



Fig. 2. (a) SAR image of a portion of western Alpha Regio including two units of plains and fine-scale lineaments. (b) Sketch map of (a) emphasizing the northwest-trending lineaments and graben and volcanos. In general, these lineaments are more abundant and have a closer spacing in the older unit P₁ than in the younger P₂. The younger unit has embayed the older, covering most lineaments. Continued deformation has caused fracturing to extend through both units. (c) Topographic profile of B-B' in (b).

volcanos and blocks of undeformed plainslike crust. Each of these features suggests that Alpha is deforming, uplifting, and possibly incorporating plains lavas onto its western edge. Gravitational relaxation of Alpha tessera may be the mechanism producing this deformation and may contribute to the features found at other type II boundaries on Venus. The total length of type II (deformational) boundaries on Venus is less than type I (embayed by plains lavas) boundaries, but type II boundaries occur at some point along many tessera blocks of all sizes [3]. We are continuing our investigation of this and other similar boundaries.

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VENUSIAN HYDROLOGY: STEADY STATE RECONSIDERED. David H. Grinspoon, Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder CO 80309, USA.

In 1987 Grinspoon proposed that the data on hydrogen abundance, isotopic composition, and escape rate were consistent with

the hypothesis that water on Venus might be in steady state rather than monotonic decline since the dawn of time [1,2,3]. This conclusion was partially based on a derived water lifetime against nonthermal escape of approximately 10^8 yr. De Bergh et al. [4], preferring the earlier Pioneer Venus value of 200 ppm water to the significantly lower value detected by Bezdard et al. [5], found H₂O lifetimes of $>10^9$ yr. Donahue and Hodges [6] derived H₂O lifetimes of $0.4-5 \times 10^9$ yr. Both these analyses used estimates of H escape flux between 0.4×10^7 and 1×10^7 cm⁻² s⁻¹ from Rodriguez et al. [7]. Yet in more recent Monte Carlo modeling Hodges and Tinsley [8] found an escape flux due to charge exchange with hot H⁺ of 2.8×10^7 cm⁻² s⁻¹. McElroy et al. [9] estimated an escape flux of 8×10^6 cm⁻² s⁻¹ from collisions with hot O produced by dissociative recombination of O₂⁺. Brace et al. [10] estimated an escape flux of 5×10^6 cm⁻² s⁻¹ from ion escape from the iontail of Venus. The combined estimated escape flux from all these processes is approximately 4×10^7 cm⁻² s⁻¹. The most sophisticated analysis to date of near-IR radiation from Venus' nightside reveals a water mixing ratio of approximately 30 ppm [11], suggesting a lifetime against escape for water of less than 10^8 yr. Large uncertainties remain in these quantities, yet the data point toward a steady state. Further evaluation of these uncertainties, and new evolutionary modeling incorporating estimates of the outgassing rate from post-Magellan estimates of the volcanic resurfacing rate, will be presented.

If Comet Halley has a mass of 10^{18} g and is approximately 50% water ice, then impact of such an object provides roughly 10% the current atmospheric water inventory on Venus. The terminal Creta-

aceous impactor on Earth may have been a 10^{19} -g comet [12]. A similar impact on Venus would provide a mass of water roughly equal to the current inventory. The occasional impact of such large comets and more frequent encounters with smaller volatile-rich objects will produce a spectrum of stochastic variations in water abundance [3]. Thus our evolutionary extrapolations that assume that the current H abundance and escape flux are representative of the overall history of the planet must be stated with the humility required by knowledge of our temporally parochial vantage point.

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DETERMINING STRESS STATES USING DIKE SWARMS: THE LAUMA DORSA EXAMPLE. Eric B. Grosfils and James W. Head, Department of Geological Sciences, Brown University, Providence RI 02912, USA.

