Understanding the Activation and Solution Properties of Lunar Dust for Future Lunar Habitation. W.T. Wallace[1] and A.S. Jeevarajan[2], [1]USRA/NASA Johnson Space Center, 2101 NASA Pkwy, Mail Code: SF, Houston, TX 77058 (william.wallace-1@nasa.gov), [2]NASA Johnson Space Center, Houston, TX (antony.s.jeevarajan@nasa.gov)

Introduction: The decision to return humans to the moon by 2020 makes it imperative to understand the effects of lunar dust on human and mechanical systems.(Bush 2004; Gaier 2005; Mendell 2005) During the Apollo missions, dust was found to cause numerous problems for various instruments and systems. Additionally, the dust may have caused health issues for some of the astronauts.(Gaier 2005; Rowe 2007) It is necessary, therefore, for studies to be carried out in a variety of disciplines in order to mitigate the effects of the dust as completely as possible.

Due to the lack of an atmosphere, there is nothing to protect the lunar soil from ultraviolet radiation, solar wind, and meteorite impacts. These processes could all serve to "activate" the soil, or produce reactive surface species. In order to understand the possible toxic effects of the reactive dust, it is necessary to "reactivate" the dust, as samples returned during the Apollo missions were exposed to the atmosphere of the Earth. We have used grinding and exposure to UV radiation in order to mimic some of the processes occurring on the lunar surface. To monitor the reactivity of the dust, we have measured the ability of the dust to produce hydroxyl radicals in solution. These radicals have been measured using a novel fluorescent technique developed in our laboratory,(Wallace et al. 2008) as well as using electron paramagnetic resonance (EPR).

While a number of studies have been aimed at understanding the dissolution properties of lunar dust and lunar dust simulants under various conditions (Mason et al. 1970; Oyama et al. 1970; Keller and Huang 1971; Eick et al. 1996a; Eick et al. 1996b; Beiersdorfer et al. 1997), there has not been a consistent and systematic method applied over the various studies. For instance, the pH values, choice of acid, choice of simulant, or choice of soil were be different. Additionally, some of these studies also chose to observe the changes in surface morphology using electron microscopy after performing the dissolution studies. These changes could be important if they were to allow some particles to penetrate further into the respiratory system, where more damage could occur. We have undertaken a study aimed at understanding the changes in dissolution of lunar dust and lunar simulant at different pH and in solutions that more closely mimic the fluids likely to be encountered by dust in the body.

Results:

Activation: We have used hand grinding with a mortar and pestle as a means of activating quartz (Min-U-Sil 15), lunar dust simulant (JSC-1A-vf), and lunar soil returned by Apollo 16 (62241). As expected, samples that have not been activated do not produce a significant amount of radicals when placed in aqueous solution, and the emission spectrum is very small. Grinding the different materials under exactly the same conditions, however, leads to quite different emission intensities. As seen in **Figure 1**, the level of hydroxyl radical production increases in the order: quartz < lunar dust simulant < lunar dust.

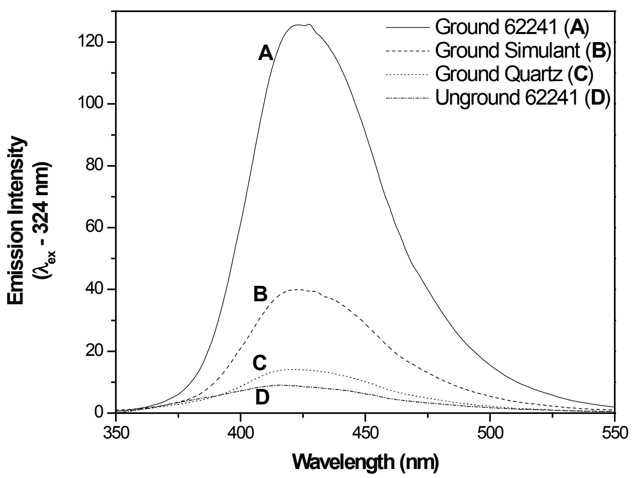

Figure1: Emission spectra comparing ground and unground Apollo 16 soil (62241) with ground JSC-1A-vf and ground Min-u-Sil 15. Increased emission represents increased hydroxyl radical production

