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Heat loss at active lava channels and tubes and controls on core cooling and flow length

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Heat loss from an active lava flow surface plays a fundamental role in determining core cooling rates, thereby influencing the cooling limited distance the flow can extend. Insulation of the flow surface in turn controls heat loss, and thus core cooling rates. Through field measurements we can classify three types of flow in terms of insulation and efficiency of heat loss: (1) heavily crusted, (2) tube-contained, and (3) poorly crusted.

(1) Heavily Crusted. Thermally, an efficient means of lava transport is achieved when the flow surface is covered by a thick, cool crust. Silicic lava flows at Santiaguito (Guatemala), for example, have extremely low effusion and advance rates of 0.5-1.6 m^3/s and 2-13 m/day, respectively. The presence of a stable, thick and cool (30-150 ˚C, typically ∼40 ˚C) surface crust, however, reduces surface heat loss and core cooling to just 0.5-1.1 x 10^3 W/m^2 and 10-12 ˚C/km, respectively. As a result, such well-insulated and thick (15-120 m) flows have the potential to extend 17-20 km before the core cools by 200 ˚C, in-spite of relatively low effusion rates.

(2) Tube-contained. If the crust becomes rooted and stationary then a tube forms. The roof again presents extremely effective insulation reducing heat losses and cooling rates. Several studies have used field measurements and/or models to determine cooling rates at lava tubes, where the literature is converging on cooling rates of 0.3–1.0 ˚C/km. Heat loss from tubes is mostly the result of conduction, convection of air around the tube and boiling off of meteoric water. For lava tubes on Kilauea (Hawaii) fed at effusion rates of 1-4 m^3/s, these result in a total heat loss of ∼5 x 10^4 W/m. Where the flow surface is exposed at skylights we have measured lava surface temperatures in the range 1017-1132 ˚C (compared with core temperatures of ∼1161˚C). The additional radiative heat loss from this high temperature surface through the skylight

increases total heat losses to a maximum of $\sim10^6$ W/m across the length of the skylight. In cases where tubes contain a significant area or number of skylights cooling rates may increase to 3-8 ˚C/km (for a tube that is 50 % unroofed) at these effusion rates. The effective insulation provided by the tube roof means that tube-fed flow has the potential to extend tens to hundreds of kilometers before the core cools by 200 ˚C, again in-spite of relatively low effusion rates.

(3) Poorly crusted. Heat losses at open channels with thin, hot surface crusts will exhibit highest heat losses. We completed a 2-day-long thermal survey of a proximal section of active lava channel at Etna (Italy) using a FLIR thermal camera during May 2001. The channel was fed by a DRE effusion rate of 0.1-0.7 m^3/s and pixel-integrated surface temperatures varied between 220 and 980 ˚C, with a mean of 680 ˚C. Heat losses were dominated by radiation (5 x 10^4 W/m^2) and convection ($\sim10^4$ W/m^2) and resulted in core cooling rates of 50-180 ˚C/km. The lack of insulation means that the flow has the potential to extend just 1-4 km at these velocities and effusion rates before the core cools by 200 ˚C. Indeed, maximum observed flow lengths were less than 2.5 km. In such cases, the only way to achieve greater distances is to increase the effusion rate and/or flow velocity (rapid emplacement). Alternatively cooling rates are reduced by the development of narrow and deep channels in which the core volume is effectively protected from extreme heat losses by virtue of a small surface area relative to the flow volume (protected emplacement).

In terms of hazard, given a constant effusion rate, by reducing heat loss and core cooling rates development of thick and stable surface crusts or a tube roof greatly increases the potential distance a lava flow can extend.