu6 | Gas-condensate Yu7 | | | |
| | | South Tambei | | Gas-condensate Yu2,Yu3, Yu4 | | Gas-condensate Yu7,Yu8 | | | |
| | South Yamal PD | Maloyamal | | Gas-condensate Yu2-3, Yu4 | | | | | |
| | | Novoportovo | | Oil-gas-condensate Yu2-6 | | | | Gas-condensate Yu11 | |
| Nadym-Pur PA | Urengoi PD | Medvezhie | | Oil Yu2 | | | | | |
| | | Samburg | Assumed productivity Yu1 | | | | | | |
| | | Urengoi | | Oil-gas-condensate Yu2, Yu3, Yu4 | | | | | |
| | | North Urengoi | Gas (potentially productive) Yu1 | | | | | | |
| | | Lenzit | | Oil Yu2 | | | | | |
| | Nadym PD | Yamburg | | Gas-condensate Yu2 | | | | | |
| | | Yurkhar | | Gas-condensate Yu2 | | | | | |
| Pur-Tazov PA | Tazov PD | Russko-Rechensk | Gas-condensate Yu1 | | | | | | |
| | | Mangazei | Oil Yu1 | | | | | | |
| | | Limbayakha | Oil Yu1 | | | | | | |
| | | Yarovoye | Oil-gas-condensate Yu1 | | | | | | |
| | | Naumov | Gas-condensate Yu1 | | | | | | |
| | | Zapolyrnoye | | Gas-condensate Yu2 | | | | | |
| | | Ust-Yamsovey | | Oil (potentially productive) Yu2; Gas (potentially productive) Yu4 | Gas (potentially productive) Yu5 | | | | |
| | | Tazov | Oil-gas (potentially productive) Yu1 | Gas-condensate Yu2-3 | | | | | |
| South Kara PA | | Pobeda | | Oil-gas-condensate Yu2-6 | | | Oil-gas-condensate Yu10-11 | | |

**Reservoir (zone) indexation:**
Vasyugan SC - Yu1;
Malyshev SC - Yu2, Yu3, Yu4;
Yuymsk SC - Yu5, Yu6, Yu7, Yu8, Yu9;
Nadoyakha SC - Yu10;
Sharapov SC - Yu11;
Zimny SC - Yu12.

Productive reservoirs: Oil; Gas-condensate; Oil-gas-condensate.
Potentially productive reservoirs: Oil; Oil-gas; Gas; (?) Assumed productivity.

*Table 2. Hydrocarbon systems of Jurassic SCs in the North of Western Siberia*

| Upper Jurassic (Callovian-Tithonian) | | | | |
|---|---|---|---|---|
| | | C1 | C2 | C1+C2 |
| OOIP | k tons | 12561 | 44938 | 57499 |
| OGIP | M $m^3$ | 12988 | 8794 | 21782 |
| OCIP | k tons | 3088 | 1366 | 4454 |
| OHCIP | k tons OE | 28637 | 55098 | 83735 |
| Middle Jurassic 1 (Lower Bajocian-Upper Bathonian) | | | | |
| | | C1 | C2 | C1+C2 |
| OOIP | k tons | 326082 | 212688 | 538770 |
| OGIP | M $m^3$ | 247417 | 668526 | 915943 |
| OCIP | k tons | 48559 | 128587 | 177146 |
| OHCIP | k tons OE | 622058 | 1009801 | 1631859 |
| Middle Jurassic 2 (Upper Aalenian-Lower Bajocian) | | | | |
| | | C1 | C2 | C1+C2 |
| OOIP | k tons | 0 | 0 | 0 |
| OGIP | M $m^3$ | 97409 | 245033 | 342442 |
| OCIP | k tons | 18490 | 32915 | 51405 |
| OHCIP | k tons OE | 115899 | 277948 | 393847 |
| Lower Jurassic 1 (Toarcian-Lower Aalenian) | | | | |
| | | C1 | C2 | C1+C2 |
| OOIP | k tons | 0 | 0 | 0 |
| OGIP | M $m^3$ | 3007 | 60531 | 63538 |
| OCIP | k tons | 467 | 9385 | 9852 |
| OHCIP | k tons OE | 3474 | 69916 | 73390 |
| Lower Jurassic 2 (Upper Pliensbachian) | | | | |
| | | C1 | C2 | C1+C2 |
| OOIP | k tons | 0 | 0 | 0 |
| OGIP | M $m^3$ | 5959 | 1152 | 7111 |
| OCIP | k tons | 362 | 70 | 432 |
| OHCIP | k tons OE | 6321 | 1222 | 7543 |
| Lower Jurassic 3 (Toarcian-Lower Aalenian) | | | | |
| | | C1 | C2 | C1+C2 |
| OOIP | k tons | 0 | 0 | 0 |
| OGIP | M $m^3$ | 12637 | 31758 | 44395 |
| OCIP | k tons | 1960 | 5220 | 7180 |
| OHCIP | k tons OE | 14597 | 36978 | 51575 |

