Effect of Trap Magmatism on the Geochemistry of Gases in the North-Western Regions of the Siberian Platform

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Abstract. Results of the studies into the effect of trap magmatism on the geochemistry of gases (free and dissolved in water) and their zoning within the boundaries of north-western regions of the Siberian Platform are reported. The maximal paleotemperatures at the moment of trap intrusion reached 650 °C at the contact for the major productive horizons: Silurian (Devilish), Ordovician (Baikit), and Cambrian (Deltulino-Tanachinsky, Abakunsky, and Moktakonsky). Hydrocarbon gases in the free and water-dissolved phases were subjected to degradation in the most active form. For instance, carbon dioxide dominates, with its content more than 90 vol. % and methane content up to 5 vol. % in intrusion-affected zone at a distance up to 100 m, while at a distance of 250 m CO₂ concentration decreases to 30 vol. %, and CH₄ concentration increases to 60-70 vol. %. No significant effect of the thickness of intrusion on gas composition was revealed.

1. Introduction

The organic matter of sedimentary rocks, gases in brines and hydrocarbon pools in the western regions of the Siberian Platform were exposed to substantial thermal action as a result of trap magmatism at the turn of the Permian to Triassic. The influence of this process on the composition of free and water-dissolved (WDG) was studied only in sole works [1, 2]. In the present work we report for the first time the results of integrated analysis and interpretation of all available data obtained through prospect and deep drilling in the western regions of the Lena-Tunguska petroleum-bearing province (Fig. 1) where unique saturation of the geological section with intrusive bodies (up to 50 % of the thickness) was established.

The problems connected with the studies of hydrogeological conditions, geothermal regime, effect of trap magmatism on the host sedimentary rocks, transformation of the organic matter, gas and oil formation, the formation and preservation of hydrocarbon (HC) pools at the Siberian Platform were considered in the works published previously (by A. S. Antsiferova, A. S. Borisenko, M. B. Bukaty, V. I. Vozhova, V. A. A. Duchkov, A. E. Kontorovich, A. A. Lapkovsky, B.N. Lyubomirova, M.P. Mazurov, N.V. Melnikova, E.V. Pinnaker, O.P. Polyansky, V.V. Reverdatto, V.V. Ryabova, V.S. Staroseltsev, AV Khomenko, SL Shvartsev and other researchers [3-18].
2. Results and discussion

The present study is based on structural charts on the major reflecting horizons (the tops of the Ust-Munduyskaya formation (Є 2-3), Deltulinskaya formation (Є 1dl), Bulayskaya formation (Є 1bl), Burusskaya formation (Є 1br), Usolskaya formation (Є 1us), Teterskaya formation (V-Є 1) and the crystal basement), mapped at the IPGG SB RAS under the supervision of Academician A. E. Kontorovich, tests over 94 objects at 18 prospecting areas, 55 thermometrics of deep wells. The electronic database is represented by the records over 42 samples of WDG and 24 samples of free gases in hydrocarbon pools. The maximal heating temperatures for the studied objects with gas testing were calculated according to the procedure proposed by the team supervised by A. E. Kontorovich [15, 19].

Figure 1. The location of the research area and the maps of the distribution of calculated maximum temperatures in the productive horizons after the introduction of trap intrusions: a – Devilish (Silurian), b – Baikit (middle Ordovician), c – Deltulino-Tanachinsky (lower-middle Cambrian), d – Abakunsky (lower Cambrian), d – Moktakonsky (lower Cambrian): 1 – isotherms, 2 – wells encountering the productive horizon.

To evaluate the effect of intrusions on gas composition, we calculated the maximal paleotemperatures at the moment of trap intrusion for the major productive horizons: Silurian (Devilish), Ordovician (Baikit), and Cambrian (Deltulino-Tanachinsky, Abakunsky, and Moktakonsky) (see Fig. 1). Silurian and Ordovician horizons were subjected to the most substantial heating, which was due to the close position of thick bedded intrusives and insignificant thickness of productive horizons (PH); the least heating was characteristic of the Lower Cambrian horizons.

The maximal paleotemperatures for the Devilish PH vary from 260 to 650 °C (the maximum was detected at the contact of the sill with the PH at the Vakunay field) (see Fig. 1a). Almost the whole territory under study was within the temperature zone above 400 °C during trap intrusion. Only small areas at the Bakhtinskaya, Tanachinskaya, Suringdakonskaya, Poymnennaya, Nizhnetungusskaya and Chiskovskaya areas are situated in the medium-temperature zones (400-300 °C). The Devilish formation and its stratigraphic analog, the Orlovskaya formation, in the east and west of the territory were only insignificantly affected by traps.

The maximal temperatures for the Baikit PH vary from 220 to 630 °C (the maxima were detected at the contact of the sill with the productive horizon in Moktakonskaya 4, 7 wells, where the thickness of the horizon is 51-52 m, and the thickness of the intrusive is 640-648 m) (see Fig. 1b). The high-temperature (above 400 °C) region was revealed at the Ustdeltulinskaya, Bakhtinskaya,
Verkhneamunnakanskaya, Vakunayskaya, Kochumdekskaya, Chiskovskaya, Ustkochumdekskaya and partially Nuzhnetungusskaya areas. Medium-temperature (300-400 °C) regions are more extensive in comparison with the heated territory for the Devilish PH – these are the Tutenchanskaya, Uchaminskaya, Marskaya, Malkitkonskaya, Zapadno-Malkitkonskaya and partially Moktakonskaya, Nizhnetungusskaya and Tanachinskaya areas. The Baikit horizon was heated to the lowest extent at the Poymennaya, Kholmkinskaya and Suringdakonskaya areas: to less than 250 °C.

