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Ewa Kmiecik

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title: **Cryopegs of the Yakutian diamond-bearing province (Russia)**

author(s): **Sergey V. Alexeev**
Institute of the Earth's Crust SB RAS, Russia, salex@crust.irk.ru

Ludmila P. Alexeeva
Institute of the Earth's Crust SB RAS, Russia, lalex@crust.irk.ru

Aleksander M. Kononov
Institute of the Earth's Crust SB RAS, Russia, kononov@crust.irk.ru

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INTRODUCTION

Cryopegs (intrapermafrost and subpermafrost negative-temperature chloride saline waters and brines) as a major component of cryolithosphere circulate in the cooled sedimentary rock and kimberlite pipes, forming aquifers regionally distributed. The interaction between the frozen rock and cryopegs, the ability of negative-temperature waters to move through permafrost diluting ice inclusions in rocks, as well as the considerable decrease in temperature during the cryopeg's migration has caused deep cooling in the geological section (Pinneker et al., 1989).

The origin of cryopegs is one of great scientific interest and now it is widely discussed among world scientists. This study helps in understanding of cryopegs formation and accordingly will be useful in diamond exploration and drainage brines disposal.

GEOLOGY AND GEOCRYOLOGY

The Yakutian diamond-bearing province with a total area of 840,000 km^2 is located in the northern part of the Siberian platform (Fig. 1). Within the boundaries the geological section consists of sedimentary rocks underlain by an Archaean crystalline basement.

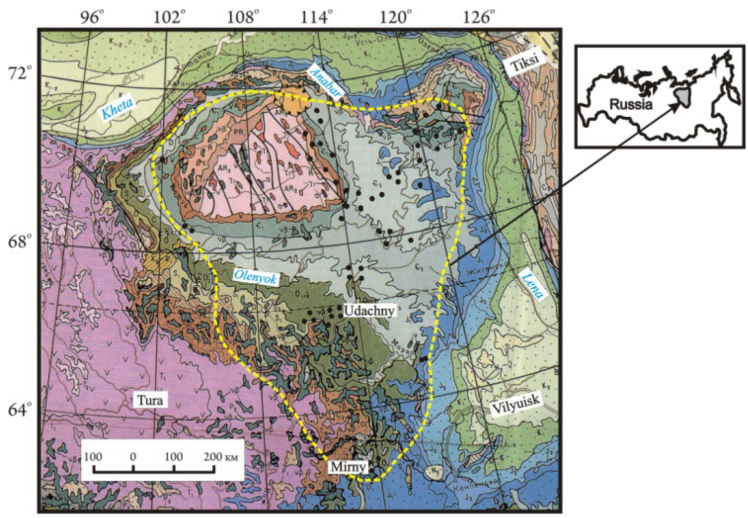

Figure 1. Location of the Yakutian diamond-bearing province. The black circles show the position of kimberlite pipes.

The thickness of the sedimentary cover varies from 2 to 3 km. Although the sedimentary rocks in the Yakutian province range in age from Proterozoic (Vendian) to Jurassic, they are dominated by Cambrian sediments. In the central part of province the Vendian rocks are mainly dolomites interlayered with marls and sandstones. The Cambrian sediments consist of dolomites and limestones interlayered by argillites, clayey limestones and gritstones.

The southern part of province has another stratigraphy. The basement is covered by Vendian-Early Cambrian sediments that are made up primarily of dolomites interlayered with argillites, anhydrites, limestones and gritstones. The Cambrian sediments overlay and consist of dolomites and limestones interbedded with marls, argillites, anhydrites and rock salts (halite). The thin layers of Jurassic sandstones and clays are exposed at the surface. In the province there are numerous Middle Paleozoic kimberlite pipes and Late Paleozoic-Early Mesozoic trappean intrusions that are confined to tectonic fault zones in the area.

