

**GEOCHEMICAL ASPECTS OF THE GEOLOGICAL HISTORY OF VENUS.** A.T. Basilevsky<sup>1,2</sup> and J.W. Head<sup>2</sup>, <sup>1</sup>Vernadsky Institute of Geochemistry and Analytical Chemistry, RAS, Moscow 119991 Russia, [atbas@geokhi.ru](mailto:atbas@geokhi.ru); <sup>2</sup>Dept. Geological Sci., Brown University, Providence, RI, 02912 USA, [James.Head@Brown.edu](mailto:James.Head@Brown.edu)

**Introduction:** The current knowledge of the geological history of Venus can be interpreted in terms of the history of the geochemical environments on this planet. One can distinguish two parts of the geologic history of Venus: the later part, for which we have morphological records supplemented by geochemical measurements on the surface and in the atmosphere, and the earlier part, for which there is indirect evidence recorded in some compositional characteristics of the atmosphere of the planet.

**The latter part of the history:** For the later part, which occupies the last 0.5-1 b.y. of the history of Venus [1], one can consider the geochemistry of the processes occurring in the crust and in the upper mantle, and the surface geochemistry.

*Geochemical processes in the crust and upper mantle* are obviously the magmatic processes. Considering the known dryness and other parameters of the atmosphere, it is logical to suggest that hydrothermal activity is not appropriate in the crust and probably on Venus magmas are dryer than terrestrial magmas. Some clue to the composition of Venus magmas can be found from the characteristics of the observed volcanic formations.

The most widespread (> 80 % of the surface) volcanic formations are represented by plains [e.g., 2-4]. Most of these show either extensive and morphologically very distinct flow-like features, obviously formed by solidified lava flows, or clusters of kms-size gently-sloping shields. Numerous larger volcanic constructs, many of which are more than a hundred kilometers in diameter, are also seen [5]; however the area they occupy is relatively small. These constructs are typically gently-sloped. The gentle slopes of the majority of the Venus volcanic constructs and the large areal sizes of lava flows on the generally horizontal plains, suggest low lava viscosity.

Considering that the most widespread volcanic plains on the Earth and the Moon are assemblages of basaltic lavas which, in turn, are expected products of partial melting of the chondrite-like materials composing the silicate parts of all terrestrial planets [6], one can suggest that the majority of the observed products of Venus volcanism are also basaltic. This is in agreement with the deduced low viscosity of the lavas and is supported by geochemical measurements [7] in seven sites where the Venera-Vega probes landed (all on the plains). So the dominant geochemical processes in the Venus crust and the upper mantle are probably partial

melting of the interior, producing basaltic melts and the subsequent crystallization of these melts. The latter, when it occurs in the erupted lavas, simply quenches the melt without significant geochemical effects, but when crystallization occurs in the plutonic environment, compositional differentiation may occur. The diversity of chemistry, especially of the potassium contents [7], observed for the Venera-Vega sites suggests that compositional differentiation indeed took place, either during magma-forming partial melting, or in the crystallization within magmatic plutons, or both.

There are two morphologic units on Venus whose characteristics may suggest non-basaltic composition. One is represented by the so-called steep-sided domes of obvious volcanic origin, typically a few tens of kilometers in diameter [8]. The steepness of the dome slopes is usually considered as an indication of high lava viscosity, which in turn may suggest non-basaltic, more silicic composition [e.g., 9]. But high viscosity might also be due to the abundance of gas bubbles in the lavas [9] or to an increased content of dissolved water and differences in lava crystallinity [10]. It was also suggested by [11] that the domes may simply be the low-eruption rate basaltic volcanoes. So, the non-basaltic composition of the steep sided domes on Venus is possible, but not certain. If however these domes are composed of non-basaltic lavas, the latter could appear as a result of partial melting within the essentially basaltic crust.

Another unit of potential non-basaltic composition is tessera terrain, which forms blocks of different sizes, up to thousands kilometers across occupying altogether ~10% of the planet surface [12]. Massifs of this highly tectonized unit typically stand above the surrounding basaltic plains. This may suggest that they are composed of the materials less dense than basalts. As an option however this higher hypsometric position could be due to a greater thickness of basaltic crust.

Nikolaeva et al. [13] compiled several lines of indications that tessera might be composed of geochemically more differentiated materials than basalts, for example, essentially feldspatic materials such as terrestrial silicic to intermediate rocks and lunar anorthosites. Later, joint analysis of the gravity field and topography of Ishtar Terra led to the conclusion that some parts of the Maxwell Montes highland, consisting of material structurally similar to tessera, could be composed of material less dense than basalt and be silicic [14].

Meanwhile, Ivanov [15] observed evidence that tessera was formed at the expense of some precursor plains. Suggesting that these plains have a basaltic composition, he concluded that the tessera material could be basaltic (see also Ivanov and Head, this volume). No Venera-Vega geochemical probe landed on tessera terrain; thus, all information about its composition is still indirect.

