GEOLOGICAL EVIDENCE FOR PETROGENETIC DIVERSITY ON VENUS: IMPLICATIONS FOR FUTURE EXPLORATION STRATEGIES. James W. Head[1], Mikhail A. Ivanov[1,2] and Alexander T. Basilevsky[1,2], [1]Dept. of Geological Sci., Brown University, Providence, RI 02912 USA, (james_head@brown.edu), [2]Vernadsky Institute of Geochemistry and Analytical Chemistry, RAS, Moscow 119991, Russia.

Introduction: A long-standing, fundamental question in planetary geoscience is: "How similar are the geological histories of Earth and Venus, and when and how did their evolution diverge?" Did Venus once have oceans and a more Earth-like climate, as suggested by Pioneer-Venus data [1]? If so, when, how, and why did it transition to current conditions, and are traces of this early period, and the transition, manifested in the currently exposed geological record? What is the evidence as seen in the surface products of mantle partial melts (the petrogenetic record)? Does Venus, like the Earth, have both mafic secondary crust (derived from mantle partial melts) and felsic tertiary crust (derived from reworking of secondary crust and potentially involving water) [2]. In this analysis we review evidence for the presence of mafic and felsic crust in the currently observed geological record of Venus in order to set a framework for addressing these questions.

Magellan radar image data revealed that the surface of Venus was composed primarily of plains units containing geomorphic features consistent with a volcanic origin [3]. Indeed, over 80% of the surface appears to have been resurfaced by effusive volcanic activity [4], primarily interpreted to be basaltic (mafic) in nature, an observation consistent with the geochemical results from the Venera/Vega landers [5]. A small number of features initially observed in the Magellan data (pancake domes [3,6-7], festoons [8]) differed from the widespread effusive, apparently low-viscosity lavas interpreted to be of basaltic origin, and were interpreted to be either of a more felsic nature [6-8], or to be basaltic magmas that attained higher viscosity through increased bubble content [6]. Subsequent to these initial global descriptions, numerous studies began placing geologic features in the context of local, regional and global stratigraphic relationships [e.g., 9]. The highly deformed tesserae were seen to be the earliest stratigraphic unit and were thought to represent either deformed volcanic plateaus or more ancient tectonically thickened crust that could be either mafic or felsic in nature [10]. Following tessera formation, a sequence of volcanic units with differing characteristics were observed, all apparently forming in the last 20% of the history of Venus [11]. Among the fundamental unresolved questions concerning the history of Venus are: 1) What is the petrogenetic diversity displayed by the array of volcanic features? 2) Is there evidence for significant compositional variation, perhaps ranging from ultra-mafic to felsic? 3) What are the geological environments in which candidate felsic materials occur? 4) How do these environments relate to the emerging picture of the geological history of Venus? 5) What insight might these observations provide for the first 80% of the history of Venus and whether water might have played a significant role in the evolution of Venus? We first describe the features that suggest petrogenetic diversity, we then examine them in the context of the stratigraphic record, and we conclude with a series of outstanding questions and how these might influence future exploration strategy.

Range of Geomorphic Features:

Tessera terrain is high-standing, highly deformed terrain lying at the base of the stratigraphic column [12]; on the basis of its thickened crust and continent-like geomorphology (high-standing continent-like plateaus surrounded by marginal deformation belts) some have interpreted tessera to consist, at least in part, of ancient rocks, perhaps more felsic in nature [13]. Others interpret tesssera terrain to be of basaltic origin, perhaps related to collapsed plumes [14] or tectonic crustal thickening processes of basaltic material [15]. Recent analysis of near-infrared thermal radiation data are interpreted to mean that the tessera may be more felsic in composition [16-18]. Thus, tessera terrain represents a prime candidate for further exploration for determining the petrogenetic history of Venus.

Pancake domes (now called farrum, singular farra) are clearly distinguished from mafic flows by their steep sides, generally circular shapes and similarities to viscous felsic domes on Earth [6-7]. Although among the most impressive candidates for higher-viscosity felsic volcanism on Venus, their felsic nature could not be distinguished, on the basis of morphology, from enhanced viscosity due to peculiarities of the Venus volcanic environment [6].

Festoons, located both in the plains and in the tessera [8,19-20], represent a class of features that also show similarities to felsic extrusive flows on Earth (steep-sided, very rough, lobate flows). Morphometric analyses suggest a viscosity consistent with andesitic-dacitic-rhyolitic flows on Earth [8].

Geological and Chronological Settings: Geological mapping at all scales has provided the opportunity to assess the stratigraphic positions and associations of these features and deposits, thus providing clues to their petrogenesis. ***Tessera Terrain*** is the best candidate for sampling ancient crust on Venus, crust that could represent the geological record of the first 80% of the history of Venus [9]. Fragments of earlier crust could have been incorporated during the events that created the highly deformed tessera, could have further survived the most recent phase of geological activity as high-standing crust, and could provide exposed samples (ranging from felsic crust to reworked zircons) from an earlier period. Most promising in detecting and mapping out such areas are techniques that might map the location of felsic materials in the tessera [16-18].

