

**WHAT LIES BENEATH: PURSUING THE VIRTUAL SURFACE BINDING THE LUNAR EXOSPHERE.**

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**Introduction:** Few laboratories intentionally place liter quantities of dirt inside a vacuum, but such environmental conditions are precisely what awaited Apollo astronauts and robotic craft at the surface of the Moon, and will soon be experienced once again by probes returning there. This was the purpose for construction of the Lunar Advanced Vacuum Apparatus (LAVA). LAVA leverages our knowledge of spectroscopy of unconsolidated powders, minerals, simulants, lunar materials, and other field samples with our decades of experience in ultrahigh vacuum (UHV) systems. Our broader intent is to conduct scientific investigation into the permeation, adsorption and diffusion of volatiles not only at the surface of the Moon, but also all regolith-laden primitive bodies in the solar system with a surface-bounded exosphere (SBE).

Despite the existence of volatiles detected at the lunar surface[1][2], their behavior within their regolith confines is poorly constrained, as is how to detect them. The development of successful remote detection techniques for these known volatiles is a goal that would greatly reduce mission risk and improve landing site targeting for the robotic rovers and instrumentation tasked with the exploration of these regolith surfaces as the precursor to long-term human habitation[3][4].

**The LAVA regolith simulation system:** For these reasons, we proposed LAVA as the next logical science step forward in space environment simulation systems reproducing the behavior of gases and volatiles at the surface of the Moon. The features we incorporated into LAVA over those of other systems are based upon lessons learned during both our SwRI-funded Polar Regolith Environment Molecular Impact Simulation Experiment (“PREMISE”, 15-R8241)[5] and NASA-funded Regolith Environment Volatile Impact Simulation Experiment (“REVISE”, NNX-14AN53G)[6][7].

The main chamber is mounted low to the floor and stands 1 m tall at the upper flange face of the gate valve shown in Fig. 1. It has 39 ConFlat®-style flange ports spanning sizes from 14” to 2.75” in. Within the chamber volume, a 2000 ml graduated cylinder is over-filled with approximately 2800 ml of JSC-1A lunar soil simulant. The 52 cm cylinder has an interior depth of 49.5 cm, making it possible to simulate a lunar surface core at this depth. Stainless steel tubing inserted into the bottom of the graduated cylinder introduces gas at the base of the sample column which is monitored by pressure gauges and a quadrupole mass spectrometer. A spectroradiometer monitors the sample surface for changes that may occur during gas bakeout or gas evolution. Various viewports allow visual inspection of the

simulant and its containment column within the graduated cylinder during vacuum operations.



Figure 1. The LAVA system after leak checking. Vacuum soil hopper permits degassing, and sifting of sample prior to pouring into main vacuum chamber through gate valve. The hopper system (2 m above floor) is removed after filling.

**Materials under investigation:** The available JSC-1A Apollo 11 sample (10084, 27) is typical of lunar regolith breccias and components found in Apollo 11 soils. Reflectance spectra of most lunar soils and rocks are dominated by the absorption spectra of pyroxenes. Although visual and IR spectroscopy has been performed on this sample for comparison with simulants, the quantity (10 g) is insufficient for studies involving volumetric gas flow through bulk material.

Due to the need for a large volume of sample, use of a lunar soil simulant such as JSC-1A is an absolute must. While investigating the provenance of JSC-1A and other available simulants, we collected a field sample of basalt from Knippa, TX. This sample was submitted for X-ray diffraction (XRD) and X-ray fluorescence (XRF) analysis to compare this local Texas

basalt with the JSC-1A, and other samples previously studied.

This geologic site for igneous materials west of San Antonio may provide a new variety of useful lunar simulants from a much more local source than the San Francisco Volcanic Field of Northern Arizona. A rigorous comparison with the NASA elemental and mineralogical Figures of Merit (FoM) is still underway and will determine the suitability of this basanitic Knippa basalt for use as a lunar analogue for some limited laboratory investigations. This local basalt is being considered as a readily-available lunar simulant for use by San Antonio STEM students in the NASA-funded Lunar Caves Analog Test Sites (LCATS) project upon which we are co-investigators (Fig. 2).



