Magmatic Diversity on Venus: Constraints from terrestrial analog experiments.

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Igneous diversity is common on terrestrial planets. This diversity has been experimentally investigated for terrestrial [1-6] and martian basalts [7-10], but only suggested for Venus [11, 12]. Since Venus and Earth are sister planets and have similar bulk chemistry [13, 14], experiments on terrestrial basalts can place constraints on the formation of the Venera and Vega basalts. Furthermore, experimental results can suggest the types of basalts that should be present on Venus if processes of differentiation similar to the Earth are occurring on Venus, as suggested by the Venera and Vega analyses (Table 1). Results from these experiments can constrain the type and quality of data needed from future missions to determine the petrologic history of surface igneous rocks.

Introduction: Extensive work has been done on exploring the data from the Venera and Vega missions (see summaries in [13, 15]). This work has shown that Venus and Earth have similar K/Th, U/Th, and K/U ratios and in general are sister planets with similar chemistry [13, 14]. The Venera 13 analysis is consistent with that of a leucitic basalt, while the Venera 14 and Vega 2 analyses are similar those of olivine tholeiites from mid-ocean ridges [e.g. 15]. Extensive experimental work has been conducted on a terrestrial olivine tholeiite at varying pressures, temperatures, and water contents in order to understand the residual liquids that could be produced by igneous differentiation [1-6]. If similar processes of magma ponding and differentiation were occurring on Venus, then compositions similar to terrestrial igneous suites would be expected. Therefore, these experimental results can constrain the types of igneous suites that could be present and the quality of data needed from future missions to distinguish the different suites.

Experiments on Terrestrial Analogs: Experiments have been conducted on terrestrial tholeiitic basalts at varying pressures and water contents to explore the compositions of rocks that can be produced by igneous differentiation [1-6]. Igneous differentiation occurs when a magma ponds and a certain depth, cools and crystallizes. The residual liquids then separate from the crystallized minerals and erupt on the surface. The residual liquids produced by differentiation in these experiments range from rhyolites to phonolites, depending on pressure of fractionation and bulk volatile content. Table 1 summarizes the experimental conditions (P, volatile content) needed to produce each terrestrial basalt suite. Figure 1 shows the compositional diversity that can be produced by fractionation at varying depths and water contents.

Surface: Fractionation at low pressure (< 2kb) produces residual liquids that follow the tholeiitic trend, for example the igneous suite of Volcano Alcedo, Galapagos and Thingmuli, Iceland [6]. These suite include olivine tholeiites, ferrobasalts, icelandites, and rhyolites [16-18].

Upper Mantle: Ponding at the base of the crust/upper mantle can produce three different igneous trends, depending on pressure and volatile content. At 5-11kb and relatively anhydrous conditions, fractionation of olivine tholeiite yields a potassic silica-saturated alkalic suite, similar to that of the Craters of the Moon [2, 3]. The suite consists of jotunites, ferrodiorites, trachybasalts, monzonites, syenites, and potassic rhyolites [19-21]. At slightly greater pressures and higher water contents (9-11kb and >0.3 wt% H_2O), fractionation of the olivine tholeiite produces a sodic alkalic trend, such as are found on Ascension Island and the Nandewar Volcano [4]. These suites

Fractionation Pressure		Volatile Content	Trend	Terrestrial Analog
Surface	0-2kb		Tholeiitic Trend	Galapagos Thingmuli
Base of the crust/Upper mantle	5-11kb	<0.3wt% water	Potassic Alkalic Series	Snake River Plain
	9-11kb	>0.3wt% water	Sodic Alkalic Series	Nandewar Ascension Island
	12-16kb	>0.3wt% water	Silica-undersaturated	Hawaii
Mantle	18-27kb	~0.2 wt% water	Phonolitic Series	Tristan de Cunha

