

EXPERIMENTAL INVESTIGATION OF GRANITE AND BASALT WEATHERING ON VENUS.

A. R. Santos¹, J. A. Lewis², F. M. McCubbin², L. M. Nakley¹, K. Phillips³, D. M. Vento¹, ¹NASA Glenn Research Center, 21000 Brookpark Rd., Cleveland, OH 44135, ²NASA Johnson Space Center, Mailcode XI2, 2101 NASA Parkway, Houston, TX 77058, USA, ³HX5 Sierra, LLC, 21000 Brookpark Rd., Cleveland, OH 44135. (alison.r.santos@nasa.gov)

Introduction: A number of different mineral weathering reactions have been proposed to take place on Venus due to its surface temperature, pressure, and atmospheric composition, all of which are unique among rocky planets in our Solar System (e.g., [1] and references within). Importantly, many of these reactions involve volatile-bearing minerals that are known to be common among rocks formed on Earth, such as carbonates, amphiboles, and micas. Weathering reactions involving volatile-bearing minerals are particularly important to understand because of the role volatiles play in planetary evolution and magmatism, with water having the strongest influence. While no measurements of Venusian mineralogy exist, a number of studies have used what is known about the environment of the Venusian surface to model possible mineral-atmosphere reactions on this planet.

The stability of a number of micas and amphiboles was investigated by [2-3] using thermodynamic modeling. They found a number of Fe²⁺-, Ca-, and/or OH-bearing micas and amphiboles are not stable on the surface of Venus and are subject to dehydration, oxidation of iron, or sulfatization reactions driven by gaseous species in the atmosphere (e.g., CO₂, SO₂). Experimental studies have also investigated some of these silicate minerals, as well as other minerals that host volatile species such as carbonates and sulfides. The amphibole tremolite was found by [4] to break down in a CO₂ atmosphere at high temperature, with a slower reaction rate with higher F contents in the mineral. Calcite was found to react to form secondary sulfides when exposed to Venus surface conditions in a nine gas atmospheric mixture including SO₂, OCS, and H₂S [5]. However, pyrite was found to be stable by [6] at Venus surface temperature and pressure in an atmosphere with CO₂, N₂, and SO₂. These experimental studies have not used uniform methods, and this variety of approaches has demonstrated both the need for better constraints on the properties of the Venus surface environment and the need to examine mineral reactions over a range of conditions until such data for Venus exist.

In an effort to better understand volatile cycling on Venus, we conducted experiments to determine the stability and weathering products of minerals found in naturally occurring rocks from Earth under Venusian surface conditions. The rocks chosen, basalt and granite, provide a range of mineral types, and include iron

bearing minerals such as Fe-oxides, as well as volatile bearing minerals such as mica. Weathering of these minerals will serve to confirm previous experimental observations of mineral reactions with a Venus-like atmosphere, and provide new insight into minerals not yet examined in experiments. The information from these experiments will be used to guide sample selection for future detailed experimental studies.

Methods: Samples used in this study were a naturally occurring granite from an unknown locality and a basalt from La Jara Creek, CO.

Two experiments were conducted using the Glenn Extreme Environments Rig (GEER) located at NASA Glenn Research Center (GRC). The samples were placed in the GEER chamber, an 800 L pressure vessel constructed of 304 stainless steel, and exposed to Venus conditions. The experiments replicated a Venus surface-like condition of 460 °C and 1356 psi (~93.5 bars) for 30 days, and 460 °C and 1344 psi (92.7 bars) for 11 days. The 11 day experiment involved planned 24 hour long excursions both below and beyond the 460 °C temperature target (and deviations in pressure correlating with the change in temperature), as well as an increase of HF concentration during the last day of the experiment. Both had initial gas mixtures of 96.5% CO₂, 3.5% N₂, 180 ppm SO₂, 30 ppm H₂O, 12 ppm CO, 51 ppm OCS, 2 ppm H₂S, 0.5 ppm HCl, and 2.5 ppb HF. During the experiments, CO₂, N₂, and SO₂ concentrations were monitored using an Inficon 3000 Micro Gas Chromatograph. While CO₂ and N₂ remained relatively constant over time, SO₂ was found to decrease with time during both experiments. SO₂ concentration in both experiments did not drop below 100 ppm before additional SO₂ was added to the system to bring the concentration back to the starting value. The 11 day duration experiment involved two granite samples and two basalt samples, while the 30 day duration experiment had one large granite sample and three basalt samples. Additional geologic and anthropogenic samples were present in the chamber during each of these experiments.

Once the experiments concluded, samples were stored in a desiccator box. Samples were then carbon coated and examined using a Hitachi S-4700 SEM with an Oxford Instruments X-Max^N 20 Silicon Drift Detector EDS system run with Aztec software housed at GRC to look for physical or qualitative chemical changes.

