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Case study

Volcanic edifice alignment detection software in MATLAB: Test data and preliminary results for shield fields on Venus

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ABSTRACT

The scarcity of impact craters on Venus make it difficult to infer the relative ages of geologic units. Stratigraphic methods can be used to help infer the relative ordering of surface features, but the relatively coarse resolution of available radar data means ambiguity about the timing of certain features is common. Here we develop a set of statistical tools in MATLAB to help infer the relative timing between clusters of small shield volcanoes and sets of fractures in the surrounding terrain. Specifically, we employed two variants of the two-point azimuth method to detect anisotropy in the distribution of point-like features. The results of these methods are shown to successfully identify anisotropy at two spatial scales: at the whole-field level and at scales smaller than a set fraction of the mean value. Initial results on the test cases presented here are promising, at least for volcanic fields emplaced under uniform conditions. These methods could also be used for detecting anisotropy in other point-like geologic features, such as hydrothermal vents, springs, and earthquake epicenters.

1. Introduction

Absent returned samples, the two methods of remotely inferring the ages of planetary surfaces are to measure the spatial density of impact craters and to examine stratigraphic cross-cutting relationships. Venus possess a dearth of the former and an abundance of the latter, meaning that relative age assessments are possible but it is difficult to correlate surface ages between distant geologic units that do not share a common set of cross-cutting structures.

Impact craters do provide some general insight about the geologic history of Venus; the small number of impact structures evident planet-wide necessitate one or more episodes of massive resurfacing (e.g., Phillips et al., 1992; Schaber et al., 1992; Strom et al., 1994). Obtaining absolute ages on Venus using craters, however, is akin to dating Earth's oceanic crust using only impact craters. While the paucity of craters are indicative of the ocean basins' youthfulness, outside of a few rare recognized impact structures (e.g., Chicxulub, Mjolnir, Chesapeake Bay), the density of craters is insufficient to provide age controls on sub-divisions of units.

Here, we seek to provide insight into an aspect of the stratigraphy of Venus by using a set of statistical tools to infer the relative timing between clusters of shield volcanoes and sets of fractures in the surrounding terrain. In particular, we employ the two-point azimuth method (Lutz, 1986) to look for anisotropy in the distribution of shields, and then determine if the inferred directionality (if present) corresponds to particular set(s) of structures, thus implying relative timing between the two. This contribution presents a software package to accomplish this task and provides some proof-of-concept examples; further results are expanded upon in a companion paper (Lang and Thomson, 2016 in prep.).

2. Background

2.1. Potential tectonic influence on the localization of volcanism

Many workers have noted the potential of tectonic factors to influence the style and development of volcanic vents and dikes. For example, the geometry of far-field portions of radiating dike swarms appear to be controlled primarily by the orientation of the regional maximum horizontal compressive stress (e.g., Anderson, 1951; Odé, 1957; Ernst et al., 1995). This notion is based upon the observation that failure in extension occurs in planes that are normal to the least principal stress, forming mode I fractures. In a similar vein, alignments of volcanic vents have been suggested to be indicative of structural control, with their distribution possibly reflecting the stress regime of the upper crust (e.g., Kear, 1964;

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Nakamura, 1977; Connor, 1990; Cebriá et al., 2011). As with dikes, emplaced features tend to be arrayed in lines that are normal to the inferred minimum horizontal compressive stress. A complicating factor with point-like vents is that, unlike a dike, they may be emplaced over a longer period of time, and thus may be reflective of potentially evolving regional stress. As discussed below in Section 5.1, a disagreement between the two methods used in this work may be indicative of changing tectonic and stress conditions.

2.2. *Shield field characteristics and importance*

Small shield volcanoes represent perhaps the most dominant manifestation of volcanism on Venus. Shields are extrusive volcanic constructs <20 km in diameter (average of ~1–2 km in diameter) that are cone, flat topped, dome, or shield shaped, and «1 km in height (Aubele and Sliuta, 1990; Guest et al., 1992; Crumpler et al., 1997). Shield fields are enhanced concentrations of shields, typically tens to hundreds of edifices, that range in density from 4 to 10 edifices per 10^3 km^2 within an area of ~10^4 km^2 (Crumpler et al., 1997). Clusters of small volcanoes are present also on the Earth (e.g., Connor and Conway, 2000), Mars (e.g., Hodges and Moore, 1994; Bleacher et al., 2009; Richardson et al., 2013), and the Moon (e.g., Basaltic Volcanism Study Project, 1981) and, in each case, likely reflect small batches of magma tapped at low rates from their presumably mantle source region (e.g., Crumpler et al., 1997). This is likely the case for venusian shield fields as well, which tend to be roughly equant in outline with diameters ranging from 50 to ~1000 km.

