N94-31113

A Tectonic Resurfacing Model for Venus; Sean C. Solomon, Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015.

Two remarkable aspects of the population of impact craters on Venus are that craters at all sizes are indistinguishable from a random population [1] and that the vast majority of craters have not been significantly modified by tectonic strain or by volcanic flows external to the crater rim [1,2], despite evidence from Magellan images that volcanic [3] and tectonic [4] features are widespread on Venus. One interpretation of these observations [2] is that most of the surface dates from the end of a catastrophic global resurfacing event that ceased about 500 My ago, and that the small fraction of craters volcanically embayed or modified by deformation indicates that volcanic and tectonic activity subsequent to that time has been at much lower levels. An alternative model, in which resurfacing occurs episodically in patches a few hundred kilometers in extent and there is a wider spectrum of surface ages, also appears to be consistent with the characteristics of impact craters on Venus [1]. A number of potential mechanisms for catastrophic resurfacing of Venus have been proposed, ranging from geologically sudden convective destabilization of the global lithosphere [5,6] to strongly time-dependent heat flux and melt generation in the underlying mantle [7-9]. In most of these geophysical models, resurfacing occurs implicitly or explicitly by volcanism. We explore here the hypothesis that, at least in the geologically recent history of Venus, the primary resurfacing mechanism has been tectonic deformation rather than volcanism. We show how such a hypothesis provides at least as good an explanation of a wide range of observations as do volcanic resurfacing models. Finally, we explore the implications of the tectonic resurfacing hypothesis for the controversy over the recent resurfacing history of the planet.

Key Observations. Any model for resurfacing on Venus should be consistent with the following observations: (i) The average crater retention age of the surface is about 500 My [1,2,10]. (ii) As noted above, the distribution of craters of all sizes is not distinguishable at high confidence from that of a random population [1]. (iii) Only about 5% of the craters are embayed by volcanic flows exterior to the rim [1,2]. (iv) About one third of the craters have been deformed subsequent to the impact event [2]; for approximately 10% of the craters the post-impact deformation has been extensive [1,2]. (v) There is some tendency for modified craters to be located in areas of low crater density [1]. (vi) There is a weak inverse correlation between crater density and radar backscatter; i.e., smooth plains have some tendency to be more densely cratered than radar-bright regions of high topography and/or high roughness [1]. (vii) The most common radar-bright regions on Venus are the intensely deformed complex ridged terrain, or tessera, that make up large areas of many highland regions [11] and occur pervasively as small exposed inliers in many lowland plains units [4]. (viii) Deformation on Venus tends to be broadly distributed rather than concentrated into narrow zones as on Earth; Venus lacks a global system of tectonic plates [4]. (ix) Topography and gravity are strongly correlated at long wavelengths [12]; many major features have a large gravity-to-topography ratio (GTR) and apparent depth of compensation [13]. (x) Evidence for tectonic activity substantially more recent than 500 My ago, in addition to the large number of deformed craters, includes the great relief and steep slopes of the mountain belts and plateau scarps of Ishtar Terra and of the equatorial chasm systems [4, 14] and elevation profiles indicating differential vertical movements along major channels [15]. (xi) Evidence that the crust and upper mantle of Venus may be stronger than predicted by simple extrapolation from Earth and the 450 K greater surface temperature include the apparently unrelaxed depths of impact craters [2] and large values of elastic lithosphere thickness derived from flexural models of topographic profiles across the margins of coronae [16]. (xii) The ^{40}Ar abundance of the Venus atmosphere is a factor of 4 less than that on Earth as a fraction of planet mass [17], suggesting that any widespread outgassing such as might accompany large-scale overturn of the global lithosphere [5,6] or upper mantle [8] was restricted to times significantly earlier than 500 My ago [18]. (xiii) While episodes of widespread volcanism at a flux greater than the long-term average for the planet have been documented for Mars [19] and Earth [20], none of the other terrestrial planets have been subjected to a global volcanic resurfacing event over the last 4 Gy.

Tectonic Resurfacing Hypothesis. An important difference between Venus and all of the other terrestrial planets is its high surface temperature. Characteristic time scales for ductile deformation of crustal and mantle material are known to vary exponentially with reciprocal temperature, so for a given thermal gradient and stress field, high rates of flow are expected to be reached at much shallower levels on Venus than on other terrestrial planets. The large values of GTR and apparent depth of compensation on Venus have been taken as evidence that Venus lacks an asthenosphere or upper mantle low-viscosity channel and that mantle convective stresses couple strongly to the overlying lithosphere [21]. In the absence of plate tectonics, these stresses should give rise to lithospheric strains that are broadly coherent over large regions. For a sufficiently weak lower crust, rates of lower crustal deformation and consequently of surface strain can be high.

