Implications of dielectric breakdown weathering for the lunar polar regolith

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Breakdown threshold:
$\sim10^{10}$ particles cm$^{-2}$
1) SEPs charge the subsurface, setting up a capacitor-like situation

2) Charging dissipates as in a capacitor.
If SEPs charge regolith faster than it can discharge (fluence of $10^{10}$-$10^{11}$ cm$^{-2}$)...

... electric field can increase to threshold for dielectric breakdown ($10^6$-$10^7$ V/m)

Colder regolith $\rightarrow$ lower conductivity $\rightarrow$ larger E-fields

Very large SEP events cause PSRs to meet the criteria for dielectric breakdown (Jordan et al., 2014)
How much energy has breakdown deposited in PSR regolith?

Event’s E-field energy density (function of SEP fluence)

Event rate (function of SEP fluence)

Rate at which energy density is deposited
Event’s E-field energy density (function of SEP fluence)

*Subsurface electric field energy density*

- **Threshold breakdown-causing SEP event**
- **CRaTER events (Jan. & Mar. 2012)**

- Event’s E-field energy density
  - Function of SEP fluence

*Jordan et al. (under review)*
How much energy has breakdown deposited in PSR regolith?

- Event’s E-field energy density (function of SEP fluence)
- Event rate (function of SEP fluence)
- Rate at which energy density is deposited
Event rate (function of SEP fluence)

North Pole

South Pole

Breakdown-inducing SEP rate (per year)
How much energy has breakdown deposited in PSR regolith?

- Event’s E-field energy density (function of SEP fluence)
- Event rate (function of SEP fluence)
- Rate at which energy density is deposited
- Exposure time (limited by gardening): $10^6$ years
- Total breakdown energy deposited
Energy density deposited over $10^6$ yr of exposure (10$^6$ SEP events): \(8.8 \times 10^8\ \text{J m}^{-3}\)

Energy density needed to vaporize all regolith:
\[
\rho_{\text{reg}} \ c_p \ (T_{\text{vapor}} - T_{\text{PSR}}) = 7.3 \times 10^9 \ \text{J m}^{-3}
\]

<table>
<thead>
<tr>
<th>Weathering process</th>
<th>Energy flux (J m$^{-2}$ yr$^{-1}$)</th>
<th>Vapor + melt production (kg m$^{-2}$ yr$^{-1}$)</th>
<th>% Gardened soil melted or vaporized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact</td>
<td>1.2</td>
<td>$2.1 \times 10^{-7}$</td>
<td>~10%</td>
</tr>
<tr>
<td>Breakdown</td>
<td>0.88</td>
<td>$1.8 - 3.5 \times 10^{-7}$</td>
<td>~10-25%</td>
</tr>
</tbody>
</table>

Jordan et al. (under review)

Breakdown weathering may be comparable to impact weathering in PSRs
Impact model of soil evolution (McKay et al., 1974):

Coarse particles → Pulverization → Fine particles → Agglutination → Agglutinates

Breakdown model of soil evolution:

What probably happens (need experiments):

Fine particles → Fragmentation → Ultrafine particles

Vapor/melt deposition?
Breakdown vaporizes channels

Expanding gas fragments some grains; vapor deposited on other grains

Recube new grains
Preliminary Monte Carlo Results

Starting particle size: 100 μm
Input breakdown energy: $10^9$ J m$^{-3}$ ($\sim 10^6$ yr)

Without impacts, decrease mean grain size by $\sim 40$ μm throughout gardened layer.

May increase porosity and thus affect trafficability.
Impact model of soil evolution (McKay et al., 1974):

Replenishment → Coarse particles → Pulverization → Fine particles → Agglutination → Agglutinates

Breakdown model of soil evolution:

What probably happens (need experiments):

Impact + breakdown soil evolution:
Conclusions

Breakdown weathering in PSRs

• may produce vapor/melt comparable to impact weathering
• may have affected 10-25% of gardened regolith
• may augment comminution and thus affect trafficability

Future work

• Could LRO or in situ instruments detect breakdown?
• Could those observations + lab work differentiate its weathering effects from those of other processes?
• Could “sparked” material be in the Apollo samples?
Spacecraft anomalies caused by the space environment
(Koons et al., 1998)
Fig. 2. Friction angle as a function of porosity for a lunar soil simulant (ground basalt).
Fig. 3. Cohesion as a function of porosity for a lunar soil simulant (ground basalt).
• Porosity is the main influence on cohesion and angle of internal friction (Costes et al., 1972)
• PSRs may have porosity of ~70% (Gladstone et al., 2012)
• Breakdown weathering may increase porosity in PSRs (Jordan et al., 2015)
• Since breakdown has affected all *gardened* regolith, the affected layer could reach ~1 m
What probably happens (need experiments):

What we model as happening:

Breakdown channel
Impacts could spread breakdown-affected regolith to lower latitudes.

~0.01% of all gardened regolith may have experienced breakdown, but only a fraction of this would make it to lower latitudes.

Breakdown may occur on the nightside, which can be < 100 K.

If so, 3-6% of all gardened regolith may have experienced breakdown.

Is it in Apollo samples?
For a given lunar soil, the void ratio or porosity appears to be the most important single variable controlling the cohesion and the angle of internal friction of the material. (Costes et al., 1972)

The most probable values of cohesion appear to be in the range of 0.1 to 1.0 kN/m². The angle of internal friction appears to range between 30 and 50 deg, with the higher values associated with the lower porosities. (Costes et al., 1972)