

CHEMISTRY OF VENUS' RECENT BASALTS AS CLUES TO ITS ANCIENT PAST. A. H. Treiman¹ and J. Filiberto², ¹Lunar and Planetary Institute, 3600 Bay Area Blvd. Houston TX 77058 <treiman@lpi.usra.edu>, ²ARES/XI, NASA Johnson Space Center, Houston TX.

Introduction: Perhaps the most important question about Venus is whether it ever had a hydrosphere: liquid water, oceans, and thus an environment suitable for life as we know it [1]. The D/H of Venus' atmosphere suggests extensive water loss [2], and climate models may be consistent with global oceans [3,4]. Rocks dating from that epoch may be preserved in Venus' tesserae (and especially Ishtar Terra) – inferred to be of felsic or silicic rock [5], which would suggest abundant water [6]. However, the exact elemental compositions of tesserae (silicic or not) will be difficult to retrieve and most of Venus' surface is basalt flows and volcanic constructs, inferred to be much younger than the oceanic epoch. Remotely sensed data are (and will be) ambiguous about the specific rock types that make up tesserae [7,8], and lander spacecraft are almost certain (in the near term) to avoid the rough and precipitous topography of the tesserae and touch down instead on flat, safe basaltic plains [9] or volcanic rises [10].

'Recent' basalts at Venus' surface could preserve chemical tracers of an ancient aqueous past, if their source regions (material that was re-melted) had been affected by water. This scenario occurs on Earth in Island Arc Basalts (IAB), where their compositions are thought to reflect aqueous alteration of parental mid-ocean ridge basalts (MORB) and incorporation of oceanic sediments [11]. Ancient Venus might have supported plate tectonic [12] and thus have had IAB equivalents; absent plate tectonics, basalt affected by aqueous alteration could have been cycled into its mantle by burial under thick sections of later basalt [13].

Our purpose is to suggest specific chemical clues in current basalts that would permit recognition of those with a history of aqueous interactions from those that did not. We compare Earth's Ocean Island Basalts (OIB) that involved little water with IAB that show chemical effects ascribable to water. It is not clear that Venus' basalts can be mapped into terrestrial tectonic settings [14]; however, it seems reasonable that aqueous geochemical processes could have (had) similar effects on both planets.

Data and Methods: The chemical compositions of Venus basalts are known from X-ray fluorescence (XRF) and gamma-ray spectroscopy (GRS) analyses by the Venera and VEGA lander spacecraft [5,15]. These data are of uncertain and poor (by modern standards) quality because of the instrumentation available at the time and the limited information available on standards

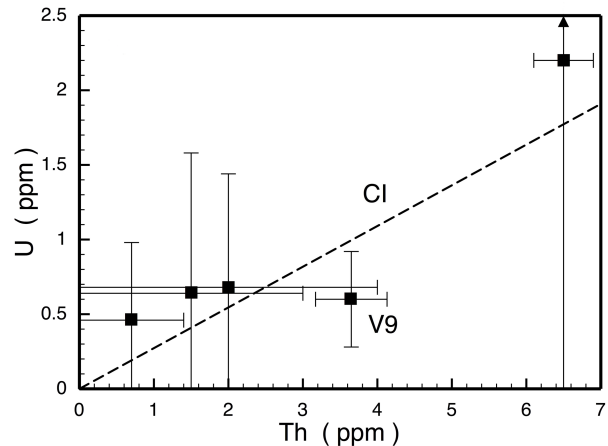


Figure 1. U vs. Th for Venus basalts [15], uncertainty bars are reported 2σ . The Venera 9 rock (V9) [16] has a sub-chondritic U/Th ratio; other analyses are consistent with a chondritic U/Th ratio.

and data processing. None-the-less, these analyses are all we have, and are accepted provisionally as accurate.

Chemical compositions of Earth basalts, OIB and IAB, are from the extensive literature.

Indicators of Aqueous Action: Geochemical indicators of ancient aqueous activity could be preserved in 'recent' basalts, provided that the conditions during melting and emplacement did not significantly alter abundance ratios of specific elements. Most of these 'unalterable' elements are incompatible in normal igneous processes – i.e., they do not partition significantly into basaltic igneous minerals (olivine, pyroxenes, feldspars) vs. basaltic magma.

