Regional Trends in Crater Density on Venus: Implications for Surface Processes

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Introduction: On the basis of the examination of Arecibo and Pioneer-Venus altimetry data and P-V imaging data for Western Aphrodite, it has recently been proposed that this region of the equatorial highlands of Venus is similar to terrestrial oceanic divergent plate boundary environments. Evidence for this conclusion derives from the nature and configuration of the linear cross-strike discontinuities (CSD's), the characteristics of the topography and topographic patterns, including bilateral topographic symmetry generally parallel to CSD's within domains, the existence of linear rise crests defined by the axes of bilateral symmetry within domains, and the offsets of these linear rise crests between domains. Similar characteristics have recently been documented for Eastern Aphrodite, extending the distribution of terrain along the Venus equatorial highlands similar to terrestrial oceanic divergent plate boundary environments for an additional 4,200 km to a total of 14,000 km, or more than one-third of the circumference of Venus. Evidence has been presented that Aphrodite Terra is the site of crustal spreading on Venus, and topographic profiles suggest that spreading rates are of the order of several centimeters a year. If divergence and crustal spreading occur in Aphrodite Terra and the adjacent equatorial regions of Venus, then there are a number of predictions that can be made, and a number of tests of this hypothesis can be proposed based on these predictions. First, if the process is widespread in the equatorial region, as it appear to be, and rates of spreading are in the range of a few centimeters a year, then the average age of the surface of Venus should be relatively young, certainly less than 1.5 billion years. Secondly, the age of the surface should increase away from Aphrodite Terra toward the poles; lower latitudes should be younger on the average than the higher latitudes. Young average age for the high latitudes: If we assume that divergence and crustal spreading characterize much of the equatorial region of Venus, then it is straightforward to compute the time for a segment of newly created crust to travel from the equator to the pole. The relationship of travel time and distance/latitude is shown for several half-spreading rates in Fig. 1. Crust moving at rates of 0.5 cm/yr will reach the pole in less than 2 by, while crust moving at rates of 3 cm/yr will reach the pole between 300 and 400 my after leaving the equator. Estimates for spreading rates in the Western Aphrodite Terra region on the basis of topographic profiles adjusted for the Venus thermal boundary layer environment suggest that spreading rates for this region lie between 1-3 cm/yr. This rate suggests that crust would take somewhere between 300 my and 1 by to reach the pole, and that crust lying between the equator and the pole along this hypothetical line would therefore lie at about 1 by old.

This exercise provides a useful sense of the implications of equatorial spreading for the ages of surfaces at high latitudes. However, 1) it is not known that divergence characterizes the equatorial highlands outside of Aphrodite Terra, or if it does, that it is occurring at those rates, 2) the obvious geometrical complexities of equatorial divergence and polar convergence would preclude the majority of newly created crust from ever reaching the poles, and 3) any process of crustal thickening and stabilization would result in older ages. Therefore, average ages for high latitudes of less than a billion years generally represent minimal ages for the case of widespread equatorial divergence occurring at rates of 1-3 cm/yr.

Crater-count data for the ages of the surface of Venus exist only for the oval-shaped region imaged by Arecibo (260-30° and 55°S-75°N), and northern regions generally above 30° N latitude imaged by the Soviet Venera 15/16 missions. Campbell and Burns derived an age for the region covering about 25% of the surface of Venus of 600-800 my. On the basis of crater numbers for these northern mid-to-high latitudes (using lunar crater production curves corrected for Venus) by Ivanov et al., an average surface age of 1.0 billion years, +/- 0.5 by has been reported. Schaber et al. have assessed these latter estimates and suggest that the 1 by crater average age for the northern hemisphere may be too high by a factor of two or more. On the basis of the population of large craters, considerations of the type of projectiles and the presence of an atmosphere, and comparisons to the terrestrial cratering record, they find no evidence to support the 1 by average age of the surface and instead conclude that the surface observed by Venera 15/16 is younger than the 450 my mean age of the Earth's crust. In summary, these estimates for the average age of the northern mid-to-high latitudes indicate a relatively young surface, one which is consistent with the range of ages predicted by spreading rates estimated by Head and Crumpler (Fig. 1).

Younging trend from pole to equator: The relatively young mean surface age for the northern latitudes is significant but says nothing about the individual ages within smaller areas or trends in age in relation to global tectonic patterns. The crater population is generally thought to be too small to determine ages of local regions within the area mapped by Venera 15/16 using crater size/frequency distributions. However, we have examined regional trends in simple crater density. Again if we assume that the process of divergence and crustal spreading occurs over a large part of the equatorial highlands, then the area of the equatorial highlands should be the youngest and should be increasingly older crust occurring toward higher latitudes. If this were indeed the case, we would predict the highest density in the polar regions and a general decrease in total crater density from the polar regions toward the equatorial highlands. Using the data of Basilevsky et al., plotted total crater density as a function of latitude in equal area latitude bands (Fig. 2). The resulting plot shows a striking trend from high crater density to an overall decrease toward the equator.
density at the North Pole to low crater density at 30° N latitude, where the Venera 15/16 data coverage terminates.

Conclusions: On the basis of estimates of the average age of the northern high latitudes of Venus and trends in the abundance of impact craters as a function of latitude (Fig. 2), we conclude that there is evidence for a younging trend from the north polar region toward the equator, and that these factors are consistent with divergence in equatorial regions and crustal spreading toward higher latitudes. Data for the southern hemisphere derived from the upcoming Magellan mission will permit an assessment of the ages and trends there, allowing additional testing of these hypotheses.


Fig. 1. Distance as a function of time for different half-spreading rates, and the equivalent latitude for crust forming at the equator and spreading poleward.

Fig. 2. Total crater density for equal $10^7$ km$^2$ areas as a function of latitude. Greater latitude width of lowermost latitude band is due to the slightly uneven latitude coverage of the Venera 15/16 data in this area. Vertical bars represent one-sigma confidence level.