VENUS VOLCANISM: VOLCANIC ASSOCIATIONS AND ENVIRONMENTS FROM MAGELLAN DATA. J. W. Head, Brown Univ., Providence, RI 02912; D. B. Campbell, Cornell Univ., Ithaca, NY 14853; Charles Elachi, JPL, Pasadena, CA 91109; J. E. Guest, Univ. London Observatory, London, England NW72QS; D. P. McKenzie, Cambridge Univ., Cambridge, England CB3OEZ, R. S. Saunders, JPL, Pasadena, CA 91109; G. G. Schaber, USGS, Flagstaff, AZ 86001; G. Schubert, UCLA, Los Angeles, CA 90024.

Initial analysis of Magellan data confirm earlier findings[1,2] that volcanism is a widespread and fundamentally important process in the formation and evolution of the Venus crust, with volcanic plains and edifices comprising over 80% of the surface observed thus far. The Magellan data also reveal great morphological diversity and details of a wide range of volcanological phenomena[3]. The associations of volcanic landforms and their physiographic and tectonic environments provide important information on petrogenetic processes and links to mantle processes. In this contribution we describe several of these associations in the regions covered in the first month of mapping.

Regional plains deposits of probable volcanic origin form the vast majority of the surface observed thus far in Guinevere, Sedna, and Lavinia Planitiae. Although there is abundant evidence for lava flows and sources (thousands of small shields and vents), suggesting the local production of the plains, it is not yet determined whether these local sources are responsible for the formation of the crust as a whole, whether they represent a veneer on other deposits, and whether or not they formed in situ.

A wide variety of narrow *linear deformation zones* with distinctive volcanic associations occur on Venus including those of extensional (rift zones and some ridge belts), compressional (mountain belts and some ridge belts), and shear origin[1,2,4]. Magellan data have revealed details of a distinctive volcanic source, Mylitta Fluctus[5] (54°S, 354°), located along a linear deformation zone in northern Lada Terra from which a family of lava flow units stream downslope into the adjacent Lavinia Planitia, forming a lava complex extending over 800 km N-S and 380 km E-W. Magellan data reveal that the source is a 325 km diameter, 700 m high shield volcano located on the linear deformation zone (58.3°S, 351.5°) which appears to be of extensional origin. The extreme flow lengths (>300-500 km) suggest rheological properties corresponding to low-viscosity, very low yield strength mafic magmas similar to some lunar mare basalts or terrestrial Archean komatiites[6]. Implied effusion rates for these flows are high (about 10^5 m^3/s). The flow volumes are high (up to about 100 km^3), much higher than the 12 km^3 of the Icelandic Laki flow, but comparable to volumes of some of the Columbia River Basalt Group flows.

Coronae are 200-1000 km diameter quasi-circular structures that are completely or partially surrounded by an annulus of concentric ridges and often have raised interior topography, a peripheral trough or moat, and numerous associated volcanic and tectonic landforms[7,8]. Large areas of coronae are usually covered by lava flows. Volcanic structures, including calderas, shields, domes, lava channels, and pits are widely distributed in the interiors of coronae[7,8]. Magellan has obtained high resolution images and topography of a portion of one of Venus' largest coronae, Quetzalpetlatl, an 800-1000 km asymmetric corona in northern Lada Terra[5]. Quetzalpetlatl rises over 2 km above the surrounding plains and is covered by radar bright and dark lava flows from widely distributed sources interior to the corona. Interior radial fractures that accompanied the early updoming of the corona have been almost completely buried by lava flows and are now preserved only in the northeastern quadrant. Volcanism is pervasive; the source region for much of the volcanism identified in Arecibo images southeast of the corona center[5] is revealed to be a 400 m deep, 150 by 200 km depression interpreted to be a caldera, within which is a concentration of channels, domical hills, and linear and circular depressions. In summary, volcanic vents are located at various places in and adjacent to the corona, but the major concentration of volcanism is centered on the very large caldera-like structure in the central part of the corona. Volcanism appears to be linked to uplift and radial fracturing, and is largely superposed on the fractures. The most recent volcanism appears to be concentrated in the central caldera region.

Upland rises are broad topographic highs located primarily along the Equatorial Highlands and characterized by associated rifting and volcanism[9]. Magellan data reveal the characteristics of one of these rises (Western Eistla Regio), a broad (2400 km x 3200 km) parallelogram-shaped highland region. Two major shield volcanoes, Sif and Gula Montes, are situated on the rise and are linked to rift zones cutting NW-SE across the rise. In addition to these major volcanoes, at least three smaller shields or volcanic centers are located on the rise, and there are occurrences of tessera patches. At this early stage it appears that Western Eistla Regio has more similarities to tectonic junctions such as Beta Regio than it does to linear deformation zones such as northern Lada Terra. Whereas the volcanism in the northern Lada linear deformation zone appears to be focused along the zone of extension, the volcanism in Western Eistla is both associated with rifting and more widely distributed on the broad rise, suggesting wider distribution of melting. Whether this represents basic differences in the planform or scale of convection, or different stages in the evolution of mantle upwelling, is not presently known.