In separate studies, we have also attempted to dismiss the idea that this increased activity is tied to the specific surface area of the ground materials. BET analysis has provided values for lunar dust (8.404 m^2/g), lunar simulant (5.369 m^2/g), and quartz (8.436 m^2/g), showing that the activity is not correlated with specific surface area. Additionally, we have monitored the time required to return the activity of its unactivated state. After grinding the dust, we have placed it in an environmental chamber set to a predetermined temperature and humidity. These experiments have shown the deactivation half-life of quartz to be ~ 2 hours, while that of lunar simulant is ~ 3 hours.

Dissolution: We have measured the solubility of JSC-1A-vf lunar dust simulant at three pH values: 4.0 (citrate buffer), 5.3 (citrate-phosphate buffer), and 6.7 (citrate-phosphate buffer). A variety of species were measured using ICP-MS. For all species, it was found that a lower pH results in a large increase in the amount of material released into solution, as would be expected. (Eick et al. 1996a; Eick et al. 1996b) Additionally, grinding of the materials prior to placing them in solution also leads to an increase in concentration. This is shown for iron in **Figure 2**. These tests have helped to develop a protocol for dissolution studies prior to testing with lunar dust returned during Apollo. Future tests will include solutions containing species found in the body, such as glycine(Kanapilly et al. 1973) or phosphatidylcholine.(Liu et al. 1998)

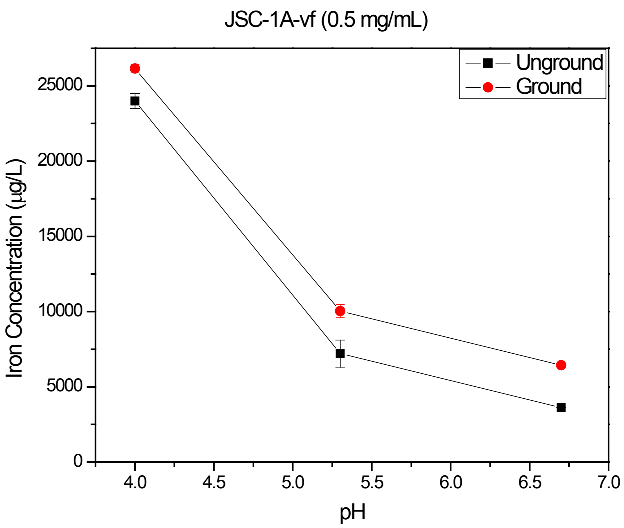

Figure 2: Changes in iron concentration upon placing JSC-1A-vf in buffers of different pH for 72 hours.

Conclusions: The health and safety of astronauts returning to the Moon is of the utmost importance. A major factor in achieving this goal is striving to understand the effects of lunar dust, which was found to be highly detrimental during Apollo. In order to most closely mimic dust on the lunar surface, we must gain an understanding of some important properties, namely activation and dissolution. These results show that we are well on our way to achieving these goals and helping to mitigate any harmful properties of lunar dust.

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Abstract

The decision to return humans to the moon by 2020 makes it imperative to understand the effects of lunar dust on human and mechanical systems. During the Apollo missions, dust was found to cause numerous problems for various instruments and systems. Additionally, the dust may have caused health issues for some of the astronauts. It is necessary, therefore, for studies to be carried out in a variety of disciplines in order to mitigate the effects of the dust as completely as possible.