Yakutian diamond-bearing province is unique in view of the extreme cooling of the geological section and is characterized by continuous permafrost, low mean annual rock temperatures (–2.9…–8.8°C on the north and –1.2…–4.0 on the south), high rock thermal conductivity (2.2–5.2 W/(m·°K) and lowest (0.008–0.027 W/m^2) intensity of heat flow (Balobaev, 1991; Duchkov, Balobaev, 2001). These characteristics have caused the formation of the anomaly thermal field and low thermal gradients. In the central part of province the position of zero isotherm varies from 720 up to 1450 m. On the south it fixes at the depths of 340–820 m. According to updated data concerning the geocryological section of the province, the cryolithozone represents the interlayering of ice-rich permafrost, dry permafrost and cooled rocks. The cooled rocks are saturated with the cryopegs (Fig. 2).

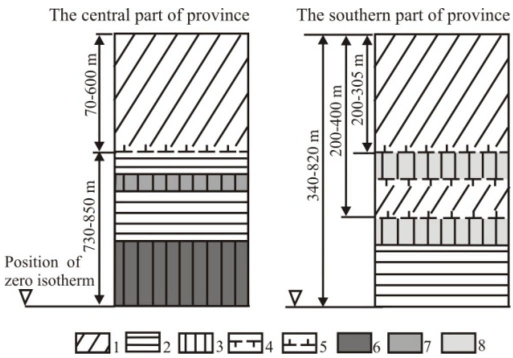

Figure 2. The generalized permafrost structure and cryopegs position in the Yakutian diamond-bearing province. 1 – ice-rich permafrost; 2 – “dry” permafrost; 3 – basal cryopegs; 4 – permafrost table; 5 – permafrost base; 6 – Cl Mg-Ca cryopegs (group A samples); 7 – Cl Mg-Ca or Ca-Mg or Ca-Na cryopegs (group C samples); 8 – Cl Na cryopegs (group B samples).

HYDROGEOLOGY AND HYDROGEOCHEMISTRY

The water samples (more than 500) collected from exploration boreholes were analyzed for chemical composition. The chemical compositions were determined by ICP-MS/ICP-AES and Ion Chromatography (IC) for cations and anions, respectively. High concentration samples were diluted 20 times before they were analyzed. The detection limits for Ca, Na, K, Mg, Li and Sr of the ICP-MS/ICP-AES method are 100, 200, 10, 100, 0.1 and 0.1 μg/L, respectively. The detection limits for Br, Cl and SO_4 of the IC method are 100, 200 and 100 μg/L, respectively.

The Yakutian diamond-bearing province is characterized by few different types of cryopegs. Two hydrochemical zones can be distinguished in the vertical section of the central part of province. The groundwaters of the Upper Cambrian aquifer within the sedimentary strata and Middle Paleozoic kimberlite aquifer are contained in the first zone. The zone is represented by saline waters and diluted brines. The chemical composition of groundwaters is only chloride. The cations balance is Ca>Mg>Na>K or Mg>Ca>Na>K or Na>Ca>Mg>K. TDS values vary from 31 to 252 g/L. Groundwater samples collected from the depths of 110–650 m, and the thickness of the first zone is limited, not more than 20 m. Cryopeg’s temperatures vary from –4.0 to –3.0°C.

The second zone contains concentrated brines of the Middle Cambrian aquifer within the sedimentary strata and Middle Paleozoic kimberlite aquifer. Groundwaters pumped from depths 600 to 1450 m. TDS values range from 224 to 404 g/L and increase depending on the groundwater occurrence. Ninety eight percent of the anion balance is represented by chloride. The mean concentrations of cations (%) are: Ca — 50–70, Na — 15–30, Mg — 15–25, K — 3–5. Cryopeg's temperatures vary from –2.6 to –1.0°C.

On the south of the Yakutian diamond-bearing province cryopegs occur at the depths of 200–400 m. The groundwaters are represented by saline waters and brines. Their occurrence corresponds to the Early-Middle Cambrian supersalt-bearing aquifer and Middle Paleozoic kimberlite aquifer. The chemical composition of groundwaters is also chloride and predominantly sodium. The cations balance is Na≫Ca>Mg>K. TDS values range between 28 g/L and 165 g/L. The peculiarity of groundwaters is high content of H_2S, up to 90–120 mg/L. Cryopeg's temperatures vary from –2.5 to –0.5°C.