Linear deformation zones characterized by shortening and compressional deformation occur in at least two environments on Venus, *mountain belts* and *ridge belts*. A major question in the understanding of the mountain belts is their thermal structure in an environment of shortening and crustal thickening, and any evidence for melting of the thickened crust. Magellan data reveal that in the eastern part of Freyja Montes there is little evidence for volcanism in the form of volcanic plains, edifices, or associated structures, even in the easternmost parts that appear to be undergoing extension and gravitational relaxation. Volcanism is common, however, in the outboard plateau to the north of Freyja Montes (Itzpapalotl Tessera)where the linear belts parallel to Freyja are separated by zones of smooth plains[10] thought to represent volcanic deposits postdating the formation of the linear belts. Magellan data clearly show the volcanic and postdeformational nature of these plains. In some cases, plains appear to be related to sinuous channels which extend for hundreds of kilometers down into the surrounding lows. Magellan data also confirm the volcanic origin of plains seen in the outboard foredeep at the base of Uorsar Rupes. In the case of Freyja Montes, volcanism appears to be linked to the outboard plateau and foredeep regions rather than to the mountain belt itself. In contrast, Danu Montes shows indications of possible local volcanism in the mountains in the form of crater chains, troughs, and associated plains and sinuous structures of probable volcanic origin. In this case, volcanism is apparently linked to extensional deformation (graben oriented NW-SE) associated with gravitational relaxation of the mountian range[4]. The volcanic deposits occur both locally in the mountains themselves, and some of the sources there appear to be linked to plains deposits at the base of the mountains both on the outboard (Vesta Rupes) and inboard (Lakshmi Planum) sides. Danu Montes, with its lower topography and more abundant evidence of extensional deformation, may be relatively older than Freyja Montes and thus heating of the thickened crust may have occurred, producing melting and volcanism both in and adjacent to the mountains.

Ridge belts have also been interpreted to be of compressional origin[11] although extensional origins have been proposed[12]. Magellan data reveal that the ridge belts in Lavinia Planitia are characterized by a complex combination of features interpreted to represent compression, shear, and extension[4] and that they formed in volcanic plains. In the central part of several belts volcanic plains and associated small shields are superposed on the deformed belts themselves, suggesting that subsurface melting is occurring in these deformed zones. Whether this is linked to crustal thickening and shortening thought to characterize these belts or is simply related to local mantle upwelling is not known.

Only one example of a *highland plateau* is known to date on Venus. Situated in Western Ishtar Terra and surrounded by orogenic belts, Lakshmi Planum is elevated about 3-4 km above the mean planetary radius and consists of volcanic plains and two large volcanic centers (Colette and Sacajawea). Although Magellan coverage is too incomplete to provide a synthesis the nature of Sacajawea is in striking contrast to volcanic sources in other environments in that there is no edifice (in contrast to Sif and Gula Montes and Mylitta Fluctus) and the diameter of Sacajawea approaches the size of the edifices (not the calderas) of volcanoes in these other environments. The volume of the caldera is about 2.4-6.3 x 10^4 km^3, a value of the same order as the edifices of Sif Mons and Mylitta Fluctus. This strongly suggests that the magma reservoir has emptied primarily through intrusion and lateral dike formation, rather than edifice buildup, implying a neutral buoyancy zone at depth below Lakshmi, and lack of magma buoyancy evolution to produce an edifice[13]. In summary, volcanism in Lakshmi is seen to be unique in several ways relative to other environments (large calderas and small to insignificant edifices, as well as significant intrusion).

Tesserae, highly deformed upland regions comprising about 15% of the terrain surveyed by Venera 15/16, display patches of dark plains and associated domes interpreted to be of volcanic origin[1]. Magellan data for Alpha Regio show that these patches are characterized by smooth plains embaying the structure of the adjacent tessera and numerous small shield volcanoes. The patches are widely distributed in area and elevation and size. In some cases, the plains have been subsequently cut by graben that occur over large parts of Alpha, suggesting that the emplacement of volcanic deposits is contemporaneous with at least the latter parts of tessera deformation. The patchy distribution and lack of large edifices and centers of volcanism in Alpha suggest that volcanism is relatively distributed and not linked to a single centralized mantle upwelling.

1) A. Sukhanov *et al.* (1989) *USGS* Map **I-2059**; V. Kotelnikov *et al.* (1989) *Venus Atlas*, ANCCCP; 2) D. Campbell *et al.* (1989) *Science* **246**, 373; 3) J. Head *et al.* (1991) Submitted to *Science*; 4) S. Solomon *et al.* (1991) Submitted to *Science*; 5) D. Campbell *et al.* (1990) *Science*, in press; 6) L. Wilson *et al*, (1990) *LPSC* **XXI**, 1347; 7) V. Barsukov *et al.* (1986) *JGR* **91**, D378; 8) A. Pronin and E.Stofan (1990) *Icarus* **87**, 452; 9) D. Senske (1990) *EMP* **50/51**, 305; 10) J. Head (1990) *Geology* **18**, 99; 11) S. Frank and J. Head (1990) *EMP* **50/51**, 451; V. Kryuchkov (1990) *EMP* **50/51**, 471; 12) A. Sukhanov and A. Pronin (1989) *PLPSC* **19**, 335; 13) L. Wilson and J. Head (1990) *LPSC* **XXI**, 1043; L. Wilson *et al.* (1990) *Microsymposium 12* **2**, 37.