Prior to the era of Venus history now preserved, therefore, if the surface temperature was comparable to that at present, the higher heat flow associated with early planetary cooling and enhanced levels of radiogenic heat production and a mantle convective vigor at least that of the present should have led to geologically rapid rates of crustal deformation over most, if not all, of the surface. Such an era would have been characterized by a nearly global extent of complex ridged terrain and few impact craters sufficiently undeformed as to be recognizable from surface images. At some point in the evolution of Venus, however, heat flow will decline to levels sufficiently low that the ductile strength of the lower crust will increase rapidly with small increments of additional cooling. Subsequent to that transition, which might appear to be rapid relative to the geological record, rates of deformation will be substantially less, and both volcanic deposits and impact craters will persist for long intervals with at most modest deformation of landforms. The observations enumerated above are consistent with this hypothesis if this transition from rapid to modest rates of surface strain accumulation occurred about 500 My ago.

Implications for Resurfacing History. The tectonic resurfacing hypothesis leads to some simple predictions that are germane to the resurfacing controversy. If Venus were laterally uniform in both crustal thickness and heat flow, then the transition in surface strain rates would occur with global synchroneity. That is, there would be a rapid change on a planetary scale from high rates of resurfacing to low rates, as is called for by the catastrophic resurfacing model [2], although no true catastrophe - and certainly no global outpouring of magma - is involved. While the assumption of uniform crustal thickness and heat flow is unreasonable, the unimodal hypsometric distribution for Venus suggests that a large fraction of the Venus surface may not depart greatly from this assumption; i.e., an apparently "catastrophic" change is not a bad first approximation. Departures from a globally uniform change in resurfacing rates are to be expected, however. In particular, highland regions, whether they owe their elevations primarily to greater than average crustal thickness or to enhanced temperatures at depth, should persist as regions of high strain rate long after the rate of deformation in lowland plains regions has dropped to modest levels. Lowlands should thus be preferred sites for the preservation of relatively undeformed volcanic deposits and impact craters, as is observed [1,3,4].

Conclusions. The hypothesis that most resurfacing on Venus has occurred by tectonic rather than volcanic processes can account for many of the important characteristics of the planet. The unusual cratering record on Venus is seen in this light to be a consequence primarily of the atmospheric greenhouse and the effect of the high surface temperature on the rheology of the crust. The hypothesis leads to the view that the resurfacing history should contain elements of both the "catastrophic" and "episodic" scenarios for crater removal, with approximately coeval stabilization of lithosphere beneath plains regions but more recent tectonic activity concentrated in highlands.

References. [1] R.J. Phillips et al., *JGR, 97*, 15923, 1992; [2] G.G. Schaber et al., *JGR, 97*, 13257, 1992; [3] J.W. Head et al., *JGR, 97*, 13153, 1992; [4] S.C. Solomon et al., *JGR, 97*, 13199, 1992; [5] E.M. Parmentier and P.C. Hess, *GRL, 19*, 2015, 1992; [6] D.L. Turcotte, *Eos Trans. AGU, Fall Suppl., 73*, 329, 1992; [7] J. Arkani-Hamed and M.N. Toksöz, *PEPI, 34*, 232, 1984; [8] V. Steinbach and D.A. Yuen, *GRL, 19*, 2243, 1992; [9] J. Arkani-Hamed, *Eos Trans. AGU, Fall Suppl., 73*, 332, 1992; [10] E.M. Shoemaker et al., *LPS, 22*, 1253, 1991; [11] D.L. Bindschadler et al., *GRL, 17*, 171, 1990; [12] W.L. Sjogren et al., *JGR, 88*, 1119, 1983; [13] S.E. Smrekar and R.J. Phillips, *EPSL, 107*, 582, 1991; [14] S.E. Smrekar and S.C. Solomon, *JGR, 97*, 16121, 1992; [15] V.R. Baker et al., *JGR, 97*, 13421, 1992; [16] D.T. Sandwell and G. Schubert, *JGR, 97*, 16069, 1992; [17] T.M. Donahue and J.B. Pollack, in *Venus*, p. 1003, Univ. Ariz. Press, 1983; [18] T. Matsui and E. Tajika, *LPS, 22*, 863, 1991; [19] K.L. Tanaka et al., PLPSC 18th, 665, 1988; [20] R.L. Larson, *Geology, 19*, 547, 1991; [21] R.J. Phillips, *GRL, 13*, 1141, 1986.