*Table 3. Initial HCIP of Jurassic sedimentary complexes*

Suite (up to 100 meters thick), which are widespread, and predicted reservoirs will be mainly confined to lithological (non-structural) traps and will be sealed, including shales of the same SC (Abalak and Bazhenov shales). Three (3) points were awarded to the Zimny Horizon, as its preservation is provided by a thick Levin unit. Two (2) points are assigned to Sharapov Horizon, considering its insignificant average seal thickness (62.5 m).

1 point is given to the Nadoyakh Horizon with the minimum shale thickness (about 30 meters on average).

**Oil source rock generation potential**

The ranking was perfomed according to the average Corg content, so the targets were ranked in the following order: Nadoyakh (3.13%), Vymsky (1.52%), Malyshev (0.94%), Vasyugan (0.79%), Zimny (0.83%), Sharapov (0.75%).

**Specific productivity of similar complexes in adjacent areas**

The best indicators of productivity by the analog field are reservoirs of the Callovian-Tithonian SC. However, the productivity of the Lower Bajocian-Upper Bathonian reservoirs based on the production test results has been proven at least 12 zones (Table 1) of the sedimentary complex; in addition, the $Yu_{2-3}$ zone at the Novoportovskoye field is already in commercial production. Therefore, the highest score for this characteristic was assigned to the Malyshev reservoirs (6 points). The productivity of Vasyugan reservoirs (score of 5) in the study region is proved at 5 fields, the maximum gas productivity is recorded at the Russnekschenskoye field (up to 34,400 $m^3$ of gas/m). Commercial gas and condensate flows from the Vymsky reservoirs were obtained in the West Tambey and Malygin fields, so they were given a third degree of priority. The maximum productivity for the Lower Jurassic zones is related to the Sharapov reservoir (4,500 $m^3$ of gas / m) of the Novoportovskoye field (3 points), the minimum specific productivity indicator corresponds to the $Yu_{10}$ (Nadoyakhsky reservoir) of the Bovanenkovskoye field (1 point).

**Distribution of SC reservoir rocks**

Malyshev, Vymsk, Nadoyakh and Sharapov reservoirs were discovered in all wells of the study region, and taking into account their regional distribution, a maximum score of 6 was assigned to this characteristic. For locally distributed Zimny (SC deposits mainly fill the slopes of positive structures and deep depressions) and Vasyugan reservoirs (shaled out in many wells in the region) was awarded a score of 3.

**Number of fields with reservoirs identified in SC**

The largest number of fields with discovered hydrocarbon reservoirs in the Malyshev zones (17 fields plus 1 field with oil and gas shows). The Vasyugan sandstones are productive in 5 fields (Table 2) of the study region (plus oil and gas shows during drilling in 8 fields), the Vymsky complex is productive in 4 fields (in addition, gas shows were recorded at the Ust-Yamsoveiskoye field). The productivity of the Zimny reservoir was proven only in one reservoir of the Bovanenkovskoye field (1 point), Sharapov – in the Novoportovskoye and the Pobeda fields, the Nadoyakh – in the Bovanenkovskoye and Pobeda fields. The ranking of the Lower Jurassic Sharapov and Nadoyakh reservoirs was made accounting for the number of discovered reservoirs: Sharapov – 3 points (8 reservoirs), Nadoyakh – 2 points (3 reservoirs).

