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A potential thermal erosion lava channel on Io

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[1] We have discovered a prominent >190 km long, ~0.5–6 km wide lava channel on Io. The channel is sinuous with interior islands and may be associated with the active Tawhaki Patera hotspot. Photoclinometric analysis of the *Galileo* images indicates that this channel, provisionally named Tawhaki Vallis, is ~40–65 m deep. Although a constructional contribution cannot be ruled out, the depth, morphology, and sinuosity of the channel is consistent with erosion by lava. Erosion of flowing silicate over silicate substrate or flowing sulfur over sulfur substrate likely requires eruption durations of days to months to form an ~50 m deep channel, whereas flowing silicate over a sulfur substrate or flowing sulfur over a frozen SO_2 substrate would likely require only hours to days. Future spacecraft observation of actively forming lava channels on Io are possible and desirable. *INDEX TERMS:* 5460 Planetology: Solid Surface Planets: Physical properties of materials; 5464 Planetology: Solid Surface Planets: Remote sensing; 5480 Planetology: Solid Surface Planets: Volcanism (8450); 5494 Planetology: Solid Surface Planets: Instruments and techniques. **Citation:** Schenk, P. M., and D. A. Williams (2004), A potential thermal erosion lava channel on Io, *Geophys. Res. Lett.*, *31*, L23702, doi:10.1029/2004GL021378.

1. Introduction

[2] Lava channels and tubes are important components in the genesis of lava flow fields on terrestrial planets and satellites. One mechanism for the formation of lava channels and tubes is thermo-mechanical erosion by flowing lava [e.g., *Kauahikaua et al.*, 1998], involving some combination of thermal melting and assimilation, and/or mechanical plucking and entrainment of underlying substrates by hot flowing lava [*Hulme*, 1973; *Huppert et al.*, 1985; *Williams et al.*, 1998]. Thermo-mechanical erosion has been proposed as a key mechanism for the formation of terrestrial komatiite-hosted Fe-Ni-Cu-(PGE) sulfide ore deposits [e.g., *Lesher*, 1989], and as a mechanism for the genesis of some of the lunar sinuous rilles [*Hulme*, 1973], some Martian lava channels [*Carr*, 1974; *Wilson and Mouginis-Mark*, 2001], and some Venusian canali [e.g., *Baker et al.*, 1992; *Kargel et al.*, 1994].

[3] The extent that thermal-mechanical erosion can form deep lava channels is a function of the temperatures and compositions of the lava and substrate, the slope, volatile content, and degree of consolidation of the substrate, and the flow rate, flow duration, and environment of emplacement of the lava [*Williams et al.*, 1999]. Recent work [*Williams et al.*, 2000, 2001a, 2001b] assessed the potential of inferred ultrabasic and sulfur lava flows to produce thermal erosion channels on Io. In this paper we discuss an Ionian channel we have detected in *Galileo* images, and we investigate the potential role of thermal erosion in its formation.

2. A Deep Channel on Io

[4] *Galileo*'s Solid-State Imager (SSI) high-resolution imaging of Io [*Turtle et al.*, 2004] was severely limited. Only one lava channel was observed at high resolution during the course of the mission, a 0.5-km-wide and >100-km-long curvilinear, dark channel within a bright yellow flow field extending east from the margin of Emakong Patera [*Williams et al.*, 2001b]. A high-resolution *Galileo* SSI mosaic [*Turtle et al.*, 2004] of the Emakong channel reveals bright "islands" and other features (Figure 1) suggesting that it was formed by low-viscosity lava, possibly sulfur and possibly involving thermal erosion [*Williams et al.*, 2001b]. Although stereo imaging is available, the vertical resolution of the DEM is only ~40 m and no channel relief is apparent.

[5] We have discovered a second large lava channel on Io located at 0°N, 73°W, ~225 km east of Hi'iaka Montes in the relatively featureless plains of Media Regio (Figure 2). Neither the origin nor terminus of the channel were observed. Tawhaki Patera, a 60 km wide dark-floored, caldera-like volcanic crater located ~100 km northwest of the known channel (Figure 2), is the nearest volcanic feature and could be the source for the lava channel, provisionally named "Tawhaki Vallis".

[6] The observed length of the channel is ~190 km; segments to the south of the main feature (broken by the terminator) suggest a total length of >250 km (Figure 2). Channel width varies from ≥500 m to 6 km, suggesting impediment due to topography or differences in substrate properties. These widths are narrower than most Venusian lava channels [*Baker et al.*, 1992]. Topographic islands are apparent (Figure 3a), producing an appearance of immature braiding.

