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RESEARCH PAPER

Hydrogeochemistry of the Arctic areas of Siberian petroleum basins

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Abstract: The available hydrogeochemical data collected over the past four decades in Siberian Arctic areas were analyzed and interpreted comprehensively for the first time, through data ranking, evaluation and analysis, systematic estimation of region, altitude background and abnormal value, and calculation of element molar ratio, different kinds of correlation coefficients in water proximity were estimated. Paleohygdrogeological reconstructions of the Siberian sedimentary basins suggest the presence of three water genetic types in petroleum deposits: (1) Waters that formed during marine sedimentation, (2) Waters of meteoric origin that infiltrated the basin and were involved in supergene processes in the geological past, (3) Waters produced by condensation from a hydrocarbon mixture. Hydrogeochemical patterns of petroleum deposits are controlled by the long geological evolution in the water-rock-gas-organic matter system. Sodium-chloride bicarbonate, sodium chloride, calcium chloride groundwaters, and other types of brines with the total salinity of 0.2-350 g/L are distributed in the Siberian Arctic sedimentary basins. Comparative analysis of groundwaters and brines in the Siberian Arctic revealed a group of sodium chloride water samples had a total salinity of over 250 g/L, suggesting the formation of the brine was related to leaching of evaporite rock. Hydrogeochemical data indicate that composition of the brine has varied dramatically with their evolution. Mesozoic groundwaters and brines of Anabar-Laptev basin and West Siberia existed only in the beginning of their chemical evolution.

Key words: Arctic; Siberia; petroliferous basins; hydrogeology; aquifer; hydrogeochemical patterns; groundwater evolution

1. Geological background

Arctic sedimentary basins received widespread attention for the tremendous hydrocarbon generating potential. At the present, commercial petroleum pools have been found in many basins worldwide: Athabasca, Beaufort-Mackenzie, West Siberian, Sverdrup and others in Canada. The Arctic commercial reserves of the studied basins are distributed widely from the ancient Precambrian to Quaternary strata. According to the IPGG SB RAS latest estimation, the initial recoverable hydrocarbon reserves of the Russian Arctic sector are over 706×10^8 t for oil and over 200×10^{12} m^3 for gas[1]. The oil and gas exploration in Siberian Arctic sedimentary basins has been initiated, Pobeda Field was discovered on the Kara Sea Shelf (New Kara Sea oil province), moreover, formation testing wells in the Yenisei-Khatanga Basin and Anabar-Laptev Basin are planned to be drilled in 2017 – 2018.

Depending on many factors, hydrogeological structures of the Arctic sedimentary basins are complex. Vast measured data on the groundwater and gas composition have been accumulated since the beginning of petroleum exploration in sedimentary basins of Siberia, including the studied Arctic regions (Fig. 1). Hydrogeological characteristics of the North Slope Alaska, Beafort-Mackenzie, Sverdrup, Canadian Shield, Alberta, Athabasca and other areas[2–8], and hydrogeochemical features of Siberian petroleum sedimentary basins were investigated previously[9–19]. Based on these, main patterns have been established.

Known hydrodynamic settings indicate hidden groundwater discharge in the West Siberian basin. The water-driven system of the basin has undergone several cycles of water exchange. Two main groundwater flows are highlighted: expelled waters in the west from the reservoir boundary of clay seals and meteoric infiltration waters in the east from the basin margin. After the analysis of the reservoir pressure distribution, these waters mix and discharge through faults due to crossflows in a zone of the Koltogorsk-Urengoy graben rift. The idea is confirmed by the Northern Arch and other several structures, where abnormally high and high reservoir pressures exist in the Aptian-Albian-Cenomanian aquifer system[20–21]. Groundwater discharge of the Pre-Mesozoic rock and aquifers in the lower part of the Mesozoic (Triassic and Jurassic) occurs to the overlying sediments due to successive vertical crossflows.

