

**VENUS TECTONICS: THE PERSPECTIVE FROM MAGELLAN AT THE HALF-WAY POINT;** Sean C. Solomon, Dept. of Earth, Atmospheric, and Planetary Sciences, M.I.T., Cambridge, MA 02139; James W. Head, Dept. of Geological Sciences, Brown University, Providence, RI 02912; William M. Kaula, Dept. of Earth and Space Sciences, U.C.L.A., Los Angeles, CA 90024; Dan McKenzie, Bullard Laboratories, Cambridge University, Cambridge CB3 0EZ, England; Barry E. Parsons, Dept. of Earth Sciences, Oxford University, Oxford OX1 3PR, England; Roger J. Phillips, Dept. of Geological Sciences, Southern Methodist University, Dallas, TX 75275; Gerald Schubert, Dept. of Earth and Space Sciences, U.C.L.A., Los Angeles, CA 90024; Steven W. Squyres, Center for Radiophysics and Space Research, Cornell University, Ithaca, NY 14853; and Manik Talwani, Houston Area Research Center, The Woodlands, TX 77381.

**Introduction.** Radar imaging and altimetry data from the Magellan mission have revealed a diversity of deformational features at a variety of spatial scales on the Venus surface [1]. The radar images from Magellan constitute an improvement in resolution by at least an order of magnitude over the best images previously available [e.g., 2,3]. In this paper we discuss what those images, and their interpretations, are revealing about the styles of lithospheric deformation on Venus, the inferred mechanical properties of the lithosphere, and their implications for the tectonic history of the planet. We focus the discussion on data obtained during the first four months of mapping, representing about 40% of the surface of the planet.

**Observations.** The plains of Venus record a superposition of different episodes of deformation and volcanism. This deformation is manifested in areally distributed strain of modest magnitude and in zones of concentrated lithospheric extension and shortening. In areas of distributed deformation, the characteristic spacing between tectonic features (graben, small ridges, or narrow lineations) ranges from 1 km or less to tens of km. The strain patterns are commonly coherent over hundreds of km, implying that even many local features reflect a long-wavelength processes.

Much of the strain in lowlands regions is concentrated in *deformation belts*: intensely deformed linear to curvilinear regions 50-100 km wide and hundreds of km long separated by radar-dark and less deformed regions of plains a few hundred km across. The deformation belts stand hundreds of meters higher than the surrounding plains, indicating that they are products of lithospheric shortening and crustal thickening. There is also an approximate correlation between radar brightness, indicative of intensity of deformation, and total relief, presumably a measure of crustal shortening. A number of older linear features show offsets and changes in trend where they cross deformation belts, indicating that some horizontal shear has accompanied shortening.

**Mountain belts**, observed to date only in Ishtar Terra, represent still greater degrees of lithospheric shortening and crustal thickening. Modest horizontal shear has accompanied compression in several mountain belt regions. Magellan images have for the first time revealed widespread evidence for lateral extension and gravitational collapse of mountainous terrain. Relationships between compressive and extensional structures indicate that lateral spreading has occurred both during and following active crustal convergence. Magmatic and volcanic activity has accompanied the lateral extension in several mountainous terrains and adjacent regions.

Venus displays two principal geometrical variations on large-scale lithospheric extension: the quasi-circular *coronae* and *broad rises* with linear rift zones. Both are sites of significant volcanic flux, and both are plausibly attributed to convective upwelling in the underlying mantle [e.g., 4,5], with the surficial expression a function of both the geometry and buoyancy flux of the upwelling.

Some of the most complexly deformed terrain are the *tesserae*: broad, elevated, radar-bright regions characterized by two or more sets of intersecting linear features [2]. Magellan images of tesserae to date reveal pervasive deformation at a variety of scales, ranging from tens of km down to the limit of radar resolution. Tesserae display significant (5 km or more) local relief as well as limited volcanism confined to the outer margins and isolated interior pockets of smooth and therefore comparatively undeformed plains.

