DISCHARGE RATE AND COMPOSITION CONTROLS ON THERMAL EMISSION FROM VOLUMINOUS LAVA FLOW EMPLACEMENT ON IO.

A.G. Davies[1], L. Wilson[2], J.W. Head[3], K. de Kleer[4] and I. de Pater[5]. [1]Jet Propulsion Laboratory-California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA (Ashley.Davies@jpl.nasa.gov). [2]Lancaster University, Lancaster, Lancashire, UK. [3]Brown University, Providence, RI, USA. [4]California Institute of Technology, Pasadena, CA, USA. [5]University of California Berkeley, Berkeley, CA, USA.

Introduction: We report on progress in modelling the thermal emission from large lava flows on Io [1]. The most powerful thermal vents on Io ("outburst" eruptions) are characterised by lava fountains feeding extensive lava flows [2], an eruption style is likely similar to that of ancient lunar eruptions [e.g., 3]. Eruptions that formed extensive, thick lava flows on the Moon and other bodies in their distant pasts are taking place now on Io. Io is therefore the ideal location to observe eruptions behaviour and to test hypotheses. Most important is the ability to constrain lava composition, which reflects the interior state of Io's upper mantle [4].

Observations: Spacecraft observations have provided intermittent snapshots of outburst activity at moderate spatial resolution in the visible and infrared. Ground-based observations [5] (Figures 1 and 2) have provided more detailed temporal coverage. We have growing confidence that these observations provide hard constraints on the emplacement mechanisms of lava flows relayted to lava composition. Therefore, to maximize the extraction of information from these data we have developed a numerical model of lava flow emplacement in a vacuum to fit to the available data. The vast thermal emission from these highly energetic (multiple TW) eruptions is hard to understand unless high initial magma discharge rates generate fast-growing lava flows whose initial motion is fully turbulent.

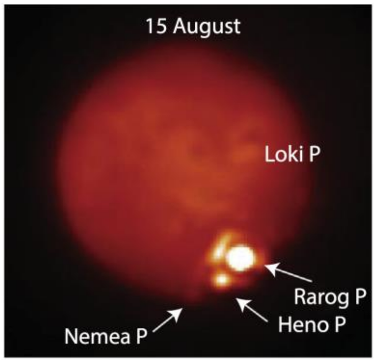

Figure 1. Two powerful (>10 TW) eruptions seen on Io on 2013 Aug 15 with the Keck telescope (shown at 2.2 μm) [5]. These high-volume eruptions exhibited an exponential decay in thermal emission and emplaced lava over hundreds of km^2 in a few days.

The Model: Our numerical model of flow emplacement (see Figure 3) is called BOXCAR. The model, initially developed in Excel, has been written in Harris Geospatial's IDL. The model has end-member compositions of a terrestrial tholeiitic basalt and a 32% MgO ultramafic komatiite, and an intermediate, high-titanium content lunar basalt. BOXCAR is (a) designed for the Io environment (and therefore also works for lunar eruptions); (b) tracks the growth of phenocrysts and the progressive onset of non-Newtonian (presumed Bingham) rheology; (c) tracks the flow regime from turbulent to laminar by

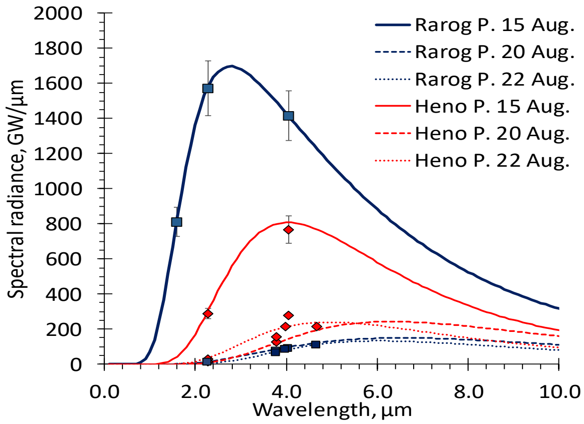

Figure 2. Evolution of the high-volume eruptions at Heno and Rarog Patera in August (after de Pater et al., 2014a). The temporal evolution of spectral radiance at different wavelengths constrains flow emplacement mechanisms – and possibly lava composition.

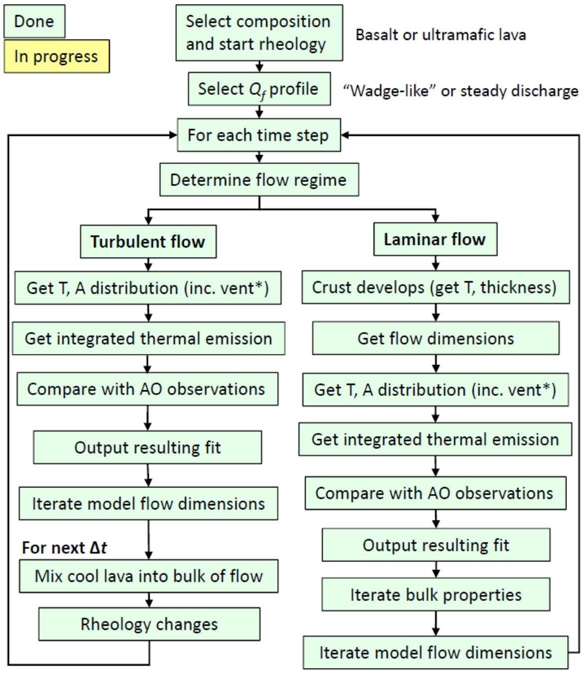

Figure 3. BOXCAR Model flow chart. (= optional).*

using the Reynolds and Hedstrom numbers; (d) allows selection of lava composition; (e) can be run for any fissure length; and (f) incorporates user-defined initial peak discharge rate and subsequent temporal change (steady or an exponential decrease in effusion rate).

