THE SUMMIT, TECTONIC AND FLANK CHARACTERISTICS OF LARGE VENUSIAN VOLCANOES: A NEW GLOBAL SURVEY. A. W. Brian[1,2], E. R. Stofan[1, 2] and J. E. Guest, [1]Proxemy Research, 20528 Farcroft Lane, Laytonsville, MD 20882 (awb@star.ucl.ac.uk), [2]Department of Earth and Planetary Sciences, University College, London, Gower Street, London WC1E 6BT.

Introduction: Large volcanoes on Venus are defined as topographically positive, broadly domical structures with lava flow aprons larger than 100 km in diameter surrounding a central volcanic vent [1]. Several surveys have been carried out since the first return of data from the Magellan mission, investigating the location and distribution of volcanoes over the venusian surface [1,2], their structure [3] and variation in size with altitude [4]. The number of volcanoes included in each survey varies from 123 [4] to 167 [2], but to date, only the 1997 survey by Crumpler et al. [2] has been published. Large volcanoes on Venus show a diversity of morphologies with some displaying similar characteristics to large coronae. It is not surprising therefore that many features included in the 1997 database [2] have been classified by others as coronae and included in other relevant corona databases [5-7]. The first task of this new study was re-examine the large volcano population to eliminate the overlap with other catalogues and to try to accurately determine the number of features on the planet.

In addition to their earlier surveys, Head et al. [8] and Crumpler et al. [9] described nine fundamental types of large volcano suggested to represent a morphological classification describing individual features and associations with each edifice. Large volcanoes are structurally diverse with many different morphologies. The 9 classes describe a mix of both summit and tectonic characteristics meaning that an individual volcano may not be described accurately by any individual field or fields. The second task was to therefore devise a new classification scheme that would better describe the major morphological features of each edifice.

Survey Procedure and Design: The new survey located and classified the population of large volcanoes using full resolution F-Maps and C1-MIDR mosaics. Magellan digital altimetry data was used to take at least two cross-sections over each volcano in order to measure the average diameter of the main edifice to the outer breaks of slope, the maximum altitude and the level of the surrounding plains. The average diameter of the flow apron and the size of any summit caldera were measured directly from F-Maps. Synthetic stereo images were used extensively and were invaluable in determining the morphological properties of each feature.

The new classification scheme (Figure 1, Table 1) describes four types of summit structure: *Simple, Caldera, Elongate and Multiple Summit*, and four types of tectonic structure: *Radially fractured summit, Radially fractured flanks, Rift/fracture zone related, Concentric fractures*. Any number of these categories can therefore be used to describe each feature. We also analysed the abundance and location of small edifices (shields, cones or domes) on each large volcano and any associated lava flows erupted from vents on its flanks. The small edifice and flank vents category may be noted as multiple entries if different styles and locations of flank activity are observed.

Results: The survey located and recorded the morphological characteristics of 134 large volcanoes. Volcano flow aprons were found to have diameters ranging from 100 – 1000 km, and edifice diameters from 50 – 740 km. The maximum heights of individual edifices varied up to 8.44 km, with the average 1.53 km. The areal density and distribution of features is largely the same as that found in earlier studies [2] with ~0.30 centres/10^6 km globally. Volcanoes are concentrated between 190º - 360ºE and more specifically clustered around the BAT region (45°S – 45°N, 190° - 320 °E). A smaller concentration also occurs around Eistla Regio (0° - 45°N, 0° - 60°E). We are in the preliminary stages of analysing the new population but initial studies highlight few obvious trends and correlations between parameters. Altitude has been suggested to influence magma chamber position and volcano growth [10], but neither high nor low altitudes appear to significantly affect the size of the edifice or flow diameter. The base level at which a volcano is built also appears to have little bearing on the maximum height of the resulting edifice.

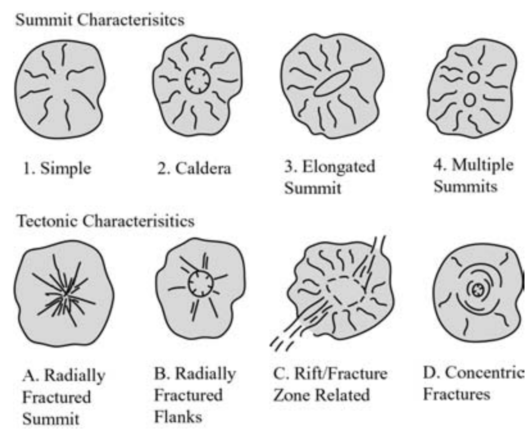

Figure 1. Summit and tectonic classification scheme.

