IDENTIFYING LAVA FLOW TRANSPORT STYLE IN RECENT HIGH RESOLUTION IMAGES OF IO AND MARS.

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Introduction: One of the main goals of planetary volcanology is to identify the way in which lava flows on the different planets were emplaced. This provides constraints on the style of the eruption and the chemical composition of the lava. As long as we are limited to imaging data, the morphology of the lava flows provides one of the most important clues to the evolution of a planet's interior.

In terrestrial volcanology, great emphasis is given to features on the cm-mm scale. For example, the distinction between aa and pahoehoe lava flows are defined by the cm scale clinker on aa flows [1]. Features on this scale are mostly produced at the flow front and record the initial seconds-minutes of lava flow emplacement.

Clearly, such small features are not observable from orbit, making it difficult to directly apply terrestrial lava flow classifications to planetary flows. Instead, we must concentrate on the lava flow morphology on the 10-100 m scale, which is generally produced by the lava transport system over a period of hours to years. It is crucial to identify the style of lava transport before application of quantitative flow models. The incorrect determination of the lava transport system can lead to errors of many orders of magnitude in modeled effusion rates and flow velocities [2].

Applicability of terrestrial analogs: Comparing planetary images to the morphology of well studied terrestrial analogs is the standard method for interpreting extra-terrestrial lava flows. However, it is necessary to understand the effects of the different planetary environments on the lava flow morphology before such comparisons can be made. The two major factors that vary between the planets are gravitational acceleration and the atmospheric properties. For laminar lava flows (where viscous forces dominate over inertial effects), lowering gravity is identical to reducing the slope.

The atmospheric density and temperature can have a strong impact on the cooling of lava flows on timescales of days-years. But, to first order, exposed liquid silicate lavas are subjected to rapid cooling in any planetary environment. The fact that terrestrial submarine and subaerial lava flows exhibit many of the same features, especially at the 10-100 m scale, suggests that cooling alone will not critically alter the style of transport of lava on the different planets. Instead, cooling can have a significant effect on the mm-cm scale surface texture and the final length of the flow (10-1000 km scale). We conclude that the direct comparison of terrestrial analogs to planetary lava flows at the 10-100 m scale can be made, with caution.

Types of lava transport systems: The basic geometry of structures that transport fluid lava from the vent to the flow front can be classified as (1) open channels, (2) lava tubes, (3) insulated sheet flow, and (4) open sheet flow. Steeper slopes and lower effusion rates favor channels and tubes while shallower slopes and higher effusion rates favor sheet flow [3]. This is simply because on steeper slopes the flow velocity is higher and a smaller cross-sectional area can accommodate a given flux of lava.

It is important to note that the lava transport system is not generally diagnostic of the surface morphology of the lava flow. For example, both aa and pahoehoe can be fed by either lava tubes or open channels. Also, the type of lava transport system can change with distance from the vent and as a function of time. It is common for open channels to crust over and become lava tubes [4]. The remainder of this abstract discusses criteria by which these different types of lava transport systems have been identified in recent high resolution images from Mars and Io.

Open-channel flow: Given adequate resolution and preservation, lava channels are straightforward to identify because the fluid filled channels almost invariably drain as the eruption wanes. The recent Galileo images of Io show several examples of unequivocal lava channels [5]. The most striking of these are within the 2-year-old Pillan flow field where the size and general morphology of the channels is very similar to those found on terrestrial volcanoes such as Mauna Loa.

Spectacular lava channels are abundant in the MOC images taken over flanks of the major shield volcanoes on Mars. Many have a particular resemblance to the channelized aa flows on the flanks of Mt. Etna. Other channels on the plains are more difficult to ascribe to lava and are likely to be dominantly fluvial in origin.

Tube-fed flows: Because they are covered, lava tubes are exceptionally difficult to identify in images. However, some criteria allow for the presence of lava tubes to be confidently inferred. Basically, if the lava traveled from the vent to the front of the flow with no visible transport system, it must be traveling under an insulating crust.