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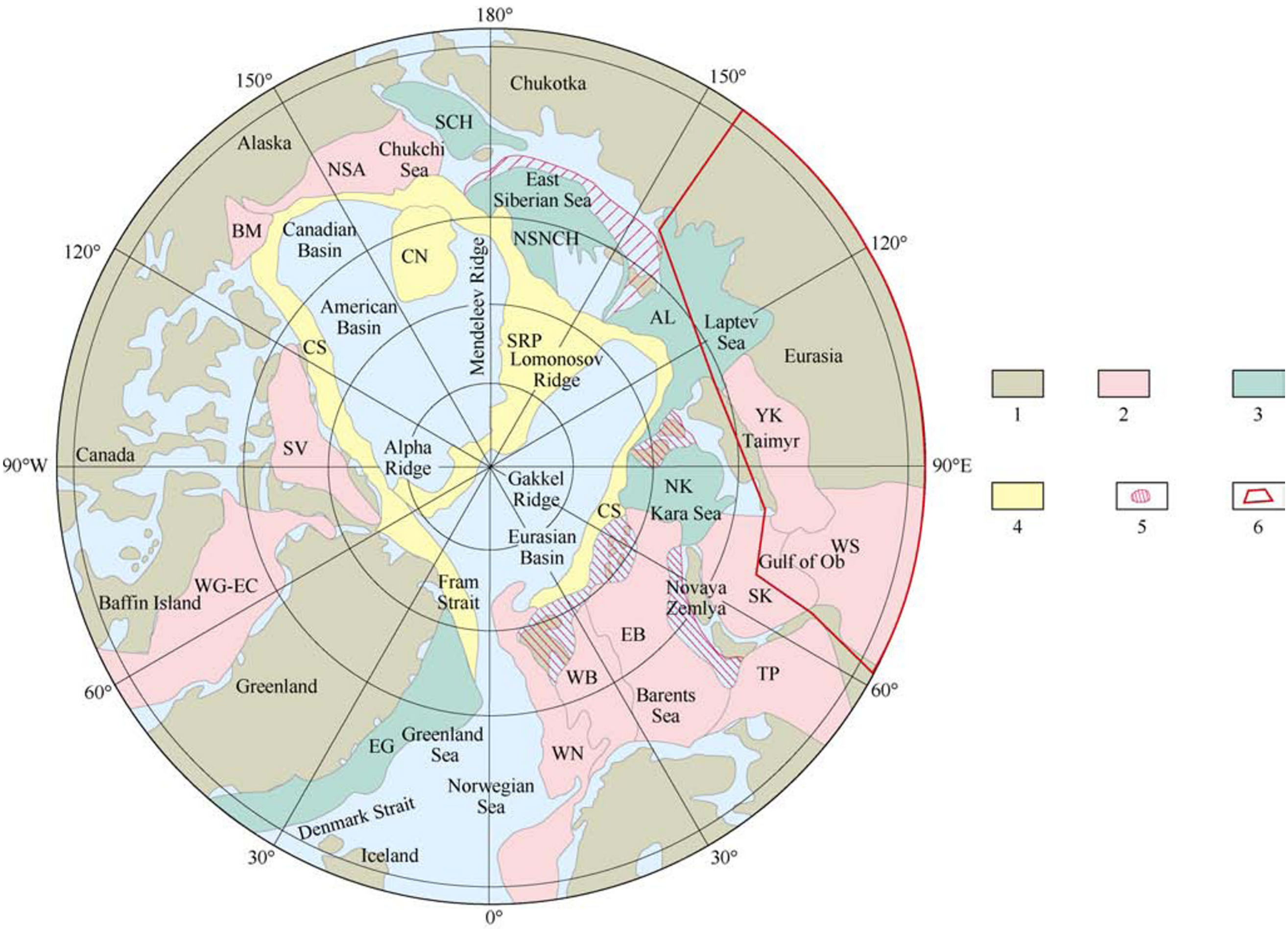

Fig. 1. Proved and potential petroliferous basins in the Arctic Ocean and adjacent land[23]. 1 – onshore areas, 2 – discovered petroliferous basins in pink: West Barents (WB), East Barents (EB), West Norwegian (WN), Timan-Pechora (TP), South Kara (SK), West Siberian (WS), Yenisei-Khatanga (YK), North Slope Alaska (NA), Beaufort-Mackenzie (BM), Sverdrup (SV), and West Greenland-Eastern Canadian (WC-EC); 3 – offshore promising petroleum basins in green: North-Kara (NK), Anabar-Laptev (AL), New Siberian-North Chukchi (NSNCH), South Chukchi (SCH), and East Greenland (EG); 4 – potential petroliferous basins in yellow: of the submarine ridges and pits (SRP), continental slope (CS), and Chukchi-Northwind (CN); 5 – dashed areas are submarine and insular rises with hydrocarbon seeps; 6 – the study area.

Groundwaters in the Hauterivian-Barremian and Aptian-Cenomanian aquifers flow along the zones of middle and low gradients in the Kara Sea. Given that the thickness of the Turonian-Paleogene seal decreases in the northern Gydan Peninsula, in the offshore area the Cenomanian aquifer is likely to spread below the Quaternary marine deposits, suggesting the aforementioned groundwater discharge and related underlying aquifers within the Kara Sea. A hidden local discharge is also possible in the boundary of the Yenisei-Khatanga basin and its adjacent areas, particularly in the northern Gydan Peninsula[17–18, 22]. In some areas, the Cenomanian sediments spread beneath the Quaternary sediments, and the Aptian-Albian-Cenomanian aquifer waters recharge a supergene zone through the local areas of thawing permafrost (taliks or unfrozen channels on river valleys). In general, Salinity increases or decreases distinctly with depth, or shows a more complex change trend. Salinity decreases in the northern Nadym-Taz interfluve, but slightly increases in the south within the depths of 1000 - 2500 m. A salinity peak is observed in the Upper Jurassic sediments, especially in the depths of 2 800 – 3 200 m. Salinity drops again in the Lower-Middle Jurassic sediments, although not in all geological structures[21].

Mesozoic sedimentary succession of the Yenisei-Khatanga basin is a continuation of the West Siberian structures in the east and has similar hydrogeochemical conditions. Brines leached from salts are widespread near the Mesozoic and Paleozoic salt diapirs in the Nordvik salt dome area (Anabar-Laptev Basin territory).

Paleohygdrogeological reconstructions of the Siberian sedimentary basins suggest the presence of three water genetic types in petroleum deposits: (a) Waters that formed during marine sedimentation, (b) Waters of meteoric origin that infiltrated the basin and were involved in supergene processes in the geological past, (c) Waters produced by condensation from a hydrocarbon mixture. Hydrogeochemical patterns of reservoirs are controlled by the long geological evolution in the water-rock-gas-organic matter system, that is to say current groundwater and brine are of secondary nature chemically based on the conducted researches.