Furthermore, there is a high correlation between wrinkle ridge trends and long-wavelength topography. Within these trends we observe quite regular interridge spacing of 15–30 km. Preliminary studies of wrinkle ridges reveal that individual structures may accommodate up to 1.5 km of shortening. Therefore the distributed shortening in the southern plains that is accommodated by wrinkle ridges is about 1–5%. A higher-resolution investigation of wrinkle ridges is necessary to refine these results and gain a better understanding of the stresses involved in wrinkle ridge formation on Venus. Thus the low-intensity wrinkle ridge deformation of the plains has consistent patterns that approach a global scale.

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COLDSPOTS OR HOTSPOTS? THE ORIGIN OF PLATEAU-SHAPED HIGHLANDS ON VENUS. D. L. Bindschadler, Department of Earth and Space Sciences, University of California, Los Angeles CA 90024, USA.

A compelling question for the terrestrial planets is the origin of the highland regions on Venus. Data on the topography, gravity signature, and surface morphology returned by the Pioneer Venus, Venera 15/16, and Magellan spacecraft represent a basis for dividing these highlands into two distinct groups: volcanic rises and plateau-shaped highlands [1]. Volcanic rises are generally thought to be due to mantle upwellings in the form of large mantle plumes [2] and are thus similar in origin to terrestrial hotspots. There is less agreement as to the origin of plateau-shaped highlands (PSH) [1,3,4]. Coldspot mantle downwelling can lead to the formation of a highland region under Venus conditions [3], and previous to Magellan some PSH (particularly W. Ishtar Terra and Ovda and Thetis Regiones) were suggested to be compressionally deformed regions of thickened crust created by mantle downwelling [5,6,7]. A hotspot model proposes that such regions are formed by magmatism and tectonism related to the near-surface ascent of either the diapir-shaped large mantle plume [8] or a solitary disturbance propagating up a plume conduit [9]. The intent of this abstract is to (1) briefly review the characteristics of both volcanic rises and plateau-shaped highlands on Venus and the models for their formation and (2) consider tests that may help to make clear which model best explains the plateau-shaped highlands.

Characteristics of Venus Highlands: Highlands on Venus can be divided into volcanic rises and plateau-shaped highlands (PSH) on the basis of their topography, long-wavelength gravity-topography relationships, and geologic features (Table 1). Volcanic rises are characterized by roughly circular topographic rises with domical cross sections, relatively large geoid-topography ratios (GTRs), and the presence of large volcanic constructs, widespread flows, and extensional tectonism (commonly manifested as radially trending rifts). They include Beta, Atla, Bell, Imdr, and Western and Central Eistla Regiones. Plateau-shaped highlands (PSH) are so named for their shape in cross sections and are characterized in plan view by a variety of shapes, by steep margins and rugged interiors, by lower GTRs than volcanic rises, and by surfaces dominated by the heavily deformed complex ridged terrain (or tessera). They generally appear to share a common sequence of tectonism: shortening (commonly margin-parallel) followed by relatively small amounts (<10%?) of extension [1]. These regions include Ovda, Thetis, Alpha, Tellus, and Phoebe Regiones, Fortuna and Laima Tesserae, and W. Ishtar Terra [1]. The inclusion of W. Ishtar Terra is arguable given its large apparent depth of compensation (ADC) [10] and GTR values as well as the presence of extensive volcanic plains and two large volcanic constructs (see Table 1). For the purposes of this work, W. Ishtar Terra is considered a PSH on the basis of its topography and the overwhelmingly compressional tectonics manifested in its orogenic belts.

Models for Plateau-shaped Highlands: Observations that must be explained by a successful model for PSH include topography, long-wavelength gravity anomalies, and surface morphology. The latter includes the abundant deformational features that dominate their surfaces. A successful model should therefore explain the style(s) of deformation (i.e., compression, extension, etc.) and the relative ages and geometries of these various structural features, information that can be derived from Magellan images because of

TABLE 1. Characteristics of Venus highlands.

Characteristic	Volcanic Rises	Plateau-shaped Highlands
Topographic cross section	Domical	Steep-sided, rugged interior
Topographic planform	Circular to elongate	Circular to polygonal
Gravity anomaly	Positive, centrally located	Positive or negative, offset from center
GTR/ADC values	~20–35 m/km ~150–300 km	~10–15 m/km ~30–90 km
Volcanic features	Shield volcanos, extensive plains, and flows	Minor plains, flows, and domes
Extensional tectonics	Rifts, numerous graben, and fractures	Small (<10 km), late-stage graben
Compressional tectonics	Largely absent	Broad (10–20 km) ridges, marginal belts

