OLYMPUS MONS: INFERRED CHANGES IN LATE STAGE EFFUSIVE ACTIVITY BASED ON LAVA FLOW MAPPING OF *MARS EXPRESS* HIGH RESOLUTION STEREO CAMERA DATA.

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Introduction: Our objective is to characterize effusive martian volcanism based on the abundance and temporal relationships of lava flow types. The technique is based on an approach to characterize and contrast the eruptive processes of Kilauea, Mauna Loa, and Mount Etna [1,2]. We are mapping the flows of Olympus Mons to estimate the percentage of surface flows that were emplaced via lava tubes or channels using ESA's *Mars Express* High Resolution Stereo Camera (HRSC) data. Results indicate that late stage effusive activity was typified by channel-forming eruptions, while older tube-forming eruptions played a more important role on the north flank than the south flank. Neither flank appears to display point sources fed directly from the magma source.

Background: Lava tubes and channels are flow structures in basaltic flow fields [3,4]. Tubes are thermally insulated conduits and channels are open structures; both transport lava to flow fonts. Terrestrial tubes form through two dominant processes: 1) roofing of lava channels, and 2) progressive advancement and/or inflation of lobate toes or sheets at the flow front [5-24]. Tube formation is facilitated by long-lived eruptions, with low to moderate, fairly steady effusion of low viscosity lavas [23-28], while channels are generally related to shorter-lived eruptions, and higher, fluctuating effusion rates of more viscous lavas [23-28]. Because channels and tubes tend to form as a result of different eruptive conditions their abundance can be used to characterize the latest effusive stage. Shields with higher abundances of tubes likely erupted lavas during steady, long-lived eruptions compared to volcanoes dominated by channel-fed flows.

If tubes transport lava below full capacity, skylights can form by roof collapse, marking the path of the tube. Further collapse, if the tube drains, results in pit chains axial to the tube [5-28]. If transporting lava at full capacity tubes can be under confining pressures. In these cases inflation axial to the flow produces elongate tumuli, ridges, and rootless vents acting as sources for secondary flows [11, 14, 16-18, 21, 23-25]. Therefore, the presence of lava tubes can be inferred on the basis of surface features such as chains of collapse pits, elongate tumuli, and rootless vents [1,2,26]. These features were used to infer the presence of tubes on martian volcanoes [29-36].

Approach: To characterize late stage effusive activity at Olympus Mons (OM) we have mapped lava flows on the north and south flank allowing us to estimate the percentage of flows emplaced via tubes or channels. We map lava tubes based on the presence of collapse pits or, when collapse pits are lacking, infer tube presence based on features interpreted to have formed by inflation. We map lava channels when leveed linear flows are detectable. These are the same features that have been used in the past to suggest the presence of martian channels and tubes [29-36]. Our mapping is based on the *Mars Express* HRSC image 0037. This image provides coverage at ~17 m/pixel, with an image swath of ~120 km, extending across the north and south flank of OM, including the caldera. Mapping is supplemented by analysis of Themis VIS images where applicable, at 18 m/pixel.

Results: We have defined eight map units: 1) channels, 2) lava tubes, 3) raised ridges, 4) fan unit, 5) mottled unit, 6) hummocky unit, 7) tabular unit, and 8) smooth unit. The lava channels are areas where repeated, sub-parallel linear patterns are present, and are the most abundant unit on both the north and south flank, being more abundant on the south flank. Channel abundances increase distally on both flanks. Lava tubes are identified when roof collapse has occurred resulting in chains of collapse pits axial to raised ridges and in planar surfaces. Smooth surfaces and flows originating from the collapses are mapped as tube-fed. South flank tubes are dominantly embayed by channels and are discontinuous, with only one exposed example extending up to ~50km. Many north flank tubes are discontinuous and embayed by channels, but several tubes are not, with one example continuous to ~100 km. Tube abundances decrease distally on both flanks. Raised ridges are similar to ridged tubes, but lack pits. This unit consists of several raised mounds in a linear feature or isolated raised mounds. Channels on both flanks dominantly embay raised ridges. This unit likely represents tubes for which roof collapse did not occur, or collapse pits are smaller than the detection limit of the HRSC dataset.

The fan unit consists of flows radiating from an apex. Flows are mapped as part of the fan unit as long as they can be distinguished from adjacent flows. The fan unit is a positive topographic feature whose flows are often truncated by channels. Fans are almost always associated with tubes or ridges at their apex, distally, or both. The mottled unit is characterized by a rough surface on the scale of 10s of meters. Margins are sometimes detectable within this unit but individual channels or tubes cannot be identified. This unit is often associated with tubes but is sometimes isolated by channels. The hummocky unit is relatively smooth with several km wide hummocks or hills. This unit is located exclusively in the summit region. Lobate sheets that cannot be associated with a channel or tube characterize the tabular unit. The smooth unit is composed of surfaces lacking detectable margins.

Discussion: The hummocky unit might represent 1) dust mantling, 2) pyroclastic deposits, or 3) primary lava flows. Tube collapses are found inside the hummocky unit and some channelized flows emerge from hummocks suggesting that this unit might represent an inflated sheet flow that transitions to channels and tubes distally. Raised ridges are likely tubes for which roof collapse has not occurred or is undetectable. Preliminary mapping showed that raised ridges in Themis daytime IR images (100 m/pixel) sometimes display roof collapse in Themis VIS images (18 m/pixel) supporting this interpretation. The relationship between tubes and fans suggests that fans represent tube breakouts as hypothesized by others [30]. We have not identified any other point sources on OM suggesting that any flank vents were covered or all effusive activity originated from the summit.

Decreasing tube, and increasing channel abundances distally are consistent with an increase in lava viscosity during emplacement inhibiting tube formation, and enabling channel formation. Embayment of lava tubes by younger lava channels on the south flank suggests a change in effusive style from channel- to tube-forming eruptions. A similar transition exists for the Hawaiian shields [2]. Older shields, farther from the source, undergo effusive style changes detectable in lava flow morphologies. Kilauea possesses the highest abundance of tubes, related to longer-lived eruptions of low viscosity lavas at moderate, steady eruption rates while the shield is close to the magma source. Mauna Loa (farther from the source) has fewer tubes and more channels as a result of shorter-lived eruptions of more viscous lavas at fluctuating eruption rates. Even older, Hualalai and Mauna Kea display channels, parasitic cinder cones, and a lack of lava tubes. Individual Hawaiian shields are moved away from their magma source by plate tectonics causing the transition from tube- to channel-forming eruptions. Although lacking plate tectonics, OM has likely undergone a similar transition as Mars cools with time.

Although channels also embay many tubes on the north flank, some tubes are not embayed. Likewise, channels are not as abundant here. These results suggest that the north flank was not exposed to channel-forming eruptions for as long as the south flank. Perhaps later stage channel-forming flows were diverted away from the north flank. Crater counts of flow units on the flanks of OM as well as continued mapping of the east and west flanks as data becomes available might provide insight to the difference between the north and south flank.

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