STABLE ISOTOPE SIGNATURES

The ^{18}O, ^{2}H, ^{37}Cl and ^{81}Br stable isotopes were analyzed by Isotope Ratio Mass Spectrometry (IRMS) in University of Waterloo (Canada). The analytical precisions for the ^{18}O, ^{2}H, ^{37}Cl and ^{81}Br isotopes are 0.2‰, 1.0‰, 0.1‰ and 0.1‰, respectively.

The $\delta^{2}H$ and $\delta^{18}O$ results range between –171‰ and –61.7‰; and –21.4‰ and –2 ‰, respectively. The pattern obtained from the $\delta^{2}H$ and $\delta^{18}O$ values is similar to that previously reported by Pinneker et al. (1987). The $\delta^{37}Cl$ values range between –0.40‰ and +1.3‰. This range is within the known variation for Cl stable isotopes of formation waters (Kaufmann et al., 1993; Eastoe et al., 2001; Frape et al., 2004). The $\delta^{81}Br$ values have a wide variation and range between –0.80‰ and +2.31‰. This variation is larger than the previously reported range (0.00‰ to +1.80‰) for Br stable isotopes for natural samples (Eggenkamp, Coleman, 2000; Shouakar-Stash et al., 2005).The different cryopegs groups are not distinguished from each other based solely on their chemical composition; they are also distinguishable based on isotopic characteristics.

Group A: the $\delta^{2}H$ and $\delta^{18}O$ values of the cryopegs samples range between –70.5‰ and –61.7‰; and between –5.52‰ and –2.0‰, respectively (Fig. 3). The $\delta^{37}Cl$ (Fig. 4) and $\delta^{81}Br$ values range between –0.4‰ and –0.2‰; and between –0.13‰ and +0.24‰, respectively.

Group B: the $\delta^{2}H$ and $\delta^{18}O$ values of the cryopegs samples range between –171‰ and –113.2‰; and between –21.4‰ and –9.57‰, respectively. The $\delta^{37}Cl$ value of one sample is +1.54.

Group C: the $\delta^{2}H$ and $\delta^{18}O$ values of this cryopegs samples range between –139.6‰ and –95.9‰; and between –16.45‰ and –10.2‰, respectively. The $\delta^{37}Cl$ and $\delta^{81}Br$ values range between –0.4‰ and +1.3‰; and between –0.8‰ and +2.31‰, respectively.

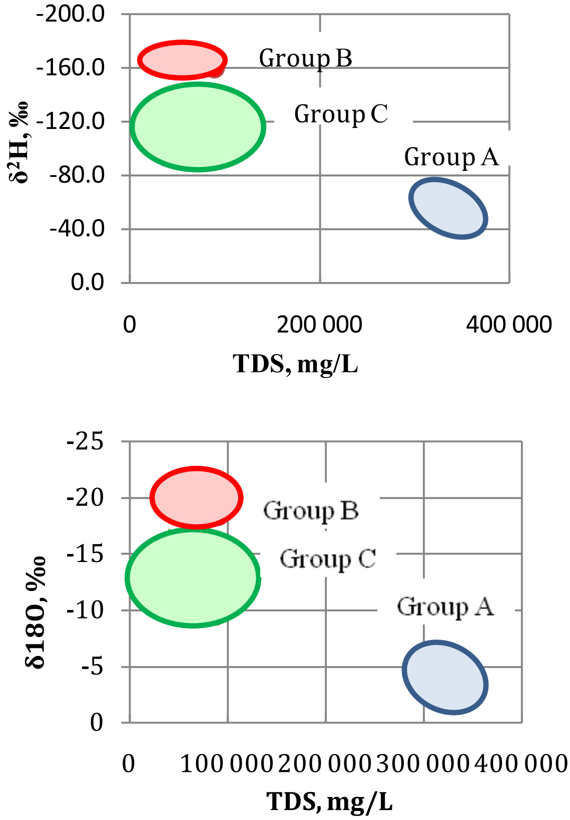

Figure 3. Stable isotopic composition (δ^2H and δ^{18}O) of cryopegs of the Yakutian diamond-bearing province. The cryopegs are distinguished on three groups: Group A (Cl Mg-Ca), Group B (Cl Na), Group C (Cl Ca-Mg or Mg-Ca or Ca-Na).