**Discussion.** A number of generalizations may be made about tectonic styles on Venus on the basis of Magellan data analyzed to date. Examples of both horizontal shortening and horizontal extension are abundant on the Venus surface at scales ranging from the 1-km scale that

characterizes the spacing between tectonic features in a number of regions to the 1000-km scale that governs the large scale physiography of major structures and the spatial coherence of many smaller scale patterns of strain. Horizontal shear has evidently occurred in the lowland deformation belts and in the mountain belts, but such shearing tends to be broadly distributed and to accompany horizontal stretching or shortening. No clear examples have yet been documented of long, large-offset strike-slip faults such as those typical of oceanic and some continental areas on Earth.

The various scales of deformation arise from the complicated mechanical and dynamical structure of the Venus interior. The 10-30 km scale is plausibly attributed to the response of a strong upper crustal layer, while the deformation of a strong upper mantle layer can account for tectonic features with characteristic scales of a few hundred km [6]. The scale of a few hundred to a few thousand km, particularly if evident in the long-wavelength gravity as well as the topography, is likely dominated by mantle convection and its associated dynamic stresses and heat transport. The scale of a few km and less involves either internal deformation of the upper crust or tectonic disruption of a thin surficial layer decoupled thermally or mechanically from the remainder of the otherwise strong upper crust.

In general compressive features are more evident than extensional features in the areas viewed to date by Magellan. To some extent this is coincidental, in that there are many large highland regions thought to be sites of lithospheric extension that have yet to be imaged. The prevalence of compressive structures, however, may be in part because compression is accompanied by crustal thickening and uplift, and the elevated terrain is less susceptible to resurfacing by volcanic burial. Extensional fault systems, in contrast, and large rift systems in particular, may show a tendency for self-erasure, in that significant lithospheric stretching should lead to pressure release melting in the mantle [7] and volcanism that will act to bury the tectonic evidence for extension. In the absence of significant weathering and erosion, the lifetime of high topography is limited by ductile flow in the thickened lower crust that must at least partly support the topographic relief once active compression ceases. The widespread evidence for lateral extrusion and surficial extension in the mountains of Ishtar Terra documents the tendency for such ductile flow to occur. The very steep regional slopes (20-30°) marking some of the edges of Lakshmi Planum and the front ranges of the mountain belts provide evidence that dynamical processes have been recently operative.

We have seen no evidence to date for tectonic behavior similar to terrestrial oceanic regions, i.e., nearly rigid lithospheric plates with horizontal dimensions of  $10^3$ - $10^4$  km and active deformation confined to plate boundary zones a few kilometers to tens of kilometers across. Nor have we seen analogues to oceanic fracture zones or to deep sea trenches. Rather much of the tectonic behavior on Venus appears to be reminiscent of actively deforming continental regions on Earth, with deformation distributed across broad zones one to a few hundred kilometers wide separated by comparatively stronger and less deformed blocks having dimensions of hundreds of kilometers. On Earth, the continental lithosphere in tectonically active areas is weaker than typical oceanic lithosphere because of the greater thickness of more easily deformable crust. Because of the much greater surface temperature on Venus, the lithosphere on Venus should behave in a weak manner for crustal thicknesses less than are typical of continental regions on Earth.

In general, the intensity of deformation and state of preservation of tectonic features on Venus are strong functions of local topographic relief. Elevated regions tend to be areas of thicker crust and therefore a thicker layer of weak lower crust susceptible to ductile flow. Such regions thereby serve as concentrators of regional lithospheric strain, such as the lowland deformation belts and the mountainous terrain. Elevated regions, particularly areas uplifted by compression and crustal shortening, are also less susceptible to volcanic resurfacing and thus are more likely to preserve records of deformation spanning one or more episodes of significant strain. We suggest that much of the surface of Venus may have only two possible fates: volcanic burial and comparatively long-term preservation as relatively elevated and intensely deformed terrain. The first fate is represented by the abundant volcanic plains. The second fate may be primarily represented by tessera terrain.

**References:** [1] S.C. Solomon et al., *Science*, in press, 1991; [2] V.L. Barsukov et al., *PLPSC 16th*, D378, 1986; [3] D.B. Campbell et al., *Science*, 246, 373, 1989; [4] A.A. Pronin and E.R. Stofan, *Icarus*, 87, 452, 1990; [5] R.J. Phillips et al., *Science*, in press, 1991; [6] M.T. Zuber, *PLPSC 17th*, E541, 1987; [7] R. White and D. McKenzie, *JGR*, 94, 7685, 1989.