Inflation also require the presence of a stable, undisrupted, insulating crust. Inflated flows can be readily recognized because inflation produces a diagnostic mottled pattern of raised areas and uninflated depressions. The geometry of the area that is raised up is a direct indication of the areas that contained larger volumes of liquid lava. Thus, hummocky flows require a network of smaller tubes while sheet flows require a continuous sheet of liquid lava [6]. It is also important to note that, as the lava flow inflates, it is capable of transmitting a given volumetric flux of lava with a narrower pathway. Thus it is common for sheet flows in Hawaii to evolve into tube-fed flows over a period of weeks. There are many terrestrial examples of elongated sets of tumuli over a tube that has formed within an inflating sheet flow [2,8].

On Io, the mottled pattern of hummocky inflated lava flows can be clearly seen within the Prometheus flow, strongly suggesting that it is tube-fed. With the active lava flows on Io, additional criteria can be used to infer the presence of a lava tubes. Volcanic features such as Prometheus, Amirani-Maui, and Culann have multiple discrete hot spots associated with a single lava flow. In each case, one of these hot spots has been identified as the vent, and other hot spots correspond to active surface flows. No hot areas connect these surface flows to the vent, indicating that the transport system is well insulated. In the case of Culann, high resolution color data shows the trace of a narrow tube, apparently outlined by condensed gases escaping along the roof of the tube.

The case for lava tubes on Mars remains more equivocal despite the new MOC images. The lack of visible lava transport systems in many of the long, narrow flows on the large Martian shield volcanoes and the ridges seen on some Alba Patera flows still argue for lava tubes. Some of the lines of pits on the flanks of Olympus Mons are likely to be partially collapsed lava tubes.

However, not one example of inflated lava has been confirmed in the mapping phase MOC images. These recently released, highest resolution, images cover some of the areas where inflation features were tentatively identified in the highest resolution Viking and the early lower resolution MOC images [9,10]. The ridges discussed in [9] appear to be related to open sheet flow and the hummocky terrain shown in [10] appears largely erosional. The lack of inflation features is particularly surprising because the Martian environment favors the formation of inflated flows [11].

Insulated sheet flows: Terrestrial flood lavas were almost exclusively emplaced as insulated sheet flows. The sheet-like geometry is the result of a combination of the low slopes these flows were emplaced upon and the high effusion rates that fed them [3]. The result is a sheet of lava with a surface that is relatively smooth and featureless on 10-100 m scale. However, due to variations in the underlying topography, and the evolution of an eruption, some tumuli, inflation plateaus, inflation pits, etc. are usually discernable [6]. The lack of any identified inflation features on the Martian flood lavas indicates that either the primary 10-100 m scale lava features have been erased or that the flows were not emplaced in the same manner as most terrestrial flood lavas. In contrast, the large Ionian flows appear to be being emplaced in the same manner as the terrestrial flood lavas. For example, the broad, flat surface of the main Zamama flow field on Io suggests that it was emplaced as an insulated sheet flow.

Open sheet flow: Wide flows without a coherent insulating crust are very thermally inefficient. Thus, most terrestrial examples of open sheet flow are small and confined to within a few hundred meters of the vent. One exception is a portion of the Laki flow field in Iceland, where surges in the eruption burst out from the insulating sheet at the flow front, producing short-lived floods of lava that advanced several kilometers. In both the small and larger terrestrial examples, this style of emplacement produces a flow surface characterized by rafted plates of lava. When the rafts collide with an obstacle, they are broken up into ridges of brecciated material.

This platy-ridged morphology has been unequivocally identified in MOC images of the surface of the best preserved Martian flood lavas [12]. This indicates that these flows were not emplaced in the same manner as terrestrial flood lavas. Initial modeling suggests that the effusion rates for the Martian flood lavas was about an order of magnitude larger than the terrestrial flood lavas [11]. The platy-ridged surface has also been seen in the highest resolution images of Io on a portion of the Pillan flow field.

Conclusions: The new images from Mars and Io are providing a new look at planetary volcanism. The full range of known lava transport systems have been identified on Io, and the scale of these are similar to those found in the geologic record of the Earth. The new images of Mars have proven more disappointing because many of the 10-100 m scale volcanic features are no longer recognizable. However, the most recent flows have a well preserved platy-ridged morphology that indicates that their transport involved a mix of insulated and open sheet flow. This leads us to conclude that the immense Martian flood lavas, which dwarf their terrestrial and Ionian counterparts, were emplaced in a fundamentally different manner. Perhaps most surprisingly, despite good evidence for both open channel and tube-fed flows, conclusive images of inflation features on Mars remain elusive.

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