

**EXPERIMENTAL STUDY OF THE ALTERATION OF BASALT ON THE SURFACE OF VENUS.** H. Tef-teller<sup>1</sup>, J. Filiberto<sup>2</sup>, M.C. McCanta<sup>1</sup>, A.H. Treiman<sup>2</sup>, L. Keller<sup>3</sup>, D. Cherniak<sup>4</sup>, and M. Rutherford<sup>5</sup>, <sup>1</sup>Department of Earth and Planetary Sciences, University of Tennessee at Knoxville (1621 Cumberland Avenue, 602 Strong Hall, Knoxville TN 37996, hteffete@vols.utk.edu), <sup>2</sup>Lunar and Planetary Institute (3600 Bay Area Blvd, Houston, TX 77058), <sup>3</sup>NASA Johnson Space Center (2101 E NASA Pkwy, Houston, TX 77058), <sup>4</sup>Rensselaer Polytechnic Institute (Troy NY), <sup>5</sup>Dept. Earth, Environmental, & Planetary Sciences, Brown University (Providence, RI 02912).

**Introduction:** Venus is world unlike Earth; it sub-jects geologic material at the surface to temperatures of ~470 C, pressures of ~90 bars, and a thick, CO<sub>2</sub>-rich at-mosphere. Under these conditions, basalt at the surface is expected to undergo chemical alteration [1]. Previous studies have worked to model chemical basalt alteration [2,3], however the rates of this alteration for non-terres-trial conditions have not been well constrained. Areas of anomalously high thermal emissivity have been used as evidence for chemical weathering of basalt on the sur-face [4], however interpreting thermal emissivity data relies on an understanding of the processes, products, and rates of alteration. Recent studies on the alteration of olivine grains in a Venus-like atmosphere suggest that alteration happens on the timescales of several months, implying that Venus has very recently been vol-canically active [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 al-ka-line basalt from Sverrefjell volcano, Svalbard [6] which is chemically similar to Venera 13 rock [7]; and a synthetic tholeiite basalt based on the Venera 14 rock analyses [7] and terrestrial analogs to fill in those ele-ments not analyzed [8]. 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 Ve-nus’ ‘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 sur-face 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) [9-10].

Experimental temperature conditions ranged from 470-700°C at a pressure of ~90-92 bars to simulate both surface conditions on Venus (470°C) and geologic time (700°C), while also staying under the glass transi-tion temperature. Samples were contained in gold tub-ing and placed into cold-seal bombs. To simulate Venus

atmosphere conditions, the chamber was pressurized us-ing pure CO<sub>2</sub> gas. Samples were run for two-week du-rations. A hematite-magnetite (H-M) solid buffer was placed inside the chamber to raise the  $f_{O_2}$  of the experi-ment to approximately that of the surface of Venus [1].

*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.

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 John-son Space Center using the focused ion beam (FIB) milling technique in order to prepare a foil of the sample ~ 80 nm thick for investigation on the transmission elec-tron microscope (TEM). Quantitative compositional data was gathered as line transects traversing from sam-ple body through sample surface using an energy dis-persive X-ray spectroscopy (EDX) system attached to a JEM-2500SE TEM at Johnson Space Center.

**Results:** Alteration of the tholeiite basalt glass sam-ples produced similar reaction fronts and alteration as-ssemblages for both experimental temperatures 470°C or 700°C suggesting that temperature is not the driving fac-tor for alteration on Venus. Preliminary observations of a 4-week run, compared to previously analyzed 2-week runs, suggests that the driving factor of alteration is time.

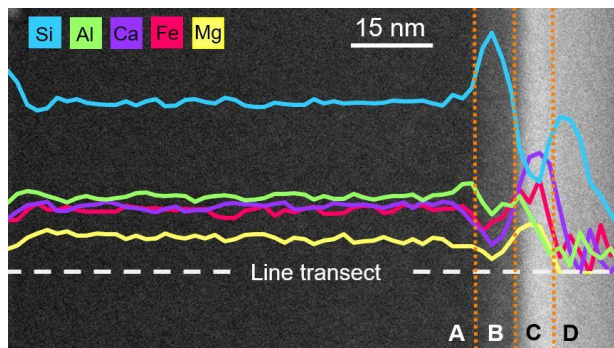
		Average concentra- tion in bulk sample (wt %)	Depleted zone (wt %)	Enriched zone (wt %)
Low-T tholeiitic glass	Al	9.75	7.52 ± 0.63	9.86 ± 0.52
	Ca	8.46	3.57 ± 0.52	15.36 ± 0.61
	Fe	7.99	5.35 ± 0.69	11.98 ± 1.75
	Mg	4.5	1.79 ± 0.27	6.23 ± 1.10
High-T tholeiitic glass	Al	12.1	6.6 ± 0.71	14.69 ± 0.93
	Ca	6.73	2.17 ± 0.36	17.4 ± 2.29
	Fe	3.45	0.98 ± 0.38	8.46 ± 2.72
	Mg	1.69	0.57 ± 0.36	1.82 ± 1.22

**Table 1.** Cations by weight percent (with measured un-certainty) in the depleted and enriched zones of

tholeiitic basalt glasses compared to their average concentrations in the bulk sample.