## Second-order characteristics

**Total resources of the SC in the study region**

The estimate of the resource base in Jurassic complexes used data from 2014 State Reserves Balance.

| Name of sedimentary complex (reservoir name) | SC № | First-order characteristics | | | | | Second-order characteristics | | | | | | Third-order characteristics | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Presence of quality seal | Oil source generation potential | Specific productivity in adjacent areas | Distribution of sedimentary complex reservoir rocks | Number of fields w/reservoirs identified in SC / with oil/gas shows | Total SC HC voulmes in study region | Average porosity | Average permeability | Average net sands of sedimentary complex | SC depth of occurrence | Reservoir vertical heterogeneity (NTG) | Enviroments of deposition | Cement composition and content in reservoir rocks | |
| | | Thickness, m | Corg/DOM content, % | gas k $m^3$ / m or oil $m^{3/}$ d/m | Regional / Local | Unit | M tons OE | % | mD | m | m | fraction | | Dominant composition | Content, % |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| **Callovian-Tithonian (Vasyugan)** | **1** | 7-90 | 1.44 / 0.35-1.21 | gas 34.4 k $m^3$ / m (Russko-Rechensk) oil 3.0 $m^3$ /d / m (Yarovoye) | Local | 5 / 8 | 84 | 8-28, average 12-18 | 0.01-1690, average 0.01-100 | 21,5 | 2450-3150 *top tvdss | 0,23 | Shallow-marine | clay-carbonate, carbonate-clay | 3-10 |
| **Lower Bajocian-Upper Bathonian (Malyshev)** | **2** | first tens to 200 m average 80-150, property degradation towards basin periphery | 2.14 / 0.53-1.33 | gas 7.7 k $m^3$ / m (Tazov); oil 4.3 $m^3$-/d / m (Novoportovo) | Regional | 17 / 1 | 1632 | 8-27, average 13-17 | 0.01-214, average 0.01-10 | 67,0 | 2520-3570 *top tvdss | 0,32 | Continental, shallow-marine | Carbonate-clay | 5-15 |
| **Upper Aalenian-Lower Bajocian (Vymsk)** | **3** | 60-150, w/sandstone, siltstone interlayers | 2.17 / 0.64-2.38 | gas 7.1 k $m^3$ / m (Malygin); | Regional | 4 / 1 | 394 | 8-23, average 11-16 | 0.01-98, average 0.01-1 | 76,5 | 2550-3700 *top tvdss | 0,45 | Continental, shallow-marine | Clay, carbonate-clay | 5-15 |
| **Toarcian-Lower Aalenian (Nadoyakha)** | **4** | first tens to 60, increase of sand to the south | 2.03 / 0.96-5.2 | gas 1.8 k $m^3$ / m (Bovanenkovo) | Regional | 2 (3 reservoirs) / 0 | 73 | 8-24, average 10-15 | 0.01-81, average 0.01-1 | 61,7 | 2770-3911 *top tvdss | 0,41 | Continental, shallow-marine | Carbonate-clay, clay-carbonate | 5-15 |
| **Upper Pliensbachian (Sharapov)** | **5** | 40-85 | 1.44 / 0.2-1.2 | gas 4.5 k $m^3$ /m (Novoportovo); | Regional | 2 (8 reservoirs) / 0 | 8 | 8-21, average 9-15 | 0.01-73, average 0.01-1 | 39,0 | 2950-4200 *top tvdss | 0,37 | Continental, shallow-marine | Carbonate-clay | 3-10 |
| **Hettangian-Lower Pliensbachian (Zimny)** | **6** | 0-207 | average - 0.83; max - 3.0 | gas 2.5 k $m^3$ + cond 0.5 $m^3$ /d/ m (Bovanenkovo); | Local | 1 (1 reservoir) / 0 | 52 | 8-18, average 8-11 | 0.01-62, average 0.01-0.1 | 31,3 | 3000-6900 *top tvdss | 0,59 | Mostly continental | Clay | 1-5 |

*Table 4. Characteristics of sedimentary complexes*

The volumes are presented in Table 3. The ranking based on this characteristic was performed in accordance with the total hydrocarbon volumes of the explored and preliminary estimated categories (ABC1 + C2) in tons of oil equivalent. The summation of HC resources was based on the following assumption 1 ton of OE here corresponds to 1000 m$^3$ of gas.

**Average porosity of reservoirs**

Average values of porosity from G.G. Shemin study for the reservoirs of sedimentary complexes are: Vasyugan (15%), Malyshev (15%, but with a lower cutoff value), Vymsk (13.5%), Nadoyakh (12.5%), Sharapov (12%), Zimny (9.5%). Targets are ranked in the appropriate order (the "youngest" complexes have the best reservoir properties and vice versa).