Model results: Figure 4 shows a sample of model output which broadly approximates both the magnitude and temporal evolution of the AO data of thermal emission from Rarog Patera [3].

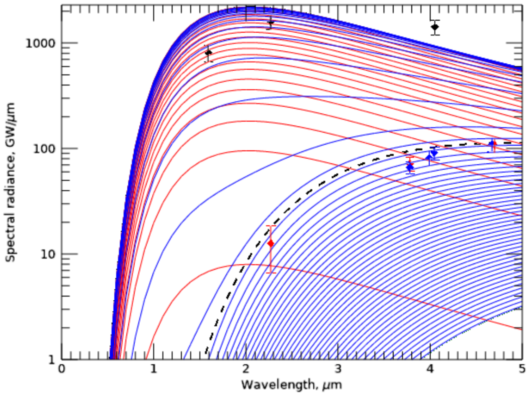

Figure 4. BOXCAR model output for the following case: Composition: tholeittic basalt; eruption temperature = 1430 K; initial effusion rate = 300,000 m/s; discharge decay coefficient = 0.5; fissure length = 60 km (or 30 km with, two flows, each flowing away perpendicular to the fissure; this could also be multiple en echelon *fissures); duration of model run = 12 days; peak thermal emission is reached after 53 minutes; flow emplacement stops after 6 hours. Length of flow =13 km. Final flow thickness at head of flow = 10 m. Total volume erupted is 13 km^3. The lava that erupted at peak discharge rate was turbulent for about 49 minutes before transitioning to laminar flow (when bulk temperature reached 1407 K) at which point a crust began to form on the lava flow.*

In Figure 4, a subset of model output spectra are shown. The red spectra are where thermal emission (from channel and levees) is waxing – the black line represents the peak of thermal emission, reached in 53 minutes.

- Blue spectra are where thermal emission is waning.
- The black dashed line is the thermal emission profile at the point where the effusion rate has dropped to the level that flow emplacement stops. The blue spectra below this line are from the cooling, crusted-over flow surfaces and levees.
- The green line is thermal emission after 10 days.
- The AO data for Rarog Patera on 2013 Aug 15 (black diamonds), Aug 20 (red diamonds) and Aug 22 (blue diamonds) are also plotted, with their uncertainties.
- Further parameter modification will yield the best fit to the Rarog Patera data, followed by fitting of the Heno Patera data.

Discussions, and conclusions so far:

1. BOXCAR runs find that a transition to laminar flow is required relatively quickly, otherwise the thermal emission will peak at shorter wavelengths than observed. This also implies that lava fountaining ends quickly, as any significant fountaining activity would push the peak in thermal emission to short wavelengths. It is apparent that the Rarog Patera eruption was likely observed within a few hours of initiation.

2. A rapid transition to laminar flow within the channel (within a few km of the vent) coupled with a rapid drop in effusion rate allows formation of broad expanses of crusted-over lava that cool quickly in the ionian environment, reducing the spectral radiance to the relatively low levels (Figure 5) observed on 20 Aug 2013 and 22 Aug 2013, although this temporal evolution, at time of writing, has not yet been reproduced in its entirety within AO observation uncertainties.

3. For the same effusion rate, however, the higher temperature, more fluid komatiites generate nearly an order of magnitude more thermal emission than tholeiitic basalt and also peak at shorter wavelengths.

4. Crucially, the temporal evolution of the AO data appears to strongly confine eruption model parameters. The need to rapidly decrease thermal emission at short wavelengths suggests a high initial discharge rate but a relatively short eruption that transitions to laminar flow relatively quickly, thus limiting the total volume erupted per unit of fissure length. To reach the magnitude of thermal emission observed, this requires a length of fissure (or fissures) 60 km long, in this example; or 30 km, assuming flows move away in two directions perpendicular to the fissure. We are examining the implications of this requirement for magma transport by dikes on Io.

In conclusion, our initial model runs suggest that lava composition and thermo-physical characteristics, combined with a discharge rate profile, provide strong constraints on the resulting spectral radiance peak and spectral emission evolution.

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References: [1] Davies, A. G. et al. (2022) LPSC 54 Abstract 1520. [2] Davies, A. G. (1994) *Icarus*, 124, 45-61. [3] Wilson, L. and Head, J. W. (2018) *GRL*, 45, 5852–5859. [4] Davies., 2007, *Volcanism on Io*, Cambridge Univ. Press. [5] de Pater, I. et al. (2014) *Icarus*, 242, 352-364. 2132.