REVISITING VALLEY DEVELOPMENT ON MARTIAN VOLCANOES USING MGS AND ODYSSEY DATA.

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Introduction: The valley networks found on the slopes of Martian volcanoes represent an interesting subset of the Martian valley networks. Not only do the volcanoes constrain the possible geologic settings, they also provide a window into Martian valley development through time, as the volcanoes formed throughout the geologic history of Mars [1]. Here I take another look at this intriguing subset of networks by revisiting conclusions reached in my earlier studies using the Viking imagery [1,2,3] and the valleys on Hawaii as an analog [9]. I then examine more recent datasets.

Volcano Valley Networks: Valleys are found on the slopes of several Martian volcanoes including Alba Patera, Hecates Tholus, Tyrrhena Patera, Hadriaca Patera, Apollinaris Patera, and Ceraunius Tholus.

Gulick and Baker [1,2] discuss the morphology of the valleys on these volcanoes. In summary, Tyrrhena Patera contains unusually wide flat-floored, monofilament theater-headed valleys which grade into isolated remnants of the volcano. On the southern and western flanks of Hadriaca Patera are long, highly degraded trough-shaped valleys that originate near the central caldera. Apollinaris Patera contains degraded radial, trough-shaped valleys. Ceraunius Tholus contains both pristine valleys with steep walls and degraded valleys with eroded, less steep walls. Hecates Tholus also contains similar pristine and degraded parallel valleys. This compound network morphology is similar to that exhibited by many of the Noachian valleys in the southern highlands [4]. Finally, particularly noteworthy are the valleys on the northern flank of Alba Patera that exhibit a fine-textured parallel to dendritic network morphology. These well-integrated tributary valley systems are restricted to areas on Alba Patera where lava flows appear to be absent. These valleys lie to the east of other valleys, termed ‘enigmatic’ by Gulick and Baker [2], which formed in areas of prominent lava flows.

Drainage Densities: Drainage densities of most valley systems on Mars range from 0.015 to 0.16 km/km^2 [4] compared to the minimum observed terrestrial value of approximately 1 km/km^2 [5]. Notably, however, valleys developed on Ceraunius Tholus, Hecates Tholus, and Alba Patera have drainage densities ranging from 0.3 to 2.3 km/km^2, comparable to the drainages densities of Hawaiian volcanoes [1,2].

Modes of Origin: Several modes of origin have been hypothesized for the valley forms on the Martian volcanoes, including volcanic density flows [10], lava [11], and fluvial erosion [e.g.,1,2,3,12,13] (surface runoff and groundwater sapping). Gulick and Baker [2] argue that the morphologies of many of the valley systems on volcanoes discussed above are most consistent with a fluvial origin (runoff, throughflow or ground-water sapping processes). In particular, the valleys tend to be continuous, widen down valley, have reaches with V-shaped or flat-floored cross sections, and often show tributaries. Morphologies associated with volcanic density flows and lava channels are generally less apparent. Several valleys on Tyrrhena, Apollinaris, Hadriaca, Ceraunius, and Hecates display morphologic features associated with sapping.

Valley Development on Hawaii: Despite a variety of modes of origin, valleys do not form until the surface runoff rate exceeds the rate of infiltration. On terrestrial basaltic volcanic surfaces valleys typically do not form until a soil layer forms by weathering or the surface is covered by ash because the permeability of fresh basalt is so high. Because of the youth of the volcanic surfaces on the island of Hawaii, the importance of a low permeability ash mantle is particularly evident. Figure 1 compares the location of valleys on the Big Island with the location of surface and near-surface ash deposits. The correlation of the two is unmistakable.

Although valleys formed on ash mantled surfaces throughout the Big Island, the degree of dissection generally increases with both rainfall and the age of the volcano. However Hualalai, which is older than Mauna Loa, remains essentially undissected because it lacks both the ash mantle and heavy rainfall of the other volcanoes. Despite receiving rainfall equivalent to that of Mauna Kea on its windward slopes, Kilauea displays essentially no dissection except where the 1790 Keanakakoi was emplaced [6]. The correlation between ash layers and fluvial features is generally not found on the older islands because sufficient time has passed for soils to form by weathering processes on basaltic surfaces.

