COMPARISON OF EXTINCT AND ACTIVE LARGE SHIELD VOLCANOES ON VENUS.

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Introduction: We wish to test the hypothesis that when Venusian shield volcanoes lose dynamic support, a large central depression forms as the volcano becomes extinct. This process is analogous to previously proposed collapse mechanisms related to coronae formation [1,2]. Imagery, gravity, and topography were examined for a set of 20 volcanoes that appear superficially similar. Our hypothesis that volcanoes with central depressions are extinct implies a correlation between the presence of a central depression, unrelated features that postdate the volcano, and Airy isostatic support.

Procedure: The 20 volcanoes were selected for their axisymmetric, radial flows that exceed 500 km in diameter. In Magellan SAR imagery the volcanoes appear roughly domical, lacking steep slopes and sharp peaks and are located away from areas of major rifting. Magellan data was utilized to document three types of features unrelated to volcanic development that postdated the activity of the volcano. We consider an impact crater that has an intact ejecta blanket and radar-bright floor to be a post-volcano feature if it is located on a volcano's flow. Venusian craters with radar-dark floors have experienced lava flooding of their floors, and these craters were not considered to be postdating features [3]. Embayment relationships with surrounding volcanic features were used to place a volcano in the context of the local volcanic-stragraphic column. Postdating tectonic deformation was noted and divided into three categories: lineaments, fractures, and wrinkle ridges. Height was measured relative to the plains surrounding the volcanoes. The width at half the height and at .5 km above the base was measured to evaluate whether the volcanoes were similar in bulk shape.

North-south and west-east topography profiles were made of each volcano using Magellan nadir-looking radar altimetry [4]. These profiles were used to divide the volcanoes into three morphometric categories. Those with central depressions with widths greater than 100 km and surrounded by an annular rim were placed in a central depression category. Volcanoes with central depressions, but with volcanic edifices inside the annular rim that filled the majority of the depressions, were listed as resurgent features. The rest of the volcanoes had a domical shape. Profiles of the geoid and isostatic gravity anomaly were made for each north-south and west-east profile. The isostatic anomaly was computed by taking the free-air gravity and subtracting the gravity signal attributed to the topography Airy-compensated at a depth of 30 km. (Crustal density was assumed to be 2900 Kg/m^3 and the 30 km-compensation depth was based on estimates of the crustal thickness [5].) A small or negative isostatic anomaly over the central region of the volcano corresponds to the interpretation that the volcano can be completely supported by Airy type isostasy. A large positive isostatic anomaly most likely corresponds to some measure of dynamic support, i.e. support by mantle upwelling.

Results: Eleven of the twenty volcanoes were placed in the domical category, six in the central depression category, and three in the resurgent category. In the domical category 22 mGals was the average isostatic anomaly, and 7 of the 11 features had isostatic anomalies above 20 mGals. The mean isostatic anomaly for the collapsed central region volcanoes was -.75 mGals. In the domical group three (27%) of the volcanoes (Table 1) had postdating features (Table 2). In contrast, all of the central depression group has experienced some degree of postdating phenomena, and many are postdated by multiple events.

Table 1: Percent Postdating Features

	Dome Shaped Group	Central Depression Group
All categories	27	100
Tectonic Deformation	18	100
Embayment	18	83
Craters	9	83

Characterization of Central Depressions: The mean width of the central depressions was 140 ± 20 km. The mean maximum depth of the depressions was .6 km with the smallest maximum depth being .4 km and the largest .75 km. Five of the six volcanoes with central depressions had visible edifices in their interiors or on their rims and had visible flows that embay the depressed region. Four volcanoes had concentric lineaments surrounding the interior of the depressed region and three had radial lineaments visible on their rims. Resurgent features had volcanic edifices that dominated the surrounding central depression. The average width of these edifices was 170 km. The resurgent features had varied gravity signals, and two of the three had postdating features. The resurgent features were of similar scale and had similar flow structures as the other volcanoes studied.

