

AN EXPERIMENTAL STUDY OF THE ALTERATION OF BASALT ON THE SURFACE OF VENUS. H. Teffeteller¹, M.C. McCanta¹, J. Filiberto², A.H. Treiman², L. Keller³, and M. Rutherford⁴, ¹Department of Earth and Planetary Sciences, University of Tennessee at Knoxville (1621 Cumberland Avenue, 602 Strong Hall, Knoxville TN 37996, hteffete@vols.utk.edu), ²Lunar and Planetary Institute (3600 Bay Area Blvd, Houston, TX 77058), ³NASA Johnson Space Center (2101 E NASA Pkwy, Houston, TX 77058), ⁴Dept. Earth, Environmental, & Planetary Sciences, Brown University (Providence, RI 02912).

Introduction: Basalts on the surface of Venus experience temperatures of $\sim 470^\circ\text{C}$, pressures of ~ 90 bars, and an oxidizing, CO_2 -rich, environment (\sim magnetite-hematite buffer), which implies that rocks on the surface are likely to be altered. Previous studies suggest that basaltic alteration on Venus should result in the formation of Fe oxides (magnetite and/or hematite), carbonate, and/or sulfate phase(s) [1-6]. Areas of anomalously high thermal emissivity have been used as evidence for chemical weathering of basalt on the surface [3], however interpreting thermal emissivity data relies on an understanding of the processes, products, and rates of alteration. Recent studies on the alteration of olivine in a Venus-like atmosphere suggest that alteration happens on the timescales of several months, implying that Venus has been volcanically active very recently [5]. Clearly, it is important to understand the chemical weathering of basalt at the surface in order to draw interpretations from old and new data alike.

Methods:

Experimental. A series of high-pressure alteration experiments on basaltic glasses were conducted in cold-seal pressure vessels at Brown University. Two starting compositions were used: a natural alkaline basalt from Sverrefjell volcano, Svalbard [7] which is chemically similar to Venera 13 rock [8]; and a synthetic tholeiite basalt based on the Venera 14 rock analyses [8] and terrestrial analogs to fill in those elements not analyzed [9]. The synthetic basaltic glass was fused from oxides at 1 atm, 1300°C , and f_{O_2} 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 ($\sim 1100^\circ\text{C}$) and the glass transition temperature for basaltic compositions ($\sim 750^\circ\text{C}$) [10,11].

Experiments were run at both 470°C and 700°C , at a pressure of ~ 90 - 92 bars to simulate surface conditions on Venus (470°C) and geologic time (700°C), while also staying below the glass transition temperature. Starting compositions were held in unsealed gold tubes, and

placed into cold-seal bombs. To simulate Venus atmosphere conditions, the chamber was pressurized using pure CO_2 gas. Samples were run for two-week durations. Hematite-magnetite (H-M) solid buffers were included with each experimental charge to hold the f_{O_2} at approximately that of the surface of Venus [4].

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

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. Sections containing alteration products were extracted on the scale of several microns at Johnson Space Center using focused ion beam (FIB) milling in order to prepare a ~ 80 nm thick foil for investigation with transmission electron microscopy (TEM). Quantitative compositional data was obtained along line transects from the sample interior through its surface, using the energy dispersive X-ray spectrometer (EDS) on the JEM-2500SE TEM at Johnson Space Center.

Results: Alteration of basalts on the surface of Venus is thought to occur in a stepwise process whereby divalent cations diffuse to the free surfaces of basalts and are then able to react with the atmosphere (Figure 1) [10,12]. Our TEM EDS results suggest that cations flux

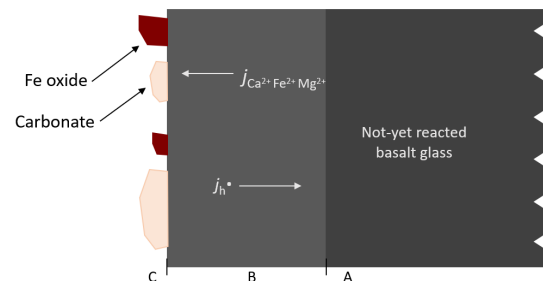


Figure 1. Schematic depicting basaltic glass alteration where divalent cations Ca, Fe, and Mg flux from unaltered basalt glass to the free surfaces of basalts where they may undergo reaction with the Venus atmosphere and form Fe oxide and/or carbonate phase(s). Modified after [10] and [12].

