ESTIMATION OF MAXIMUM EFFUSION RATE FOR THE PILLAN 1997 ERUPTION ON IO: IMPLICATIONS FOR MASSIVE BASALTIC FLOW EMPLACEMENT ON EARTH AND MARS.

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Introduction: In 1997 the *Galileo* spacecraft observed a huge eruption at Pillan, on the jovian satellite Io, which emplaced at least 56 km^3 of lava which covering more than 5000 km^2 in less than 200 days [1-3]. By considering varying effusion rate Q_F following the treatment of Wadge (1981) [4], we estimate peak values of Q_F in the range 1.87 x 10^4 to 5.94 x 10^4 m^3 s^{-1}. This is in the range proposed for rubbly pahoehoe flood lava flows on Mars and the Earth [5,6].

Pillan 1997 eruption: The 1997 eruption of Pillan on Io was characterized by active lava-fountaining and the rapid emplacement of extensive flows of mafic or ultramafic composition that covered over 3000 km^2 of Io's plains and the floor of Pillan Patera, another 2500 km^2. If all of these flows are 10 m thick [2], the flow volume is 56 km^3, making Pillan Patera one of the largest eruptions ever documented by humankind. By comparison, the Laki eruption of 1783-1784 emplaced a dense rock equivalent of ~15 km^3 [7] and the 1815 Tambora eruption involved ~30 km^3 of magma [8]. This volume does not include the extensive low-albedo pyroclastic deposits that covered ~4 x 10^5 km^2. These lavas were emplaced in a minimum of 52 days and a maximum of 167 days [1, 2]. The best estimate, based on the cooling of the lava flows, yielded a duration of ~99 days [1]. A review of the thermal and visible activity at Pillan is given in [1,2].

Q_F verses Q_E: Estimates of the rate of eruption in previous studies calculated mean eruption rate, Q_E, the average rate at which lava was emplaced, yielding values of 2000-7000 m^3 s^{-1} with ~3000 m^3 s^{-1} being the preferred value [1,2]. As shown by Wadge [4], while Q_E is useful for providing a comparison between eruptions, it is not particularly illustrative of the what is actually taking place. Wadge separated eruptions into a short waxing phase as the eruption rapidly builds up to peak Q_F, followed by a longer waning period as Q_F decayed exponentially. This is shown in Figure 1. The area under the curve is the total volume erupted.

Calculation of Q_F: Selecting a suitable duration for the waxing phase (we use 5 days) and knowing the volume of lava erupted, for any period of waning activity a Wadge-like curve can be iteratively determined. Results are shown in Table 1. Maximum Q_F values range from 5.94 x 10^4 m^3 s^{-1} for a 52-day eruption (waning phase = 47 days) to 1.87 x 10^3 m^3 s^{-1} for a 167-day eruption (waning phase = 162 days). Max Q_F values can be compared with values of Q_E (Table 1).

Rates of areal coverage: With direct measurment of Pillan flows yielding a thickness of ~10 m [2], the changing rate of areal coverage can be calculated. This ignores lava flow inflation, which may be reasonable for this relatively short-lived eruption. Values are shown in Table 1. It is likely that the Pillan flows, like the flows at Tvashtar and other Io outburst eruptions issued from fissures [9,10]. From fissures, flows can advance on a broad front. If 25 km wide, then the maximum flow front advance rate is only 0.25 m s^{-1} (or ~1 km per hour).

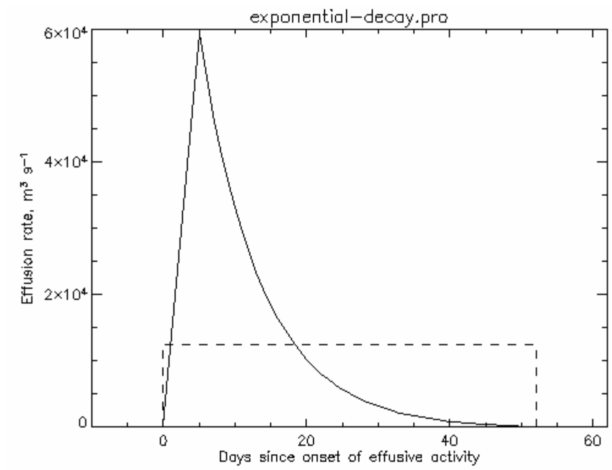

Figure 1: Wadge-like profile showing Q_F against time, for a 52-day eruption at Pillan erupting 56 km^3 of lava. The dotted line shows Q_E (see Table 1).

Table 1. Q_F, Q_E, and max dA/dt rates for Pillan 1997.

Duration days[a,b]	Max Q_F[b] m^3 s^{-1}	Q_E m^3 s^{-1}	Max dA/dt[c] m^2 s^{-1}
52	5.94 x 10^4	1.25 x 10^4	5.93 x 10^3
99	3.20 x 10^4	6.55 x 10^3	3.20 x 10^3
167	1.87 x 10^4	3.88 x 10^3	1.87 x 10^3

a assumes waxing period of 5 days.
b for erupted volume of 56 km^3.
c assumes 10 m thick flows [2].