Uranium-Thorium. Uranium and Th are refractory, lithophile, and incompatible in igneous processes; the U/Th ratio should be unaffected by most processes of planet formation and differentiation, and remain at the chondritic (CI) value (Figure 1). However, U is readily mobilized in aqueous fluids (as UO_2^{2-}), while Th is not [17]; this could help explain why Earth IAB typically have non-CI U/Th [17]. The Venera 9 analysis also has a non-CI U/Th ratio (Fig. 1) and is consistent with aqueous processing, and thus (possibly) be evidence for an earlier wet epoch. Sadly, V9 did not carry an XRF, and landed in a complex area of plains, tesserae, and impact materials (Fig. 2); hence we do not know what sort of rock its analysis represents.

Large-Ion Lithophile Elements. LIL elements, like alkali (Na, K, Rb) and alkaline earth (Ca, Sr, Ba) cations, are typically mobile during terrestrial aqueous

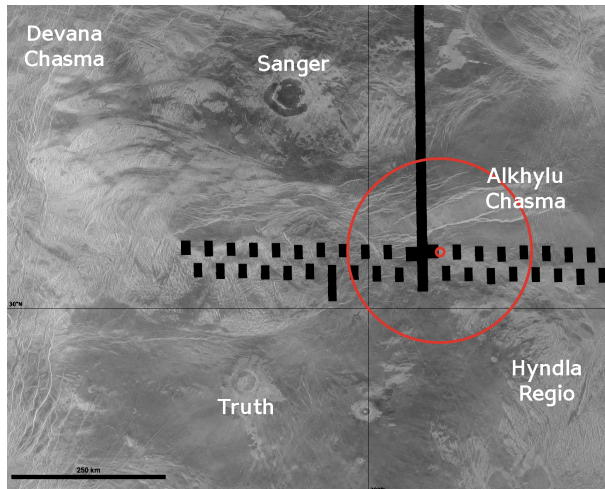


Figure 2. Venera 9 nominal landing site (31.0°N 291.6°E) and 300 km uncertainty circle (both red) on Magellan SAR image. Area is near Devana Chasma and Rhea Mons (NW of image) After [16]; see also [18].

alteration of basalt, which can lead to excesses or deficits in IAB [19]. Abundances of K were analyzed by all landers, but only Th can be used as a reference for calculating excess/deficit. Within large uncertainties, the K/Th ratios of Venus basalts are comparable to that of the Earth, except for V9 [15]. The V9 rock has a K/Th ratio about half that of Earth's mantle and OIB [15], consistent with its low U/Th ratio (Fig. 1) and suggesting that the source of the V9 rock had lost some of its original of water-soluble material.

Venus' basalts have low Ca (and Ca/Al) [15], which could represent aqueous activity. However, low Ca is also a normal character of partial melts from eclogite [15,20,21]; it is reasonable that Venus basalts could represent partially melted eclogite [13].

Abundances of other LIL elements have been useful discriminators for IAB vs OIB on Earth – Ba, Pb, Rb etc. ratioed to aqueous immobile elements like Nb [h19]. For instance, IAB tend to be enriched in Pb, Ba, and Cs [19]; we have no Venus data for these elements.

High Field Strength Elements (HFSE). The HFSE tend to be immobile in terrestrial aqueous environments, but can be affected by pressure and by oxidation state (as they can affect minerals that partition them, e.g., rutile) [22]. Pearce [23,24] showed that Ti-Zr-Y abundance ratios can be used to distinguish among MORB, OIB, and arc/continental basalts. Likewise, "The key feature of all volcanic arc basalt samples is the significant negative Nb anomaly with respect to Th and Ce.... Tholeiitic VAB is characterized also by an absolute depletion relative to N-MORB of Nb, Zr, Ti, and Y" [24]. These discriminators could be useful for Venus, backed by experimental data on how these ratios change during remelting of an eclogite or basalt.

Lander Instruments: To use these potential indicators of ancient aqueous activity, lander instruments must be able to analyze these elements at precisions and accuracies comparable to routine analyses on Earth [25]. Gamma-ray spectrometry (GRS) would seem the method of choice for U and Th (and K), measuring natural rock radioactivity as was done by on Venera and VEGA. X-ray fluorescence (XRF) is likely the method of choice for other elements, as was done also by Venera and VEGA. X-ray technology has improved enormously since then (e.g., SSD detectors), and it might be possible to measure abundances of many first- and second-row transition elements (K-Zn, Rb-Mo) and others (e.g., Ba, La, Ce). It will be critical to understand which element abundances and ratios are useful, and design spacecraft analytical instruments to accommodate that understanding [25].

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