LARGE VOLCANOES ON VENUS: EXAMPLES OF GEOLOGIC AND STRUCTURAL CHARACTERISTICS FROM DIFFERENT CLASSES;

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INTRODUCTION. Large volcanoes (>100 km) characterized by radial lava flows and similar evidence for a topographic edifice are widely distributed over the surface of Venus and geologically diverse. Based on the global identification of more than 156 examples [1] and preliminary geologic mapping, large volcanoes range from those characterized geologically as simple lava edifices to those bearing evidence of complexly developed volcanic and structural histories. Many large volcanoes exhibit characteristics transitional to other large magmatic center types such as coronae and novae [1; 2]. In this study we examine the geology and structure of several type examples of large volcanoes not addressed in previous studies which are representative of several of the morphological classes.

MORPHOLOGIC CLASSIFICATION. Nine fundamental types of large volcano morphology were identified previously [2] and include: (Type I) Simple large edifice characterized by a symmetric, radial distribution of flows and few prominent structural features; (Type II) Large edifice containing central or summit caldera(s); (Type III) Large edifice with one or more flanking rift zones that are arranged more or less along radial directions from the summit region (as in Hawaii). (Note that this type differs from Type VII below); (Type IV) Large edifice with elongated summit often with multiple caldera-like features (e.g., Gula Mons); (Type V) Large edifice with multiple morphologic or topographic summits (e.g., Sapas Mons); (Type VI) Large edifice surrounded by an exterior set of radial fractures, commonly pre-dating the flow units from which the edifice is constructed; (Type VII) Large volcanoes arranged astride through-going regional rift zones or fracture belts; (Type VIII) Large volcanoes in which there is a nova-like central region consisting of a high density of radial fractures radiating from the morphological or topographic summit; and (Type IX) Large volcano in which a corona-like central area comprises a large fraction of the volcano diameter, but does not obscure the radial lava flows distinguishing large volcanoes from more intrusive morphologic features such as coronae.

PRELIMINARY GEOLOGIC MAPS OF TYPE EXAMPLES. In the following, geologic maps prepared at a scale of 1:~4 M of Types II, VI, VII, VIII, and IX (Figures 1,2,3,4, and 5) are discused briefly. No attempt is made to give the full details or stratigraphic history of each example because the limited space here, and only some salient characteristics are addressed. Maps of the remaining types are not presented because Type I is relatively simple and requires little explanation, and because the type examples of III (Tepev, Sif Mons), IV (Gula Mons), and V (Sapas Mons) are relatively well known from initial Magellan data analysis, and have been mapped and discussed in several previous reports [3] .

Type II (Caldera). The apparent simplicity of the type example (MVC 19/80LV, Figure 1) of this class is deceptive, and actually represents one of the more challenging and informative volcanoes mapped. Two radial lava units pre-date an adjacent large volcano (V), and rest on pre-existing fractured plains near the juncture of two, and perhaps three fracture belts, the lower unit (S) relatively smooth, the upper unit (D), more digitate in appearance. A discontinuous annulus of radial fractures denotes the rim of a central and summit depression , the floor of which is covered by relatively smooth flows (Si) surrounding a fractured pre-existing central peak-like area (C) ; these flows also largely post-date the flank unit (D), the radially fractured caldera rim unit (R), and are superposed by late concentric fractures and small central pit calderas. The central region appears to represent an area structurally sagged during an intermediate stage in the development of the large volcano.

Type VI (Radially Fractured Exterior). Sekmet Mons (MVC 44.5/240.5LV, Figure 2) is a relatively simple example of this class, although topographically higher than many large volcanoes on Venus. It lies at the intersection of at least two sets (belts) of fractures distinctly radial to the edifice on the lower flanks. The lava patterns are asymmetric, and early and widespread digitate unit (D) flood plains to the east and pre-existing fractures. Flows and fractures are centered on a relatively small central region characterized by smaller digitate flows, and radial to a centrally concentrated field of unusual, very small (~1 km) shield volcanoes (C). Stratigaphically decreasing size of the edifice lavas and late, summit small shield fields suggest that the volume rate of volcanism at Sekmet steadily diminished with time.

Type VII (Rift-related). This type (MVC -12/261.5LV, Figure 3) graphically illustrates the relatively simple situation in which a fracture belt or rift has been the site of early digitate lavas (D1). Repeated eruptions of digitate flows (D2) thereafter became centralized and a large volcano developed astride the rift trend. In this example the volcano is the last event, but in several other examples of this class, continued rifting subsequent to the last eruptions have deformed and overprinted the volcano.

