VENUS’ BULK AND MANTLE COMPOSITIONS: ARE VENUS AND EARTH REALLY TWINS? A. H. Treiman, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058 (treiman@lpi.usra.edu)

Introduction: Venus is Earth’s twin in size and bulk density [1], but obviously has a very different climate and climate history. Direct comparison of their histories [2] assumes implicitly that they have similar chemical compositions and internal structures; parts of these assumptions are testable with Venera and VEGA chemical analyses of Venus’ surface. From available chemical analyses, it is reasonable that the Earth and Venus are indeed twins, with similar bulk compositions (at least for non-atmophile elements), mantle compositions, and core sizes [3,4]. Such similarity between Earth and Venus is not necessarily consistent with current models of planetary accretion.

Principles: Solar system planetary bodies apparently all accreted with cosmochemically refractory elements (e.g., U, Th, Ca, Ti, Al, Mg) in nearly the same proportions as CI chondrites and the sun [1]. The planets contain less of cosmochemically moderately volatile elements (e.g., alkalis, Fe, Mn, S, etc) than do CIs [1], with depletions in these elements varying among the planetary bodies. After accretion, a planet would differentiate to form a metallic core; Fe and other siderophile elements are partitioned there, while lithophile elements remain in the silicate mantle and crust [6,7]. Finally, the basalts we analyze are generated by silicate melting and crystallization [6,7]; incompatible elements (e.g., U, Th, K, REE) are partitioned into the basalt relative to the abundant solids (from a chondritic base composition), and compatible elements (e.g., Ni) are partitioned into the solids.

By comparing abundances of elements of differing volatility but similar behavior in igneous and core-forming processes (e.g., K/Th), one learns about the whole planet’s volatile content. By comparing abundances of elements that behave differently in core formation, but have similar volatility and igneous behavior (e.g., Fe/Mn), one learns about core formation.

Data: Chemical data on Venus’ rocks are from the Venera and VEGA landers, summarized by [3,10] with reference to original English publications. Major elements were analyzed by XRF on rock powders, but lack data for Na & Cr. K, Th, and U were analyzed by gamma-ray spectrometry. Here, I assume that the analyzed compositions represent local rocks, unaffected by alteration or weathering (although such effects are possible and possibly significant [8,9]).

Refractories: Abundances of Th and of U (though relatively imprecise) are broadly consistent with a CI chondritic ratio (Fig. 1). The most precise analysis, V9, has U/Th significantly below the CI ratio. If real, this U/Th could represent fractionation involving garnet, aqueous fluid, or carbonate-sulfate magma [10-14].

Calcium, Ti, and Al are refractory and lithophile in planetary accretion and core formation, and are incompatible in basalt genesis with moderate degrees of partial melting (leaving residue of olivine ± orthopyroxene). In a graph of Ca/Al vs. Ti/Al (Fig. 2), basalt melted from a chondritic mantle with ol+opx residua should have chondritic Ca/Al/Ti, and plot near the 1:1 point. Basalts like the eucrites, Earth MORB, and Adirondack-class basalt in Gusev crater (Mars) plot at the CI ratios; Martian meteorite and lunar basalts have superchondritic Ca/Al and Ti/Al, which represent source mantle depletion in Al in early magma oceans.
All the Venus basalts could (within 2σ uncertainties) have chondritic Ca/Al, but more likely have subchondritic Ca/Al (Figure 2). A possible explanation is that partial melts of dry eclogite (garnet pyroxenite) with MORB-like compositions also have subchondritic Ca/Al [15,16]. On the other hand, Ca could have been lost in weathering [8,9].

**Volatile elements:** Potassium, Fe, and Mn are the moderately volatile elements analyzed by Venera and VEGA. Potassium is lithophile and strongly incompatible, so the K/Th and K/U ratios of Venus’ basalts should reflect those of the whole planet. Though imprecise, all but one of the analyses are consistent with those of the Earth: K/U and K/Th ~ 0.15 x CI (Fig. 3). The exception is V9, which also has an anomalous U/Th (Fig. 1). So, the very limited data are consistent with Venus and Earth having similar abundances of volatile elements.

**Mantle & Core:** Abundances of Fe, Mn, and Mg in the Venera and VEGA basalts are comparable to those in Earth basalts, and suggest similar mantle compositions and core sizes.

The FeO/MnO ratio of basalts constrains core formation in a differentiated planet, because Fe and Mn have similar volatility (Mn slightly more volatile) and similar igneous behavior. However, Mn does not enter Fe-rich metal during core formation, so that FeO/MnO tracks Fe-metal separation in a planet. Venera and VEGA data for Mn are imprecise [3,5,10], nearly all as upper limits at the 2σ level. If one takes the nominal Mn values as precise, Venus’ FeO/MnO is ~50, similar to that of Earth basalts at ~60 [10]. Thus, it is reasonable to infer that Venus and Earth have cores of comparable sizes.

Primitive basalts have approximately the same FeO content as the mantle they melted from [17,18]. Magnatic fractionation raises the FeO contents of basalt, so the FeO contents of Venus basalts are upper limits to those of their peridotitic mantle sources. The Venera/VEGA analyses average ~8% FeO, comparable to those of primitive Earth MORBs. This similarity suggests that the Venus mantle has a FeO content comparable to that of the Earth’s mantle.

In a basalt, the ratio Mg*=100•Mg/(Mg+Fe) [molar] marks both degree of a the basalt’s fractionation and partition of Fe between mantle and core. The Venera and VEGA analyses for Mg are imprecise [3,5,10], nearly all as detections at the 2σ level. The most precise data are for V2, which yields Mg*=73^{+31}_{-21}. This value is within uncertainty of those of primitive Earth basalts (Mg*=68), which represent equilibrium with mantle olivine of Fo91; again, the Venus mantle composition seems similar to that of the Earth.

**Conclusion:** Within the imprecise constraints of Venera and VEGA analyses, the chemical compositions of Venus and the Earth are quite similar. Both planets have comparable abundances of a moderately volatile element, K, which suggests that they have comparable abundances of Fe and Mn (somewhat less volatile than K [1]). If so, FeO/MnO and Mg* of the Venus basalts suggest that the Venus mantle has a bulk composition comparable to that of the Earth, and thus that Venus’ core is comparable to the Earth’s in composition and size. So, the differences between Earth’s and Venus’ evolutions cannot be ascribed to bulk solid composition, core size, or mantle composition. Also, it is not obvious from dynamical models that Venus and the Earth should have identical or similar compositions [19]. Precise, accurate chemical analyses of Venus basalts will be needed to test these tentative inferences.

**References:**