

EXPERIMENTAL STUDY OF THE ALTERATION OF BASALT ON THE SURFACE OF VENUS. H. Tefeteller¹, M. McCanta¹, D. Cherniak², A. Treiman³, J. Filiberto³, M. Rutherford⁴, and Johnson N.⁵ ¹Department of Earth and Planetary Sciences, University of Tennessee at Knoxville (1621 Cumberland Avenue, 602 Strong Hall, Knoxville TN 37996, hteffete@vols.utk.edu), ²Rensselaer Polytechnic Institute (Troy NY). ³Lunar and Planetary Institute (3600 Bay Area Blvd, Houston, TX 77058), ⁴Dept. Earth, Environmental, & Planetary Sciences, Brown University (Providence, RI 02912). ⁵Goddard Space Flight Center (Greenbelt, MD).

Introduction: The surface of Venus is composed primarily of basalt, in plains, shield volcanos and other constructs, that represent igneous activity since Venus' major resurfacing event of 300-600 Ma [1-2]. Material on the surface of Venus experiences temperatures of ~470°C and pressures of ~90 bars, comparable to the terrestrial greenschist metamorphic facies. The atmosphere of Venus, however, is composed mostly of carbon dioxide (CO₂) with trace amounts of sulfur dioxide (SO₂). Therefore, basalts at the surface should undergo chemical alteration via gas-solid interactions with Venus' atmosphere [3]. Electromagnetic data interpretations and *in situ* chemical analyses from Venera 13, Venera 14, and Vega 2 landers using X-ray fluorescence spectrometry [4] rely on an understanding of the processes, products, and rates of basalt alteration. The oxidation state of the atmosphere of Venus is near the magnetite-hematite buffer, while basalt should represent more reduced conditions; near QFM for Earth and lower for Mars, Moon, and most asteroids. Therefore, weathering of basalt on Venus is likely dominated by oxidation reactions [5]. Spectral data from the Venera/VEGA landers and from the VIRTIS spectrometer on Venus Express suggests that hematite coats much of the material on the surface of Venus [6-8]. Previous work on the oxidation of basalts at temperatures greater than 550°C suggest that Fe²⁺, Mg²⁺, and Ca²⁺ cations will likely migrate to the surface to form oxides [4,9,10]. However, prior studies of basalt alteration have been conducted under terrestrial atmospheric conditions making it unclear how applicable their results are to the surface of Venus. Here, we present preliminary results from laboratory experiments on alteration processes and products of basalts under P, T, and atmospheric compositions similar to those at the Venus surface. This will provide constraints on potential phase assemblages that will be of great importance to future Venus lander missions.

Methods:

Experimental. A series of high-pressure alteration experiments on basaltic glasses were done in cold-seal pressure vessels at Brown University. Two starting compositions were used: a natural alkaline basalt from Sverrefjell volcano, Svalbard [11] which is chemically similar to Venera 13 rock [12]; and a synthetic tholeiite basalt based on the Venera 14 rock analyses [12] and terrestrial analogs to fill in those elements not analyzed [13]. The synthetic basaltic glass was fused from oxides at 1 atm, 1300°C, and *f*_{O₂} at the QFM buffer. The tholeiitic composition represents Venus 'plains' basalts,

while the alkaline basalt represents Venus' 'plume' basalts. Samples of natural basalt were sawn and polished prior to reaction; the synthetic glass broke to yield relatively flat surfaces and was not treated further before reaction. We have chosen to work on glass samples because previous experimental studies confirm that basaltic glass should be present on the surface of Venus as the surface temperature is lower than that of basalt magma (~1100°C) and the glass transition temperature for basaltic compositions (~750°C) [14-15].

Experimental temperature conditions ranged from 470-700°C at a pressure of ~90-92 bars to simulate surface conditions on Venus (470°C) as well as simulate geologic time on the surface of Venus (700°C) while staying under the glass transition temperature (Table 1). Samples were contained in gold tubing and placed into cold-seal bombs. To simulate Venus atmosphere conditions, the chamber was pressurized using pure CO₂ gas. Samples were run for two-week durations. Runs VEN-4 (A,B) and VEN-5 (A,B) included a hematite-magnetite (H-M) solid buffer to raise the *f*_{O₂} of the experiment; all others were buffered only with CO₂ resulting in reducing conditions near the GCO (graphite-CO) buffer.

Analytical. The geochemistry of the natural alkaline basalt was characterized prior to experimentation at the University of Tennessee using the Phenom Pro scanning electron microscope (SEM) and the Cameca SX-100 electron probe micro-analyzer (EPMA). Bulk chemistry was calculated using estimated modal abundances and average chemical composition of minerals and glass (Table 2).

Following the experiments, alteration assemblages were characterized by SEM, and the largest fragments from each sample were sent to Rensselaer Polytechnic Institute for Rutherford Backscatter Spectroscopy (RBS) analysis.

