THE EVOLUTION OF FOUR VOLCANO/CORONA 'HYBRIDS' ON VENUS. P. M. Grindrod[1], E. R. Stofan[1,2], A. W. Brian[1,2] and J. E. Guest[1], [1]Department of Earth Sciences, University College London, Gower Street, London, WC1E 6BT (p.grindrod@ucl.ac.uk), [2]Proxemy Research, 20528 Farcroft Lane, Laytonsville, MD 20882.

Introduction: The Magellan mission to Venus revealed a planet with widespread volcanism and tectonism [1-4]. Synthetic Aperture Radar (SAR) images revealed numerous large volcanoes and coronae widely distributed across the planet. Large volcanoes are defined as volcanic centers with diameters ≥ 100 km in diameter, which are dominated by radial flows and positive topography [5,6]. Coronae are volcano-tectonic features that might be unique to Venus. They have a wide-range of morphologies and are thought to be the surface manifestation of buoyant mantle diapirs [7-10]. Over 130 large volcanoes [6] and over 500 coronae [11, 12] have been identified on the surface of Venus. However, as a result of numerous volcanoes and coronae showing characteristics typical of both feature types, some have been classified as both large volcanoes and coronae by different authors [e.g. 5,8,11]. To date, only a handful of these 'hybrid' structures have been studied in detail (e.g. Anala Mons and Sappho Corona [13,14], Mbokomu Mons [5,8] and Kunhild and Ereshkigal Montes [15]). We are conducting a detailed analysis of four volcano/corona 'hybrids' (Api, Atai, Kokyanwuti and Uti Hiata Montes). We are using photogeologic methods to determine superposition relationships between different units and tectonic features and thus a geologic evolutionary sequence for each feature. The aim is to further understand the formation processes and conditions of large volcanoes and coronae on Venus.

Geologic Analyses: *Api Mons (38.9^{o}N, 54.7^{o}E).* This hybrid feature is situated in north-eastern Bell Regio and lies ~ 1.5 km above the surrounding plains. It has a sub-circular lava flow apron with an average diameter of 500 km and a surface area of ~ 1250 km^2. Api Mons has a topographic profile that is broadly domical with shallow outer slopes, typically in the range of 0.41-0.48^o. It has a summit diameter of about 70 km, with a volcanic center in the west (~ 0.3 km above surrounding summit) and a remnant partial rim structure to the north-east.

The topographic shape of Api Mons consists of shallow slopes rising towards an off-centered summit volcanic center. There is a relatively radar-bright partial rim to the north-east and south of the summit. This remnant, radially-fractured annulus is not distinguishable in the topography data, and is therefore of a similar order height as the summit.

Api Mons is surrounded by a mostly radar-dark to intermediate lava flow apron whose boundary is in places difficult to distinguish from the surrounding plains. The flows can be split into two main groups: digitate and sheet flows. The digitate flows are typically radar-bright to intermediate, have high aspect ratios and show central channels. The sheet-flows are radar-bright, flood low-lying terrain and probably consist of multiple irresolvable flows. There is relatively little tectonism at Api Mons: some flows to the east are deformed by wrinkle-ridges, while other digitate and sheet flows to the north and west are not. Some concentric fractures are present at the summit region. Superposition relationships suggest the following general evolutionary sequence: 1. volcanism and corona-like annulus formation 2. summit volcanism, and 3. summit collapse.

Atai Mons (-22^{o}N, 291^{o}E). This hybrid lies in south-eastern Phoebe Regio, at the terminus of the Pinga Chasma fracture belt, and is about 1.7 km above the surrounding area. It has a sub-circular lava flow apron with an average diameter of 400 km and surface area of approximately 1000 km^2. There is extensive tectonic deformation in and around the Atai Mons region, affecting the summit region, lava apron and the surrounding plains and tesserae.

The topographic profile of Atai Mons is not typical of large volcanoes on Venus [e.g. 16], but is more reminiscent of coronae. It has a summit depression approximately 100 km in diameter, which is bounded by a partial topographic rim that is ~ 50 % complete. The summit depression has been flooded by radar-dark lava flows, some of which have broken out of the summit region to the east. The slopes on the outside of the rim are relatively shallow compared to other Venusian volcanic summits [e.g. 16], averaging between 1.12-2.77^o.

The lava flows at Atai Mons can be split into digitate and sheet flows. The digitate flows are similar to those at Api Mons, but here they originate from flank eruptions sites and there is little evidence of these flows being channel-fed. The sheet flows are moderately dark to dark in SAR images, have no definite flow patterns and often have indistinguishable boundaries with the surrounding plains. The digitate flows superpose the sheet flows, thus post-dating their formation.

Atai Mons is affected by radial, concentric and Pinga Chasma-related tectonism. The radial fractures have generally formed earliest, followed by the concentric fractures and then the extension related to Pinga Chasma. Pinga tectonism affects most units apart from the summit lava flows, which are observed to bury these fractures. Superposition relationships suggest the following general evolutionary sequence: 1. volcanism, 2. uplift, 3. downwarping, 4. summit volcanism, 5. summit collapse, and 6. summit volcanism.