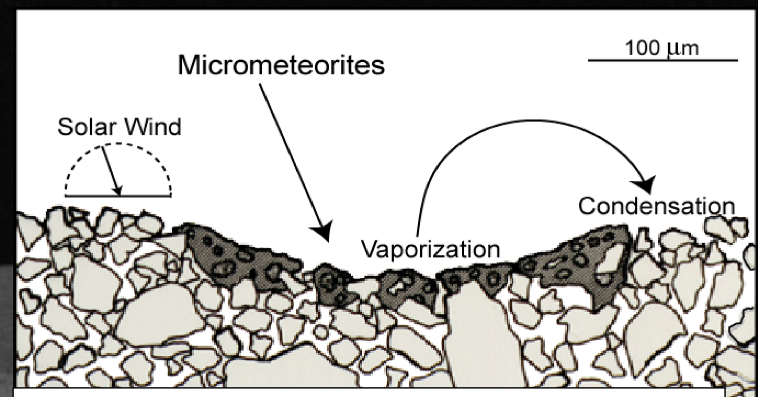
The Problems

"I think dust is probably one of our greatest inhibitors to a nominal operation on the Moon. I think we can overcome other physiological or physical or mechanical problems except dust."

Gene Cernan
Apollo 17
Technical Debrief

Obscured vision
Apollo 15: vision completely obscured below 60 ft when landing
Clogged equipment
Apollo 12: wrist and suit hose locks clogged with dust
Coated surfaces
Apollo 11: T.V. cable caused tripping after dust covering
Inhalation
Apollo 15: gunpowder smell
Apollo 17: "hay fever" symptoms
Degraded radiators
Apollo 16: degraded instrument performance from overheating
Caused seal failure
Apollo 14: measurable leaking of suits
Abraded surfaces
Apollo 16: gauge dials unreadable from scratching

Space Weathering



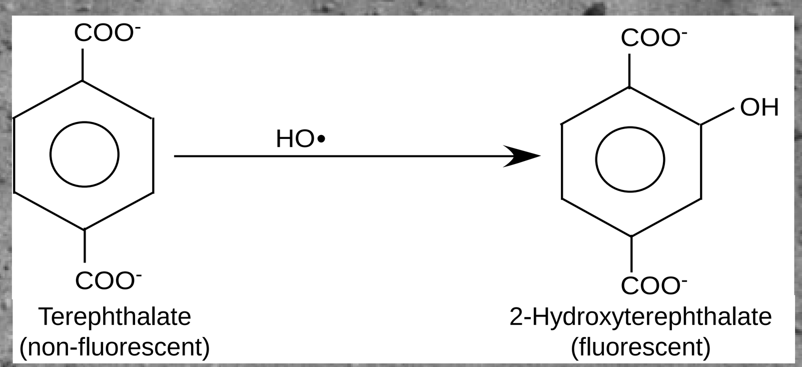
L.A. Taylor and T.T. Meek, *J. Aerospace Eng.* **18** (2005) 188.

Lunar soil is formed by a combination of comminution (breaking down), agglutination (clumping together), and vapor deposition.

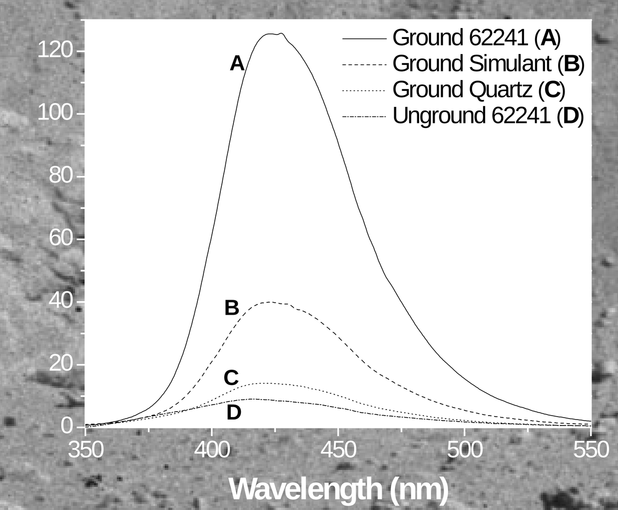
How Does Space Weathering Affect the Chemical Reactivity of Lunar Dust?