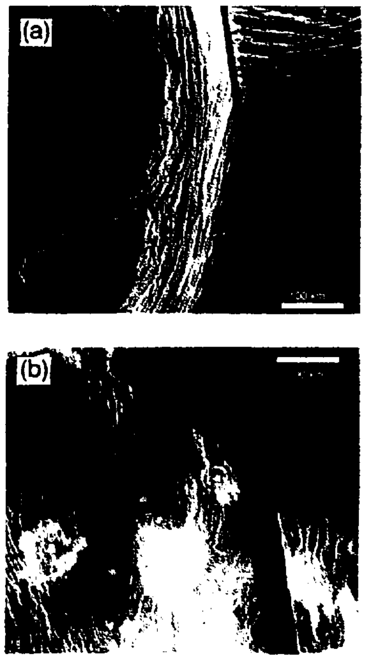

Fig. 2. Magellan SAR images showing (a) the northeastern edge of the Artemis Chasma foldbelt and (b) wrinkle ridges from the southern plains. Note the concentration of strain in the foldbelt when compared with the distributed strain of the wrinkle ridges.

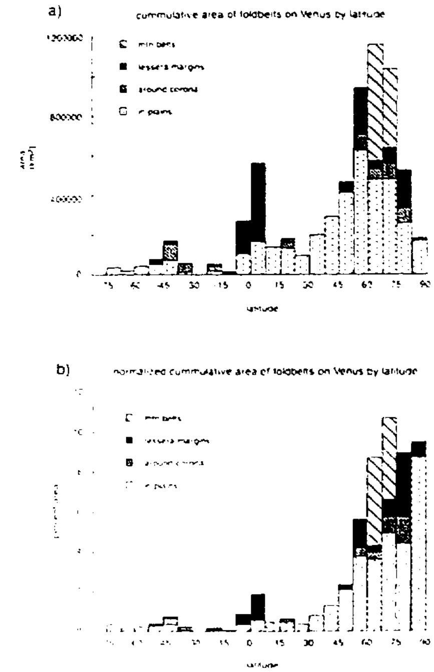

Fig. 3. Latitudinal distributions of foldbelts on Venus. Note the dominant concentration in the northern hemisphere and the poleward increase in the normalized plot.

hemisphere. Those that can be adequately resolved with the Magellan SAR are comprised of angular folds and/or an outcropping thrust-fault.

The plains fold belts, termed ridge belts on Venus [5,6], are concentrated between 150° and 250° longitude in the northern hemisphere and show a strongly north-south (longitudinal) trend [7,8]. Ridge belts cover 3.6×10^6 km^2, almost 1% of the venusian surface. Another 0.6% of the surface of Venus is covered by fold belts along the borders of major crustal blocks or structures such as coronae, novae, tesserae highlands, and the high plateau of Lakshmi Planum. The surface area covered by fold belts increases with latitude in the northern hemisphere as shown in Fig. 3a. If we normalize by the latitudinal area (Fig. 3b) we find that the percent area of fold belts very strongly increases poleward in the northern hemisphere. This observation agrees with previous tectonic models [9,8] that propose an internally deforming lithospheric shell that converges toward the north pole. These models call upon an equatorial rift system to generate the new crust that balances this compressive deformation. If we assume modest shortening within the northern hemisphere fold belts (≈100%), we find that relatively small amounts of rifting (≈150-km one-way extension) are necessary to produce all the obvious compressional deformation in the northern hemisphere.

The distribution of wrinkle ridges in the southern hemisphere is being mapped (Fig. 4); the most striking result is the strongly coherent pattern of orientation over many thousands of kilometers.

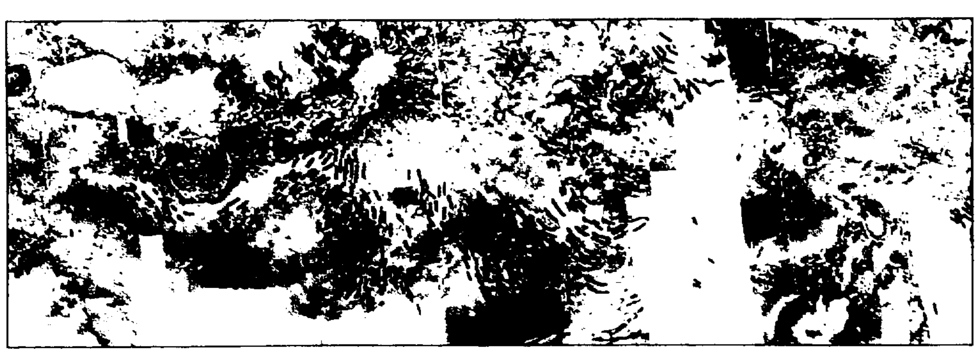

Fig. 4. Trends and relative densities of wrinkle ridges (black lines) in the southern plains mapped onto mercator projection of topography. Note the high correlation between topography and the deformational trends.