**Average permeability of reservoirs**

A similar trend is observed for permeability. Permeability of reservoir rocks decreases with the subsidence depth. The average permeability cutoff values: Vasyugan (0.01-100 mD), Malyshev (0.01-10 mD). The average ranges for permeability variation of the SC four lower reservoirs coincide, however, the maximum recorded values of the Vymsk, Nadoyakh, Sharapov and Zimny ones decrease with depth and are 98 mD, 81 mD, 73 mD, 62 mD, respectively.

**Average net sands**

The average thickness of the reservoirs in the Jurassic sedimentary complexes was determined from a sample of wells in the Yamal fields – Kharasavey, Bovanenkovo, Neytin, Arctic, Sredniamalsk, Nurmin, Novoportovo. The results of the SC net sand averaging in Yamal wells: Vasyugan (21.5 m), Malyshev (67 m), Vymsk (76.5 m), Nadoyakh (61.7 m), Sharapov (39 m), Zimny (31.3 m).

**SC depth of occurrence**

For the further exploratory well planning and determination of capital costs for drilling, it is extremely important to rank the prospective complexes by the depths of occurrence. With increasing depths of productive deposits, with all other things being equal, the likelihood of field development and subsequent commercial hydrocarbon production from deep-seated reservoirs can be significantly reduced. In this case, the oldest Jurassic sedimentary complexes have correspondingly higher depths of occurrence.

**Zone vertical heterogeneity**

An important indicator of the vertical heterogeneity of the formation in terrigenous rocks is the net-to-gross ratio (NTG). For the ranked sedimentary complexes, this factor was determined for the wells of Kharasavei, Bovanenkovo, Neytin, Arctic, Sredniamalsk, Nurmin, Novoportovo fields. The final order of the Jurassic complexes according to this characteristic in the order of decreasing NTG is represented as follows: Zimny (0.59), Vymsk (0.45), Nadoyakh (0.41), Sharapov (0.37), Malyshev (0.32) and Vasyugan (0.23).

## Third-order characteristics

The ranking of this group of characteristics was based on the studies of G.G. Shemin, A.Yu. Nekhaev, A.L. Beisel published in 2011 (Shemin et al., 2011).

**EODs**

The prioritizing of this characteristic assumed that rocks of shallow-marine genesis have the best reservoir properties, usually with better sorted sand material, and prediction of the presence and distribution of sand bodies of shallow-marine origin is somewhat simpler than predicting, for example, the position of river channels. The complexes under study are characterized by three depositional environments – shallow-marine, mixed (shallow-marine and continental) and exclusively continental. Thus, the Jurassic complexes formed in shallow-water environments were assigned a maximum score of 6, mixed conditions – 4 and continental – 2 points.

**Dominating composition of sedimentary rock cement**

The greatest negative impact on the further development of reservoirs is the content of clay cement in the inter-pore space. This is especially evident if the composition of the clay admixture is not uniform, the various forms of clay minerals create serious obstacles to the fluid movement. In addition, clay minerals can react differently to injection of water into the reservoir in order to maintain reservoir pressure (RPM). For example, mixed-layer minerals (montmorillonite) can increase in volume several times, plugging the vug-pore space, and chlorite is less susceptible to this, or not at all. For the carbonate cement the development solution is standard – hydrochloric acid treatment of the reservoir (RAT). Thus, the ranking by this characteristic relied on the clay component content in reservoir rocks. The result of the Jurassic target ranking is as follows: 6 points – Vasyugan (cement is mainly clay-carbonate, less often carbonate-clay), 5 points – Nadiyakh (carbonate-clay, in some cases clay-carbonate), 4 points – Sharapov (carbonate-clay, but with a lower percentage of cement content), 3 points are Malyshev (carbonate-clay), 2 points are Vymsk (mostly clay, less often carbonate-clay), 1 point is Zimny (exclusively clay cement).