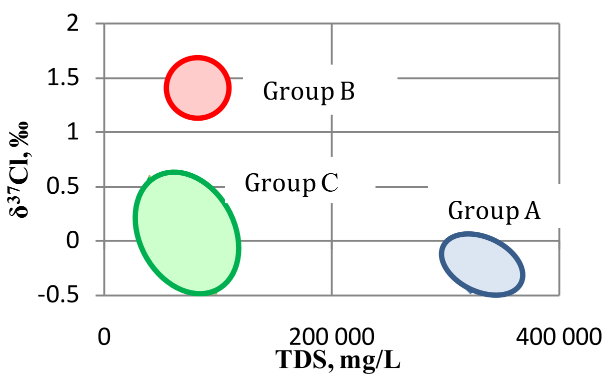

Figure 4. Plot of the δ^{37}Cl versus TDS for the cryopegs.

CONCLUSIONS

The cryopegs of the Yakutian diamond-bearing province classified into three different groups based on their chemical composition and isotopic features (H, O, Cl and Br stable isotopes).

Group A includes Cl Mg–Ca brines. They pumped from depths 600 to 1450 m and are characterized by TDS 224–404 g/L. Cryopeg's temperatures vary from –2.6 to –1.0°C. The O, H and Cl stable isotope signatures of these cryopegs are the most enriched in comparison to the other groups. It is postulated that they are residual brines of evaporated paleoseawaters (Shouakar-Stash et al., 2007).

Group B samples are Cl Na. They occur at shallower depths (200–400 m) and their TDS values range between 28 g/L and 165 g/L. Cryopeg's temperatures vary from –2.5 to –0.5°C. The waters are the most depleted in O, H and Cl stable isotopes of all samples and their signatures are very different from group *A* signatures. Data obtained for group *B* indicate that these groundwaters are derived from halite dissolution, most likely as a result of recharge in a colder climate, possibly Pleistocene derived water.

Group C consists of Cl Ca–Mg or Mg–Ca or Ca-Na type waters. Groundwater samples collected from the depths of 110–650 m and their salinity vary from 31 to 252 g/L. Cryopeg's temperatures vary from –4.0 to –3.0°C. The isotopic data are disposed between isotopic values of group *A* and group ***B*.** Data interpretation could not lead to a definite brine source. However, the available data suggest that these waters were modified greatly via a number of scenarios; geochemical evolutionary processes such as permafrost freezing, mixing, leaching of salt and water–rock interaction could have all affected their chemistries and isotopes.

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REFERENCES

Balobaev V.T., 1991. *Geothermy of permafrost of the Northern Asia.* Nauka, Novosibirsk, 192 p. (Балобаев В.Т. *Геотермия мерзлой зоны литосферы севера Азии.* Новосибирск: Наука, 1991.–192 с.).

Duchkov A.D., Balobaev V.T., 2001. *The evolution of the thermal and phase condition in the Siberian cryilithozone.* Environment global changes. Novosibirsk: SB RAS publ.house, 79–104 (Дучков А.Д. Балобаев В.Т. Эволюция теплового и фазового состояния криолитозоны Сибири. Глобальные изменения природной среды-2001. Новосибирск: Изд-во СО РАН. Филиал ГЕО, 2001. С. 79–104).

Eastoe, C.J., Long, A., Land, L.S., Kyle, J.R., 2001: *Stable chlorine isotopes in halite and brine from the Gulf Coast Basin: Brine genesis and evolution*. Chem. Geol. 176, p. 343–360.

Eggenkamp, H.G.M., Coleman, M.L., 2000: *Rediscovery of classical methods and their application to the measurement of stable bromine isotopes in natural samples*. Chem. Geol. 167, p. 393–402.

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