Morphologically, the majority of edifices (56%) have simple summits whilst 40% display calderas and

5% show summits with multiple volcanic centres. Tectonically, large volcanoes show a range of characteristics with the majority being associated with zones of fractures or rifts. The small edifice classification showed that 55% of all volcanoes have cones, domes or shields around their summits or flanks, of which over a third of these are located around the summit regions. Almost half the volcanoes with small edifices also have significantly large flows associated with these vents, identified as flank eruptions. These flows showed a range of morphologies but were predominantly (88%) emplaced as fans of lava.

Discussion: *Volcano Interpretation*: The main difference in numbers between this and previous surveys [1-4] is due solely to the interpretation of whether a feature is a volcano or not. The 1997 survey [2] lists 20 features that are classified as coronae by either Stofan et al. [5] or Squyres et al. [7], and a further 19 which are marked as questionable. Many large coronae have similar characteristics to volcanoes; they are the sources for extensive associated lava flows, may have a raised, domical topography, or display large volcanic edifices located within their centres [5-7]. The main differentiation between the two features is that coronae are usually characterised by a well-defined circular fracture annulus, and volcanoes are not. Stofan et al. [6] however have found over 100 Type 2 coronae that do not display a ring of fractures but that do have corona topography; therefore this definition does not always apply. There are several examples in recent literature where volcanoes are identified as coronae and vice-versa, and also 'hybrid' structures which display the characteristics of both (e.g. Anala Mons and Sappho Corona [11], Mbokomo Mons [1, 5, 12] and Kunhild and Ereshkigal Montes [13]). We have tried to single out these hybrids from the new database but it is possible that some still remain.

Volcano Morphology: Large venusian volcanoes show a range of morphologies indicating that they are formed by complex processes. We see no obvious correlation of volcano size with altitude suggesting that factors other than neutral buoyancy (e.g. volcano age, duration and strength of magma supply, local thermal gradient and geological setting) contribute to edifice growth on Venus. The observation that most edifices are associated with zones of fractures indicates that these features are largely controlled by the local stress regime. The presence of small edifices built on large volcanoes indicates that flank eruptions are an integral part of volcano formation [14]. Individual flows from these sources are very difficult to detect, even at the highest resolution of the data, due to their relatively small size and often similar radar backscatter to the flow apron they are emplaced upon. The number of flank flows identified in this study is therefore a lower bound, and probably does not represent the total contribution of material from sources on the flanks.

Conclusions: We have resurveyed the large volcano population and identified 134 individual edifices. Volcanoes on Venus show a broad range of morphologies, indicating that they have formed by complex processes. We plan to further analyse the relationships between different summit and tectonic morphologies and the affect of altitude, location and setting. Along with detailed studies of individual volcanoes [15], this new data will provide insights into the basic processes that govern the formation of large volcanoes on Venus.

References: [1] Head J. W. *et al*. (1992) *JGR 97*:13,153-13,197 [2] Crumpler L. S. *et al*. (1997) *in Venus II,* 697-756. [3] McGovern P. J. and Solomon S. C. (1998) *103*, 11,071-11,10. [4] Keddie S. T., and J. W. Head, (1995) *JGR* 100:11,729-11,754. [5] Stofan, E. R. *et al* (1992) *JGR* 97:13,347-13,378. [6] Stofan, E. R. *et al*., (2001), *GRL, 28,* 4267. [7] Squyres, E. R. *et al* (1992) *JGR* 97:13,347-13,378. [8] Head J. W. *et al*. (1992) LPSC XXIII, 23, 1, 513-514. [9] Crumpler L. S. *et al*. (1993) LPSC XXIV, 24, 1, 365-366. [10] Head J. W. and L. Wilson (1992) *JGR 97:*97:3,877-3,903. [11] McGill G. E., (1994) *JGR 99*:23,149-23,161, 1994. [12] Brian A. W. and E. R. Stofan (2002) *map in review, USGS*. [13] Herrick, R. R., and P. J. McGovern, (2000) *GRL,* 27, 839–842. [14] Brian et al., (2000) LPSC XXXI, #*1653.* [15] Stofan et al., (2002) LPSC XXXIII, #*1105.*

Summit Class	Tectonic Class	Caldera Class	Small Edifice Class	Flank Vents Class
1.Simple	A. Radially fractured summit	Shape: *Circular or elliptical*	Abundance: *None, scattered or abundant*	Vent Type: *Cone, fissure, pit*
2. Caldera	B. Radially fractured flanks			Location: *upper, lower, b.o.slope*
3. Elongate	C. Rift/fracture zone related	Complexity: *Simple or complex*	Location: *Summit, flanks, rift related, break of slope*	Flow Type: *sheet, fan, digitate*
4. Multiple	D, Concentric fractures			

Table 1. Classifications used to describe each large volcano. Volcanoes may be described by more than one entry in a particular class.