**Cement content in reservoir rocks**

By the cement percentage in the six Jurassic complexes, 3 intervals of values are allocated. The maximum priority corresponds to the minimum cement content and vice versa. Six (6) points were assigned to the Zimny target (1-5%), 4 points to Vasyugan and

| SC name | № | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Callovian-Tithonian (Vasyugan) | 1 | 4 | 3 | 5 | 3 | 5 | 4 | 6 | 6 | 1 | 6 | 1 | 6 | 6 | 4 |
| Lower Bajocian-Upper Bathonian (Malyshev) | 2 | 6 | 4 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 | 2 | 4 | 3 | 2 |
| Upper Aalenian-Lower Bajocian (Vymsk) | 3 | 5 | 5 | 4 | 6 | 4 | 5 | 4 | 4 | 6 | 4 | 5 | 4 | 2 | 2 |
| Toarcian-Lower Aalenian (Nadoyakha) | 4 | 1 | 6 | 1 | 6 | 2 | 3 | 3 | 3 | 4 | 3 | 4 | 4 | 5 | 2 |
| Upper Pliensbachian (Sharapov) | 5 | 2 | 1 | 3 | 6 | 3 | 1 | 2 | 2 | 3 | 2 | 3 | 4 | 4 | 4 |
| Hettangian-Lower Pliensbachian (Zimny) | 6 | 3 | 2 | 2 | 3 | 1 | 2 | 1 | 1 | 2 | 1 | 6 | 2 | 1 | 6 |

*Table 5. Ranking of sedimentary complexes*

| SC name | № | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Callovian-Tithonian (Vasyugan) | 1 | 12 | 9 | 15 | 9 | 15 | 8 | 12 | 12 | 2 | 12 | 2 | 6 | 6 | 4 |
| Lower Bajocian-Upper Bathonian (Malyshev) | 2 | 18 | 12 | 18 | 18 | 18 | 12 | 10 | 10 | 10 | 10 | 4 | 4 | 3 | 2 |
| Upper Aalenian-Lower Bajocian (Vymsk) | 3 | 15 | 15 | 12 | 18 | 12 | 10 | 8 | 8 | 12 | 8 | 10 | 4 | 2 | 2 |
| Toarcian-Lower Aalenian (Nadoyakha) | 4 | 3 | 18 | 3 | 18 | 6 | 6 | 6 | 6 | 8 | 6 | 8 | 4 | 5 | 2 |
| Upper Pliensbachian (Sharapov) | 5 | 6 | 3 | 9 | 18 | 9 | 2 | 4 | 4 | 6 | 4 | 6 | 4 | 4 | 4 |
| Hettangian-Lower Pliensbachian (Zimny) | 6 | 9 | 6 | 6 | 9 | 3 | 4 | 2 | 2 | 4 | 2 | 12 | 2 | 1 | 6 |

*Table 6. Total score using characteristics of 1st, 2nd, 3d order*

| SC name | № | Total score | Rank |
|---|---|---|---|
| Callovian-Tithonian (Vasyugan) | 1 | 124 | 3 |
| Lower Bajocian-Upper Bathonian (Malyshev) | 2 | 149 | 1 |
| Upper Aalenian-Lower Bajocian (Vymsk) | 3 | 136 | 2 |
| Toarcian-Lower Aalenian (Nadoyakha) | 4 | 99 | 4 |
| Upper Pliensbachian (Sharapov) | 5 | 83 | 5 |
| Hettangian-Lower Pliensbachian (Zimny) | 6 | 68 | 6 |

*Table 7. Results of Jurassic sedimentary complexes ranking*

Sharapov (3-10%), 2 points to Malyshev, Vymsk and Nadoyakh. All Jurassic sedimentary complexes were ranked for each of the 14 characteristics (Table 4). For the final ranking, each obtained score must be multiplied by a factor depending on the degree of priority of each characteristic – the first order must be multiplied by the maximum factor of 3, the second order by the factor of 2 and the third order by factor of 1 (Table 5). The sum of all the scores with the weighting factor is presented in Table 6, the ranking result is in Table 7.

## Conclusions

Thus, the primary targets of further exploration in the Jurassic section based on the ranking are the Middle Jurassic reservoirs of the Lower Bajocian-Upper Bathonian and Upper Aalenian-Lower Bajocian sedimentary complexes, and the third priority exploration targets are the Upper Jurassic Callovian-Tithonian reservoirs. The most promising Lower Jurassic SC is certainly the Toarcian-Lower Aalenian, primarily due to the enormous generation potential of the Toarcian shales, and it is still premature to speak about the potential of underlying complexes.

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*Manuscript received 25 January 2017;*
*Accepted 25 August 2017; Published 30 November 2017*