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Quantitative analysis for thermal erosion of lava flow forming the sinuous rille

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Sinuous rilles on the moon and terrestrial planets are conspicuous morphological features.　The primary formation process of the lunar sinuous rille is produced by low-viscosity lavas sustained in the lava channels and/or tube by thermal erosion (e.g., Carr, 1974; Hulme, 1982).　The basaltic lava compositions of the moon can be estimated with high accuracy because of the Apollo and Luna missions samples.　Because on the lunar surface, the morphology of the sinuous rille has been preserved from atmospheric weathering, we can compare the depth of the sinuous rille with calculated erosion feature by using our model simulation.

We reconstruct the thermal erosion model on the formation of the sinuous rille (Williams et al. 2000).　We assume one-dimensional turbulent flows with constant flow rate.　We also assume that the lava flow erodes thermally into the bed rocks. The advantage of our model is the employment of heat transfer coefficient [W/m^2K] which indicates lava temperature and rheological properties along with lava flow.　We estimate the lava temperature as a function of distance from the vent which depend on initial temperature and initial thickness of the lava, and we also estimate the thermal erosion rate into the substrate.

Next, we estimate the viscosity of lunar basaltic lava as a function of temperature and composition of basalts returned by Apollo and Luna missions by using the algorithms of Shaw (1972) and McBirney (1984).　The calculated basaltic lava viscosity is from 1.56 [Pa s] to 0.15 [Pa s] at 1637 [K].　The lowest viscosity of lunar basaltic lava is three times as high as that of komatiitic lava at the same temperature.　The density of lava is calculated by the method of McBirney (1984) as a function of temperature and a function of composition of basalts.　The thermal conductivity of the lunar basaltic lava is newly proposed as a function of temperature normalized by liquidus temperature, which includes the radiative conductivity and phonon conductivity.　These thermal conductivity is evaluated by compiling the data of Murase and McBirney (1973) for the radiative thermal conductivity.　The specific heat of lava is calculated using the algorithm of Lange and Navrotsky (1992) as a function of composition.

On the basis of the geophysical study for the eruption of lunar basaltic lava, mare basalts of Oceanus Procellarum were superheated up to 1900 [K] in their source region to erupt through the lunar crust (Wieczorek et al., 2000, 2001). Furthermore, the lunar basaltic lava should be superheated for the efficient formation of sinuous rille (e.g., Carr, 1974; Hulme, 1982).　Thus, we assume the initial temperature of lunar basaltic lava at the vent is higher than the liquidus temperature of the lava.　We also assume the initial thickness of lava is 10 [m].　The initial thickness of lunar basaltic lava at the vent is estimated by the eruption rate of the lava (e.g., Hulme and Fielder, 1977; 8 x 10^5 [m^3/s]).

We calculate lava temperature as a function of distance from the vent.　The temperature gradient along with the lava flow is very small, i.e., a few [K/km].　Consequently, the lava is easily maintaining the temperature higher than the liquidus temperature from vent to several tens [km].　Also, the thermal erosion rate into the substrate at 10 [km] from vent is from 2.0 [m/day] to 0.5 [m/day] at the case of the initial temperature of 1873 [K] and 1673 [K], respectively.　Therefore, it clarifies that the calculated thermal erosion rate is sufficient to form the typical lunar sinuous rilles.

At present, the advanced model calculation is in progress.　In the model, we include sub-liquidus condition of basaltic lava, in which the progressive crystallization effects on the maintaining the lava temperature due to latent heat.　On the other hand, the progressive crystallization affects increasing the viscosity of the lava due to suspension of solid particles in the lava.