Table 1. Samples and experimental run conditions.

sample name	chemical type	run conditions	run time
VEN-1	tholeiite	470 C, 92 bars	15 days
VEN-2	alkaline	470 C, 92 bars	15 days
VEN-3	tholeiite	700 C, 90 bars	15 days
VEN-4A	alkaline	700 C, 90 bars	15 days
VEN-4B	tholeiite	700 C, 90 bars	15 days
VEN-5A	alkaline	470 C, 90 bars	15 days
VEN-5B	tholeiite	470C, 90 bars	15 days

Table 2. Composition of starting materials. Composition of the synthetic material is as weighed and composition of the natural sample was determined using EPMA analyses.

wt. % oxides	Plains (synthetic)	Plume (natural)
SiO ₂	48.7	47.9
TiO ₂	1.3	2.8
Al ₂ O ₃	17.9	18.0
Cr ₂ O ₃	0.05	0.0
FeO	8.8	9.6
MnO	0.2	0.1
MgO	8.1	3.3
CaO	10.3	7.7
Na ₂ O	2.4	6.0
K ₂ O	0.2	2.7

Results: The alkaline basalt sample consists of basaltic glass with microphenocrysts and microlites of olivine, augite, plagioclase (labradorite), and rare chromite (Fig. 1). The olivine and augite show normal chemical zonation (magnesian cores and ferroan rims). The plagioclase appears unzoned and is commonly surrounded by rims of diopside.

The surfaces of all altered samples were decorated with discontinuous coatings of iron oxide(s), which are concentrated along edges of glass faces and along fractures (Fig. 2). The oxide mineral species could not be determined with SEM alone, though we anticipate that magnetite or wüstite formed in VEN-1, -2, and -3 because graphite was also found on those samples. We expect that the Fe oxide on VEN-4 and -5 was hematite. Oxides appear to have formed in comparable amounts on both alkaline (Fig. 2) and tholeiitic starting compositions, at both temperature conditions, and at both oxidation states (all CO₂ vs. H-M). We interpret these oxide

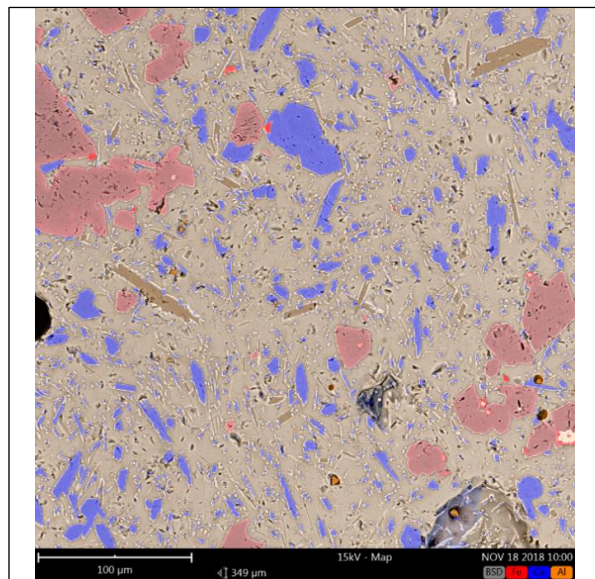


Figure 1. SEM-EDX element map of natural alkaline basalt sample before alteration. Blue = diopside; bright red = chromite; dull red = olivine; brown = labradorite plagioclase.

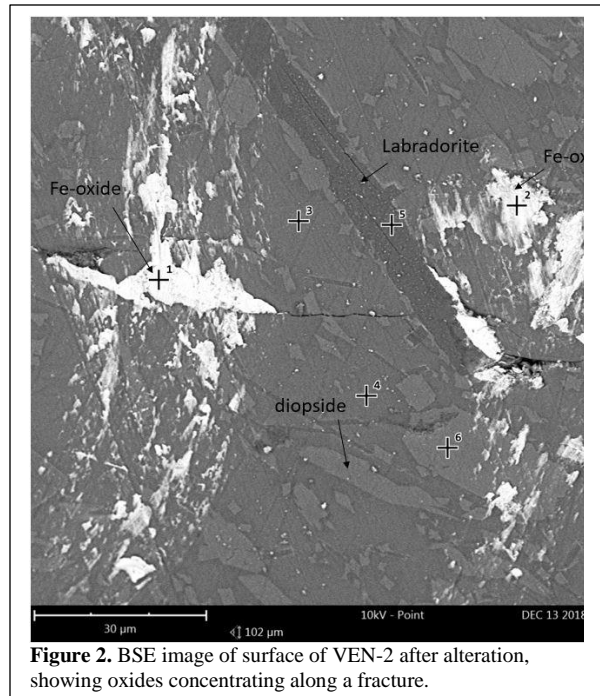


Figure 2. BSE image of surface of VEN-2 after alteration, showing oxides concentrating along a fracture.

coatings as representing iron having diffused from the glass to the surface, responding to the chemical potential gradient established by the differences in oxidation state of rock and gas [9,14]

Future Work: RBS analysis is on-going. Altered samples will be analyzed by transmission electron microscopy (TEM) to identify the alteration mineral(s), thicknesses of reaction zone(s), and oxidation states of diffusion zones in the glass. Weathering rind thickness is a function of time [9,14], and data here and from future experiments will allow us to determine rate laws and constants, and thus constrain the mechanisms of weathering. Parallel experiments are being run in the Goddard Venus Chamber, and future experiments will include SO₂ gas to better simulate the Venus atmosphere.

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