The Deltulino-Tanachinsky horizon was heated during trap intrusion to a lower extent than the above-lying Ordovician and Silurian sediments (see Fig. 1c). This is connected with the amount and thickness of stratal bodies and with thicker deposits of the Deltulino-Tanachinskaya layer (up to 800 m at the Tanachinskaya and Nizhnetungusskaya areas). The regions heated to 300-400 °C occupy a vast territory, namely, the central, eastern and partially northern parts of the region under study. The region of insignificant heating (below 300 °C) was located at the east of the territory (the Chiskovskaya, Uchaminskaya and Vakunayskaya areas), in the centre (the Suringdakonskaya area) and partially in the north-west (the Poymennaya and Nizhnetungusskaya, Vostochno-Noginskaya areas).

The layers of the Abakunsy and Moktakonsky horizons are affected by intrusion-related heating to the lowest extent (see Fig. 1 d, e). This is due to the presence of only one Usolsky sill, which passes from one level to another stepwise within the boundaries of the Yasengskaya, Moktakonskaya, Marskaya and Abakunskaya formations. The maximal temperatures in the Abakunsky horizon are assumed in the Kholmkinskaya 212 well (above 550 °C). The medium temperature field (300-400 °C) covers the region of the wells: Malkitkonskaya 211, Vakunayskaya 3, Moktakonskaya 6, 7, Nuzhnetungusskaya 6 and Ustdeltulinskaya 214. The rest territory was heated to a temperature below 300 °C. The minimal heating (below 200 °C) of the horizon occurred in the west of the studied territory and partially at the Moktakonskaya area (wells 3 and 5). The Moktakonsky horizon is penetrated by the smallest number of deep wells. It was most strongly heated in the north of the studied region in the Malkitkonskaya 211 well, which is due to the occurrence of a thick intrusion directly in the horizon. The horizon is rather strongly heated also in the Kholmkinskaya 212 well (above 400 °C), which is connected with a thick intrusion (140 m) located closely in the Abakunskaya formation. At the Tanachinskaya and Moktakonskaya areas, some regions are observed in which the heating temperature of the Moktakonsky horizon was below 200 °C.

3. Conclusion

Thus, the brines of the Abakunsky and Moktakonsky PH were subjected to the least heating effect, the brines of the Deltulino-Tanachinsky horizon were affected to the medium extent, and the brines of the Devilish and Baikit horizons were heated to the higher extent.

The brines contain WDG of diverse composition because of the substantial influence of trap magmatism processes on brine geochemistry. The following chemical types of WDG were established: hydrocarbon class with the prevalence of CnHm ≥ 50 vol.% (methane, nitrogen – methane, and carbon dioxide – methane types); nitrogen class with N2 ≥ 50 vol.% (nitrogen, methane – nitrogen, and carbon dioxide - nitrogen types), and carbon dioxide type with CO2 + H2S ≥ 50 vol.% (carbon dioxide and methane – carbon dioxide types) (Fig. 2a-b). Gas pools in the region under study have similar composition (Fig. 2c-d).

Non-uniform, contrast heat field during the intrusion of trap sills caused a substantial transformation of host rocks and the organic matter present in them: HC decomposition processes were sharply activated, the formation of elemental carbon and hydrogen took place, and the composition of the initial HC mixture got simplified. These regularities are observed in the most distinct manner in the changes of WDG composition depending on the contact with intrusions and on heating temperature. For example, carbon dioxide with the concentration above 90 vol.% dominates in the sill-affected zone up to a distance of 100 m, with methane content up to 5 vol. %, while at a distance of 250 m CO2 concentration decreases to 30 vol. %, and methane concentration increases to 60-70 vol. % (Fig. 3a). Similar trends are observed for the entire series of homologues, from ethane to hexane. The concentrations of these components at a distance of (0-100/350/600 m) from intrusion, vol.% (Fig. 3b): ethane - 0,25/3,5/no data; propane –
0.25/2.2/no data; butane isomer – 0.2/0.8/no data; n-butane – 0.2/0.7/3.2; pentane isomer – 0.2/0.6/2.0; n-pentane – 0.15/0.5/1.4; hexane – 0.2/0.6/1.3. No substantial effect of the thickness of intrusions on gas composition was established.

Figure 2. Diagrams of the total composition of gases and the composition of the heavy hydrocarbon (HH) fraction of water-dissolved gases and free gases of the pools in the north-western regions of the Siberian platform.

Results of paleotemperature calculations showed that the destructive effect of traps on WDG composition is observed starting from 200 °C, and it is accompanied by an increase in carbon dioxide content to 80 vol.%. The effect of the intrusive body on the transformation of the composition of water-dissolved gases is leveled at a distance of about 400 m. The composition of free gases follows the same trends established previously by A. E. Kontorovich and co-workers [1].

Figure 3. The content of CH$_4$ and CO$_2$ (a) and methane homologues (b) in the composition of free and water-dissolved gases depending on the distance to the nearest intrusion.
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