Understanding the Reactivity of Lunar Dust for Future Lunar Missions

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“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
What is lunar dust?

- **Lunar soil** is defined as the loose fragmental material with a grain size smaller than 1 cm on and near the surface of the moon. It is a subset of the lunar regolith which includes all size fragments including boulders.

- **Lunar dust** is the finest size fraction of lunar soil. A working definition of lunar dust is that it is all grains smaller than 20 µm.
Lunar Dust

- Contains silicon-based minerals, other oxides, and trace metals
- Magnetic
- Particles are oddly shaped, with jagged edges, and do not pack together well

Dave McKay, JSC
Glassy rims produced by vapor/sputter deposition. Also contain ~ 10 nm Fe nanoparticles (nanophase iron)
Lunar Dust Simulant

Only 842 lbs of material returned from the moon! Simulant material needed for preliminary studies.

- JSC-1A-vf
- Made from volcanic ash
- 50% silicon-containing minerals
- 42-45% other oxides (Al\textsubscript{2}O\textsubscript{3}, FeO, MgO, CaO)
- No trace metals
- Size distribution of particles similar to samples of lunar dust
- 90% smaller than 13 µm diameter
Lunar Dust Activation

- Constant activation of lunar dust by meteorites, UV radiation, and elements of solar wind
- No passivating atmosphere
- Active dust could produce reactive species in the lungs
  - Freshly fractured quartz
- Must determine methods of deactivation before new lunar missions
- First, must understand how to reactivate dust on Earth
What Does “Activated” Mean?

- Presence of reactive sites on surface
  - Free radicals
- Ability to produce reactive species in solution

\[ \text{Reaction 5} \]
How Should We Monitor ·OH?

- **Electron Spin Resonance**
  - Provides quantitative measure of radical production
  - Equipment is costly and bulky

- **Fluorescence Spectroscopy**
  - Can also provide quantitative analysis
  - Large number of chemical sensors already in use for other systems
  - Need to determine correct probe
Hydroxyterephthalate as a Probe of Hydroxyl Radical Generation

Terephthalate (non-fluorescent) → 2-Hydroxyterephthalate (fluorescent)

The diagram shows the reaction of hydroxyterephthalate with hydroxyl radicals, resulting in the formation of 2-hydroxyterephthalate, which is fluorescent.
## Materials Used

<table>
<thead>
<tr>
<th>Sample</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>TiO₂</th>
<th>FeO</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>P₂O₅</th>
</tr>
</thead>
<tbody>
<tr>
<td>JSC-1A-vf, % oxides</td>
<td>48.77</td>
<td>15.65</td>
<td>1.49</td>
<td>8.88</td>
<td>0.19</td>
<td>8.48</td>
<td>10.44</td>
<td>2.93</td>
<td>0.81</td>
<td>0.66</td>
</tr>
<tr>
<td>Apollo 16 Soil (62241), % oxides</td>
<td>44.65</td>
<td>27</td>
<td>0.56</td>
<td>5.49</td>
<td>0.7</td>
<td>5.84</td>
<td>15.95</td>
<td>0.44</td>
<td>0.13</td>
<td>0.1</td>
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<tr>
<td>Min-U-Sil Quartz, %</td>
<td>99.0-99.9</td>
<td>&lt; 0.8</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
</tbody>
</table>

Activity Comparison of Ground Lunar Soil, Lunar Simulant, and Quartz

What causes the reactivity increase?

• 10 minute grinding
• 4 mg/mL
• 10 mM Terephthalate

Effects of Nanophase Iron

## Soil Chemistry and Maturity

<table>
<thead>
<tr>
<th>Sample I/FerO</th>
<th>Lo-Ti Mare</th>
<th>Hi-Ti Mare</th>
<th>Highlands</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>15071</td>
<td>15041</td>
<td>71061</td>
</tr>
<tr>
<td></td>
<td>52</td>
<td>94</td>
<td>14</td>
</tr>
<tr>
<td>SiO₂</td>
<td>45.9</td>
<td>46.4</td>
<td>39.8</td>
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<tr>
<td>TiO₂</td>
<td>1.81</td>
<td>1.83</td>
<td>8.76</td>
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<tr>
<td>Al₂O₃</td>
<td>13.1</td>
<td>13.5</td>
<td>10.5</td>
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<tr>
<td>Cr₂O₃</td>
<td>0.41</td>
<td>0.41</td>
<td>0.48</td>
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<tr>
<td>MgO</td>
<td>11.3</td>
<td>10.8</td>
<td>10.5</td>
</tr>
<tr>
<td>CaO</td>
<td>10.3</td>
<td>10.3</td>
<td>9.90</td>
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<tr>
<td>MnO</td>
<td>0.19</td>
<td>0.20</td>
<td>0.24</td>
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<tr>
<td>FeO</td>
<td>14.9</td>
<td>14.2</td>
<td>17.5</td>
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<tr>
<td>Na₂O</td>
<td>0.37</td>
<td>0.41</td>
<td>0.41</td>
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<tr>
<td>K₂O</td>
<td>0.13</td>
<td>0.19</td>
<td>0.09</td>
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<tr>
<td>P₂O₅</td>
<td>0.18</td>
<td>0.21</td>
<td>0.06</td>
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<tr>
<td>SO₂</td>
<td>0.12</td>
<td>0.13</td>
<td>0.15</td>
</tr>
</tbody>
</table>
Effects of Dust Source (Highland vs Mare)

Mature

Mare 79221
$I_s/FeO = 81$

Highland 62231
$I_s/FeO = 91$

Quartz

Effects of Dust Source (Highland vs Mare)

Emission Wavelength (nm)

Emission Intensity ($\lambda_{ex} = 324$ nm)

Mare 71061
$I_s$/FeO = 14

Highland 67461
$I_s$/FeO = 25

Quartz

Effects of Maturity on Reactivity

Deactivation after Grinding
Deactivation of JSC-1A-vf

T = 25 °C
Humidity = 50%
[dust] = 4 mg/mL
\(\tau_{50\%} \sim 2 \text{ hours}\)
Deactivation of Lunar Soils

$t_{50\%} = 217 \pm 87$ minutes
Summary

- Fluorescence and EPR can be used to measure the reactivity of lunar soil

Lunar soil is highly activated by grinding
  - Reactivity is dependent upon soil maturity and locale

- Maturity is based on the amount of nanophase iron (np-Fe) in a soil relative to the total iron (FeO)

- LUNAR SOIL ACTIVITY IS A DIRECT FUNCTION OF THE AMOUNT OF Np-Fe PRESENT

- Reactive soil can be “deactivated” by humid atmosphere
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