Ash Mantles on Mars: Because one does not expect thick soils on Mars, one would expect that, like the young volcanic surfaces on Hawaii, fluvial valleys on volcanic landscapes would be associated with ash mantles. Indeed inspection of THEMIS

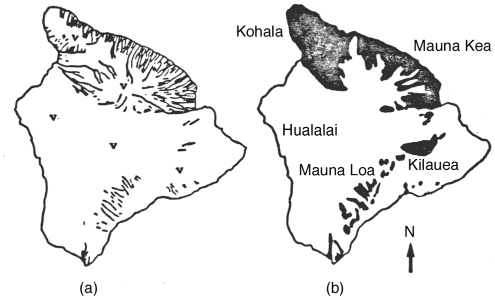

Figure 1: (a) Distribution of valleys on Hawaii (after Macdonald et al. [7]). Volcano centers denoted by 'v'. (b) Location of surface and near-surface ash deposits (after Stearns [8]). Figure modified from Gulick [9].

visible and IR images of Alba Patera and Hecates Tholus supports the association on these two volcanoes. Valleys on Hecates originate near the summit in regions that are dark in THEMIS nighttime IR images. However the walls of impact craters and collapse pits are bright in the nighttime IR and suggest a high thermal inertia unit underlying the mantling unit. This relationship is consistent with an ash mantle overlying a basaltic unit. This mantling may have been the emplaced by pyroclastic flows during explosive eruptions of Alba and Hecates [13, 14]

Similarly on Alba Patera, the dendritic valleys originate within morphologically smooth units that are dark in nighttime IR and bright in daytime IR images (Figure 2 right). Closer to the summit there is clear evidence from MOC images that ash mantles lava flow units, as on Hawaii.

The enigmatic valleys (Figure 2 left), in contrast, form among morphology indicative of prominent lava flows that are bright in nighttime IR images, supporting the hypothesis that these networks are associated with lava-flow features. However, there does appear to be some mantling in these areas suggesting that ash was also emplaced but to a lesser degree. These observations support the hypotheses [1] that the enigmatic valleys have a mixed lava and fluvial (perhaps fluvially modified) origin.

Valley Evolution on Mars: Initiation of valley development on the Martian volcanoes likely required the emplacement of an ash mantle or some other low permeability layer of material that decreased the surface infiltration capacity sufficiently to permit both overland flow and throughflow processes. Once such flow was initiated (e.g., snowmelt via geothermal heating [1, 2,3,15]), water collected in the topographically low regions and eroded channels into the surface material, eventually forming rills or parallel gullies, similar to those now forming on the Keanakakoi ash deposits on Kilauea volcano. As these drainages became more efficient in transporting water down the flank of the volcano, a network of tributaries formed. The erosion in this phase probably also exhumed lava flow features, including lava channels. With continued erosion and down cutting into the surface materials, deeply incised drainages locally tapped subsurface aquifers within the volcanic strata. The addition of groundwater to the network of incised drainages enlarged the valleys by concentrating erosion at points where the subsurface water intersected the surface environment.

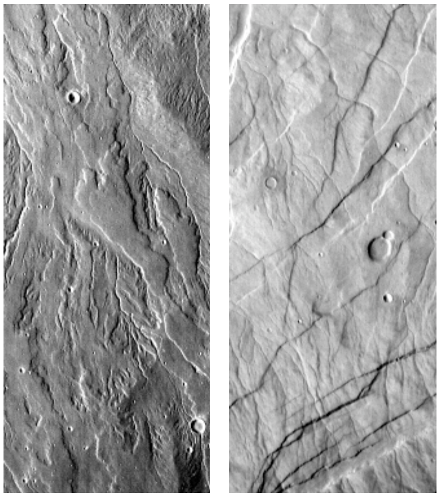

Figure 2: Daytime THEMIS IR images at two different locales on Alba Patera. Region of enigmatic valleys (left) and dendritic valleys (right).

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