CHEMICAL DIFFERENTIATION, THERMAL EVOLUTION, AND CATASTROPHIC OVERTURN ON VENUS: PREDICTIONS AND GEOLOGIC OBSERVATIONS; J. W. Head, E. M. Parmentier, and P. C. Hess, Dept. of Geol. Scis., Brown University, Providence RI 02912 USA.

Observations from Magellan show that: 1) the surface of Venus is generally geologically young[1,2]; 2) there is no evidence for widespread recent crustal spreading or subduction[3]; 3) the crater population permits the hypothesis that the surface is in production[1,2], and 4) relatively few impact craters appear to be embayed by volcanic deposits suggesting that the volcanic flux has drastically decreased as a function of time[1]. These observations have led to consideration of hypotheses suggesting that the geological history of Venus may have changed dramatically as a function of time due to general thermal evolution[4,5] and/or thermal and chemical evolution of a depleted mantle layer[6], perhaps punctuated by catastrophic overturn of upper layers[6] or episodic plate tectonics[5]. We have previously examined the geological implications of some of these models[7]; here we review the predictions associated with two periods of Venus history (1. Stationary thick lithosphere and depleted mantle layer, and 2. Development of regional to global instabilities) and compare these predictions to the geological characteristics of Venus revealed by Magellan.

Presence of a stationary thick lithosphere and/or depleted mantle layer: In these scenarios, the crust has thickened to several tens of km (less than the depth of the basalt/eclogite transition) and overlies a thick depleted mantle layer[6] and/or the lithosphere has greatly thickened[4-6]. Rates of surface volcanic extrusion should have decreased with time due to evolving lithospheric thickness and increase in depleted layer thickness and should be low; present rates of volcanism are apparently low (<0.5 km^3/a), comparable to terrestrial intraplate volcanism rates[8]. Plumes ascending from depth would not penetrate to shallow depths and thus should undergo less pressure-release melting; coronae apparently represent plumes[9] and the bimodal distribution of associated flow fields may be related to time-dependent variations[10]. Plumes undergoing pressure-release melting at the base of this layer would produce MgO-rich melts which should yield very voluminous, low-viscosity surface flows[11], perhaps related to abundant large-volume lava flows and sinuous rille-like features observed[8,12]. Volcanism should be concentrated in regions above the largest upwellings; this could be consistent with the observation that much of the volcanic activity is associated with large rises such as Beta, Atla, Themis[8]. The apparent depth of compensation of many regional-scale features is much greater on Venus than on Earth[13]; these could be related to the presence of a thick lithosphere or depleted layer[5,6].

Implications of instabilities developing in a thick lithosphere and/or depleted mantle layer: Two scenarios for instabilities and surface deformation and volcanism seem plausible. In one, the residual layer becomes negatively buoyant[6] and diapirism is widespread, but the diapirs, while widespread, are not laterally or vertically coupled with the uppermost mantle and crust, and surface deformation is limited and localized to the region above the negative diapir. In this scenario, fertile mantle material would flow in to replace the lost diapir region and pressure-release melting at depths previously occupied by the depleted layer would cause extensive regional volcanism. Resurfacing would take place focused on these regional centers of diapirism. In another scenario, lithospheric instability would cause large-scale downwelling and subduction[5,6] and local crustal thickening, and rifting and the initiation of crustal spreading to create new crust in distal regions. Crustal spreading could be a major part of the renewal process, with old crust being thickened, deformed, underthrust, and possibly subducted over regions of downwelling; crustal thinning, large-scale pressure-release melting, and crustal spreading would occur over the complementary regions of the planet. Such scenarios may be consistent with many aspects of the crater population which can be interpreted to be in production and superposed on a substrate that was produced over a very short period of time about 500 m.y. ago[1]. In the process of development and evolution of instabilities in either of the two scenarios, crustal shortening, thickening, and surface deformation is likely to occur. The scales and styles will be related to the scale of the instabilities and the rheology of the crust and upper mantle material. We consider the possibility that the tessera regions represent relict sites of downwelling associated with such instabilities[7]. Tesserae are highly deformed[14], represent regions of thickened crust[15], make up about 10% of the planet[16], often have borders suggesting deformation and underthrusting[17], and show crater densities suggesting ages somewhat older than surrounding plains[18]. Tessera borders often extend for many hundreds to thousands of km, indicating that the underthrusting events were large-scale[17]. Thus, these regions could be linked to large-scale downwelling events associated with depleted layer instabilities. For example, the major tessera occurrences (Western Ishtar, Fortuna, Laima, Tellus, Ovda, Thetis, and Alpha) could mark the sites of the individual downwellings and the collection of thickened and deformed crust; the arcuate nature of many of the borders of these tessera would indicate the regions where downwelling or underthrusting was most prominent[17]. There is good evidence that tessera extends beneath the volcanic plains in many areas, particularly in the intervening regions between the major tessera occurrences[17,20]. In addition, these major occurrence are localized in a large region centered at about 45°N, 45°, and most of the arcuate boundaries are convex away from this region. Thus, this large region is a candidate for the location of concentrated downwelling during a catastrophic event. In the subduction and catastrophic plate tectonics hypothesis[5], an organized array of spreading ridges and new crustal formation would be anticipated in regions complementary to the downwelling. Modest crustal spreading rates (similar to those on the Earth, e.g. ~5 cm/a) for a total ridge length equivalent to a planetary circumference could result in creation of new crust for between one-third and one-half of the planet in 100 million years[19]. So far, evidence for such regions has not been recognized, although some of the linear planitiae (e.g., Aino, Niobe, Sedna) flanking the tessera regions could be candidates. Alternatively, broader complementary regions of upwelling might be anticipated. Candidates for these include the Beta-Atla-Themis region, a concentration of volcanic features, extensional tectonism, broad rises, and positive gravity anomalies that makes up about 20% of the surface of Venus[8,21]. In addition, a second less well-developed region occurs in the Eistla-Bell area[22]. Thus, geologic evidence exists for both broad regions of downwelling and upwelling that might be characteristic of, or a result of, catastrophic overturn events.

Further development and tests of these scenarios: No one observation can be shown to uniquely confirm these models and scenarios, but many of the features predicted are consistent with the observed characteristics of Venus geology and geophysics. These models therefore merit further consideration; some of the things that are required to permit further analysis and testing are: 1) Better definition of the growth, stability and style of renewal of the crust, depleted layer, and lithosphere. 2) Analysis of the scale and nature of instabilities; are they characterized by catastrophic surface turnover and crustal spreading, or deeper negative diapirs and resurfacing of a relatively stable veneer? 3) If crustal spreading occurred, what geometries and rates are compatible with the cratering record. 4) What resurfacing rates are required to be consistent with the crater record and is this reasonable from a magma generation point of view?

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