GLOBAL CHARACTERIZATION OF POLYGONALLY FRACTURED TERRAIN ON VENUS AND IMPLICATIONS FOR A CLIMATE CHANGE ORIGIN.

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Introduction: On Earth, polygonal fractures with spacings of 1-100 cm form in lava flows that cool slowly under isotropic stress conditions. On Venus, polygonal fractures are observed with typical fracture spacings of 1-2 km, covering regions 10s to 100s of km across. These features have been proposed to form via cooling of lava flows or above subsurface intrusions [1], or due to surface cooling caused by climate change [2]. A watershed algorithm was modified to search the entire Magellan image database autonomously for terrains with polygonal fractures [3]. Here we characterize the 204 polygon terrains found using this method (including over 170 newly identified regions) with respect to size, morphology, stratigraphy, and geologic setting. These results are used to examine different models of origin.

Polygon Size and Area: Typical polygon diameters range from the limit of resolution (several hundred m) to 8 km. The mean diameter is 1.8±0.9 km. In 7 regions polygon diameters exceed 8 km, such as at Nightingale Corona [1]. However, in at least some of these regions the apparent diameter of the polygons is increased where subsequent lava flows cover some polygon segments. At Nightingale, this also enhances the apparent decrease in diameter of the polygons away from the corona. In some areas, there are two scales of polygons, with the larger scale typically 10-25 km across. The areal extent of the regions containing polygonal fractures varies from 30 km to over 600 km across. The total extent of terrains identified in this study is 8.5×10^6 km^2, or ~2% of the surface of Venus. The automated method averages fractures spacing over an 80km by 80km area, so regions with diameters significantly less than this may have been overlooked. Additionally the method breaks down in areas with extremely high radar noise. Thus some additional polygon-containing areas may exist.

Morphology and Orientation: In the majority of areas, the width of the polygonal fractures is too small to determine whether they have positive or negative relief. In a limited number of regions, polygonal fractures are large enough to cast 'radar shadows'. Most of these fractures have the straight sides and lower, flat floors of extensional graben. In a few cases, the radar data indicate topographic highs. Since most fractures are too small to determine their relief, we instead use their shape to determine whether they are most likely extensional or compressional. Those with sharp, linear boundaries are classified as likely extensional, while those that are broader and locally sinuous are classified as compressional. Apparently compressional features comprise ~15% of the population.

Typical polygons are equant and have 6 sides. In regions where polygons occur along with larger scale tectonic fractures, such as wrinkle ridges or fractures radiating from the interiors of coronae, the polygons have a preferred orientation parallel to the larger fractures.

Association with Geologic Features: Over half (133) of the areas containing polygonal fractures also have numerous small volcanic edifices, referred to as shield fields. The observed stratigraphic relationships indicate that the polygons formed contemporaneously with the shields. Nearly one quarter of the polygonally fractured areas are associated with coronae or coronae-like features, including arachnoids. Typically the polygonal fractures extend out from the corona rim to a distance larger than one coronae diameter. In most cases, the polygons appear to have formed contemporaneous with the coronae, in that the polygons follow the orientations of fractures associated with corona formation. In other cases the polygons appear to form subsequent to the formation of the corona. In some areas, polygons are also associated with tessera (37), wrinkle ridges (41), and impact craters (3). In the tessera and impact crater locations, the polygons are formed in volcanic deposits that fill the craters or tessera valleys, and thus are not likely to have a genetic association with the craters or tessera. In areas containing both polygons and wrinkle ridges, the relative age relationships are not obvious. However, in some cases the wrinkle ridges are composed of shorter, less continuous segments than typical wrinkle ridges, suggesting that pre-existing polygons may have controlled the location of wrinkle ridge segments.

In addition to identifying association of polygons with major geologic features, we examined the relationship between polygons and lava flow boundaries. This association would be characteristic of polygons that formed on a cooling lava flow. We found no examples of polygons terminating at a flow boundary, except where polygons were covered by later flow fields. In numerous locations, polygons cross flow boundaries, as defined by light and dark regions with flow-like margins.

Implications for the Origin of Polygons: The hypothesis that polygons on the scale we detect form on cooling lava flows can be ruled out. The required flow thickness and cooling rates are implausible. Further, we find no examples when polygons extend only to the edge of a flow.

The association of many polygons with coronae and shield fields supports the hypothesis that polygons form over subsurface intrusions. However, this model would predict that the size of the polygons decreases away from the center of the intrusion, where the thermal pulse is largest. This is observed only in a very few examples. In the case of Nightingale Corona, this appears largely due to burial of polygon fractures by subsequent lava flows.

The climate change hypothesis for the origin of polygons is based on the climate change analysis of Bullock and Grinspoon [4], which predicts a cooling-heating-cooling cycle of climate change following large increases in volcanic gases caused by a resurfacing event. The predicted temperature excursions can be up to 100°C, depending on assumptions about the amount of gas introduced into the atmosphere and other modeling considerations. Anderson and Smrekar [5] showed that the cooling cycles are sufficient to produce brittle failure of the lithosphere down to ~1 km. In some extreme cases (e.g. weak lithosphere and/or the largest predicted temperature variations), brittle compressional failure due to heating can occur on the scale of several km. Solomon et al. [6] pointed out that wrinkle ridges may occur in this manner. Similarly, some extreme conditions can also produce ductile extensional failure on the scale of 10-20 km.

Several characteristics of polygonal fractures are consistent with the climate change hypothesis. First, polygons are widely distributed around the planet. They would not be expected to cover the planet for two reasons. First, an isotropic stress field is required for their formation. In the presence of a regional stress field, preferentially oriented features such as the gridded plains [7] would be produced by climate change related stresses [5]. Highly deformed regions, such as rifts or tessera regions would preclude an isotropic stress field, as would regional slopes. Second, subsequent flows have clearly partially covered some polygons fields and may have obliterated others.

The larger scale of polygons that sometimes occurs with the typical 1-2 km scale polygons is predicted by the viscous extensional failure mode that occurs at higher thermal gradients or temperature pulses. The compressional ridges that form polygonal shapes are consistent with the deformation cycle predicted by cooling-heating-cooling. Indeed, it is difficult to image how these features would form without the presence of preexisting extensional polygons.

Finally, some polygons occur without any clear source of subsurface volcanic heating. Although most polygonal fractures form contemporaneously with shield fields, it is very possible that the pressure release melting that forms the shield fields is also a result of climate change. The cooling-heating-cooling cycle would permit polygons to form, followed by small shields, with a final episode of extensional fracturing.

Formation of polygons via surface temperature variations during climate change explains the observed characteristics of polygonally fractured terrains on Venus. However, some regions of polygons may form through a variety of processes, such as response to a series of deformation events.

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