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## SPATIALLY EXTENSIVE UNIFORM STRESS FIELDS ON VENUS INFERRED FROM RADIAL DIKE SWARM GEOMETRIES: THE APHRODITE TERRA EXAMPLE. Eric B. Grosfils & James W. Head, Dept. Geological Sciences, Brown University, Providence, R.I. 02906

**Overview:** The high resolution and near global coverage of Magellan radar images is facilitating attempts to systematically investigate the stresses that have deformed the venusian crust. Here we continue earlier efforts<sup>1</sup> to utilize ~170 large, radially lineated structures interpreted as dike swarms to assess the orientation of the regional maximum horizontal compressive stress (MHCS) which existed in their vicinities during emplacement. Examination of swarms near the equator reveals a link to broad scale regional structures, such as Aphrodite Terra, across distances in excess of 1000 km, suggesting the existence of first order stress fields which affect areas of more than  $10^6$  km<sup>2</sup> in a uniform fashion. Focusing further upon the Aphrodite Terra region, the MHCS field in the surrounding lowlands inferred from radial swarms is oriented approximately normal to the slope of the highland topography. This stress configuration appears, at a simple level, to be incompatible with that expected during either upwelling or downwelling construction of the highlands. In addition, the relatively undeformed geometry of the radial structures within the highlands implies that these dike swarm features formed more recently than their highly deformed surroundings. We therefore conclude that the differential stresses which existed during emplacement of the dike swarms within and adjacent to the Aphrodite Terra highlands are related to the gravitational relaxation of pre-existing topography.

**Basic Principles:** Application of continuum mechanical principles has shown that terrestrial dikes propagate perpendicular to the least compressive stress direction<sup>2</sup>. Thus, when intruded laterally at shallow levels within the crust, dikes are expected to align with the direction of MHCS. Given geologically contemporaneous formation or a temporally persistent far field stress configuration, therefore, dikes will orient perpendicular to folds and other structures formed by compressive buckling and parallel to extensional features such as rift zones. This kind of behavior has provided data for recent attempts to characterize the global organization of shallow stress fields on Earth at a continental scale<sup>3</sup>. The success of this paleostress analysis suggests that a similar approach can be utilized for other terrestrial planets as well.

**Application to Venus:** Ongoing consideration of radial dike swarms<sup>1,4</sup> and wrinkle ridges<sup>5,6</sup> suggests that Venus is a good candidate for spatially extensive shallow stress analyses. Across equatorial domains many  $10^6$  km<sup>2</sup> in area the behavior of radially lineated swarms indicates that sequential stress fields are recorded in the geologic record, and that careful structural mapping may provide insight into their origin at the regional level. One interesting example, discussed in further detail below, occurs within and adjacent to the Aphrodite Terra highlands.

**Aphrodite Terra:** Radial dike swarms associated with Aphrodite Terra (Figure 1) adopt two general geometric configurations. The first is comprised of swarms with almost purely radial geometries. From this configuration, dominant within the highland areas and along their southern margin, we infer that the swarms were emplaced in the presence of a low differential far field stress. In addition, these swarms appear to have undergone far less strain than their highly deformed surroundings, and thus are interpreted to have formed subsequent to construction of the highland areas. The second geometric configuration is one in which swarms that are radial near their focus gradually become unidirectional at greater radial distances. From this we infer that, as the dikes increase in length, the influence of the local intrusive stresses at the swarm's focus gradually diminishes, causing the dikes' orientations to realign with the far field MHCS direction. This type of geometry dominates in a broad, stratigraphically indeterminate swath north of Aphrodite Terra which curls around to the east of Atla and then terminates along its southern border. For all swarms within this swath, as well as one isolated example south of and intermediate to Ovda and Thetis Regiones, the direction of MHCS indicated is oriented nearly perpendicular to the highland topography.

At present there is an ongoing debate about whether hotspot upwelling or coldspot downwelling, each described briefly below, is the more likely explanation for formation of the Aphrodite Terra highlands. One obvious course of action is to compare the stress states recorded by the radial swarms with those predicted by the two models. The hotspot model predicts uplift, rifting, and shield volcanism followed by intrusion and continued extrusive volcanism that thicken the crust<sup>7</sup>. The coldspot model predicts downward flexure and small strains followed by thickening of the lower crust through inwardly directed ductile flow<sup>8</sup>. The post-constructional stages of both models involve gravitational relaxation of the highland topography, producing increasingly extensional stresses in the interior portions of the plateau and radially directed compressional stresses near the margins.