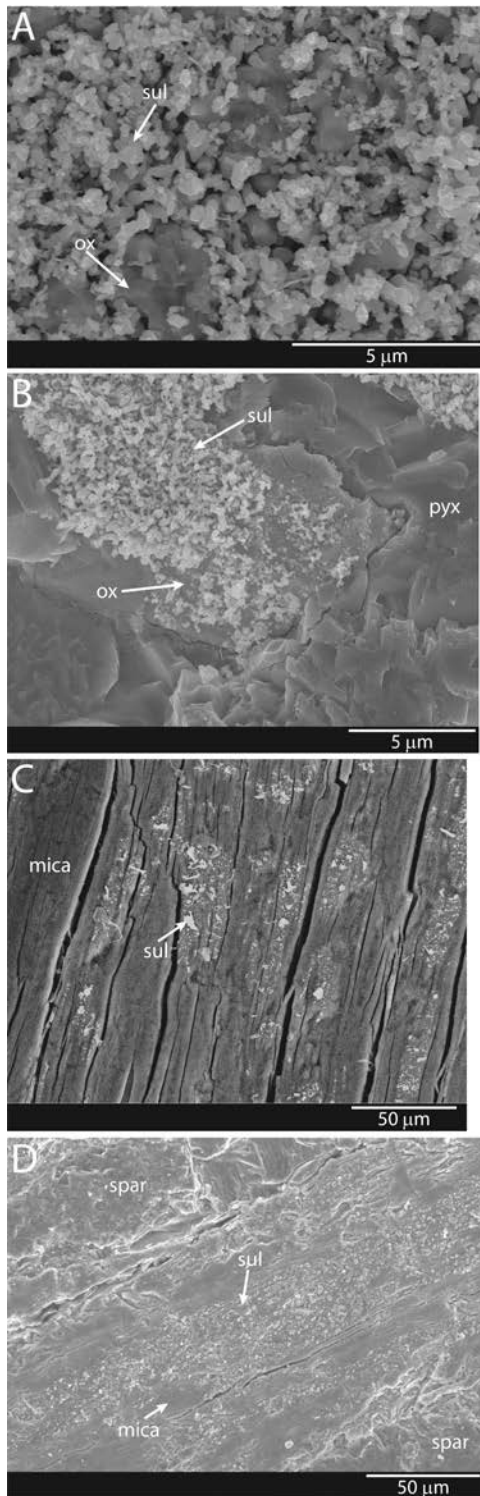


Figure 1: Secondary electron images of reaction products on basalt (A: 11 day exposure, B: 30 day) and granite (C: 11 day, D: 30 day) samples from GEER experiments. Phases present include Fe-sulfide (sul), Fe-Ti oxide (ox), Na-feldspar (spar), and pyroxene (pyx).

Results: In both experiments, samples appeared blackened upon removal from the GEER chamber.

Sample trays were also darkened and in some cases the areas of the tray under the samples were clean, suggesting the darkening is due to a surface coating.

Basalt. The basalt samples from the 11 and 30 day experiments show an iron sulfide phase growing out of what appears to be an iron-titanium oxide (Fig. 1A, B). These secondary sulfides are composed of fine grained, anhedral crystals forming fluffy piles on the sample surface. The boundary of these secondary mineral growth areas appears to follow the boundary of the original oxide grains. These reactions are seen in multiple discrete Fe-Ti oxide grains across the samples while other minerals appear unaltered.

Granite. The granite from the 11 and 30 day experiments show patchy secondary mineral growth on mica grains (Fig. 1C), with other phases appearing unaltered. This phase appears to be an iron sulfide as well, and has similar morphology to the sulfides seen in the basalt samples. However, the secondary sulfide on the mica occurs in patches and does not completely cover the surface of mica grains in any observed occurrence. The sulfide patches on the mica do not appear as thick as the sulfides on the iron oxides of the basalt. After 30 days, the sulfides still do not form deep or continuous layers over the mica, but some larger patches are present (Fig. 1D).

Discussion: The current results suggest some mineral-atmosphere reactions on Venus likely occur rapidly, since both the basalt and granite showed secondary mineral growth after only 11 days at surface conditions. The results also demonstrate the importance of sulfidization reactions for iron bearing mineral stability, as indicated by previous experimental studies and modeling [1-3, 5-6]. A more detailed study of the Fe-bearing mica is needed to determine if the observed reaction caused loss of volatile species such as OH to the atmosphere.

It is important to remember that a difficulty with Venus mineral stability experiments is the limited data available from the Venusian surface, similar to the difficulties in modeling discussed in [1]. The atmospheric composition chosen for an experiment will dictate parameters such as oxygen and sulfur fugacities, and thus until better constraints are placed on the real surface conditions on Venus, experiments over a wide range of conditions (P , T , composition) would provide useful information.

References: [1] Zolotov M.Y. (2018) *RIMG* 84, 351-391. [2] Zolotov M. Y. et al. (1997) *Icarus*, 130, 475-494. [3] Zolotov M.Y. et al. (1999) *Planet. And Space Sci.*, 47, 245-260. [4] Johnson N.M. and Fegley B.F. (2003) *Icarus*, 165, 340-348. [5] Radoman-Shaw B.G. et al. (2017) *LPSC XLVIII*, Abstract #2701. [6] Kohler, E. (2016) Theses and Dissertations U. Arkansas, 1473.