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Thermal maturity of uppermost Middle Jurassic sediments in the West Siberian basin

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Abstract

More than 1500 measurements of vitrinite reflectance (R^o_{vt}), along with mathematical modeling and computing, have been used to map the uppermost Middle Jurassic sediments of the West Siberian basin according to thermal maturity (catagenesis). The thermal maturity varies within the grades PC_3 to AC_2. Sediments are the least mature along the margins of the basin, and the maturity grade increases progressively toward its central and northern parts (grades MC^2_1–MC_2). It reaches a maximum in the north (AC_2), where the sediments which subsided to large depths became exposed to high temperatures and pressures. The maturity zones of Jurassic sediments in the West Siberian basin form a typical pattern of regional catagenesis.

Keywords: West Siberian basin; Jurassic sediments; organic matter; thermal maturity; catagenesis

Introduction

Organic matter (OM) undergoes a continuous natural process of maturation (catagenesis) under the effect of high temperatures and pressures, with voluminous release of liquid and gaseous hydrocarbons, at certain stages of the sedimentary evolution. Correlation between thermal maturity and petroleum potential of reservoirs was discovered over 150 years ago (Rogers, 1863). Later David White (1915) distinguished biological and chemical phases of OM maturation and suggested a theory of carbon ratio, or the percentage of fixed carbon, as a criterion of thermal maturity and coalification of sediments related to the occurrence of oil and gas. Ivan Gubkin appreciated the coalification theory of White and developed it in his book *Treatise of Oil* first published in 1932 (Gubkin, 1975). He divided the coalification process into stages, with generation of different types of oil at each stage and dry gas formation in reservoirs of relatively high thermal maturity (Gubkin, 1975). Many Russian petroleum scientists (V.V. Veber, M.V. Abramovich, V.A. Sokolov, N.B. Vassoevich, V.S. Vyshemirsky, A.E. Kontorovich, S.G. Neruchev, A.A. Trofimuk, and others) further elaborated Gubkin's model and demonstrated that maturation controls the type (oil or gas) and composition of generated hydrocarbons and their accumulation in reservoirs. Thus, the maturation conditions have important implications for many issues in petroleum geology.

Thermal maturity of Jurassic sediments in the West Siberian basin has been largely studied (Ammosov et al., 1987; Bostrikov and Fomichev, 1991; Ermakov and Skorobogatov, 1990; Fomin, 1992; 1995; Kontorovich et al., 1967a,b; 1975; Lopatin and Emets, 1984; Parparova et al., 1981; Rovenskaya and Nemchenko, 1989). However, most of publications are restricted to specific areas of the basin. Alexei Kontorovich and his group were the first to synthesize the available data on catagenesis on the regional-scale in their early works (Kontorovich et al., 1967a, 1975) and continued the research till recently (Kontorovich et al., 2009). They have successfully predicted the maturation history of Jurassic reservoirs in Arctic and Subarctic West Siberia. Since then a wealth of data has been collected which allows updating the earlier models considerably. More than 1500 measurements of vitrinite reflectance (R^o_{vt}), along with mathematical modeling and computing, have been used to map the thermal maturity (catagenesis) of uppermost Middle Jurassic sediments in the West Siberian basin. The map was compiled with reference to the cited publications, following the method reported by Kontorovich et al. (2009). The machine-aided contouring results for some areas were corrected and smoothed.

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Results

Upper Jurassic sediments (Tyumen' Formation and its equivalents) were stripped in numerous wells within the West Siberian petroleum basin. Their thermal maturity varies within grades PC_3 to AC_2 (Fig. 1, the maturity grades are color-coded; the sizes (orders) of structures mentioned in the text below are specified in Map and Legend). The sediments in the north, where they subsided to relatively large depths and became exposed to high temperatures and pressures, are more mature than in the marginal, southern, and even central parts of the basin (MC_2 to AC_2 against PC_3–MC_1^2, respectively). The maturity grade is the lowest (low PC_3, $R^o_{vt} < 0.50\%$) on the basin periphery, while vitrinite reflectance (R^o_{vt} –0.46%) in the southern Baraba–Pikhtovaya monocline in the Tatiana area corresponds to medium PC_3. The zone of incipient maturation (protocatagenesis) extends eastward and spans the southern Teguldet semisyncline and then continues northward, in a broad belt, across the Fore-Yenisei monocline along the eastern basin margin as far as the Yenisei–Khatanga regional trough, where R^o_{vt} is 0.40–0.48% (PC_3) within the Sukhaduda, Dzhangoda, and Tundra areas. Mathematical modeling predicts that the PC_3 zone extends further into the Fore-Taimyr monocline. The maturity grade is within PC_3 over a large part of the Tyumen' monocline (western part of the basin) but corresponds to high PC_3–low MC_1^1 ($R^o_{vt} = 0.49$–0.50%) south of the Shaim basement uplift (Leushin and Polovinka areas). Another zone of lowest maturity may exist in the western Trans-Ural monocline and continue northward as far as the Paikhoi–Novaya Zemlya monocline.