Kokyanwuti Mons (35.5°N, 212°E). This hybrid is located to the west of Bellona Fossae in Ganiki Planitia, and lies 2.2 km above its base. It has a well-defined lava flow apron with a maximum diameter of 500 km and a surface area of ~ 900 km^2.

Kokyanwuti Mons has a topographic shape that is comparable to a plateau-shaped corona rather than a typical volcano, with a flat summit region 250 km in diameter. To the east of the summit lies a partial topographic rim, ~ 0.5 km in height, and to the west, a small volcanic construct ~ 10 km in diameter. This small volcano has undergone at least 5 caldera-like collapse stages, providing evidence of dynamic (shallow) magma chamber activity.

At least 10 flow units have been identified at Kokyanwuti Mons. Approximately 90 % of the flows are digitate in appearance. The digitate flows are sourced to both flank and summit eruption sites. Flows to the west show cross-cutting relationships with flows from an unnamed corona, indicating overlapping stratigraphic histories. Kokyanwuti Mons shows little evidence of tectonism. There is however some concentric fracturing in the south of the summit, and some of the most distant sheet flows have undergone wrinkle-ridging. Superposition relationships suggest the following general evolutionary trend: 1. volcanism, 2. plateau formation, 3. summit collapse, and 4. summit volcanism.

Uti Hiata Mons (16°N, 69°E). This hybrid lies in plains south of Lemkechen Dorsa, about 1.7 km above its base. It has a roughly circular lava flow apron with a maximum diameter of 500 km and a surface area of approximately 1000 km^2.

The topographic profile of Uti Hiata Mons consists of a central depression, 100-150 km in diameter, that lies within a partial rim structure. The rim is most clearly defined to the east, where concentric fractures also occur on the outside. The summit depression has been flooded by material of intermediate radar brightness, which has broken through the rim to the west and north, where it is at its lowest. Individual and linear chains of pits extend radially from the summit, and are presumed to be dike-related.

The lava flow apron consists almost entirely of overlapping digitate flows with well-defined flow patterns and high aspect ratios. Approximately half of these flows originate from flank vents and contain central flow channels. Flows from the summit region do not show any evidence of being channel-fed. Tectonism at Uti Hiata Mons is restricted to some summit concentric fracturing and regional-scale NW-SE trending fractures that are seen to both pre-date and post-date Uti Hiata material. Superposition relationships suggest the following general evolutionary sequence: 1. uplift (?), 2. downwarping and volcanism, and 3. summit volcanism.

Conclusions: The only characteristics common to all four hybrids are distinctive lava flow aprons and relatively late-stage summit volcanism. In each case the summit volcanism has buried concentric and radial tectonic features, thus obscuring some evidence of features observed at coronae. The large-scale volcanism has occurred at different times in the geologic history of each hybrid feature. We do not observe any simple trend of uplift preceding volcanism [17], but do see that in most places digitate flows overly more sheet-like flows [5,16]. Large-scale downwelling analogous to that at coronae occurs at hybrids in the plains (Uti Hiata) and at a rift zone (Atai). The similarities between hybrids in very different geologic settings indicates that hybrid formation is unlikely to be governed primarily by lithospheric thickness [15], but instead may reflect some basic characteristics of the formation process, such as the degree of melting associated with the rising diapir. We finally observe that hybrid formation is the combined result of processes found both at coronae and large volcanoes, and cannot be described simply as the evolution of one into the other [e.g. 14].

References: [1] Saunders R.S. and Pettengill G.H. (1991) *Science, 252,* 247-249. [2] Solomon S.C. and Head J.W. (1991) *Science, 252,* 252-260. [3] Saunders R.S. et al. (1991) *Science, 252,* 249-252. [4] Saunders R.S. et al. (1992) *JGR*, 97, 13067-13090. [5] Head J.W. (1992) *JGR*, 97, 13153-13198. [6] Brian A.W. et al. (2003) LPSC XXXIV, #1333. [7] Squyres S.W. et al. (1992) *JGR*, 97, 13611-13634. [8] Stofan E.R. et al. (1992) *JGR*, 97, 13347-13378. [9] Smrekar S.E. and Stofan E.R. (1997) Science, 277, 1289-1294. [10] Stofan E.R. et al. (1997) *Venus II*, 931-965. [11] Stofan E.R. et al. (2001) *GRL*, 28, 4267-4270. [12] Glaze L.S. et al. (2003) *JGR*, 107, art. no. 5135. [13] McGill G.E. (1994) *JGR*, 99, 23149-23161. [14] McGill G.E. (1998) *JGR*, 103, 5889-5896. [15] Herrick R.R. and McGovern P.J. (2000) *GRL*, 27, 839-842. [16] Stofan E.R. et al. (2001) *Icarus,* 152, 75-95. [17] Campbell I.H. and Griffiths R.W. (1990) *EPSL*, 99, 79-93.