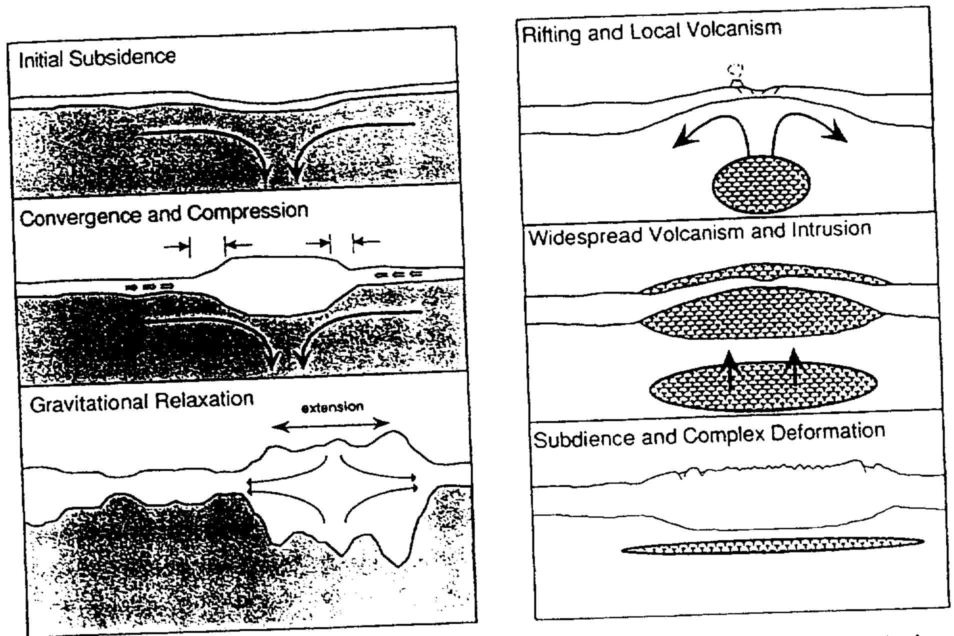

Fig. 1. Sketches illustrate the sequence of events in proposed coldspot (left), and hotspot (right) models for the formation of plateau-shaped highlands on Venus. Hotspot sketch adapted from [8].

their high spatial resolution (120–300 m) [11]. Three models have been suggested as explanations for all or parts of these observations: (1) coldspot tectonics, (2) hotspot tectonics, and (3) asperity tectonics.

Coldspot models [1,5,6] hold that PSH form over mantle downwellings, which are an expected feature of any convecting system, and are thought to represent the highest velocities and strain rates at the top of a convecting mantle [12]. The basic evolution of a PSH (Fig. 1) includes initial subsidence, crustal thickening, and tectonic deformation, which leads to formation of a highland, followed eventually by relaxation and spreading of the highland once downwelling ceases. A necessary condition for this process to operate is that the effective viscosities of the lower crust and upper mantle be sufficiently small and sufficiently similar in magnitude for crustal thickening to proceed within geologically reasonable timescales (<0.5 Ga). This condition appears to be satisfied for Venus conditions and compositions [5,13], but flow laws for crustal material remain a major source of uncertainty. Hotspot models hold that PSH form by magmatism and tectonism caused by the near-surface approach of large volumes of hot, plume-related material (Fig. 1) and are described in more detail elsewhere [8,3,4]. An asperity tectonics model suggests that any crustal plateau (however formed) represents a lithospheric strength discontinuity ("asperity"), which causes the plateau to act as a "magnet" to strain [10,14]. This occurs because the crustal plateau is relatively weak and is thought to deform more easily than stronger, surrounding provinces.

Test of Models: Significant questions of each of the three above models remain unanswered. To understand the formation of PSH it is necessary to answer the following questions:

1. Under what conditions can coldspot models produce gravity and topography that provide acceptable fits to Magellan and/or Pioneer Venus data? Are these conditions plausible, given our knowledge of Venus?

2. What are the detailed kinematics of a coldspot-produced PSH? Do the predicted style, sequence, and relative geometry of tectonic features match Magellan observations?

3. Can hotspot-related tectonic processes (including gravitational spreading/sliding, membrane compression due to subsidence, and deformation related to thermoelastic stresses) qualitatively match observed PSH deformation? Can these processes quantitatively produce enough surface deformation to explain complex ridged terrain?

4. What are the relevant timescales for hotspot tectonic processes and are they geologically reasonable?

5. Can an asperity tectonics model focus sufficient strain into a crustal plateau to explain the observed disparity between PSH and surrounding lowlands in terms of their degree of deformation?

Items (1) and (2) are currently under study and any progress will be reported at the colloquium.

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