GIANT RADIATING DIKE SWARMS: CONSTRAINING THE FORMATION AND EVOLUTION OF THE SURFACE OF VENUS Eric B. Grosfils (Geology Dept., Pomona College, Claremont, CA 91711) and James W. Head (Dept. of Geological Sciences, Brown University, Providence, RI 02912).

Overview: Interpretation of giant radiating dike swarms on Venus indicates that the tectonic and volcanic characteristics of the population are strongly correlated with the modern arrangement of topography [1,2]. Stratigraphic and crater density data, however, suggest that the population of swarms was emplaced shortly after an interval of global resurfacing [3] which occurred hundreds of millions of years ago [4], indicating that the swarms are old rather than young. Assessment of the combined dike swarm data leads to the conclusion that the configuration of the surface topography on Venus (and the nature of any associated mantle processes) has remained broadly constant since the cratering record was reset.

Observations & Interpretations: Examination of the globally distributed population of 118 giant radiating dike swarms on Venus provides information about several key aspects of the planet's geologic history. These are summarized below.

TECTONIC — Interpretation of the dike swarm geometries indicates that Venus exhibited uniform stress fields which extended thousands of kilometers across the planet when the dike swarms were emplaced [1]. From 330-210°E longitude, maximum horizontal compressive stress directions recorded by the swarms align approximately normal to the current long wavelength topography, dominated by the Aphrodite Terra equatorial highlands. Across the remainder of the planet, the maximum horizontal compressive stresses generally align parallel to the triangular system of rifts which connect the Beta, Atla and Themis highlands. The global stress patterns are most consistent with formation via isostatic compensation of existing long wavelength topography and/or convective coupling between mantle flow and the overlying lithosphere.

VOLCANIC — The presence of giant radiating dike swarms indicates that conditions within the venusian crust frequently promoted magma stalling, reservoir formation and laterally extensive, shallow volcanic intrusion. It can be demonstrated [2] that: (a) statistically, at >99.5% confidence, the observed hypsometric distribution of swarms on Venus is not random; (b) the observed distribution agrees closely with predictions based upon an altitude-dependent model of magma neutral buoyancy [5] across at least 90% of the surface of the planet; and, (c) the observed relationship between extrusive [6] and intrusive reservoir-derived volcanism is sensitively attuned to the modern configuration of topography.

RELATIVE AGE — Previous interpretation of observed stratigraphic relationships in areas where giant radiating dike swarms occur indicates that the swarms were emplaced after tessera formation, regional volcanic flooding and most wrinkle ridge deformation but prior to most impact cratering and rifting [3,7]. Another way to evaluate the relative age, however, is through calculation of the density of impact craters superimposed directly upon the dike swarm population [3]. While it is difficult to determine the true crater density because the radiating lineaments that characterize the swarms are typically superimposed upon older volcanic plains (which need not be related to the dike swarms), it is possible to define reasonable criteria through which a crater density minimum can be obtained. This permits meaningful comparison with crater densities obtained for other units, and, more importantly in light of the stratigraphic data, defines the youngest possible relative age for the dike swarm population.

The surface area of each swarm was calculated directly using digital data at C1-MIDR scale enhanced to facilitate the visibility of both surface lineaments and volcanic flow boundaries. Each dike swarm area includes regions densely populated by radiating, dike-induced fractures as well as those volcanic flows which were identified as dike-fed with a high degree of confidence; dike swarm areas are thus overestimated through the necessary inclusion of the older volcanic plains upon which the radiating fractures are superimposed. Digital determinations of lineament and flow extents were cross-checked through comparison with F-MIDR and C1-MIDR photoproducts, and through examination of digital data at F-MIDR resolution where possible. The areas of all 118 swarms were added together to define that of the entire population, which encompasses 22.23 million square kilometers, or approximately 5% of the total surface area of the planet.

Craters were counted toward the surface density if they met three criteria: (a) only those craters which fell at least partially within the defined areas were considered; (b) the crater or its ejecta had to exhibit a direct stratigraphic interaction with either the radiating fractures or their associated flows; and, (c) on the basis of this interaction, the crater had to be the younger feature. Any crater which fell within the defined

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swarm areas yet failed to interact directly with the swarm could potentially predate the swarm, and was thus discarded. These constraints provide a conservative accounting of the number of younger impact craters superimposed upon the dike swarm population subsequent to its emplacement.

