A MODEL FOR THE GEOLOGICAL HISTORY OF VENUS FROM STRATIGRAPHIC RELATIONSHIPS: COMPARISON TO GEOPHYSICAL MECHANISMS.

James W. Head[1] and Alexander T. Basilevsky[1,2], [1]Dept. Geological Sci., Brown Univ., Providence, RI USA 02912, [2]Vernadsky Institute, Moscow, Russia. (James_Head@brown.edu).

Introduction: Analysis of local and regional stratigraphic relationships has permitted the assessment of the nature of geological units and tectonic structures and their distribution throughout the observed history of Venus [1-6]. We have used these data to identify some of the main geological events in the history of Venus [7] and to point out some of the major unknowns and outstanding questions [8]. In this contribution we formulate a synthesis of this information into a model for the geological evolution of Venus. We then compare this model to geophysical mechanisms for the thermal and tectonic evolution of Venus, concentrating here on the depleted mantle overturn model [9}.

The data on stratigraphic and structural relationships: Geological mapping of Venus using the global Magellan data set has provided a series of maps and stratigraphic columns at a variety of scales and over more than half the surface of Venus as independent analysis and as part of the Venus geological mapping program [1-6 and references therein]. Although units mapped in different areas have been given different names, there are numerous common units and structures, and the basic sequences are commonly the same. This information has enabled the major themes of the geological history of Venus to be identified. Although debate is of course ongoing about various aspects of the stratigraphic relationships and tectonic and volcanic interpretations of units, we have used our data from geological mapping of about half the surface of Venus, as well as that of our colleagues [2-5] to develop the following model.

A model for the geological history of Venus: On the basis of these data we divide the geological history of Venus into five phases and we briefly describe these here. Although these phases appear to represent distinctive time intervals when certain processes dominated, clearly in many cases there was overlap between the events dominating each phase, and this is why we use the term 'phase' which means 'a transitory state between changes in appearance, structure, character...' **Phase 1 (Pre-Tessera):** This period represents at least the first 80% of the history of Venus, a time prior to the formation of the presently observed surface geological units. The exact duration of this period is uncertain, but may be as long as 4 Gyr. Venus is unusual, and similar to Europa, Io, and Earth, in that the vast majority of its observed surface history is geologically young. Rocks dating from this phase may be exposed in the oldest units of Phase 2 and in impact crater ejecta. **Phase 2 (Tessera Orogenesis):** The earliest recognizable geologic unit, consistently appearing lowest in the stratigraphic column, is tessera, a complexly deformed terrain exposed over about 8% of the surface. Its presence demonstrates that orogeny was occurring at least over this part of Venus and an important question is whether tessera is exposed under the remaining younger units, whether different units might occur there, or whether tessera deformation is laterally transitional to earliest Phase 3 events. In any case, terrain deformed to this level is not observed regionally in the subsequent geological record. **Phase 3 (Distributed volcanism, long wavelength deformation, coronae initiation):** This phase is characterized by widespread volcanic plains that are initially highly deformed (densely fractured) and very voluminous, and later dominated by the presence of an abundance of small shield volcanoes on almost undeformed plains and by broad deformation belts spaced from many tens to hundreds of km apart (ridge belts, some fracture belts). One of the most significant events in this period is initiation of the formation of a large number of coronae, distributed almost globally. Although the influence of these coronae continue to be observed in later phases, there is evidence that many began at this time. **Phase 4 (Vast volcanic plains):** This phase is characterized by widespread volcanic plains presently covering the majority of the surface of Venus, and deformed subsequent to their emplacement by networks of wrinkle ridges. In contrast to shield plains, these have few vents and instead display sinuous channels, the longest of which is many thousands of km. A change from Phase 3 is clear in volcanic emplacement style, distribution and number of source vents, and possibly composition. Although the duration of emplacement cannot be constrained by the size frequency distribution of impact craters, other evidence suggests that the emplacement of the plains may have occurred over a period less than a few tens of millions of years [10]. The broadly distributed deformation indicated by the wrinkle ridges represents a change from the scale and wavelength of deformation seen in Phase 3, but there is evidence that some of the broad topographic patterns represented by post plains topography indicate that deformation along the trends of the ridge belts continued, although with waning significance [11]. Corona evolution continued throughout this phase; some corona had ceased activity and are largely buried by these plains, while others were still undergoing tectonic deformation of their rims, subsidence of their interiors, and some associated volcanism. **Phase 5 (Rifting and Large Shield Volcanoes):** Subsequent to the emplacement of the regional plains with wrinkle ridges the main geological activity was focused on localized, but globally distributed, volcanism and tectonism. Tectonic activity changed from distributed strain associated with wrinkle ridge formation in Phase 4, to strain concentrated in linear rift zones that form planet-wide networks with nodes located at several large rises (e.g., Beta and Atla). Volcanic activity changed from emplacement of vast plains typical of Phase 4 to the construction of large shield volcanoes, both at the rises and in the adjacent plains, and the formation of lobate flows many of whose sources are along rift zones and the latest stages of some corona features located there. Young shield deposits clearly postdate the regional plains, but the initiation of shield formation (presently buried) may have been in an earlier phase.