[7] High-sun imaging at 1.4 km/pixel shows nearly featureless bright plains (Figure 2), and do not reveal any albedo features in association with this channel, suggesting that any (presumably dark) lava flows transported through this channel have been subsequently covered by bright ballistic plume or other deposits. No new dark or bright lava flows were detected between the *Voyager* and *Galileo* missions, although Tawhaki Patera is a known hotspot

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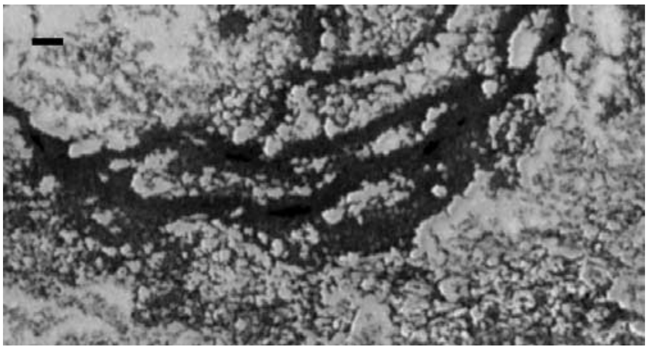

Figure 1. *Galileo* high-resolution (35 m/pixel) orbit I32 image of dark-floored lava channel on Io associated with Emakong Patera (off image to left). Branching and "islands" are apparent. Scale bar is 1 km. See *Williams et al.* [2001b] for a regional view. North is to top in all figures.

[*Lopes et al.*, 2001], whose dark patera floor is consistent with a silicate composition [*Geissler et al.*, 1999, 2004].

[8] Unlike the Emakong channel, the low-sun (~10° elevation) observation of "Tawhaki Vallis" allows for the use of photoclinometry (PC) techniques [*Schenk*, 2002], also known as shape-from-shading, to construct a digital elevation model (DEM) of this region and to estimate channel depth (Figure 3b). To model local slopes from apparent brightness, we employ the lunar-lambert photometric function [*McEwen*, 1990], where an "L" term describes the relative contributions from the lunar-like and lambertian components. Based on analysis of other images of Io, we estimate L~0.4 for this observation. The lack of contrast in low-phase-angle images (Figure 2) indicates that there are no significant albedo variations associated with this region, removing one of the major sources of error.

[9] Measured channel depths range between 40 and 65 m (Figures 3b and 3c), with most between 50 and 60 m. The channel is <5 to 20 pixels across in these images and cumulative PC elevation errors are estimated to be only a few meters over these distances. Apparent depths drop below these values in the narrowest sections of the channel but we suspect this may be a resolution effect. Our PC-DEM is not reliable over long wavelengths. Slopes on shield volcanoes and volcanic plains elsewhere on Io are generally no more than ~0.5° or so [*Schenk et al.*, 2004], and we infer that regional slopes on this plain are similarly low.

[10] The sinuosity of the Tawhaki Vallis channel and topographic islands within it are consistent with formation by flowing lava. The islands are similar to those in the Emakong Patera channel [*Williams et al.*, 2001b]. We do not see any evidence for pit chains or partially roofed over channels (i.e., lava tubes). The channel appears to have been open and continuous for at least 190 km. This may indicate that the lava was superheated, not allowing a solid crust to form [*Williams et al.*, 2001b].

[11] Several profiles across the channel show possible evidence of raised rims (Figure 3c). These levee-like features are up to 20 m high, but this is similar to topographic variations seen elsewhere in the DEM. Contiguous levees are not immediately evident from visual inspection of the DEM or image and are considered suspect in this case.

[12] Thermal-mechanical erosion of channels requires either laminar flow of extended duration (weeks to months [*Fagents and Greeley*, 2001; *Kerr*, 2001]), or turbulent flow of shorter duration (days to weeks), depending on lava and substrate composition and the substrate's degree of consolidation and volatile content [*Williams et al.*, 1999, 2001a, 2001b]. Because evidence for constructional levees is suspect and the bottom of the channel is below local ground level, we suggest that Tawhaki Vallis may be erosional in origin.