Figure 2. Knippa S2 sample versus the Lunar Analog JSC-1A sample

The Knippa sample, consists of olivine, orthopyroxene, and clinopyroxene, and has been analyzed in the lab using an Analytical Spectral Devices (ASD) FieldSpec® 3 portable spectroradiometer. To assess the FoM for this Knippa sample, the material was shipped to Core Lab, for analysis by XRD and XRF.

The raw sample was hand-ground in a mortar and pestle and split for XRD and XRF analysis. A ball mill was used for subsequent grinding into a fine powder for XRF. A more extensive method of sample preparation was used for XRD that included a detailed procedure for removing and analyzing the clay content within the powder matrix. Clay contributions to the composition are attributed to weathering of the sample.

**Results of Knippa XRD and XRF Analysis:** XRD analysis showed the material to be composed of predominantly pyroxene (augite), with significant amounts of olivine (forsterite) and nepheline, a feldspathoid mineral. The sample also contains lesser amounts of Ti-magnetite, perovskite, and phyllosilicate minerals, including smectite (nontronite), antigonite (serpentine), chlorite, and an illite-like mineral.

*No quartz or feldspar minerals were identified.* Because the lab has no calibration data for several of the

atypical mineral phases detected, quantitative analysis could not be performed. The lack of quartz ( $\text{SiO}_2$ ) present suggests this basalt originated from within the Earth's upper mantle and had insufficient time upon passing through the crust to accumulate the silicic properties observed in more mature basalts.

**XRF Analysis** – The very low  $\text{SiO}_2$  value (33.47%) was considered extraordinary by Core Lab and placed the sample well into the category of ultramafic igneous rocks ( $< 45.0\% \text{SiO}_2$ ).

Based on the XRD and XRF data, the sample is described as an ultramafic igneous rock composed predominantly of pyroxene, nepheline, and olivine, and containing lesser to minor amounts of oxide minerals of Fe, Ca, and Ti. The sample was also found to contain minor amounts of clay/phyllosilicate minerals, but these are interpreted to be weathering products and not associated with the original (un-weathered) igneous rock. The lack of quartz and feldspar minerals, as determined by XRD, coupled with the very low silica content determined by XRF, suggest the source magma for the Knippa Basalt originated in the upper mantle.

**Conclusions** – A new space environment simulation system is being developed to reproduce the behavior of gases and volatiles at the surface of the Moon. The Knippa S2 sample is proposed to be one of the first materials tested with the chamber. We will extend optical spectroscopy measurements to multiple samples once insertion and evacuation of JSC-1A into the chamber and optical alignment of the spectrometer with the sample surface is achieved. A key component of this work is observation of any change in optical properties resulting from the bakeout, as this removes adventitious surficial water from the mineral grains, with implications for probing the surfaces of primitive bodies.

In addition to the planned optical spectroscopy and mass spectrometry of diffusing gases through the simulated lunar regolith column, we also plan to extend our studies to other materials. Preliminary results of these gas permeation and diffusion measurements will be presented, along with comparisons of the surface optical properties of the samples under investigation.

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**References:** [1] Colaprete, A. et al. (2010) *Science* 330, 463-468. [2] Gladstone, G. (2012) *JGRP* 117, E12. [3] Patrick E. et al., (2014) ASCE ICESCOE 14. [4] Hooper, D. et al., (2013) LPI Golden Spike Abstract 6022. [5] Patrick, E. et al. (2015) *Icarus* 255 30-43. [6] Patrick, E. et al. (2016) *LPSC* 47, #2649. [7] Patrick, E. et al. (2017) *LPSC* 48, #2300.