MORPHOMETRY OF SHIELD VOLCANOES ON EARTH AND MARS AND IMPLICATIONS
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The topography of basic constructional landforms such as volcanoes has long been recognized as fundamental in quantitative studies of crustal growth and surface evolution of planets[1,2]. It is difficult to reliably constrain such critical landform parameters as volume (V), surface area (SA), aspect ratio (height H divided by basal diameter D), and slope distribution without adequate topographic information. Quantitative models for the growth and subsequent degradation of a broad variety of volcanic constructs can now be developed given the recent availability of new topographic datasets. For example, digital elevation models (DEM) of many martian volcanoes can be extracted from USGS digital topographic map data of Mars and 100 m horizontal resolution DEM are available for more than 30% of the Earth. In addition, airborne laser altimeter-derived topographic profiles with meter-scale horizontal and vertical resolution have been acquired for a suite of terrestrial volcanoes including Mt. St. Helens, Icelandic lava shields and table mountains, lava flows, domes, scoria cones, and explosion craters [3]. Such data now permit detailed morphometric comparisons between different types of volcanoes on Earth and Mars, and eventual extension to Venus using Magellan data. The objective has been to resolve whether any classes of volcanoes exhibit allometric growth behavior; that is, whether there is a continuum of volcano shapes and volumes as a function of various dimensional parameters such as D, H, H/D. In this study of shield volcanoes, we report on the preliminary implications of comparisons of derived parameters such as V/SA ("landform thickness" or **T**), V/SA/D ("diameter-normalized landform thickness" or **Td**) and V/SA/H ("height-normalized landform thickness" or **Th**), versus D, H, H/D and "shape". The volcanoes selected for comparison are a reasonably representative suite of 1-50 km scale terrestrial shields, as well as the four major Tharsis edifices on Mars.

Fig. 1 illustrates the noteworthy lack of correlation between **Th** and H/D for the nine shields under study. However, one can observe two well-defined clusters from the plot which suggest similarity of behavior. First, the classic Icelandic lava shield Skjaldbreidur (d) and the major Hawaiian shield Mauna Loa (e) are grouped together in a cluster distinct from smaller lava shields from both Iceland (a,c) and Hawaii (b), as well as from the martian shields. The smaller shields (a-c) appear to cluster with Olympus Mons, the ~700 km diameter martian composite shield. The two Tharsis volcanoes Pavonis and Arsia Mons define a third behavioral class, leaving Ascraeus Mons as an outlier. The well-developed association of ~10 km diameter lava shields with larger shield volcanoes in the two major clusters observed in Fig. 1 suggests that volumetric volcano growth and aspect ("shape") are essentially scale-independent.

We have identified a strong correlation between **T** and volcano height H for shield volcanoes ranging in size from ~2 km to ~1000 km; **T** ~ $H^{0.92}$ with a correlation coefficient R^2 = 0.99 for a set of Icelandic, Hawaiian, and martian shields. This suggests that the effective volcano thickness parameter **T** is linearly related to apparent volcano height H across a wide range of diameters. In contrast with Fig. 1, the **Td** vs H/D correlation (Fig. 2) is strong for terrestrial Icelandic and Hawaiian shields: **Td** ~ $[H/D]^{0.64}$ with R^2 = 0.98, but when the four martian shields are included there is a major change in behavior: **Td** ~ $[H/D]^{1.15}$ at R^2 = 0.85. In Fig. 2, the 10 km diameter Skjaldbreidur lava shield behaves similarly to the 50 km Mauna Loa shield (d and e), while the lower aspect ratio Icelandic shields such as Lambahraun (c) are broadly similar to some martian volcanoes (g,i). Most venusian "domes" in the 2-20 km diameter size class [4,5] display morphometries similar to low Icelandic lava shields (a,c); the larger Venus shields [6] would also plot in the same region on Fig. 2 (near a-c). Essentially all of the simple volcanic constructs described and mapped from Venera and Arecibo imagery of Venus display shield-like morphometries (either a-c or d-e type), suggestive of low-viscosity basaltic effusive eruptions from relatively shallow magma storage regions [6].

In order to facilitate systematic inter-volcano *shape* comparisons, we have defined a generalized polynomial volume of revolution (of a typical topographic cross-section):

$$V(n) = (\pi/4)\ (n/(n+2))\ D^2\ H$$

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where H is mean volcano height and D is mean basal diameter. From this simple equation one can solve for **n**, the order of the polynomial which best matches the volume estimated from a typical topographic cross-section, so that:

$$n = (8V)/(\pi D^2 H - 4V).$$

Thus **n** can be computed if only D, H, and V can be estimated from available topography for a given volcano. If n=1 the volcano is best modelled as a simple cone, while for larger n, a given volcano would progressively develop a more convex morphology, such as a dome. For n<1, the volcano flanks evolve to become more concave. Initially, we have examined n-values for shields on Earth and Mars, as well as the correlation between **Th** and n, in order to identify various growth mechanisms as a function of eruption style and composition.

The correlation of the polynomial shape parameter **n** with a morphometric parameter such as **Th** is shown in Fig. 3; in general, simple shield volcanoes display n-values between 0.66 and 0.79, in contrast with scoria cones (n~1.0), stratocones (n<0.60), and silicic lava domes (n>1.4). The very low-aspect ratio lava shields (a-c), however, display n-values of 1.16-1.33, perhaps a reflection of their rapid formation histories. Fig. 3 indicates that there is a strong correlation between "shape" (n) and **Th**; hawaiian shields (b,e) are grouped with the Icelandic shield Skjaldbreidur (d), but distinguished from low Icelandic lava shields (a,c). The 2-20 km scale venusian domes [4,5] would mostly fall in the cluster defined by i-c-a, distinct from typical Tharsis and hawaiian shields. A continuum of shield volcano "shapes" is suggested as a function of **Th**, and hence volumetric volcano growth. However, this continuum is apparently scale-independent. We would predict venusian shields at all scales to fall on the trend defined in Fig. 3; data from Magellan can be used to test this hypothesis. {This research was partially supported by NASA RTOP 465-44-03 (Ridge Volcanism); we are grateful to M. Baltuck of NASA HQ for her support}.

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Fig. 1

$V/SA/H = 0.4495 \ H/D^{0.1533}$
⊕ $R^2 = 0.0918$

Fig. 2

$V/SA/D = 0.4495 \ H/D^{1.1533}$
⊕ $R^2 = 0.8513$

Fig. 3

$V/SA/H = 0.3142 \ n^{0.6433}$
⊕ $R^2 = 0.9528$

a: Sandfellshaed$_{S \to N}$
b: Kilohana$_{N \to S}$
c: Lambahraun$_{NW \to SE}$
d: Skjaldbreidur$_{W \to E}$
e: Mauna Loa
f: Arsia Mons
g: Ascraeus Mons
h: Pavonis Mons
i: Olympus Mons