All samples had discontinuous Fe-oxide grains at the surface; tholeiitic glasses formed a reaction zone characterized by a region of cation depletion followed by a region of cation enrichment that advanced from the surface of the glass towards the interior between ~10 nm to ~25 nm depending on experimental temperature conditions. Table 1 shows the deviation in weight percent of cations in the depleted and enriched zones relative to their average concentration in the bulk sample. Both low and high temperature tholeiite basalt glasses have an enrichment in the concentration of cations (specifically Ca, Fe, and Mg) on the surface of the glass. RBS analysis confirms an enrichment of Fe in the upper few nanometers (nm) when compared to the amount in the bulk of the sample. This enrichment allows secondary phases like Fe-oxide to form. The absence of a secondary phase rich in Ca or Mg is likely due the inability of CO<sub>2</sub> to combine with these cations as readily as Fe at these conditions.

Figures 1 and 2 show line transects for a low temperature (470°C) and high temperature (700°C) run where the same style of alteration is observed for both samples. A similar line transects through a glassy alka-

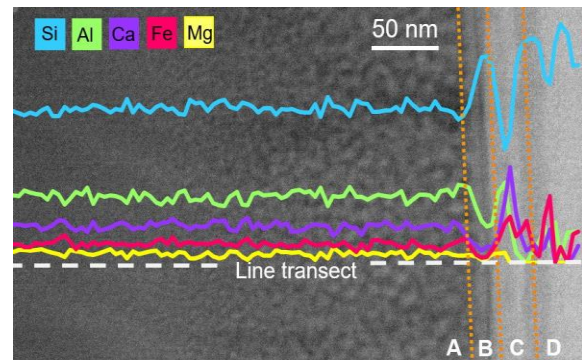


**Figure 1.** TEM image of an experimentally produced reaction front on a tholeiitic basalt glass; experiment ran for 2 weeks at 470°C, 90 bars pressure, and under oxidized conditions. Region A is unaltered glass, B is the depleted zone, C is the enriched zone, and D is the carbon coat applied to the surface of the sample.

line basalt yielded different results; the same pattern of alteration did not occur. The alkaline basalt sample analyzed contained an olivine grain and normal zonation pattern for the olivine was observed where the Fe concentration increased at the rim. The absence of a reaction front suggests that crystalline material is more resistant to this style of chemical alteration than glassy material.

**Implications:** Under surface conditions on Venus, a reaction front developed from the surface of the glass to the interior ~ 15 nm in two weeks' time. While data for

longer run times is still needed, this implies a relatively



**Figure 2.** TEM image of an experimentally produced reaction front on a tholeiitic basalt glass; experiment ran for 2 weeks at 700°C, 90 bars pressure, and under oxidized conditions. Region A is unaltered glass, B is the depleted zone, C is the enriched zone, and D is the carbon coat applied to the surface of the sample.

fast rate of alteration which would mean that basalt on the surface is able to undergo detectable chemical alteration on the order of 10s to 100s of years.

**Future directions:** Glassy regions of alkaline basalt samples will be analyzed to directly compare to glassy tholeiite basalts. The same experimental design will be used for experimental run times of four weeks instead of two. We expect that this will cause the reaction front to advance farther into the sample and that the amount of Fe-oxide on the surface will increase. This could also be enough time to potentially form other secondary mineral phase at the surface.

The team will continue to run a series of experiments investigating the effects of both CO<sub>2</sub> and SO<sub>2</sub> gas; we suspect that the secondary minerals that form under the presence of SO<sub>2</sub> will differ from those formed under a CO<sub>2</sub>-only environment. Preliminary results from this study will be discussed elsewhere.

**References:** [1] Zolotov M.Y. (2018) *Reviews in Mineralogy and Geochemistry*, 48, 351-92. [2] Treiman A.H., and Allen C.C. (1994) *LPS XXV*, 1415-1416. [3] McCanta M.C. et al. (2014) *American Mineralogist*, 99, 291-302. [4] Smrekar S.E. et al. (2010) *Science*, 328, 605-8. [5] Filiberto J. et al. (2020) *Science Advances*, 6, eaax74. [6] Skjeltvåg B.-L. et al. (1989) *J. Volcanol. Geotherm. Res.*, 37, 1-19. [7] Treiman, A.H. (2007) *American Geophysical Union (AGU)*, 7-22. [8] Filiberto, J. (2014) *Icarus*, 231, 131-36. [9] Cooper R.F. et al. (1996) *Geochim. Cosmochim. Acta*, 60, 3253-3265. [10] Bender J.F. et al. (1978) *Earth Planet. Sci. Lett.*, 41, 277-302.