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Understanding thermal impacts of volcanic systems on ice sheets

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Recent discoveries of volcanoes under the Western Antarctic Ice Sheet (WAIS) have refocused broader interest on feedbacks between volcanoes and ice sheets. Given uncertainties in the time-scales of ice response to global climate change and its impact on glaciovolcanoes, understanding the constraints on heat transfer between volcanoes and ice sheets is critical for predicting ice sheet response to future volcanism. Recent field, theoretical and experiment work has produced new insights into these heat transfer processes. While most studies focus on heat transfer after eruption initiation, volcanic systems can impact overlying ice well before an eruption begins via degassing. For example, a basaltic melt with 1 weight percent H_2O and 1000 ppm CO_2 will begin to form a separate, almost pure CO_2 volatile phase within the magma at depths of $\sim$5 km. Thus, as soon as the magma encounters fractured rocks that can allow gas escape, those gases can transfer heat into the base of the overlying ice. Shallow level degassing (<2 km) may include S-species and H_2O too. The longer magma is stored at shallow levels, the more heat will be transferred by this process. Thus, even without an eruption, shallow level intrusions can impact ice sheets. The degassing process, while minor, may account for some of the ice melting seen at Icelandic volcanoes (e.g., Katla, Bardarbunga, Oræfajökull). Once magmas reach the bedrock-ice interface, a new set of factors controls rates of heat transfer and melting. While theoretical limits on ice melting during eruptions are quite high (basalt can melt up to 14 times its mass of ice using sensible and latent heat, rhyolite about 10 times), practical limits are strongly influenced by eruption rates, eruption styles (effusive vs. explosive), degrees of fragmentation, and amount of heat lost due to heat transfer to newly generated meltwater. At this stage, heat transfer is also critically controlled by ice sheet hydrology. For frozen based ice, eruptions are likely to produce englacial lakes within the ice sheet. While the growth of such lakes is hard to constrain, if they do not drain they can continue to impact the eruption dynamics by inhibiting fragmentation processes as they exert hydrostatic pressure on the vent area. In 'leaky' ice sheets, rapid drainage of meltwater can lead to more rapid onset of explosive eruptions, which maximize heat transfer and impact on the surrounding ice sheet. Even the surface of ice sheets can be directly impacted by volcanism. Eruptions like those at Veniaminof volcano Alaska send lava flows from a supra-ice cone down onto the surface of the surrounding ice cap, where they can produce surface meltwater drainage as well as melting downwards from the ice surface. Finally, tephra deposited on the ice will significantly affect local albedo, acting to either insulate ice or enhance surface melting. Because heat transfer between volcanoes and glaciers depends on interactions between two highly complex systems, future work on understanding the impact of climate change on these linked systems will require integrated knowledge of all the effects briefly outlined above.