Pancake domes are not randomly distributed in space and time; the vast majority appear to be correlated with an early mafic volcanic unit (shield plains) that represents significant globally distributed basaltic volcanism from tens of thousands of small source vents [21-22]. This association has been interpreted to mean that the pancake domes formed from associated distributed melting and remobilization of basaltic crust to produce more felsic compositions [11,21]. A second association is with the near-summit areas of later individual mafic shield volcanoes, interpreted to mean that pancake domes can also form more felsic compositions during the evolution of large magma reservoirs [23].

Festoons are also not randomly distributed across the surface, occurring both in the plains and in the tessera. One of the most prominent occurrences of these features is in Ovda Region tessera, where a 250 x 300 km feature estimated to be ~5500 km^3, appears to have formed during a very short period of time at the summit of Ovda at ~4.4 km above MPR [19-20]. On the basis of the morphology, stratigraphic relationships, and tectonic setting (interpreted to be at the summit of terrain representing significant downwelling and crustal thickening), this unit has been interpreted as melting of thickened basaltic crust and generation of high-viscosity felsic magmas [19,24]. These correlations and interpretations provide some of the best evidence for the largest occurrences of candidate felsic crust on Venus.

Summary and Implications for Exploration Strategies: Several lines of evidence suggest that felsic crust is likely to exist on Venus among the following candidates: 1) felsic tessera components (analogous to continental crust), 2) viscous domes commonly associated with an early phase of distributed melting of basaltic crust (shield plains), 3) magmatic evolution in shield volcano reservoirs, and 4) festoon structures, the most prominent of which lies atop the highest tessera and may represent basal melting of thickened crust. Needed are: 1) more detailed analyses of tessera terrain to explore variations in structure [12], tectonic setting [10], thermal-IR characteristics [16-18], and interpretations [10,13-14,25-26]; 2) further analysis of the setting and associations of candidate pancake domes and festoons [e.g., 27] in order to identify the most meaningful and accessible candidates for further exploration and investigation, and 3) identification of measurement objectives and exploration strategies to address these important questions [28-30]. Future exploration scenarios [31-32] should involve landers on tessera and pancake-domes/festoons, balloons that can obtain high resolution remote sensing data and touch-down chemical analyses, and orbiters that can help distinguish different units and surface mineralogy; these missions will pave the way for sample return. One of the most fundamental goals of the ongoing [33] and future exploration of Venus should be establishing the link between the currently observed geologic record and its petrogenetic diversity, and the nature of the first 80% of the geological, geodynamical and climate history of Venus [9,34-37].

References: [1] T. Donahue et al. (1982) Science 216, 630. [2] S. Taylor (1989) Tectonophysics 161, 147. [3] J. Head et al. (1992) JGR 97, 13,153. [4] M. Ivanov (2008) LPSC 39, 1017. [5] Y. Surkov (1997) Exploration of Terrestrial Planets from Spacecraft, John Wiley, 446 pp. [6] B. Pavri et al (1992) JGR 97, 13,445. [7] A. Basilevsky et al. (1992) JGR 7, 16315. [8] H. Moore et al. (1992) JGR 97, 13479. [9] A. Basilevsky and G. McGill (2007) AGU Monograph 176, 23. [10] M. Ivanov and J. Head (2008) PSS 56, 1949. [11] J. Head et al. (1996) LPSC 27, 525. [12] M. Ivanov and J. Head (1996) JGR 101, 14861. [13] W. Kaula et al. (1997) Venus II, Arizona, 879. [14] V. Hansen et al. (1997) Venus II, Arizona, 797. [15] D. Bindschadler et al. (1992) JGR 97, 13495. [16] G. Hashimoto annd S. Sugita (2003) JGR 108, 5109. [17] G. Hashimoto et al. (2008) JGR, in press. [18] N. Mueller et al. (2008) EPSC2008-00421. [19] J. Head and P. Hess (1996) LPSC 27, 513. [20] S. McColley and J. Head (2004) LPSC 35, 1376. [21] M. Ivanov and J. Head (1999) JGR 104, 18907. [22] M. Ivanov and J. Head (2004) JGR 109, E10001. [23] S. Keddie and J. Head (1994) EMP 65, 129. [24] J. Head (1990) EMP 50/51, 25. [25] M. Ivanov and J. Head (2008) this volume. [26] A. Basilevsky and J. Head (2008) this volume. [27] P. van Thienen et al. (2004) tectonophysics 394, 111. [28] L. Esposito et al. (2007) AGU Monograph 176, 23. [29] A. Treiman (2007) AGU Monograph 176, 7. [30] A. Baslievsky (1990) EMP 50/51, 3. [31] J. Cutts et al. (2007) AGU Monograph 176, 7. [32] M. Gilmore et al. (2005) Acta Astronautica 56, 477. [33] F. Taylor et al (2007) AGU Monograph 176, 157. [34] S. Smrekar et al. (2007) AGU Monograph 176, 45. [35] D. Grinspoon and M. Bullock (2007) AGU Monograph 176, 191. [36] M. Bullock and D. Grinspoon (2001) Icarus 150, 19. [37] D. Grinspoon et al. (2008) this volume.