A QUANTITATIVE APPROACH TO VENUS SHIELD FIELD STRATIGRAPHY.

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Introduction: Volcanism on Venus is most commonly manifested as small (<20 km diameter), low-lying, shield volcanoes. These volcanoes are found in clusters recognized as "shield fields" containing as many as several hundred vents. Over 550 shield fields have been found spread across the surface. The distribution of shield fields on Venus is unlike the linear arrangements of volcanism along plate boundaries found on Earth, and is more readily compared to intraplate hotspot volcanism [1]. The widespread spatial distribution of these fields makes them useful for answering unresolved questions about the history of resurfacing on Venus given the stratigraphic relationships of the shield volcanoes to the general terrain and other endothermic features. In this work, we search for the potential alignment of shields within a field that may suggest a stratigraphic relationship between the shields and the local geology. Two end-member models of resurfacing on Venus predict different outcomes for these local stratigraphic relationships that we determine.

Previous Studies: The two end-member theories which have been advanced to explain the volcanic history of Venus are referred to here as "directional" and "non-directional" [e.g., 2,3]. At one extreme, the evolution of the planet's resurfacing may have been "non-directional" or relatively steady-state with regional volcanism occurring at different points in history, akin to our understanding of the Earth's volcanic history. The alternative view is that of a "directional" evolution in which Venus's surface developed through more global volcanism occurring relatively concurrently. Two large studies attempted to test these theories by examining the relative ages between a number of shield fields and surrounding geologic units and structures, only to reach opposite conclusions. One study favored the "non-directional" model [4,5], while other authors favored the "directional" model [6].

Methods: In order to address the opposed conclusions of the two previous studies, we apply a quantitative analysis to a subset of the 15 shield fields investigated in common by both groups [4–6]. This project aims to investigate whether the azimuthal distribution of vents in selected shield fields have a particular alignment, and if so, how the alignment compares to regional features such as wrinkle ridges and fractures caused by perpendicular stress and strain, respectively. Of the 15 locations analyzed in common by the prior studies, 8 results were opposed, 5 were ambiguous, and only 2 were in agreement. In our study, we have chosen 4 of the 15 locations to examine more closely: 2 opposed, 1 agreed, and 1 ambiguous. Each selected site has at least 50 shields to provide a data set large enough for effective azimuthal analysis.

Venus Magellan SAR image mosaics were examined at each of the four shield field sites. Beginning with point mapping of individual shield volcano vents, the spatial extent of each field was determined. In general, each site contains a single cluster of vents, though there are occassionally outliers of ambiguous relation in the surrounding region. In order to better correlate with previous works, the area estimates of *Addington* [4,5] were used to approximate the extent of vents to be included in analysis. Based on the spatial extent of the field, nearby and crosscutting local features were mapped in ArcMap: namely fractures and wrinkle ridges (**Fig. 1**). Classifications of each linear feature type were determined to better draw relationships. Relative chronology of the local features was determined by analysis of possible strike-slip displacement and cross-cuts in relation to the region's geology.

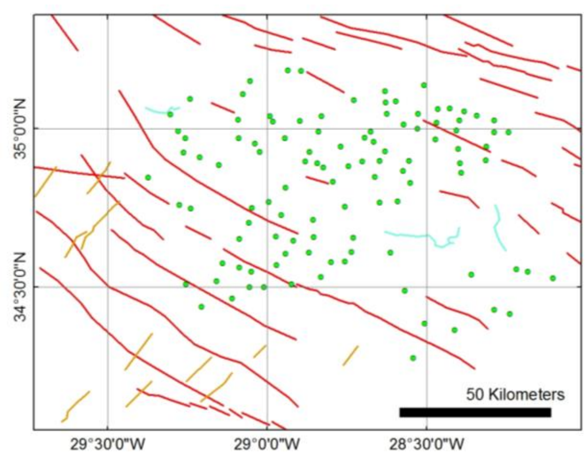

Figure 1. 1:750,000 scale map of the shield field site centered at 34°45'N, 28°45'W. Shield construct locations are given with green circles; prominent linear features are also mapped: NW-SE fractures (red), NE-SW fractures (orange), and wrinkle ridges (cyan).