[13] Recent modeling of thermal erosion [cf. *Williams et al.*, 2001a, 2001b] (Figure 4) suggests that turbulent ultramafic lavas eroding into ultramafic substrates on Io have low erosion rates (<0.1 m/day), whereas turbulent sulfur lavas eroding into sulfur substrates are faster (1–4 m/day),

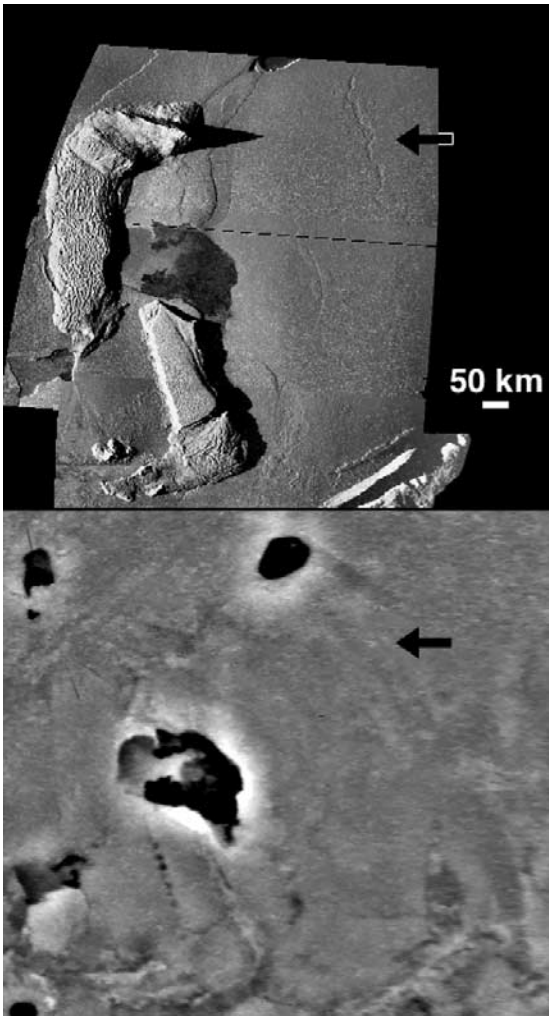

Figure 2. *Galileo* mosaics of part of Media Regio, Io. (top) Low-sun 260 m/pixel resolution mosaic obtained during orbit I25 (Nov. 1999), featuring >250 km long lava channel (arrow). Hi'iaka Montes are the two large mountains at left. (bottom) High-sun image mosaic of same region obtained during orbit I24 (Oct. 1999), showing lack of major albedo features in the region of the lava channel (arrow). Oblong dark caldera Tawhaki Patera (top center) may be source for the lava channel. This mosaic has been processed using a high-pass filter to enhance detail.

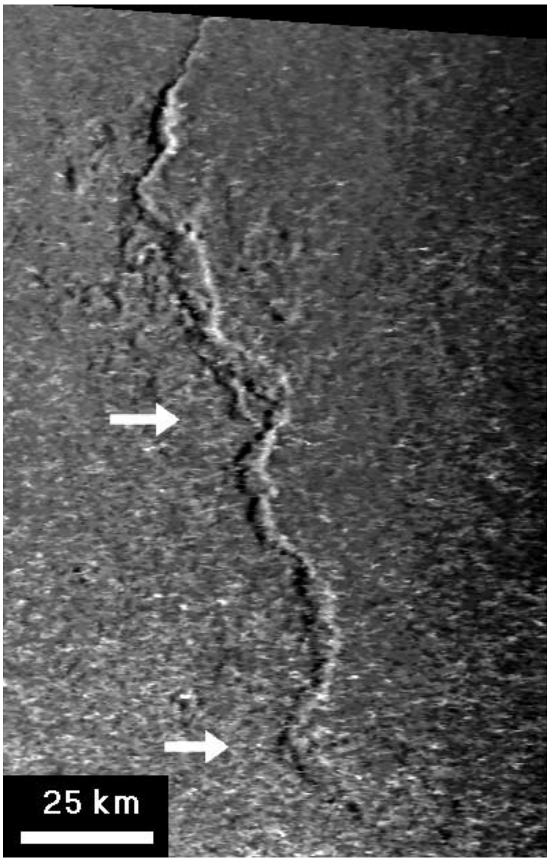

Figure 3a. Closeup of Figure 2 (top), showing morphologic details in and near lava channel. Arrows indicate several topographic mesas or "islands" within the channel margins. Subtle features near top of channel and at right may be additional channels. Inferred direction of flow is north to south.

