



## **Paragenesis of thermal denudation with gas-emission crater and lake formation, Yamal Peninsula, Russia**

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Gas-emission craters (GECs) found in the North of West Siberia in 2014 occur in an area of wide tabular ground ice (TGI) distribution. TGI observed in the GEC walls also provokes thermal denudation: a complex of processes responsible for formation of thermocirques (TCs). TCs are semi-circle shaped depressions resulting from TGI thaw and removal of detached material downslope. Shores of many lakes are terraced and have ancient to recent traces of thermal denudation activity. TCs are numerous in the GEC area giving reason to assume that GEC, TGI, TC, and lakes are interrelated.

First found Yamal crater (GEC-1) expanded from initial 18 m wide deep hole in 2013 to an irregularly-shaped lake up to 85 meters wide in 2016. Expansion of the GEC was controlled by TGI thaw. This can be considered in terms of thermal denudation and analyzed on the basis of TC study in the adjacent area. In summer 2014 and 2015 (the lifetime of the GEC-1) its wall retreat covered the area of 1730 square meters, which gives 865 square meters per year. In 2016, which was the warmest for the period of observation at weather station Marre-Sale, retreat area increased to 2200 square meters per year.

TC, which exposed TGI similar to that in the walls of GEC-1, is observed on the nearest lakeshore. TC activation probably started in 2012 as elsewhere on Yamal. In 2015 its area according to GPS survey reached 4400 square meters (a four-year average 1100 square meters). Since September 2015 and till October 2016 its area expanded by 2600 square meters, thus increased by 59%, and more than twice compared to previous annual average.

Lake adjacent to GEC-1 in 2016 was separated from crater edge by only a 13 meter wide isthmus, most likely both GEC-1 lake and adjacent lake merge in few years. Therefore, single basis of erosion for thermal denudation appear. After lakes merge, it would become hard to determine what the initial process for the lake formation was if not for the occasional discovery of the GEC-1.

Thus, the rate of thermal denudation measured as area expansion: (a) inside the GEC was between 865 square meters per year in 2014-2015, and 2200 square meters in 2016, (b) on the adjacent lakeshore thermal denudation expanded by 1100 square meters per year in 2012-2015 and was as high as 2600 square meters in 2016. In both landforms higher rates were observed in the warmest 2016 and were rather similar. Lower rate for the GEC-1 at its initial stage is due to its steep slopes and narrow hole with little sunshine reaching lower parts of the hole.

Adjacent lake providing basis of erosion for both features expands towards the GEC-1 lake and outside into tundra by thermal denudation activity and determines formation of a new feature: merged lake with components having different origin.

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