Because of their widespread occurrence across the surface, understanding the timing of venusian shield emplacement is critical for unraveling Venus' volcanic history. Yet there remains disagreement about the relative age assignments given to many shield fields. At least two major investigations into the stratigraphic relationships between shield fields and their local surroundings have reached diametrically opposed conclusions (Addington, 2001; Ivanov and Head, 2004). Addington (2001) examined 179 shield field clusters and found that 42% appear to be younger than or postdate the regional plains, 10% contain some indications that they are older, and 47% are ambiguous (i.e., no clear stratigraphic relationships could be inferred). In contrast, Ivanov and Head (2004) examined 141 shield fields and found that 69% of shield fields appeared to be older than or predate regional plains, 8% postdate, and 25% are either ambiguous or synchronous.

Part of this discrepancy may be due to the difficulty in trying to discern small-scale geologic contact relationships at or below the limits of resolution, which is 75 m for Magellan full-resolution SAR (synthetic aperture radar) data. To help address this concern, we have undertaken an independent examination of the spatial distribution of individual edifies in shield fields to determine if there are preferred alignments, and, if so, determine the relationship between these alignments and local stress conditions as determined from fractures, wrinkle ridges, and other stress-strain markers.

3. Method

3.1. *Two-point azimuth method (lutz)*

In this work, we focus on azimuth methods that were initially developed by Lutz (1986) to quantify preferred orientations in clusters of terrestrial point-like features. In this method, the azimuth or orientation between each feature and all of the other points in a population are determined. For N points, there are $N(N-1)/2$ such orientations. The results are binned into a histogram

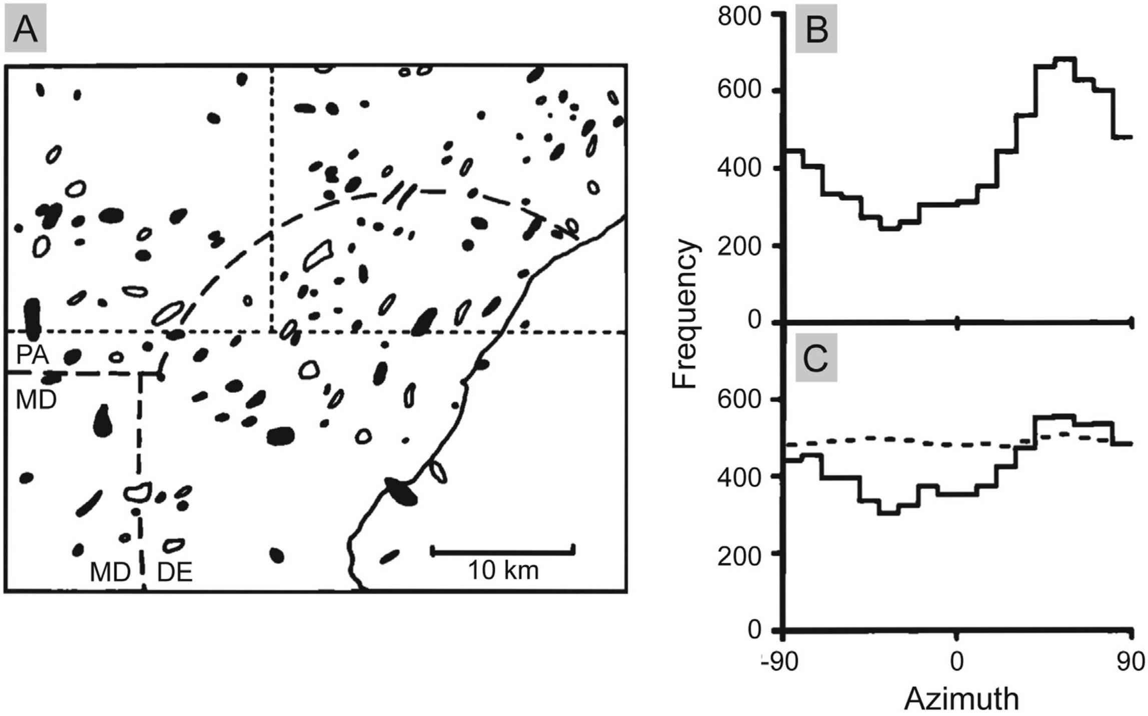

Fig. 1. (a) Map of magnetic anomalies in the Pennsylvania, Maryland, and Delaware region (from Lutz (1986), their Fig. 13 after Thompson and Hager (1977) their Fig. 9). The centroids of the 125 features were used in Fig. 1b–c. (b) Raw distribution of azimuth values binned into 10° intervals (from Lutz (1986), Fig. 14(a). (c) Corrected azimuth distribution; dashed line indicates 95% threshold value (mean$+2\sigma$) (from Lutz (1986), Fig. 14b).