Introduction: Initial examination of the Magellan coverage of Venus has revealed between 150 and 300 large, radially lineated landforms distributed across the planet's surface [1,2]. Where the lineaments have been examined in detail, the majority fail to exhibit signatures indicative of relief at or above the resolution of the radar; however, when the sense of topographic relief may be ascertained, the lineaments commonly appear as fissures or flat-floored trenches interpreted as graben. Individual lineaments can display graben, fissure, and zero relief behavior along their length, suggesting either that these differences are a function of the resolution of the radar, or that the morphological distinctions are real but somehow genetically linked. In many instances, radial lineaments exhibiting these characteristics are directly associated with surface volcanism, including flanking and terminal flows, superimposed shield domes and pit chains, and central, calderalike topographic lows. These observable characteristics, as well as theoretical studies and comparison with similar terrestrial features, have led to the working hypothesis that many of the radial fracture systems on Venus are the surface manifestation of subsurface dikes propagating laterally from a central magma source [3-7]. If this interpretation is correct, studies of terrestrial dikes suggest that the lineament directions, with localized exceptions and barring subsequent deformation, should be perpendicular to the orientation of the least compressive stress at the time of their formation [8-11]. To test this hypothesis, we briefly examine a radial fracture system (63.7°N, 195°E) located between two deformation belts in Vinmara Planitia, and verify that the lineaments to the east behave in the expected manner. We have also chosen this feature, however, because of its proximity to Lauma Dorsa to the west. On the basis of Venera 15/16 data, both compressional and extensional origins for this deformation belt have been proposed [12,13]. By examining the stratigraphy and applying our interpretation that the fracture system is linked to the presence of subsurface dikes, we present an independent evaluation of the stress

state associated with Lauma Dorsa, and thus contribute to the assessment of its origin.

Test of the Dike Hypothesis: Vinmara Planitia is a section of flat, deformation belt-bounded lowlands a few hundred meters below the mean planetary radius of 6051.84 km [14]. Bounding the plains to the east is a tessera belt trending north to south, roughly 75 km wide and slightly concave west in plan view. Although sections of the belt approach the altitude of the surrounding lowlands, most of the belt is elevated from a few hundred meters to as much as 1500 m above the level of the plains. At a finer scale, the tessera is characterized by long, narrow ridges as well as fissures at the crest indicative of gravitational collapse, all striking parallel to the local trend of the belt. Both the fine-scale and regional morphology are consistent with the general interpretation that ridge belts form in compression rather than extension, in this case implying an east-west compressive field [15-17].

Superimposed on the plains is a fracture system extending radially outward up to 450 km from a centrally located circular depression some 50 km in diameter. The depression is bounded by concentric graben and is interpreted as a caldera, perhaps associated with magma withdrawal from a central storage region. The lineaments exhibit the negative relief associated with dikes, as well as rare examples of shield domes and pit chains superimposed upon individual lineaments. Terminal and flanking flows are not observed; however, closely spaced parallel fractures and an echelon behavior, both characteristic of terrestrial near-surface dike emplacement, are present [18]. These latter features imply a component of vertical propagation in addition to the dominant lateral sense, suggesting dike top depth variations caused by either small-scale topography or changes in driving pressure and temporal supply rate [19].

To the east the fracture system displays lineaments that vary smoothly from radial orientations near the central depression to strikes that are perpendicular to the plains-tessera contact along the edge of the concave west border. While this behavior is exemplified to the northeast, it also occurs to the southeast. If the lineaments are dikes, this suggests they were emplaced in an east-west compressive regime. This conclusion is in agreement with the stress state inferred to have formed the tessera belt, and thus supports the hypothesis that dikes form perpendicular to the direction of least compressive stress.

Application to Lauma Dorsa: To the west of the radial fracture system is Lauma Dorsa, a north-south trending diffuse ridge belt that extends up to 300 km in width. While the topography varies along its length, Lauma Dorsa coincides with a long linear depression ranging from a few hundred meters up to 2000 m in depth. While some contend that the coincidence of the depression and belt argue for formation in an extensive regime [12], others maintain that the observations are better explained by a compressional origin, invoking underthrusting or subduction to explain the depressed topography [13]. Examination of the radial lineaments striking westward from the central caldera may provide an independent means of testing these hypotheses.

To the northwest of the caldera, the radial lineaments appear to curve beneath the ridge belt, striking northwest, and then reappear further north, striking to the northeast. The interpretation of this "buried" set of lineaments is based strongly upon observations of adjacent lineaments that do not curve beneath the edge of the ridge belt. These leave the caldera region radial to the center, parallel to those further west that then vanish at the edge of the ridge belt, then