Table 1. Experimental conditions (pressure and water content) of magma ponding and fractionation to produce 5 terrestrial igneous suites [1-6]. Examples of each terrestrial igneous suite are include and are possible analogs to Venus igneous suites (and possibly volcanoes). Color coded the same as Figure 1.

include alkali-basalts, hawaiites, mugearites, benmoreites, trachytes, and rhyolites [22, 23]. At even greater pressures (18-27kb), fractionation of that same olivine tholeiite produces silica-undersaturated rocks like those of the Kohala and Mauna Kea volcanoes of Hawai'i [5]. These rocks consist of alkali-basalts, nepheline-hawaiites, nepheline-mugearites, and phonolites [24-27].

Mantle: At greater depths within the mantle, fractionation of the olivine tholeiite produces a phonolitic series, like that of Tristan de Cunha [1]. This suite includes lavas like alkali-picrite, olivine-basanite, olivine-nephelinite, and mellite-nephelinite [28].

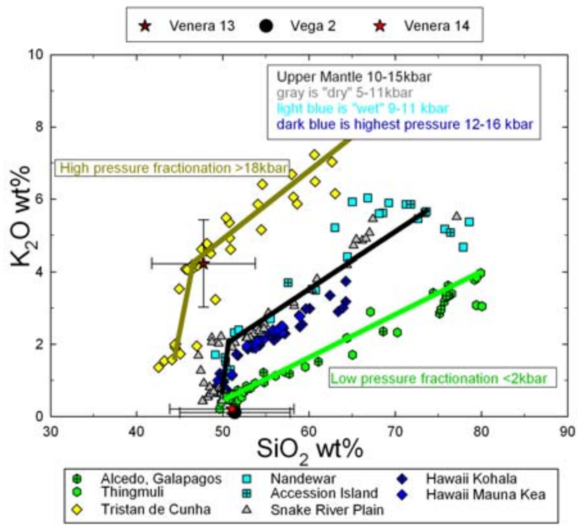

Figure 1 K_2O vs. SiO_2 showing trends found in terrestrial intra-plate suites and their conditions of formation [1-6]. Modified after [9, 29]. References for rocks and fractionation conditions are within the text. Venera and Vega analysis include 2 sigma error [13]. All data re-normalized to 100 wt% without sodium or phosphorous to be able to directly compare terrestrial rocks with the Venera and Vega data.

Venus basalts: Figure 1 compares the compositional diversity of terrestrial magmatic suites with the Venera 13, 14 and Vega 2 data. The results shown here suggest that Venera 14 and Vega 2 basalts are comparable with an olivine-tholeiite from a continental or ocean island hotspot. Olivine-tholeiitic compositions on Earth can be produced at pressures less than 18kb and various water contents [1]. This suggests an upper mantle origin for the Venera 14 and Vega 2 basalts; more precise analyses are needed to fully constrain the depths of formation and water contents of the Venus basalts.

The Venera 13 analysis is comparable with a silica-undersaturated rock (possibly a basanite or nephelinite). This suggests a deeper origin than the Venera 14 and Vega 2 basalts. If the Venea 13 basalt formed in similar ways to terrestrial basalts then it formed at relatively high pressure (>18 kbar) and from a hydrous source region (~0.2 wt% bulk water in the basalt). However, more precise and complete analyses, including mineralogy and abundances of Na, Cr, and P, are needed to fully understand the origin of these K-rich basalts.

Summary: Extensive experimental work on terrestrial olivine-tholeiite compositions demonstrate that simple igneous fractionation can produce a wide range of igneous compositions from a single magma type. Analyses of surface materials from the Venera and Vega landers suggest that Venus' lavas include olivine tholeiites and silica-undersaturated compositions. This suggests that Venus igneous rocks maybe as compositionally diverse as those found on the Earth. Future missions that provide high precision bulk chemical analysis of igneous rocks, and surface chemistry, can constrain the diversity of the Venus surface and explore if Venus truly is our sister planet.

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