Ascent of molten material through the thickened crust and formation of dike swarms will be aided by the extensional stresses developed in the interior as the topography relaxes. The abundance of swarms in Thetis Regio relative to Ovda Regio suggests, therefore, that Ovda is the younger and least relaxed of the

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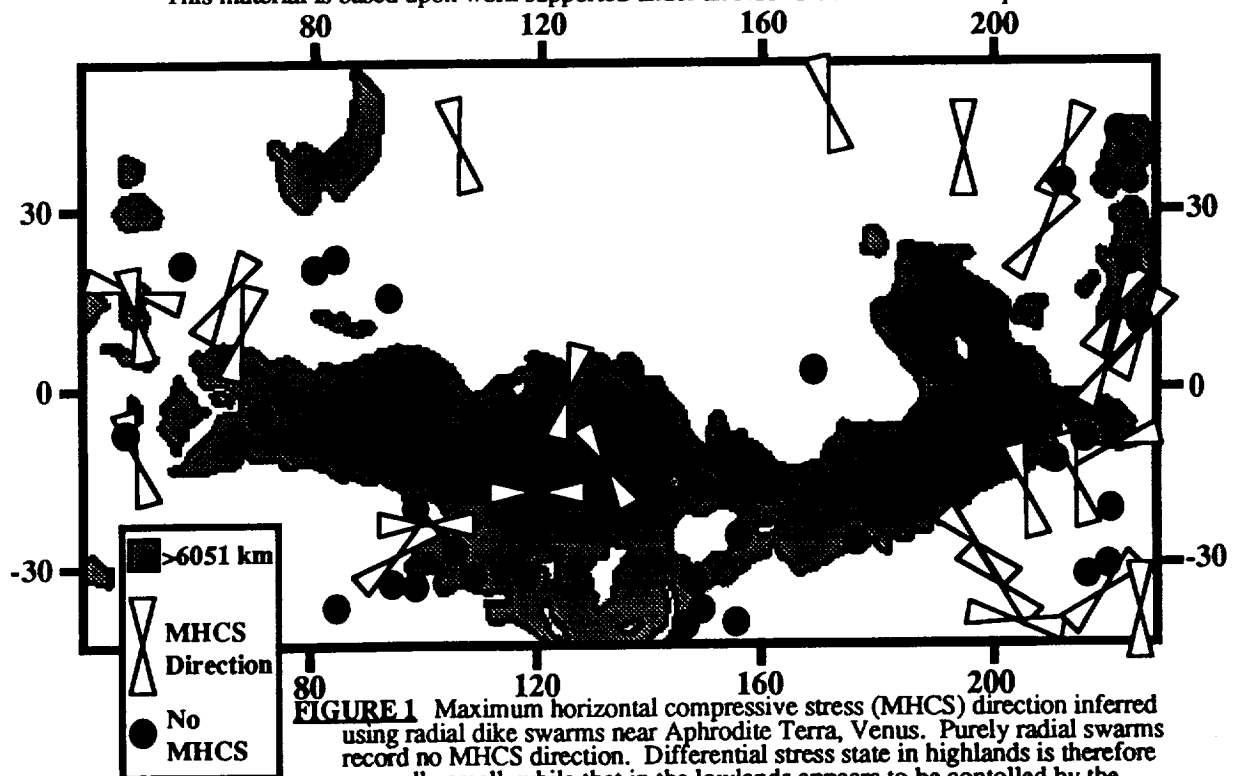
two regions, in agreement with predictions based upon the superposition of graben upon older compressional structures<sup>9</sup>. In addition, the overall strain predicted to accumulate in the highlands through relaxation is minor<sup>10</sup>; combined with the swarms' lack of structural disruption relative to their surroundings, this further supports the contention that the radial dikes were emplaced preferentially during the post-constructional phase of the highland's evolution. If, as suggested, the highland's construction is essentially complete at the present time, this may help explain the lack of a distinguishing correlation between Ovda and Thetis Regiones and either upwelling or downwelling plumes<sup>11</sup>.

As deduced for the highlands, neither model's constructional phases appear to account for the behavior of swarms in the surrounding lowlands. Stresses resulting from dynamic uplift, such as that produced by impingement of a mantle plume, should not extend any significant distance beyond the resultant rise<sup>12</sup>. Similarly, at a simplistic level the inward flow of material and compression caused by downwelling must, at some distance, disperse through strain induced by compensating extensional stress oriented normal to the highland topography, producing unidirectional swarm orientations perpendicular to their current alignment. Stress orientations induced in the surrounding lowlands by gravitational relaxation, however, are similar to those inferred from the dike swarms' behavior and should pass from highland to lowland. Thus we postulate that topographic relaxation is currently controlling the differential stress state in the lowland areas, and that tessera formation within the highlands has effectively ceased.

**Conclusion:** The geometry of radial dike swarms within and adjacent to the Aphrodite Terra highlands appear to record differential stress fields controlled primarily by the gravitational relaxation of pre-existing topography. Similar to the results from mapping of wrinkle ridges across broad regions<sup>5, 6</sup>, the MHCS direction recorded by the dike swarms surrounding Aphrodite Terra implies that shallow stress fields on Venus, as on Earth, are capable of uniformly affecting areas of more than  $10^6$  km<sup>2</sup>. We are presently examining other portions of Venus to assess the extent and character of the differential stress fields recorded by radial dike swarms in order to decipher their relationship to regional structure and stratigraphy.

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**FIGURE 1** Maximum horizontal compressive stress (MHCS) direction inferred using radial dike swarms near Aphrodite Terra, Venus. Purely radial swarms record no MHCS direction. Differential stress state in highlands is therefore generally small, while that in the lowlands appears to be controlled by the gravitational relaxation of pre-existent topography.