*Surface geochemistry* on Venus in the latter part of its history is controlled by the chemical interaction of the surface materials with the atmosphere. The latter is dominated by CO<sub>2</sub> and has minor admixtures of other gases. Physical-chemical calculations [see e.g., 16-17] suggest several effects of surface-atmosphere interactions on Venus, including: 1) oxidation and sulfurization of surface rocks through gas–solid-type reactions; 2) isochemical weathering of individual solid phases with respect to elements being nonvolatile at surface temperatures on Venus (e.g., Al, Si, Mg, Fe, Ca, Na); and 3) a strong elevational effect for the chemistry and physics of gas–surface interactions. Current hydration of anhydrous phases is considered to be unlikely and any original hydrated phases (if they existed at all) would be dehydrated [17]. These calculations, however, suffer from the poor knowledge of the redox state of the lower part of the atmosphere on Venus.

An essential characteristic of the surface geochemistry of Venus is that the surface materials could acquire some chemical elements from the atmosphere (S, O), but most of their chemical components should stay practically immobile. So the chemical weathering effects on Venus are expected to be limited to a very thin surface layer. Based on the observed absence of impact craters smaller than 1 km in diameter on the hundreds of million of years old plains suggests that the currently observed large mass of the atmosphere of Venus (which is also a cause of the high surface temperature) was also characteristic of the past.

*The earlier part of the history of Venus.* The most striking and least doubtful piece of evidence on this is the discovery by one of the Pioneer Venus probes of the so-called deuterium anomaly, a D/H ratio larger by a factor of 150 than it is in Earth's oceans [18]. This implies significant hydrogen escape from the planet, suggesting that early in its history Venus could have lost a large amount of water. Some models even suggest the presence of oceans on Venus at that time [e.g., 19]. We may only guess about the geotectonic environment of Venus at that time. An abundance of water could affect not only the surface, but also influence the interior of Venus. This in turn could change the rheology of crustal materials [20] and even favor plate tectonics and its related geochemical aspects, including

formation of felsic materials [21]. So if tessera terrain is found to be felsic it could be a message of that time.

If water on the surface of Venus during that time was present in liquid form, this requires a relatively cool environment, this should result in Earth-like surface processes, including hydrous geochemistry with significant compositional differentiation. But if this abundant water was present as vapor in the hot dense atmosphere, the surface geochemical processes would perhaps be similar to pneumatolytic processes in the contact zones of terrestrial magmatic bodies. This could lead, for example, to transportation through the atmosphere of some rock components (e.g., SiO<sub>2</sub>) from the hotter lowlands to the colder highlands.

**Conclusions.** The current knowledge of the geochemistry of Venus is rather poor and essentially hypothetical. To make significant progress in this area new missions to Venus are necessary. They should provide much more reliable data on the minor chemical components of the atmosphere of Venus, especially on the components indicative of the redox state of the lower part of the atmosphere. New geochemical measurements of the surface composition are crucial. They should provide information on the compositions of the geologic units not directly geochemically investigated earlier, first of all, landing on tessera terrain and then on some other units [22]. These new missions should be equipped with instruments providing more information than acquired by the Venera-Vega landers. A sample return mission to Venus, although more difficult, should be on the near horizon.

**References:** [1] McKinnon W. et al. (1997) Venus II, Univ. of Arizona Press, 969-1014. [2] Head J. W. et al (1992) JGR, 97, 13,153-13. [3] Basilevsky A. T. & Head J. W. (2000) PSS, 48, 75-111. [4] Ivanov M. A. (2007) LPSC-39, abs. 1017. [5] Crumpler L. S. et al. (1997) Venus II, Univ. Ariz Press, 969-1014. [6] Basaltic Volcanism on the Terrestrial Planets (1981). Pergamon Press, Inc., New York. 1286 pp. [7] Surkov Y. A. (1997) Exploration of Terrestrial Planets from Spacecraft, John Wiley, 446 pp. [8] Ivanov and Head (1999) JGR, 104, 18907-18924. [9] Pavri B. et al (1992) JGR, 97, 13,479-13,493. [10] Bridges N. T. (1995) GRL, 22, 2781-2784. [11] Fink J. H. & Griffiths R. W. (1998) JGR, 103, 537-545. [12] Ivanov and Head (1996) JGR, 101, 14861-14908. [13] Nikolaeva O. V. et al. (1992) Venus Geology, Geochemistry and Geophysics, Univ. Ariz Press, 129-139. [14] Kuchinskas A. B. et al. (1996) JGR, 101, 4725-4736. [15] Ivanov M.A. (2001) SSR, 35, 1-17. [16] Fegley B. Jr. (2003) Treatise on Geochemistry, 1, 487-507. [17] Zolotov M. Yu. (2007) Treatise on Geochemistry, 10, 349-370. [18] Donahue T. M. et al (1982) Science, 216, 630-633., and A. J. Watson, Venus was wet: A measurement of the ratio of D to H, , 1982. [19] Grinspoon D. H. & Bullock M. A. (2003) BAAS, 35, 44-03. [20] Mackwell S. J. et al (1998) JGR, 103, 975-984. [21] Taylor R. S. & McLennan S. (2008) Planetary crusts. Cambridge Univ. Press, 400 pp. [22] Basilevsky A. T. et al. (2007) PSS, 55, 2097-2112.