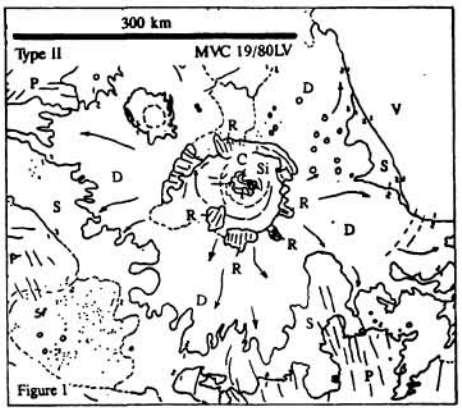
Type VIII (Nova-like Interior). The example chosen (MVC -8/243LV, Figure 4) actually has some characteristics transitional to Type IX, but dramatically illustrates the basic characteristics of Type VIII. Early ridged and fractured plains (P) and a fracture belt (F) were inundated by radially dispersed, smooth plains-forming flows (S) and later digitate flows (D). Initial mapping suggests that the radially fractured proximal interior (R) was concurrent with the regional fracture belt and was itself a source of radial flows. Within this elliptical region of radial fractures lies an annulus identifiable as a circular discontinuity in the radial pattern, interior to which radial fractures attain an even greater density comparable to the plexus of fractures identified as nova. In this example, although the central nova-like structure was one of the last events, the exact timing of the emplacement of nova-like fractures during volcano formation will require more detailed geological mapping from both the VDAP program and topical studies.

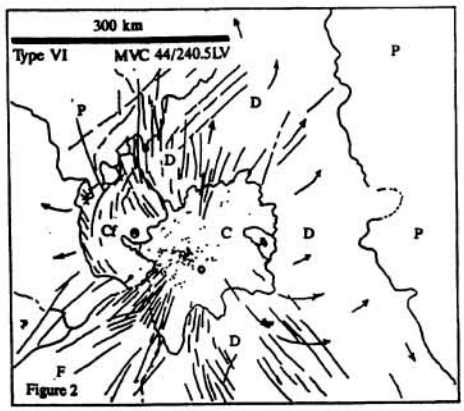
Type IX (Corona-like Interior). Many large magmatic centers on Venus, such as MVC 10/261.5LV (Figure 5), have the geologic characteristics of radial flow (D) emplaced on a pre-existing surface (S) and are superimposed by a concentric deformation annulus (R) meeting the criteria for coronae. The corona-like annulus frequently consists of a combination of radial and concentric fractures. A central depression with a smooth floor (Si) and central edifice consists of a

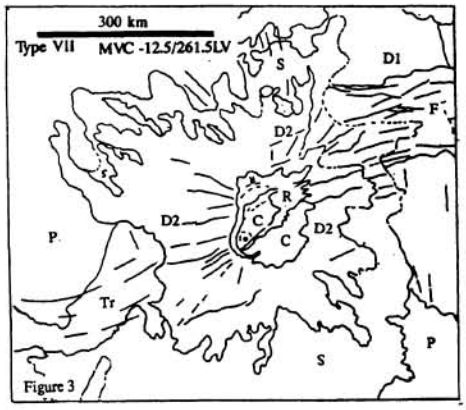
digitate, radial flow pattern. Edifice development has clearly continued subsequent to the development of corona-like characteristics.

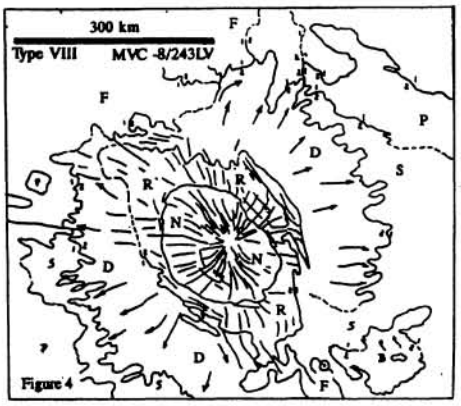
SUMMARY. Geologic mapping of some examples of large volcanoes from among the nine previously identified classes, illustrates that both lava flow accumulation and structural deformation have been important in most magmatic centers. In addition, many large volcanoes are transitional to other defined types of magmatic centers such as novae and coronae. Based on this study, the stratigraphic sequence frequently follows a pattern of early, generally voluminous, lava flows to late radially patterned, digitate flows followed by some type of central structural deformation. However, in many examples the volcano developed at a site bearing pre-existing structural characteristics. A simple sequence in which large magmatic centers evolved from one feature type to another (for example, large volcano to corona, or *vice versa*) is not universal, and considerable diversity in evolution of each center is indicated.

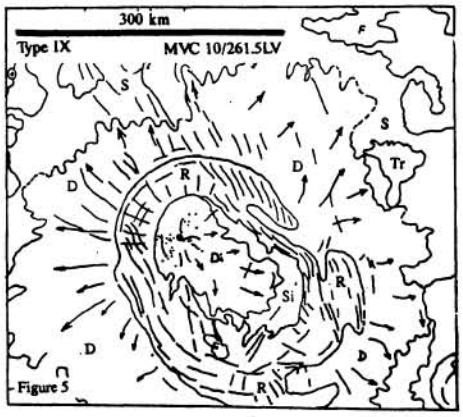
REFERENCES. [1] Head et al, 1992, LPSC, 23, 513; [2] Head et al., 1992, JGR, 97, 13153; [3]Senske et al., 1992, JGR, 97, 13395; Keddie and Head, 1992, LPSC, 23, 669].











Figures 1 - 5. Geologic maps for five of the nine classes of large volcano on Venus. Shown are the main units and representative structural patterns. See text for discussion of units and symbols. Mapped at 1:~4 M scale from SAR image base