VOLUMES AND DEPTH OF BURIAL OF THE LESSER THARSIS VOLCANOES, M.S. Robinson, H. Garbeil, Planetary Geosciences, SOEST, University of Hawaii, 96822.

Utilizing the newly released USGS Mars global digital terrain model, DTM, we have calculated the volumes of the edifices and calderas of the lesser Tharsis volcanoes (LTV; Biblis Patera-BP, Ceraunius Tholus-CT, Jovis Tholus-JT, Tharsis Tholus-TT, Ulysses Patera-UlP, Uranius Patera-UrP, Uranius Tholus-UrT) which occur in the Tharsis volcanic province on Mars. These data were collected in order to compare the relative volumetric significance for each of these volcanoes, as well as to aid in comparison with other martian and terrestrial volcanoes. To augment the global DTM, we have also taken high resolution shadow measurements of the relief of each caldera where possible. From these new measurements we find that the caldera floors of five of these volcanoes (BP, JT, TT, UlP, UrP) actually lie below the level of the surrounding, embaying, lava plains [1, 2, *3]. An extreme case of burial is exhibited at Ulysses Patera, where the volume of the caldera is actually larger than that of the exposed edifice (Table). This is unusual in that the volume of a caldera represents a minor percentage of the total volume of the whole edifice for terrestrial basaltic shield volcanoes [4]. Estimates of the thickness of these LTV embaying lavas range from a few hundred meters [5] to 1000-1500 m [6,3]. In support of the upper estimate of burial we interpret that the caldera floor elevations (relative to the surrounding plains) of these five volcanoes indicates >1km of burial, on average, on the basis of the observation that there are no large terrestrial shield volcanoes with the caldera floor lying below the pre-existing terrain.

To further constrain the depth of burial for these martian volcanoes, we examine the relationship between height of volcanic edifice to caldera depth (H/d). This was considered due to the fact that five of the lesser Tharsis volcanoes have caldera floors that lie below the surrounding plains (Table). Additionally, these five calderas are also deep (compared with other martian and terrestrial examples) thus indicating that significant portions of the original caldera remain unfilled. Typically, the ratio of volcano height to caldera depth is greater than 20 for terrestrial shield volcanoes [4]. Volcanoes with a low height to depth ratio (H/d) would be less likely to have experienced large scale infilling, while volcanoes with a large H/d may have experienced large amounts of infilling. Simply put, volcanoes with a small H/d are probably most representative of types that have experienced relatively little infilling since their formation. In this context it is useful to examine the terrestrial volcanoes of the Galapagos Islands as they contain a significant H/d range (H/d = 4-22). In particular the caldera of Fernandina (H/d = 4) and Volcan Wolf (H/d = 6) exhibit low H/d not only within the Galapagos Island examples, but also for terrestrial basaltic shields in general [4]. It is also instructive to compare the H/d for the four major Tharsis shields and Apollinaris Patera with these terrestrial examples. For martian and Galapagos volcanoes the lower limit is about four (Apollinaris Patera and Fernandina). Since no large scale terrestrial basaltic shields have H/d of one or lower, this value (H/d = 1) is considered an extreme lower bound, in all likelihood the real value of H/d should be higher. The depths of the calderas of the predominately effusive lesser Tharsis volcanoes are great by any standard (average 2400 m), and thus it is reasonable to apply the low end H/d range to estimate their preburial height (H/d of 1-4). The depth of burial is determined by the product of the respective (H/d) and measured caldera depth (dm), minus the measured height of the edifice above the surrounding terrain (hm), $b = [(H/d) \times dm] - hm$. BP is a particularly useful example to apply this method, since it has what appears to be a relatively unfilled caldera . The reconstructed depths of burial for BP are 1, 4 and 10 km for H/d of 1, 2 and 4, respectively. The greater estimate of 10 km is nearly equivalent to the height of the Tharsis rise, and thus is probably an overestimate [c.f. *9]. The mid-range estimate of burial, 4 km, is consistent with both constructional and mixed constructional/upwarping models [9] for the origin of the Tharsis rise. The lower reconstructed burial, 1 km, is probably too low on the basis of terrestrial H/d values and the sparsity of neighboring impact craters with diameters of 5 km and greater (they are buried). Thus, it is here proposed that the average depth of burial lies in the range of 1-10 km, with the estimate of 4 km being the most reasonable.