On the basis of the criteria described above, the average density for the radiating dike swarm population, with 2σ error bars (90% confidence), is 1.80 ± 0.57 craters per million square kilometers; the global average is 2.01 ± 0.14 craters per million square kilometers (Table I). When compared with crater densities on other units (Table I), this value falls along a younging trend which is consistent with stratigraphic observations. Both means of evaluating relative age therefore indicate that the dike swarm population on Venus is old.

Discussion: Taken together, the information recorded by the population of giant radiating dike swarms provides important insight into the formation and subsequent evolution of the venusian surface.

FORMATION — The timing and geometry of the global stress field recorded by the dike swarms, in conjunction with other evidence [4,8,9] supports the prediction [10] that resurfacing on Venus occurred through large-scale catastrophic overturn of a depleted mantle layer; no other resurfacing model agrees as well with the observations [3]. Furthermore, based upon the nature of the stress fields and the associated regional geology, we have previously suggested that the observed configuration of deformation during and just subsequent to the time of global resurfacing was dominated by the residual effects of downwelling beneath Aphrodite Terra and upwelling beneath the Beta-Atla-Themis region [11].

EVOLUTION — The stress orientations recorded by the dike swarms [1] as well as the swarms' hypsometric distribution [2] are sensitively linked to the current configuration of long wavelength gravity and/or topography. Nevertheless, both stratigraphic data and crater density calculations indicate that the dike swarm population is relatively old [3]. This combination of information suggests that the process(es) of catastrophic mantle overturn had, by the end of global resurfacing, evolved into stable, relatively quiescent convective patterns akin to those thought to exist at present [9]; this inference is consistent with the paucity of modified craters [4] and numerous other geological observations. It thus appears that there has been minimal alteration of the long wavelength configuration of topography (and perhaps gravity) since completion of the global resurfacing event which reset the cratering record a few hundred million years ago.

References: **1**] Grosfils, E.B. & J.W. Head, *GRL 21*, 701 (1994). **2**] Grosfils, E.B. & J.W. Head, *P&SS 43*, 1555 (1995). **3**] Grosfils, E.B. & J.W. Head, *JGR*, (in press). **4**] Strom, R.G., *et al.*, *JGR 99*, 10899 (1994). **5**] Head, J.W. & L. Wilson, *JGR 97*, 3877 (1992). **6**] Keddie, S.T. & J.W. Head, *P&SS 42*, 455 (1994). **7**] Grosfils, E.B. & J.W. Head, *LPSC XXVI*, 523 (1995). **8**] Bindschadler, D.L., *et al*, *JGR 97*, 13495 (1992). **9**] Simons, M., *et al*, *Science 264*, 798 (1994). **10**] Parmentier, E.M. & P.C. Hess, *GRL 20*, 2015 (1992). **11**] Grosfils, E.B. & J.W. Head, *LPSC XXVI*, 521 (1995).

TABLE I.

Terrain	Area (10^6 km^2)	#Craters	Density	Source
Global Average	409.60	841	2.05 ± 0.14	Namiki & Solomon, 1994
Global Average	443.00	843	1.90 ± 0.13	Ivanov & Basilevsky, 1993
Global Average	442.74	891	2.01 ± 0.13	Price & Suppe, 1994
Global Average	451.04	932	2.07 ± 0.14	Strom *et al.*, 1994
Tesserae	37.44	78	2.08 ± 0.47	Strom *et al.*, 1994
Tessera, uncorr	37.00	76	2.05 ± 0.47	Ivanov & Basilevsky, 1993
Tessera, corr	37.00	104	2.81 ± 0.55	Ivanov & Basilevsky, 1993
Tessera	39.54	72	1.82 ± 0.43	Price & Suppe, 1994
Plains	306.15	684	2.23 ± 0.17	Price & Suppe, 1994
Dike Swarms	**22.23**	**40**	**1.80 ± 0.57**	**Grosfils & Head, in press**
Rifts	36.45	54	1.48 ± 0.40	Price & Suppe, 1994
Coronae+CLF	48.54	59	1.22 ± 0.32	Price & Suppe, 1994
Coronae	27.00	33	1.22 ± 0.43	Namiki & Solomon, 1994
Coronae	38.40	43	1.12 ± 0.34	Price & Suppe, 1994
Flows	8.72	8	0.92 ± 0.65	Price & Suppe, 1994
Volcanoes	19.52	10	0.51 ± 0.32	Price & Suppe, 1994
Volcanoes	25.00	26	1.04 ± 0.41	Namiki & Solomon, 1994