Summary and discussion: These five phases represent the complex interplay of tectonic and volcanic process that are changing in style, intensity, flux, and location, with time. Certain combinations of these yield identifiable average differences in the activity operating on the planet at a given time, in some cases resulting in sufficient change to define discontinuities in deposits. Additional important facts are 1) that the surface of Venus is so young geologically, 2) that so many of the craters are relatively unmodified and appear to postdate the emplacement of the regional plains, and 3) that the level of activity in the most recent geological history appears to be much lower than that previously.

How does the record of Venus compare to other planets? In the latter history of the Earth, plate tectonic processes are operating continuously to create magmatic and volcanic crust at high rates and produce associated regional orogenies in different parts of the planet at different times. Similar processes and styles are operating at any given time in this part of Earth history, but they change in location depending on the distribution of continents and plate boundaries, and mantle hot spots. In contrast, the record on Venus appears to represent sequential changes in history (phases), rather than the simple redistribution of certain types of activity at certain locations with time. In this sense, Venus appears more similar to the Moon and Mars, where different phases of tectonic and volcanic activity are often related to changes in thermal evolution and state of stress in the lithosphere, and to earlier Earth history where a range of phenomena dominate or typify certain periods (e.g., komatiites, greenstone belts, anorthosites, various magmatic assemblages, lack of preserved record for the first part of its history).

Comparison to geophysical mechanisms: We are in the process of further refining this model and comparing its major points to predictions derived from a range of geophysical mechanisms. In our initial analysis we are testing a model of vertical crustal accretion and residual depleted mantle layer foundering [9]. We find that this mechanism accounts for a number of the salient points of the geological history. Depleted mantle layer foundering, which is predicted to be global in nature, could create globally high strain rates in the overlying crust, erasing morphological evidence of the previous record and replacing it with highly deformed tessera terrain. Exposed tessera blocks could represent regions of thicker crust formed during this period. Foundered cold depleted mantle would be replaced by hotter material, steepening the near-surface global thermal gradient, which could produce widespread and abundant shallow melting to form the fractured and shield plains. Coronae initiation could be formed by instabilities associated with the overturn. Residual mantle convection patterns associated with the overturn could account for the longer wavelength deformation of Phase 3, and the continuation of minor deformation on these features into later periods. The movement of deeper fertile mantle layers to nearer the surface following an overturn event should result in a global phase of pressure-release melting, which would be geologically rapid and relatively short-term (as the new material came to thermal equilibrium). This could account for the widespread and apparently rapid emplacement of the regional plains and the change in volcanic style from earlier periods. As the upwelled hot fertile mantle cooled and came to thermal equilibrium, contraction and thermal subsidence should occur, perhaps accounting for the phase of wrinkle ridge formation. Finally, as post-overturn thermal equilibrium is approached, geological activity associated with this phenomenon would wane. This may account for the relative quiescence of the present period of the history of Venus. Isolated volcanoes, the importance of regional rifting, and geological activity concentrated there and in broad rises, could conceivably be patterns related to the aftermath of the depleted mantle layer event, or could be the result of the resurgence of the influence of broad mantle convection patterns (hot spots, etc.) unrelated to it. Thus, we conclude that the depleted mantle layer overturn mechanism can account for many of the salient aspects of the geological history. We are presently proceeding with tests of other geophysical mechanisms.

References: 1) A. Basilevsky and J. Head, EMP, 66, 285, 1995; Planet. Space Sci., 43, 1523, 1995; JGR, 103, 8531, 1998; A. Basilevsky et al., LPSC 30, 1295, 1999; 2) K. Tanaka, USGS OFR, 94-438, 1994; 3) M. Price, Tectonic and volcanic map of Venus, Princeton Univ., 1995; 4) D. Senske et al., LPSC 25, 1245, 1994; 5) K. Tanaka et al., in Venus II, 667, 1997; 6) M. Ivanov and J. Head, LPSC 29, 1261, 1998; 7) J. Head and A. Basilevsky, Geology, 26, 35, 1998; 8) M. Ivanov and J. Head, LPSC 29, 1419, 1998; 9) E. Parmentier and P. Hess, GRL, 19, 2015, 1992; 10) G. Collins et al., LPSC 28, 243, 1997; 11) E. Stewart and J. Head, LPSC 30, 1173, 1999.