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# The influence of ice and unfrozen water content on the thermal conductivity of frozen volcanic ashes (Kamchatka)

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Geocryological prognosis and estimation of main permafrost characteristics (e.g. thickness, active layer depth) are impossible without thermal characteristics of frozen grounds. The knowledge of phase composition of water (the content of unfrozen water, ice and steam) in them is necessary for analysis.

Studies on the thermal properties of the pyroclastic volcanic deposits are insufficient. Generally existing data was received for volcanic massive rocks or tuffs and for thawed states. Analyze of available data is difficult to work with because there is no information about age, humidity and density.

The study of thermal properties of frozen volcanic cinders and ashes was started in 2004 in the Geocryological Department of the Lomonosov Moscow State University. It was found that the thermal conductivity of thawed frozen volcanic ashes and cinders was much lower than that of mineralogical grounds (e.g. clays, cinders, loams, sandy loams). It's connected with mineralogical and granulometric composition and porosity of pyroclastic rocks and as well as unfrozen and ice content ratio for frozen ones.

The ash samples of different ages (from 35 years to 8000 years) were collected in the Kluchevskaya volcano group (Kamchatka). By their granulometric composition we can see all ashes refer to very fine sands. According to silicon dioxide volcanic glass can be divided to three types: andesite, basalt and rhyolite. IR–spectroscopy of mineral structures for volcanic ash reveals the presence of two amorphous minerals: opal and allophane. Opal is hydrated silicon dioxide. Allophane is hydrous aluminium silicate clay mineral. The particle density $\rho_s$ and hygroscopic water $W_g$ were in the range 2.1-2.79 g/sm$^3$ and 0-7.3 %.

The regularity of dependencies of unfrozen water ($W_w$) content on temperature ranging from 0 to –15 $^o$C obtains for all investigated ashes of different ages. There is no considerable change in the unfrozen water content in the temperature ranging from –3 $^o$C till –15 $^o$C. And unfrozen water content in the investigated ashes ranges from 0 % to 11 %. Occurrence of the unfrozen water is presumably connected with transformation of volcanic glass depending on age and clay minerals (allophane) occurrence that have a high surface area.

Measurements of thermal conductivity were made for volcanic ashes of different age, mineral, chemical and granulometric composition. On condition that the density ($\rho_d$) and humidity ($W$) are changing from 0.7 to 1.65 g/sm$^3$ and from 10 to 80 % respectively the thermal conductivity ($\lambda$) increases from 0.37 to 1.0 W/(m·K) in a thawed state and from 0.41 to 1.27 W/(m·K) in a frozen state.

All properties of frozen grounds are formed by unfrozen water ($W_w$) and ice content ($W$–$W_w$) because the thermal conductivity ($\lambda$) of ice (2.2 W/(m·K)) is greater than $\lambda$ of water (0.56 W/(m·K)). Therefore the influence of unfrozen water and ice content ratio on the forming of the thermal conductivity in the frozen volcanic ashes has been estimated. In the ashes containing opal, there not much unfrozen water, the unfrozen water and ice content ratio varies from 0 to 0.08. In the ashes containing allophane, there unfrozen water content ranges from 2 to 11%, the ratio $W_w/(W–W_w)$ varies from 0,08 to 0,58.

Even a little change of water and ice ratio (for example, from 0.02 to 0.04) in the ashes of opal composition induces the decrease of thermal conductivity by a factor of 2. As for ashes containing allophane this change happens by a greater variation of this ratio (from 0.19 to 0.58).