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
young1,2; 2) there is no evidence for widespread recent crustal spreading or subduction3; 3) the
crater population permits the hypothesis that the surface is in production4,5 and/or thermal
and chemical evolution of a depleted mantle layer6, perhaps punctuated by catastrophic overturn of upper layers6 or episodic
plate tectonics5. We have previously examined the geological implications of some of these
models7; 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 layer6 and/or the lithosphere has greatly thickened4-6. 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 km³/a), comparable to terrestrial intraplate volcanism rates8. Plumes
ascending from depth would not penetrate to shallow depths and thus should undergo less
pressure-release melting; coronae apparently represent plumes9 and the bimodal distribution of
associated flow fields may be related to time-dependent variations10. Plumes undergoing
pressure-release melting at the base of this layer would produce MgO-rich melts which should
yield very voluminous, low-viscosity surface flows11, perhaps related to abundant large-volume
lava flows and sinuous rille-like features observed8,12. 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, Themis8. The apparent
depth of compensation of many regional-scale features is much greater on Venus than on Earth13;
these could be related to the presence of a thick lithosphere or depleted layer5,6.

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 buoyant6 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
subduction5,6 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.
ago1. 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. Tesserae are highly deformed, represent regions of thickened crust, make up about 10% of the planet, often have borders suggesting deformation and underthrusting, and show crater densities suggesting ages somewhat older than surrounding plains. Tessera borders often extend for many hundreds to thousands of km, indicating that the underthrusting events were large-scale. 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, Theissi, 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. There is good evidence that tessera extends beneath the volcanic plains in many areas, particularly in the intervening regions between the major tessera occurrences and 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. 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?