The reconstructed burial of UlP (3.5 km, from H/d = 2) is consistent with the depth of burial of BP (Table). UlP and BP are spatially close (<50 km), so it is reasonable to assume that their depth of burial should be similar if they were both emplaced prior to all the embaying lavas. Stratigraphic mapping by [7] indicates that BP and UlP predate all embaying lavas. Thus, it is consistent to infer that the thickness of the embaying lavas around BP and UlP is on the order of 3-4 km. The mid-range estimate of burial (H/d = 2) for UrP (2.4 km burial) is significantly greater than the previous estimate of 500-600 m [6] and essentially equivalent to the 2.1 km estimate of [3]. This depth of burial (2.4 km) is consistent with those of BP and UlP in that UrP is further (400 vs. 900 km, respectively) from the putative source of the Tharsis flood lavas, the Tharsis Montes. It is reasonable to expect a radial thinning of the flood lavas from the source, resulting in less burial outward from the Tharsis Montes. Consistent with a radial thinning of the Tharsis flood lavas, is the depth of burial of JT (3.0 km; H/d = 2). This depth of burial is intermediate to those of BP, UlP (3.5-4.0 km) and UrP (2.4 km). JT has a correspondingly intermediate distance from the Tharsis Montes (700 km). The neighboring volcanoes to UrP, CT and UrT, both have shallow calderas that appear to be relatively infilled and are proposed to be dominantly of explosive origin, hence, it is not appropriate to apply the H/d method. However, due to their close spatial location to UrP it is assumed that their depth of burial is similar (2.4 km). Due to the highly irregular shape of TT, it is difficult to apply the H/d method due to uncertainties regarding a valid edifice height (relief above the surrounding terrain) and depth of caldera. However, using the eastern caldera wall height of 2.4 km, and applying the H/d method, the corresponding depths of burial for H/d of 1, 2 and 4 are 1.0, 3.5 and 8.5 km, respectively. The mid-range burial estimate (H/d = 2) of 3.5 km is consistent with the other lesser Tharsis volcanoes, on the basis of relative proximity to the Tharsis Montes (600 km). Clearly these estimates are rough and are subject to unconstrained errors, probably 1 to 2 km. However, these estimates indicate that the commonly inferred average thickness of 500-1500 m [6, 7, 8] for the lavas on the Tharsis rise are low. The observation that the calderas of BP, JT, TT, and UlP are all at least 1 km below the surrounding plains argues strongly that only the upper range (1500 m) of the previous estimate is plausible. In support of a greater total thickness of the Tharsis flood lavas is the observation that the flood basalts of the Deccan Traps, India, have an average thickness in excess of 2 km [10]. Similar or greater thicknesses, of similar type martian deposits are not unreasonable, and possibly even expected, due to gravity differences. Individual lava flows that compose a flow unit should have greater thicknesses on Mars relative to the Earth [11]. On the basis of this new model, the caldera elevations, and terrestrial analog, it is plausible to assume that the average thickness of lavas on the Tharsis rise is greater than 1500 m, and may be as much as 4 km locally. For the LTVs this means that the volume of the buried portion, for the minimum H/d of one, is greater than the volume of the exposed portion for BP, JT, UlP and UrP. The mid-range estimate of H/d of two indicates the buried volume for each of the LTVs (excluding TT) is, on average, greater than 15x the exposed volume (Table).

References:[1] Plescia and Saunders (1979), *PLPSC* 10, p. 2841.[2],Greeley and Spudis (1981), *RGSP* 19, p. 13. [3] Whitford-Stark, (1982), *JGR* 87, p. 9829. [4] Pike and Clow, (1981), *USGS OFR*-81-1038. [5] Plescia, (1993), abstract *LPSC* XXIV, p. 1155. [6] Plescia and Saunders, (1980), *PLPSC* 11, p. 2413. [7] Scott and Tanaka (1980), *JGR* 87, p. 1179. [8] DeHon, (1982), *JGR* 87, p. 1179. [9] Solomon and Head (1982), *JGR* 87, p. 9755. [10] Cas and Wright, (1988), *Volc. Succ. Modern Ancient,* p. 369. [11] Wilson and Head, (1983), *Nature* 302, p. 663.

	E D	E H	E Vol	B, V	C D	C d	C Vol
BP	184	2000	22	*4.0, 350*	52	3000	4.0
CT	115	6000	27	*--, 59*	24	1000	0.4
JT	54	1000	1	*3.0, 23*	26	2000	0.4
TT	114	6000	22	*3.5, --*	30	2400	2.2
UlP	97	1000	2	*3.5, 83*	55	2240	4.2
UrP	264	2000	33	*2.4, 292*	100	2200	7.5
UrT	61	3000	4	*--, 16*	21	220	<0.1

Table. Pertinent measurements of the lesser Tharsis volcanoes. E=edifice, D=Diameter (km), H=edifice height (m), Vol=volume (10^3 km^3), B=depth of burial estimate from H/d=2 (km), V=reconstructed volume from H/d=2 (10^3 km^3), C=caldera, d=depth (m).