

Cryovolcanism on the Earth: Origin of a Giant Crater in the Yamal Peninsula (Russia)

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The crater was found in the summer of 2014 in the central Yamal Peninsula, 30 km southeast of the Bovanenkovo gas field. Its size and unusual shape were surprising to all experts. The crater is a hole, 20 m in diameter, with vertical walls and a conical chimney in the upper part, encircled with a parapet-like ridge of ejected rocks. Its observed depth exceeded 50 m: the maximum of 52 m was measured on 16 July 2014. It became quickly filled with water and turned into a lake in the autumn of 2016. The studies reveal signatures of back freezing of a pre-existing talik, inferred from the structure of ground ice, distribution of gas in frozen sediments, and chemistry of the mineral and water (ice) components of permafrost. Judging by its chemical and isotope composition, gas has no relation to the nearby gas field; it is of biogenic origin and accumulated during freezing. There is possibility and potential for the formation of carbon dioxide hydrates. The results confirm the cryogenic origin of the Yamal crater. The processes of talik freeze-back and pingo growth with subsequent collapse, which are responsible for the crater origin, have been simulated in a mathematical model. The reconstructed process of cryovolcanism consists of three main eruption stages. Pneumatic stage of gassing from the talik top: gas pressurized to ~10 bar releases through cracks and expands adiabatically. Hydraulic stage (few hours) of water outpouring from the crater: pressure drop leads to in CO₂ degassing from water and ascent of the gas-water mixture (“champagne” effect). Phreatic stage of unfrozen soil eruption: gas releases either from pore water in unfrozen soil or from decomposed carbon dioxide hydrates. Cryovolcanism has been commonly assumed to have a warm source at the depth. This is partly true, but our results show that eruption may result from water crystallization rather than warming. The water-to-ice transition increases pressure and triggers a catastrophic explosion. The mechanism proposed for the Yamal crater can explain the formation of water jets on Europe. Injection of liquid water into Europe’s icy crust produces water diapirs pressurized upon freezing. Quite strong explosions can occur under these conditions.

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