Evolution of the Lunar Regolith

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Major Processes

- Impact communication
- Impact melting
- Formation of agglutinates
- Solar wind sputtering
- Impact vaporization
- Impact vapor condensation
- Shock welding of grains
- Thermal welding of grains
Concept of soil maturity

Maturity of lunar soil is the collection of properties which have changed over time as the soil has been exposed at or near the surface.

- Immature soils have had little exposure.
- Mature soils have significant exposure.
- The most mature lunar soils have had around 100my exposure time.
What happens as lunar soils mature?

- The mean grain size decreases
What happens as lunar soils mature?

• The mean grain size decreases and the agglutinate abundance increases
• The standard deviation decreases
What happens as lunar soils mature?

- The mean grain size decreases
- The standard deviation decreases
- Agglutinates increase
What happens as lunar soils mature?

- The mean grain size decreases and the agglutinate abundance increases
- Agglutinates increase
- The shape of the grain size distribution changes
How do lunar size distributions compare to experimental data?
Differential grain-size distribution after select number of shots (shot number in upper right-hand corner). Note that the population of >16-32 mm fragments, initially constituting 56% by weight, is ultimately destroyed and the grain-size distribution changes from positively to negatively skewed.
Soils follow an evolution path as they become more mature (Path 1)
Soils may also follow a different evolution path (Path 2)

**SOIL EVOLUTION PATH 2**

MAIN CHARACTERISTIC: MIXING DOMINATES REWORKING

- Fresh ejecta from large crater penetrating bedrock
- Immature soil
- Submature soil
- Mature soil

Physical mixing in discrete increments caused by impacts

- Immature soil type 2 fractional maturity
- Submature soil type 2 fractional maturity
Mixed, path 2 soils may have unusual properties
The evolution of lunar soils can be modeled:
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The model can be described by equations
The evolution of lunar soils can be modeled:

\[
\begin{align*}
\frac{dC}{dt} &= fR - (\kappa_c + \beta) C(t), \\
\frac{dF}{dt} &= (1 - f) R + \kappa_c C(t) + \kappa_a A(t) - (\alpha + \beta) F(t), \\
\frac{dA}{dt} &= \alpha F(t) - (\kappa_a + \beta) A(t).
\end{align*}
\]
Fig. 2. A soil can be plotted as a point on a ternary diagram with coarse particle, fine particle, and agglutinate end members. In a given system, a fresh ejecta soil matures along a calculable trajectory from the CF side to a steady state soil near the center of the diagram. An immature soil and a mature soil from the Apollo 17 site are plotted for illustration. The cross marks on the trajectory represent the positions of an evolving soil in this system at five equally spaced time intervals.
How does regolith evolution relate to regolith thickness?

- **Thin Regolith**: Steady state floor established by lateral mixing.
- **Thick Regolith**: Steady state floor established by lateral mixing. Equilibrium determined by balance between pulverization and agglutination.

Excursions from the steady state caused by nearby impacts which penetrate through regolith to bedrock.

Grain size:
- **Coarse**
- **Fine**

Time
How does regolith evolution relate to regolith thickness?
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Conclusions

- The lunar regolith has evolved in a complex but predictable way.
- Soil maturity is a key concept that must be considered an independent parameter in planning lunar operations.
- For some lunar surface operations it is more important than chemistry or mineralogy.
- Simulants must consider maturity-related properties.
- Simply grinding rock will not produce an adequate simulant.
- Determination of grain size distribution must a key element of future exploration.
A simulant workshop was held 14 years ago; the report is available at LPI.