Grinding Could Provide a Mimic of Meteorite Impact (10 min-mortar/pestle)

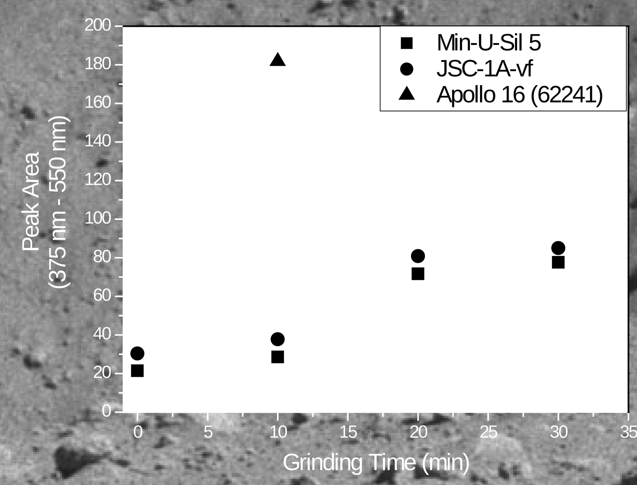
Fluorescence



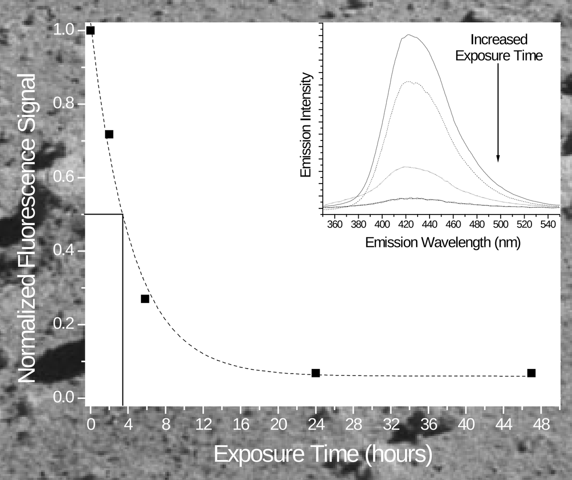
Use a fluorescent probe to quantify the production of hydroxyl radicals in aqueous solution. Hydroxylation of the symmetric terephthalate molecule produces a single product



Emission spectra (λ_{ex} = 324 nm) comparing ground and unground Apollo 16 soil (62241) with ground JSC-1A-vf and ground Min-u-Sil 15 (quartz). The concentration of dust was 3.8 mg/mL.



The effect of grinding time on the integrated fluorescence signal from quartz and lunar simulant solutions. The integrated signal of lunar dust ground for 10 minutes is included for comparison.

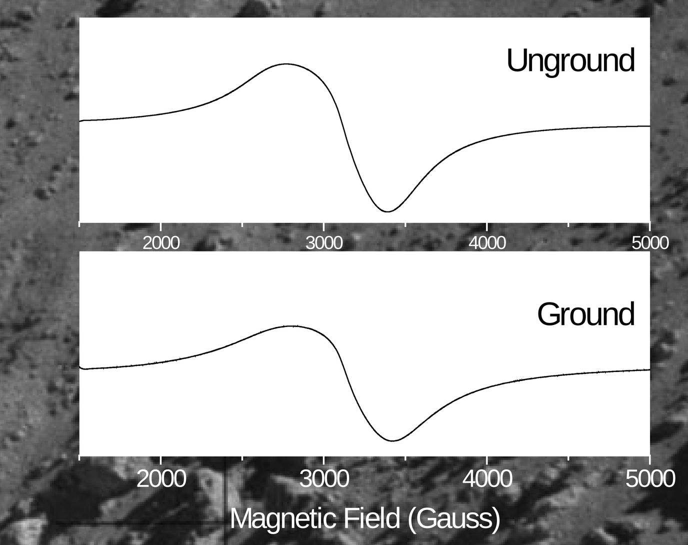


Deactivation of freshly-ground lunar dust simulant (JSC-1A-vf). Fractions of ground simulant were placed in an environmental chamber at 25 °C and 50% relative humidity for defined periods of time before exposure to the terephthalate solution. The activities of the deactivated samples were normalized to that of the freshly ground material. Inset: Change in emission spectra with increased exposure time.

