ASSUMPTIONS IN THE EVALUATION OF LAVA EFFUSION RATES FROM HEAT RADIATION

Michele Dragoni [*]

University of Bologna
Department of Physics
Viale Berti Pichat, 8
40141 Bologna
Italy

Andrea Tallarico[†]

University of Bari
Department of Geology and Geophysics
Via Orabona, 4
70127 Bari
Italy

1. INTRODUCTION

The availability of high-resolution thermal imagery of active lava flows has stimulated the use of radiance maps for the evaluation of lava effusion rates. This is made possible by simple formulae relating the lava flow rate to the energy radiated per unit time from the planimetric surface of the flow. Such formulae are based on a specific flow model and, consequently, their validity is subject to the model assumptions. An analysis of these assumptions reveals that the current use of the formulae is not consistent with the model. The reason why they provide reasonable, although very rough, values for effusion rates appears to be that the actual radiated energy is controlled by a feature (the nonuniform temperature of flow surface) which is not accounted for by the model and which counterbalances the effect of inconsistent use of the formulae

The effusion rate of lava from an eruption vent is the primary quantity that controls the evolution of the ensuing lava flow. For this reason much effort is devoted to the evaluation of this quantity, which involves the measurement of flow velocity and cross-sectional area [1]. The knowledge of effusion rates plays also a major role in real-time simulations of lava flow paths which is carried out when lava flows may threaten inhabited areas [2]. Direct measurement of effusion rates in the field is difficult and calculation from other flow parameters would require the measurement of such parameters [3], which may be equally problematic. In recent years, the availability of thermal images of volcanoes during eruptions has stimulated the evaluation of lava effusion rates from the measurement of heat radiation. Thermal data obtained from high resolution radiometers mounted on Earth's satellites were first used to monitor active lavas by [4] and [5]. Thermal images from hand-held radiometers on the ground are also used [6]. The evaluation of lava effusion rates is based on a formula originally proposed by [7] and relating the flow rate to the planimetric area of a flow. If the flow rate is assumed to coincide with the effusion rate, the formula states that the effusion rate is proportional to the heat radiated per unit time by the surface of the flow. [8] modified the formula, by including the thermal contributions of convection in the air and crystallization of lava, and used it in order to estimate the effusion rate from radiance maps. The contribution of heat conduction to the ground was included later [6]. The radiance of a hot body is related to the surface temperature at a given instant of time. If the body is a flowing liquid, the connection between the radiated heat and the flow rate is not straightforward. The singularity of this formula was noted by [9], who observed that it is not immediately obvious how a measurement of the heat lost from an entire lava flow surface over a period of 1 s can be used to determine the volume of lava issuing from a vent during the same period of time. They suggest that the apparent success of the formula in giving reasonable values of effusion rates is due to a numerical coincidence between a constant by which [8] multiply space-based estimates of lava flow area and the empirical ratio between effusion rates and flow areas found by [7] for a suite of Hawaiian flows. [10] assert that the technique gives time-averaged discharge rates. In the present paper we propose a different explanation. In fact Pieri and Baloga's formula [7] can be only obtained in the framework of a lava flow model based on several simplifying assumptions. We shall make explicit such assumptions in order to ascertain which of them are acceptable approximations of real lava flows and which instead impose strong limits to the applicability of the model. We shall also consider whether the current use of the formula is consistent with the model itself.

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[*] Thanks to INGV-DPC agency for funding.

[†] Thanks to INGV-DPC agency for funding

2. CONCLUSION

The formulae by [7] and [8] are currently employed to evaluate the effusion rate of lava flows on the basis of the sole measurement of the total instantaneous heat flow from the flow surface. Although they yield reasonable results, [6] admit that the error is quite large, being nearly the scale of the measurement itself. Our aim has been to explain the reason of the apparent success of these formula. In this regard, we believe that the assumption of uniform crust temperature plays a crucial role.

An analysis of the model from which the formulae are derived shows that a further information should be supplied, i.e., the difference between the lava temperatures at the vent and at the front. If this difference is assumed to be the same for all flows, as is currently done, the formula states that the effusion rate is an increasing function of flow length and a decreasing function of flow thickness, which is unrealistic.

Apparently reasonable results are found since a weakness of the model, assuming a uniform crust temperature, is compensated by the inconsistent use of the formulae. In the real world, the average surface temperature is lower for longer flows and is higher for thicker flows. The measured heat flow incorporates these effects, which happen to counterbalance the use of a constant temperature difference between the vent and the front of the flow.

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