Table 2 – Description of Volcanoes Studied

Name	Lat.	Long.	Group[a]	Isostatic Anom. (mGals)	Anomaly Correlation [b]	Height (km)	Half-Width (km)	.5km Width (km)	Post-Dating Features [c]
Api Mons	38.5	55.0	D	3.0	N	1.75	200.0	241.5	
Unnamed	2.5	45.5	D	25.0	Y	1.75	137.5	155.0	
Ushas Mons	-25.0	323.5	D	60.0	Y	2.00	212.5	225.0	
Tepev Mons	29.5	45.5	D	45.0	Y	5.00	137.5	187.5	
Innini Mons	-34.5	328.0	D	28.0	Y	2.25	180.0	250.0	
Hathor Mons	-39.0	325.5	D	28.0	Y	2.25	287.5	350.0	
Tuulikki Mons	10.0	274.5	D	-26.0	N	2.00	225.0	275.0	E
Dzalarhons Mons	0.0	34.0	D	45.0	Y	3.00	112.5	200.0	
Sif Mons	22.0	352.0	D	46.0	Y	2.50	125.0	175.0	
Uretseti Mons	-12.5	261.5	D	0.0	N	2.25	125.0	141.5	E,F
Kunapipi Mons	-34.0	86.0	D	-12.0	N	2.50	200.0	308.0	C,F
Kokyanwuti Mons	35.5	211.5	C	2.5	N	1.25	200.0	250.0	C,E,F
Itanua Corona	19.5	154.0	C	18.0	N	0.75	200.0	162.5	E,C,R
Uti Hiata	16.0	69.0	C	-5.0	N	1.75	262.5	287.5	E,F
Nzambi Corona	-45.5	287.0	C	2.0	N	0.70	200.0	187.5	C,E,R,L
Kunhild	19.0	80.0	C	-10.0	N	1.50	250.0	400.0	C,R
Mielikki Mons	-28.0	281.0	C	-12.0	N	1.50	300.0	300.0	C,L,E
Nyx Mons	30.0	49.0	R	65.0	Y	1.25	400.0	500.0	E
Atanua Mons	9.5	308.5	R	-11.0	N	1.50	275.0	275.0	
Nagavonyi Corona	-18.0	259.0	R	5.0	Y	0.75	200.0	175.0	F

[a] (D) DENOTES dome shape, (C) central depression, (R) resurgent features.

[b] Specifies whether the isostatic anomaly is centered on the volcano (Y) or is dominated by an unrelated regional trend (N).

[C] (C) impact crater, (E) embayment, (R) wrinkle ridges, (F) fractures, (L) lineaments of unknown tectonic setting.

Conclusions: The similarity in appearance, the similarity in widths measured at .5 km high, and the similarities in flow structure and flow scale justifies the assertion that the depressed central region volcanoes and the domical volcanoes are related. Large shield volcanoes are thought to be directly linked to mantle upwelling on Venus [6]. The large positive isostatic anomalies over the domical volcanoes along with their relative lack of postdating features indicates they may still be located over mantle upwelling. The central depression volcanoes presumably formed from similar scale mantle upwelling, but as a family they appear to have been inactive for an extended period due to the large number of postdating features. Furthermore, the gravity signals above the central depression volcanoes indicate that, as a class, they appear to be supported by Airy isostasy without significant amount of dynamic support. The central depression volcanoes, therefore, appear to be endmembers of the class of large shield volcanoes cut-off from the dynamic support of mantle upwelling.

The formation of the central depressions can be compared to the modeled formation of coronae on Venus. Many coronae observed on Venus have a raised rim and an interior central depression [1]. Squyres, et al. outlined a three-step process for the formation of coronae; rising mantle diapirs dome the crust, then the diapir flattens as it rises, creating a plateau shaped feature; finally gravitational relaxation produces a central depression [2]. For the volcanoes in our study, the presence of lineaments surrounding the central depression that postdates the major flows of the volcano is consistent with the depression forming after the active stage of the volcano. Once mantle upwelling is removed from beneath the volcano, the volcano ceases to emit major flows, the central region collapses, and the volcano lapses into a steady-state isostatic balance with compensation from a low-density root. The picture is complicated by the presence of small edifices in the depressed central regions that have produced some flows that embay the rim. Resurgent features may be the result of the reestablishment of mantle upwelling in the area. The similarities between the formation of coronae and large central depressions on shield volcanoes suggest that volcanoes and coronae may be more related than previously thought. Whether a corona or volcano forms may be related to the duration and intensity of mantle upwelling, and existing lithospheric conditions. For example, plume duration may control the amount of volcanism, so shield volcanoes form over long duration plumes and coronae over short duration plumes [7].

References: [1] Stofan E.R. et al. (1997) Venus II, 931-965. [2] Squyres S.W. et al. (1992) JGR 97, 13611-13634. [3] Herrick R.R. and Sharpton V.L., Lunar and Planetary Sci. Conf. 30, Abstract 1696. [4] Plaut J.P. (1993) Guide to Magellan Image Interp. 19-31. [5] Grimm R.F. and Hess P.C. (1997) Venus II 1205-1244. [6] Grimm R.E. and Phillips R.J. (1992) JGR, 97, 16035-16054. [7] Herrick R.R. and Marsh C.A. (1997) Lunar and Planetary Sci. Conf. 28, 555-556.