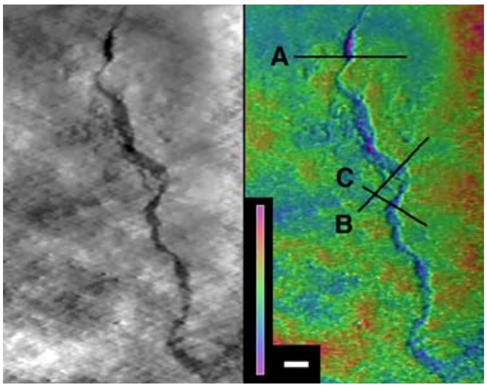

Figure 3b. Digital Elevation Model (DEM) of Tawhaki Vallis channel. Gray-tone version (left) and color-coded version (right) overlain on original image mosaic. Elevation data are from 2-D photoclinometry analysis of Figure 3a. Smaller scale features (knobs and hummocks, and mesas) are either real textural variations within these plains or artifacts due to radiation-induced noise in the original images. Horizontal scale bar is 10 km; vertical color scale bar shows elevation range of 0–150 meters.

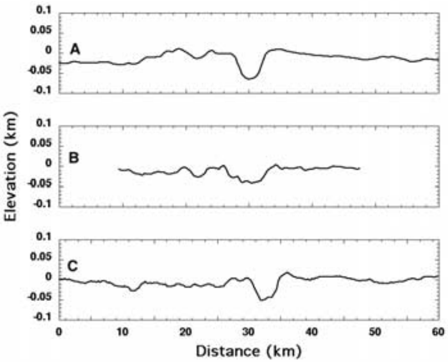

Figure 3c. Topographic profile across lava channel on Io. Locations of profiles shown in Figure 3b.

depending on eruption conditions. If the substrate consisted of frozen SO_2, then erosion rates by silicate or sulfur lava could be an order of magnitude higher (Figure 4). (Erosion rates will be enhanced if the substrate consists of partially unconsolidated deposits.) Thus either "long" eruptions would be required to erode a 40–60 m deep channel in similar composition substrates (400–600 days after initiation of erosion for ultramafics, 10–60 days for sulfur), or if a high-T lava flowed over a substrate of drastically lower melting temperature, then a deep channel might be formed in hours to days (Figure 4). Candidates include (now buried) ultramafic lava over sulfur substrate or sulfur lava over an SO_2-rich substrate. As Io appears to have ubiquitous coverings of frozen SO_2 and S_2, these latter candidates seem likely. Further modeling is encouraged.

[14] Our observation of a "deep" lava channel in Media Regio at least superficially similar to those observed on

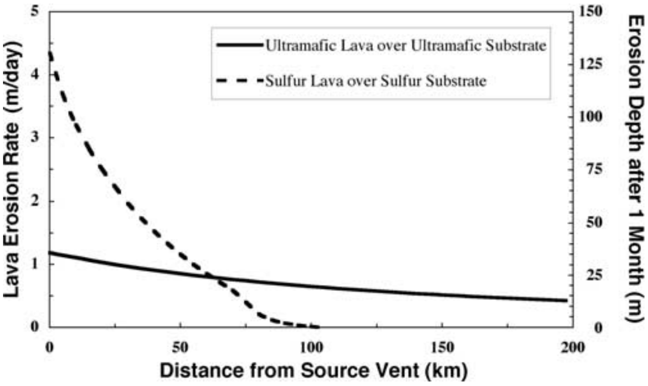

Figure 4. Estimated erosion rates (left) and depths (right) for two types of channel-fed Ionian lavas erupted over substrates of similar composition, based on *Williams et al.* [2001a, 2001b]. Results are for initially 10 m thick flows erupted over ground with low slopes (0.5°) at −158°C. Eruption temperature is 1610°C for ultramafic lava and 160°C for sulfur lava. The erosion rate is higher for the cooler sulfur lavas because solid sulfur has much lower density, specific heat, and heat of fusion than silicate, making a sulfur substrate easier to erode. Still higher erosion rates may result when lavas flow over substrates with much lower melting temperatures: ~7 m/day for sulfur lava over solid SO_2, ~110 m/day for ultramafic lava over sulfur.

Mars, Venus, and the Moon suggests that thermal erosion may be a significant process on Io. Global mapping of the distribution and origins of such channels on Io will require systematic mapping at low-sun illumination at resolutions better than 300 m. The detection of two channels on Io despite limited global mapping raises the probability that a future dedicated Io spacecraft could detect and observe lava channels actively forming.

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