Variability of thermal emission: Figure 2 shows the variation of areal coverage rate over a 52-day eruption, assuming 10 m thick flows are emplaced. Taking the areas emplaced on each day, the cooling profile for thick flows in an Ionian environment [11], the integrated thermal emission spectrum over the increasing areas of the flow field can be calculated. Note that this analysis does not include thermal emission from a lava-fountain component. Figure 3 shows the variation in thermal emission at different wavelengths for the 52-day duration example. Figure 4 shows the integrated thermal emission spectrum for day 6 of this scenario. The total thermal emission exceeds 10^{13} W, consistent with thermal emission from Io's large thermal outbursts. With longer duration eruptions, the maximum thermal emission is almost an order of magnitude lower, consistent with total thermal emission observed at Pillan by *Galileo* NIMS during 1997, ~10^{12} W [1].

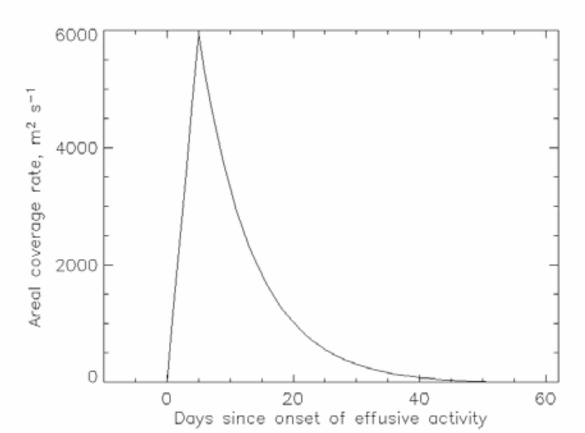

Figure 2: Areal coverage rate during 52-day eruption.

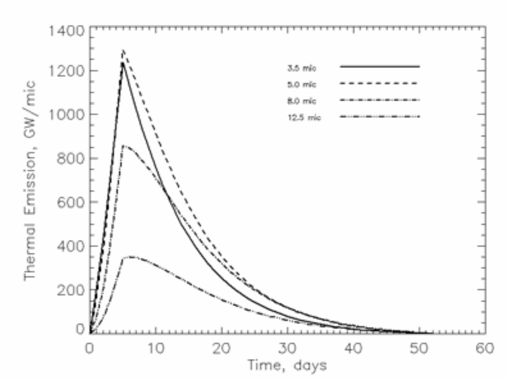

Figure 3: Variation in thermal emission at different wavelengths with time (52-day eruption).

Martian and terrestrial flood lavas: It is interesting to compare what was observed at Pillan to what has been inferred for flood lava eruptions on Mars and the Earth. The initial model that flood lavas were emplaced as turbulent floods with $Q_F > 10^6$ m^3 s^{-1} [12] has been shown to be physically plausible but inconsistent with the field constraints [13]. Instead, most terrestrial flood lava flows form inflated pahoehoe sheet flows with volume fluxes of ~10^3 m^3 s^{-1} [13]. However, a substantial minority of flood lava flows on Earth have brecciated flow tops and a 4-part internal structure (termed "rubbly" pahoehoe) [6]. These flows were inferred to form when the lava flux exceeded ~10^4 m^3 s^{-1}. The surface of these flows are characterized by rafted plates and compressional ridges [6]. The one high spatial resolution *Galileo* SSI image of the lava flows hints at such plates, but the garbling caused by radiation damage to the camera's electronics confuses matters [3]. However, our new results from Pillan lend additional quantitative support to the idea that terrestrial rubbly pahoehoe flows and Martian "platy-ridged" flows are diagnostic of eruption rates $>10^4$ m^3 s^{-1}.

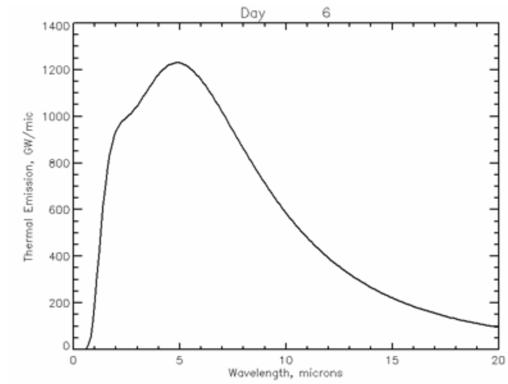

Figure 4: Thermal emission on day 6 of a 52-day eruption, with 2% of the active flow area being hot cracks.

Future observations of Io volcanism: This analysis forms the basis of further work investigating eruption mechanisms at Pillan and interpreting low-resolution remote-sensing data of Io's volcanism.

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