The uppermost Middle Jurassic sediments show thermal maturity within the MC_1^1 grade ($R^o_{vt} = 0.50$–0.65%), mainly in the southern and central West Siberian basin, the highest in the southern North-Mezhovka monocline (Tatar area). The same maturity grade is observed further in the north (Pakhomov, Mezhovka, Bochkarev, Chekov, and Ostrov areas). A zone of the MC_1^1 grade extends in a narrow N–S belt across the Mezhovka nose (plunging anticline), with the Vitin, Dedov, Bergul, Upper Tara, and Maloicheskaya areas, covers the western Chuzik-Chizhap saddle (Lvov, Solonovka, Kulga, South Tabagan, Tambai, Gerasimovka, Urman, Kalinovaya, Ponomarevo, and Pud areas), and almost the entire Shinginka saddle (Selveika, Selimkhanov, Yubilei, Luginets, and Kyka areas). Another MC_1^1 zone extends over the eastern Middle Vasyugan swell (Myldzha, Kolensale, Ragozin, Middle Vasyugan, and Selskaya areas) and then westward from the Chuzik-Chizhap saddle, where the sediments are slightly less mature (low–medium MC_1^1 grade).

The same MC_1^1 maturity grade is inferred for sediments eastward from the southern North Mezhovka monocline over the northern Baraba–Pikhtovaya monocline (Baraba, Tenis, and Goluba areas), as well as the adjacent parts of the Kalgach swell (Parbig) and the Chuzik-Chizhap saddle. Sediments in the northeastern Parabel' swell (Kolpashevo, Upper Karza, Basma, Kalchan, Parabel', Silga, and North Silga areas) reach slightly higher maturity within the same grade (high MC_1^1). The thermal maturity within the Snezhnaya and Trostniki areas is transitional from MC_1^1 to MC_1^2 ($R^o_{vt} = 0.65\%$). A zone of medium–high MC_1^1 grade spans the southern North Parabel' monocline (Kochebil and Kargasok areas), the Zaikino saddle (North Kolpashevo area), and the southern Paidugina swell (Beregovaya and Kurzhin areas).

The zone of medium MC_1^1 maturity spans the whole East Paidugina basin (Elan and Karba areas) and the Vladimirovka nose (Nyarga, Mart, and Vezdekhod areas). The OM maturity grade decreases eastward and corresponds to low–medium MC_1^1 in the Chachan and Yar areas, and in wells Vostok-3 and 4. The maturity grade is the same in the southern Kurzhinka ridge (Azharma, Zapadnaya, Korbyl, Kananak, and Gromov areas) and is higher (high MC_1^1) in well Vostok-1. The MC_1^1 zone fully covers the Pyl'-Karamin swell, with medium MC_1^1 in its south (Pulsetsk, Chimulyak, Malyi Chimulyak, and Sibkrai areas) and low MC_1^1 in the north (Pyl'-Karamin and Kulynigol areas), as well as the entire Karama saddle (Kotyg-Egan, Sabun, Lariyak, Emtor, and Lineinaya areas). The maturity is slightly higher (high MC_1^1) further south and in the western Ust'-Tym depression (Trassovaya, Murasov, and Vartovsk areas). The low MC_1^1 (Vakh and Poiskovaya) and medium MC_1^1 (Mygytyn, Lyukpai, Koshil, and Ob areas) maturity grades are inferred for most of the Aleksandrov arch. The maturity increases to the west toward the Koltogory trough and reaches high MC_1^1 in the Protochnaya, Nadezhda, South Okhteuriev, and Severnyi areas. A zone of medium MC_1^1 appears also north of the Aleksandrov arch (Khokhryakov, South Enitor, and Enitor areas).

The MC_1^1 maturity grade is common to sediments over the greater part of the Krasnyi Selkup monocline: high MC_1^1 in its south (North Khokhryakovo, Upper Kolik-Egan, East Sabun, North Sabun, Priozernaya, and Upper Karalka areas) and slightly north of these areas (Tolka and North Tolka), and low–medium MC_1^1 in its east, within the adjacent parts of the Fore-Yenisei monocline (Vanzhil, North Lymbel', and Kys-Egan areas). Then the MC_1^1 zone continues in the northern direction, toward the Yenisei–Khatanga basin, where the maturity grade corresponds either to low MC_1^1 (Lower Kheta and Zimnyaya, in the Ust'-Port basement uplift) or to high MC_1^1 (Maya, Messoyakha, and South Solenino areas). MC_1^1 to MC_1^2 transition ($R^o_{vt} = 0.65\%$) occurs in the Gorchinka and Pelyatka areas. Mathematical modeling predicts eastward and northward extension of this zone, where it spans the southern and western sides of the Fore-Taimyr monocline.

The zone of the same MC_1^1 maturity grade covers almost the whole Krasnoleninskii monocline: low MC_1^1 in the south (Omsk, Novolyubinsk, Sargat, and Tarbazhin areas) and in the adjacent parts of the Tyumen' monocline (Malinovka, Vikulovo, and Mikhailovka areas); medium MC_1^1 in the Pokrovka,