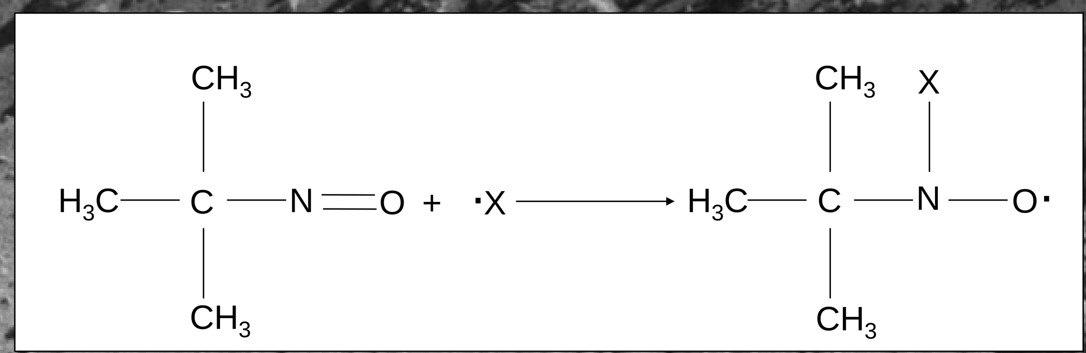
How Do We Assess the Reactivity?

Fluorescence and Electron Paramagnetic Resonance (EPR)

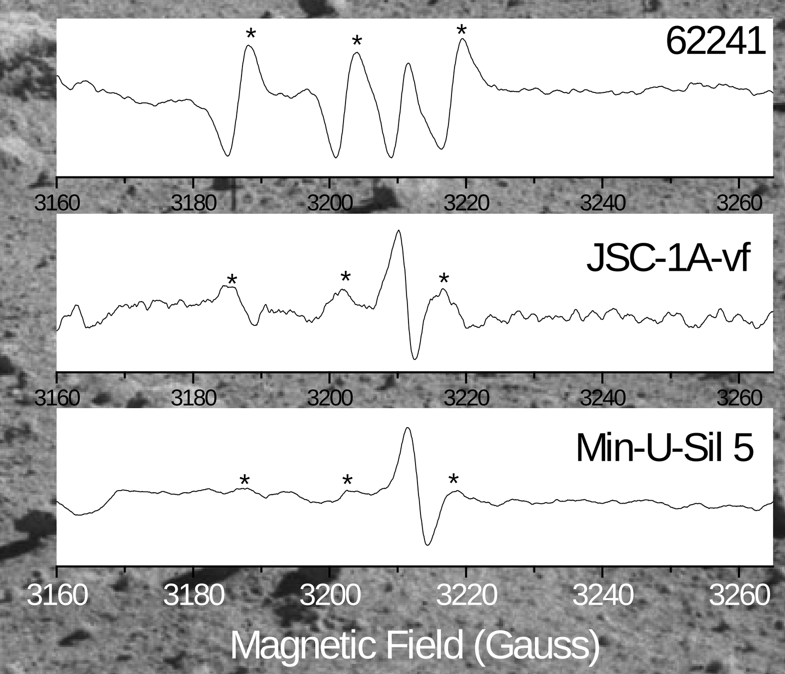
EPR



EPR spectra of unground (top) and ground (bottom) Apollo 16 lunar dust sample 62241. The changes in peak shape and g-values are similar to those seen previously.