through the basalts on the order of several nanometers over the course of 2 weeks (Figure 2). An alteration front was formed on the original basalt, comparable to a

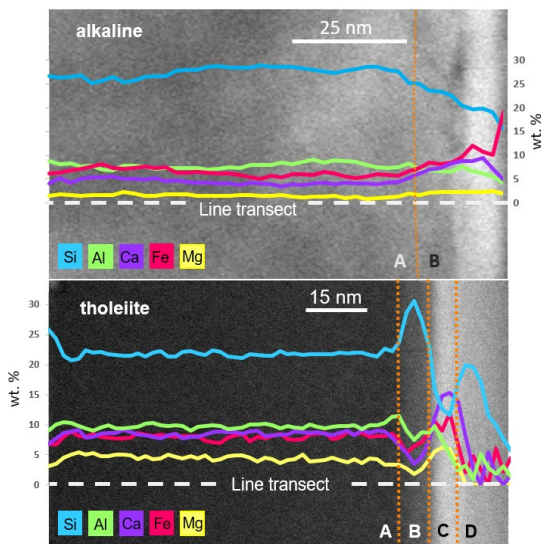


Figure 2. TEM bright-field images and EDS element abundances along line transects of weathered samples; Top sample is an alkaline basalt and bottom sample is a tholeiitic basalt. Both basalts were subjected to 470°C and 90 bars pressure under oxidizing conditions for fifteen days.

weathering rind, that was characterized by a region of cation enrichment at the surface on top of a region of cation depletion on top of unaltered basalt that advanced from the interior of the sample to the surface, ranging from ~16 nm to ~121 nm depending on experimental temperature conditions and basalt composition. When these cations reach the surface of the basalt they are able to react with the simulated atmosphere to form a discontinuous coating of Fe oxide grains and occasional carbonate grains - calcite on the alkaline basalts, and siderite on the tholeiitic basalts (Figure 1).

Our experimental results show that basalts held at Venus surface conditions (~470°C, 90 bars) form weathering rinds at a rate of 0.4 mm ky⁻¹ and 0.3 mm ky⁻¹ for tholeiitic and alkaline basalt glass, respectively. The alteration fronts observed are characterized by enrichments in Ca (1-2 wt.%) and Fe (0.5-2 wt.%), indicating that divalent species diffuse at different rates (Ca > Fe > Mg) [12], see Fig. 1. These results agree well with previous laboratory experiments and thermodynamic equilibration models [4-6,13,14].

Implications: Under surface conditions on Venus (~470°C, 90 bars, *f*O₂ near MH), our results show how basalt glasses interact with a CO₂-rich atmosphere to form Fe oxide(s) and/or carbonate phases. If basalt alteration is somewhat continuous, our results suggest that the extent of alteration could be used as a method to age

date specific flows on the surface for regions where there are possibly younger lava flows like Idunn Mons in Imdr Regio. Effective diffusivity of cations in the alteration front can be determined using the total distance cations traveled through basalts based on TEM EDS chemical data. Using diffusivity rates from our Venus surface temperature experiments, it would take anywhere from 240 to 12,000 years to develop a weathering rind that could be detectable from an orbiting VNIR spectrometer (≥ ~20 μm thick). Several future missions like NASA's VERITAS or DAVINCI+ or ESA's ENVISION, all in phase-A study, could identify lava flows with fresh-basalt signatures using spectral data of the surface [15-18]. Age interpretations could then be guided by these experimental results.

Future directions: [19] further constrains potential alteration reactions with a simulated Venus atmosphere by adding an SO₂ gas component to the experimental runs. Preliminary data indicates the same basalt specimens will react to form sulfate(s), Fe oxide(s) and carbonate phases in the presence of SO₂, however more needs to be done to constrain the timescales at which sulfur-bearing phases form. While our basalts had Fe oxide(s) and/or carbonates on their surfaces, the extent of their formation over time is not well constrained. Further, it is not clear how discontinuous coatings of these phases on an alteration front would affect the emissivity spectra of basaltic rock on the surface under Venus conditions.

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