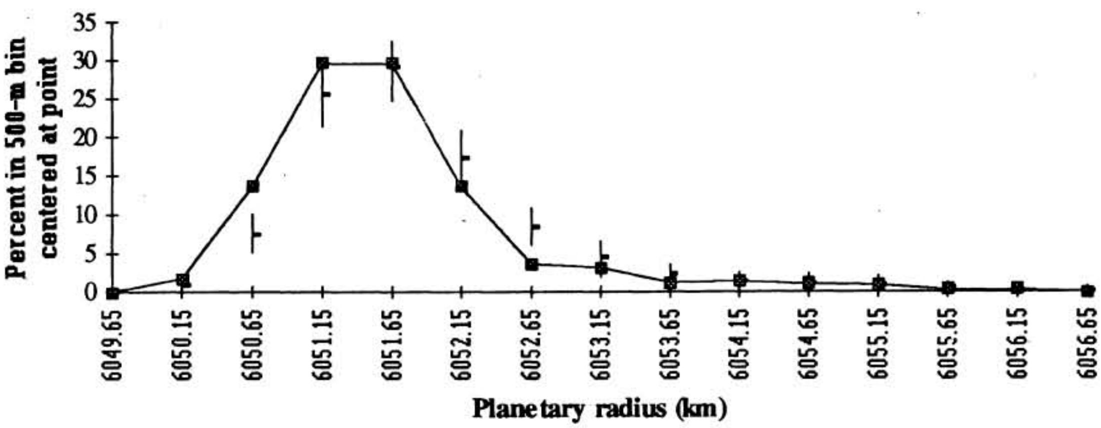
THE THREE AGES OF VENUS: A HYPOTHESIS BASED ON THE CRATERING RECORD; R. R. Herrick, Lunar & Planetary Institute, 3600 Bay Area Blvd, Houston, TX 77058

The elevation range of 6051.9 - 6053.9 km on Venus is deficient in craters but has a high proportion of embayed and tectonically deformed craters. On the basis of this data and previous work, I propose that Venus has experienced three distinct geologic ages: pseudo-plate tectonics until 1 - 2 Ga, volcanic flooding of low-lying areas, and currently hot spot tectonics.

THE CRATERING RECORD. Previous work [1] showed that the global areal distribution of impact craters cannot by itself be distinguished from a spatially random population, but embayed (by volcanism exterior to the crater) and tectonized (fractured or faulted floor) craters are in areas with lower-than-normal crater density and high crater density is associated with areas of low radar backscatter. However, the crater distribution is distinctly nonrandom with elevation. Figure 1 shows elevation histograms (% of craters in 500-m elevation bins) for the observed crater population and 100 Monte Carlo simulations of randomly placed crater populations. The observed crater population is deficient relative to the mean of the simulations in the 6051.9 - 6053.9 km elevation range, and below the minimum of the simulations in the 6051.9 - 6052.9 km range. Similarly, an excess in the observed data exists in the 6049.9 - 6051.4 km range, and this excess is above the maximum of the simulations for 6050.4 - 6051.4 km. Thirty-two percent of the planet's surface area resides in the 6051.9 - 6053.9 km range, which contains only 22% of the craters. Thirty-five percent of the surface is in the 6049.9 - 6051.4 km range, which contains 45% of the craters.

Figure 1. Histograms of impact craters vs. elevation. Connected squares are observed data and vertical line seqments are maximum, minimum, and mean of 100 Monte Carlo simulations of a random distribution.



For the scenario of a near-global resurfacing followed by a constant rate of limited resurfacing, Figure 1 implies that the limited resurfacing has covered 40 - 50% of the planet since the global event. If all elevation ranges are undergoing resurfacing, the rate in the 6051.9 - 6053.9 km range must be double the rate for the 6049.9 - 6051.4 km range. The idea that resurfacing has been concentrated in the 6051.9 - 6053.9 km range is supported by the fact that the mean elevation of unmodified craters is 6051.6 ± 0.8 km, but the mean for embayed craters is 6052.8 ± 1.3 km and the mean for tectonically deformed craters is 6052.3 ± 1.1 km. Furthermore, 33% of the craters in the 6051.9 - 6053.9 km range are either embayed or tectonized, as opposed to only 5% of the craters in the 6049.9 - 6051.4 km range and 18% of the entire crater population.

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GEOLOGICAL AND GEOPHYSICAL OBSERVATIONS. Of course, differences in resurfacing with elevation actually correspond to differences in resurfacing rates for different geologic settings. Elevations below mean planetary radius (6051.9 km) are dominated by largely featureless plains, whereas the highest elevations are composed of mountain belts, tesserae, or volcanic summits. The middle elevations (6051.9 - 6053.9 km) are populated by rifts, coronae, and volcanic swells. Initial analysis of the terrain type that an impact crater is located in indicates that embayed craters occur preferentially on or near volcanoes and tesserae terrains but generally are not found in the plains. Tectonically deformed craters occur preferentially in rift/coronae systems and tesserae and also are usually not in the plains.

Before using the above observations to speculate on the resurfacing history of Venus, it is important to note some of the properties of the different geologic settings on Venus. Tesserae regions are the only areas on Venus that show large-scale horizontal movement of the crust, as evidenced by linear compressive mountain belts [2], large-offset strike slip faults [3], and indenter zones [3]. Tesserae are generally embayed by plains and may be "basement" material for a large percentage of the planet's surface [4]. Large volcanoes are often connected by systems of rifts and coronae and frequently have numerous flows that extend out onto otherwise featureless plains. The long-wavelength geoid is strongly correlated with the locations of large volcanoes on Venus, suggesting that these regions are currently active [5]. However, no correlation exists between the geoid and locations of large tesserae regions [5].

THE THREE AGES OF VENUS HYPOTHESIS. On the basis of the above observations, I propose that Venus has undergone three distinct geologic episodes:

1. Some form of pseudo-plate tectonics existed until 1 - 2 Ga. Pseudo-plate tectonics ceased when mantle cooling reduced the surface-mantle temperature differential enough to make the lithosphere too bouyant to subduct. Tesserae represent the remnants of this age. The term "pseudo-plate tectonics" does not necessarily imply a well-organized set of distinct plates as on Earth but does imply crustal formation through lithospheric spreading, crustal recycling through subduction, and large-scale horizontal movement of surface material.
2. Cessation of crustal recycling effectively changed the mantle convection boundary condition from free-slip to no-slip. Consequently, the mantle temperature rose enough to induce a brief period of partial melting in the uppermost mantle that caused global volcanic fooding of low-lying areas.
3. Since the time of global volcanic flooding, the style of volcanism and tectonism on Venus has been dominated by "hot spot" tectonics [6], heat release through lithospheric thinning over upwelling plumes. The upwelling plumes and their associated lithospheric stresses cause large volcanoes and limited horizontal movement of the lithosphere and is manifested as rifts and associated coronae.

The relatively rapid and synchronous formation of the plains accounts for the mostly pristine and uniform crater population. Active crustal recycling and deformation prevented the tesserae regions from being more than a few hundred Ma older than the plains. The deficit of craters at 6051.9 - 6053.9 km is a consequence of hot spot tectonics.

FUTURE WORK. Much work needs to be done before the above hypothesis can be considered a viable theory. The proposed cooling history for the Venusian mantle needs to be tested for plausibility through convection modeling. Traditional stratigraphic analysis of Venus needs to be done, particularly with regard to whether any major regions of tesserae are stratigraphically young. The cratering record for different terrain types, or even different geologic units, needs to be carefully analyzed. Detailed analysis of existing and future gravity data sets may yield further insight on which surface features are geologically active.

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