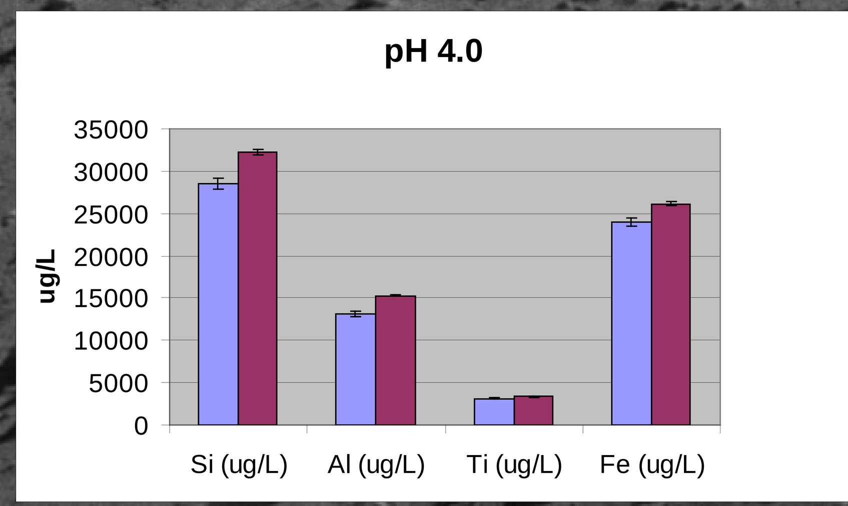
Reaction of MNP with a generic radical to produce a spin adduct. Spin-trapping allows the measurement of transient radicals, such as hydroxyl radical.

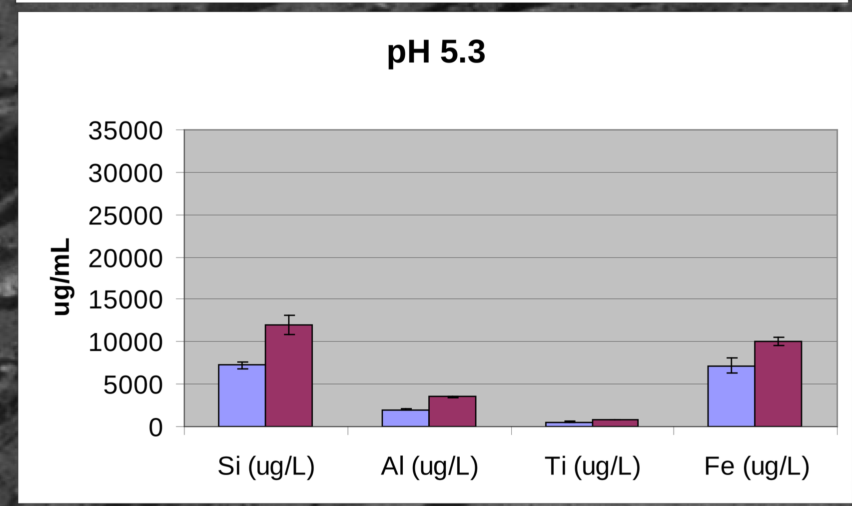


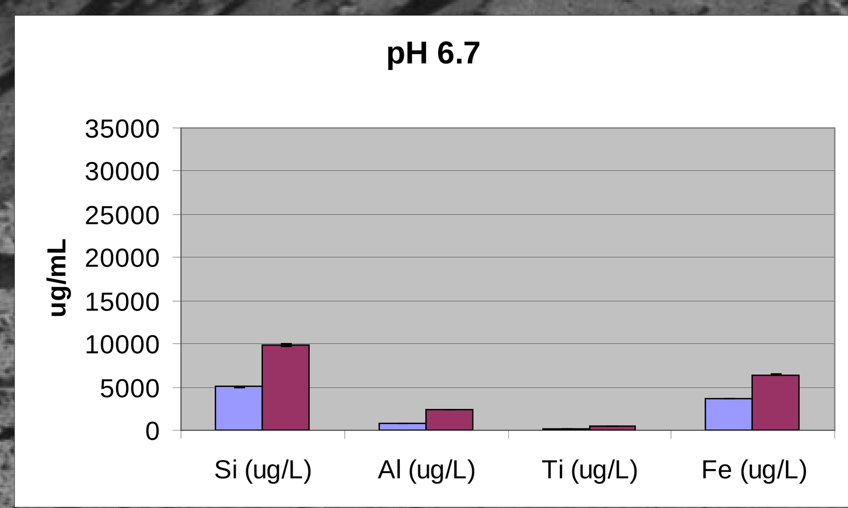
EPR spectra of a 100 mM MNP/acetonitrile solution after exposure to ground quartz (Min-U-Sil 5, bottom), lunar simulant (JSC-1A-vf, middle), and Apollo 16 lunar dust (62241, top). The lunar dust and lunar simulant were ground for 10 minutes, while the quartz was ground for 30 minutes. The asterisks denote the position of the spin adduct triplet. The peak-to-peak splitting arise from nitrogen in the spin adduct of the transient radical.

