ceous 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 en 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

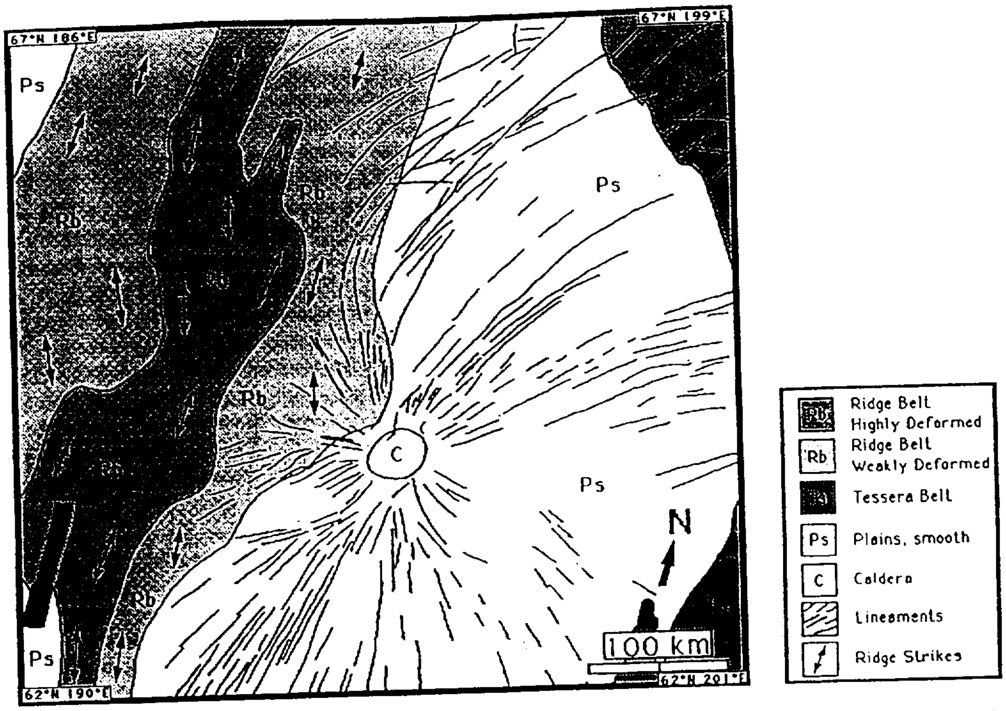

Fig. 1. Arachnoid in Vinmara Planitia. The lineaments shown include graben, fissures, and fractures. Note the right-angle intersection with the adjacent tessera belt, as well as the unusual behavior to the northwest of the caldera. For details, see text.

arc back toward the northeast, assuming the same strike as those lineaments that "reemerge" from beneath Lauma Dorsa. It is not clear from the stratigraphic relations in this region whether the radial lineament set is older and has been disrupted by formation of the ridge belt, or whether the two formed contemporaneously.

Due west of the caldera the stratigraphic relationships are clearer. Radial lineaments both crosscut and are deformed by large antiform structures associated with the ridge belt. This implies that the belt and radial fracture system formed at roughly the same time, and therefore presumably under the same regional stress conditions. If this is so then a number of factors suggest that the region was not undergoing east-west extension during rift formation. First, if one can assume that all the lineaments formed in a geologically brief interval, then the proposed dikes to the east are unlikely to have formed under east-west extension. Second, the curvature to the northwest is inconsistent with extensional rifting, since this regime offers no incentive for the dikes to deviate from a rift-parallel path. Finally, like those to the east, the orientation of the lineaments due west of the caldera is not consistent with east-west extension. As a complication, dikes southwest of the caldera strike predominantly parallel to the ridge belt along a topographic bulge. This type of behavior is consistent with formation during east-west extension, and the lack of relative stratigraphic markers does not allow us to rule out this option. Another possible interpretation, however, is that the dikes propagate along the crest of a flexural bulge produced by compression, with the near-surface stress in the upper half of a bending elastic plate favoring an orientation parallel to the antiform [20].

Conclusion: Many radial lineament patterns are interpreted as the surface manifestation of laterally propagating subsurface dikes. The stress state implied by one of these structures, located in Vinmara Planitia, is consistent with the surrounding geology, supporting the contention that this fracture system is analogous to a radial terrestrial dike swarm. By using this information, additional insight is gained into the origin of Lauma Dorsa. While examination of the dikes to either northwest, west, or southwest of the central caldera alone can be ambiguous, behavior of the radial system as a whole offers firmer insight into the stress state associated with formation of Lauma Dorsa, suggesting that the belt is associated with regional shortening rather than an extensive regime.

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