If a set of linear features can be related to the shield field based on the alignment, then the stratigraphy of local features relative to the field can explain the age relative to global units. Here we make estimates of the relative age of a shield field based on its stratigraphic relationship to local geologic surroundings. Since shield fields and similar terrestrial volcanic fields are presumed to have formed parallel to the local principal horizontal stress [e.g., 7,9], we can constrain stratigraphy and thus chronology based on the matching of the distribution of alignments with linear structures (fractures, compressional ridges) in the local vicinity [9].

Alignment Software. This study aims to involve quantitative analysis in the form of a MATLAB GUI to better determine the relationship of volcanic constructs to their surroundings. The initial success of this program has been demonstrated in previous reports [10,11]. From each individual construct's x and y coordinates measured in ArcMap, the latitudes and longitudes can be read into Thomson's MATLAB GUI [9,12]. Two methods of analyzing the field alignment have been utilized: *Lutz* [13] and *Cebria et al.* [14]. The *Lutz* model and *Cebria et al.* model may give different results due to the grouping of the volcanoes at different spatial scales. Lutz determines the orientation between each vent in the field by a two-point azimuth method. For N points, there would be N(N-1)/2 calculated azimuths. The *Cebria et al.* method performs a cluster analysis which only calculates the orientations within a specified maximum distance; azimuths are considered only if the two vents are within one third the difference between the mean distance and one standard deviation. Since not all clusters in a particular field may have formed together, breaking the field into smaller clusters may be a more appropriate analysis if conditions in the region have changed. The result of this azimuth calculation is then run through a Monte Carlo model to determine the statistical significance for a final result.

The results are compared to ArcMap azimuthal calculations of regional linear features so that conclusions can be drawn about the local stratigraphy. If the distribution of constructs is found to be in alignment with existing linear structures, this may suggest a temporal relationship which can then be compared to crosscutting relationships.

Results: Azimuthal analysis of the site at 34°45'N, 28°45'W suggests a prominent shield field orientation from 30–60°E, (40–50°E most prominent), implying a relation to the mapped NE–SW orientated extensional features (**Fig. 2**). From interpreting cross-cut relationships, the NW–SE fractures appear older than the NE–SW fracture set. Following that the shield constructs are younger than the associated NE–SW fractures, the shield field also must be younger than the NW–SE fractures which represent an extensive system of fractures in the Sedna Planitia quadrangle (V-19). This suggests that for this site the finding of *Addington* [5], that the shield field post-dates regional plains, is most appropriate.

Conclusions: Whether a sizeable fraction of shield fields pre-date or post-date the nearby surface structures may have implications on the geological history of Venus. We will be able to compare the conclusions of these individual sites to the diametrically opposed results of *Addington* [4,5] and *Ivanov and Head* [6]. The discrepancies in the approach of the two studies must also be addressed as a source for their disagreements.

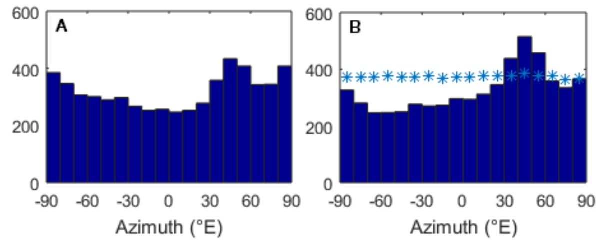

Figure 2. MATLAB GUI results for the site at 34°45'N, 28°45'W. (A) Raw frequency of *Lutz* model azimuth results. (B) Results adjusted by 100 Monte Carlo models where 30–60° range surpasses significance threshold value marked by asterisks.

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