Dissolution

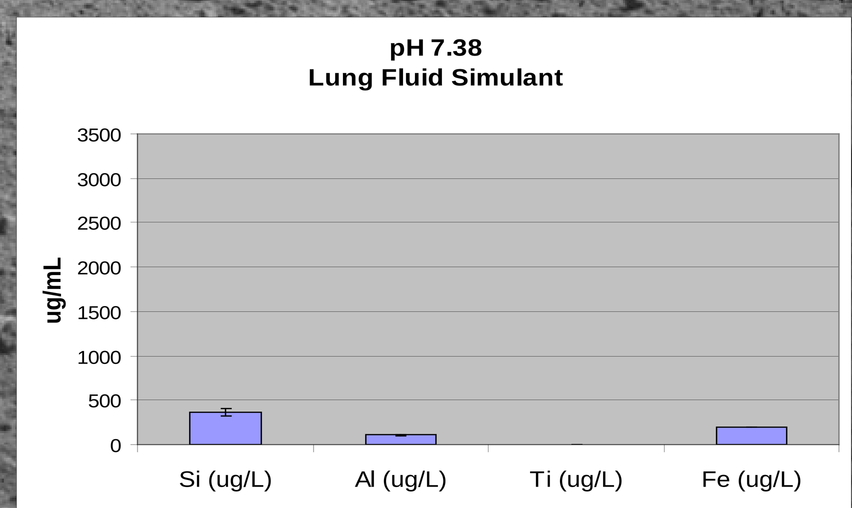
What Happens to Lunar Simulant at Different pH or in Lung Fluid Simulant?







Change in concentration of various elements measured by ICP-MS after placing JSC-1A-vf in buffer solutions of different pH for 72 hours. Maroon: ground, Blue: unground. The concentration used for all tests was 0.5 mg/mL.



Change in concentration of various elements measured by ICP-MS after placing JSC-1A-vf in lung fluid simulant for 72 hours at 0.5 mg/mL. Note the change in scale for the lung fluid simulant graph in comparison to the above graphs. The lung fluid simulant used for these studies contained 1.8 mM $CaCl_2 \cdot 2H_2O$, 1.12 mM $MgCl_2$, 2.68 mM KCl, 11.9 mM $NaHCO_3$, 136.89 mM NaCl, 0.42 mM NaH_2PO_4, 5.55 mM D-Glucose, 10 mM NH_4Cl, 0.2 mM trisodium citrate, 6 mM glycine, and 0.5 mM Na_2SO_4.

Conclusions and Future Studies

Grinding of lunar dust leads to the production of radicals in solution and increased dissolution of lunar simulant in buffers of different pH. Decreases in pH lead to increased leaching from lunar simulant. The use of lung fluid simulant does not lead to increased leaching. These results have provided evidence for the need for further studies on the various properties of lunar dust prior to returning to the Moon. Future studies planned in our laboratories and with collaborators include grinding of lunar dust under inert conditions to determine any changes in activity level or deactivation rate. Additionally, we plan to perform further spin trap testing with a dedicated *OH trap. Further studies are also planned to understand the dissolution rate of lunar dust.

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