# Lunar ~~DUST~~ Simulant Standard

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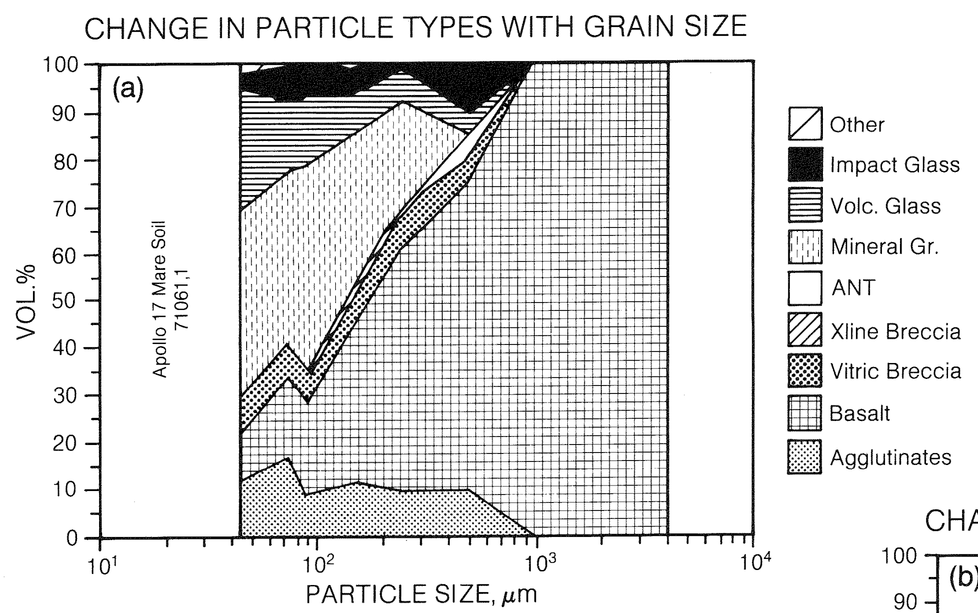
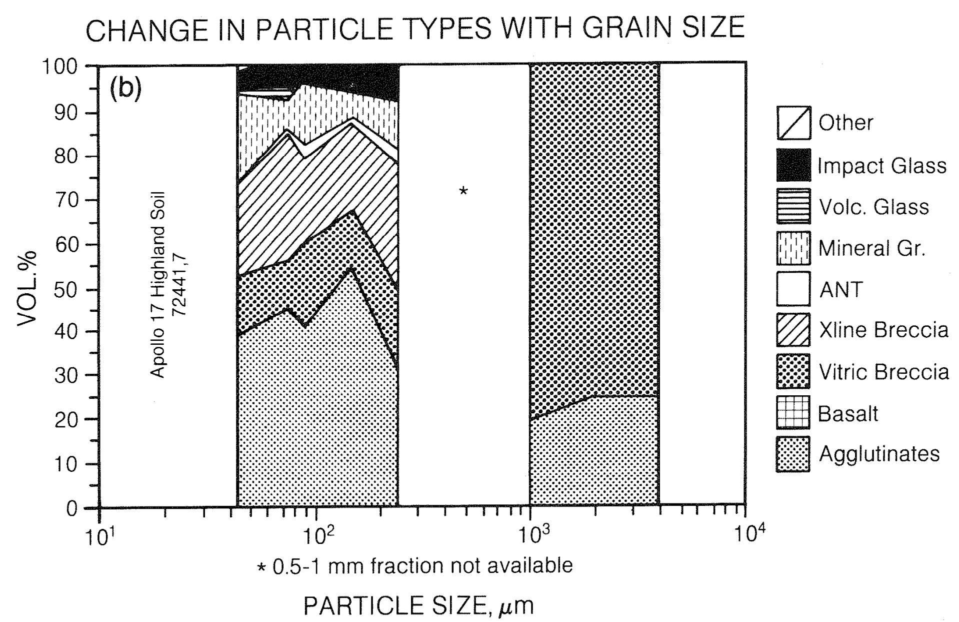
# A Description of Lunar Regolith




Lunar Sourcebook, 1991

# Basic Facts about Regolith

- Sample heterogeneity is higher than anything terrestrial.
- Lithology and mineralogy range across the igneous spectrum but are dominated by a small subset.
- Some of the compositions of interest are at the limits or outside the bounds of terrestrial samples.
- Lithic fragments, glass, minerals and agglutinates are the major constituents
- Many minor phases (less than 5% but greater than 1000 ppm) exist and are wide spread. Some of these phases are likely to be major problems for extractive processes. Examples include S, P, Cl, and F.
- Agglutinates are locally very abundant, forming the majority of the regolith.
- Very, very little is known about the material <20 micrometers.

# Intended Users

- Manufacturers
- Users
  - Procurement
  - Limitations
  - Storage
  - Use
  - Reuse
- Project Management

# Considerations

- List of properties of know interest is very long, > 25. Many more are likely to become of interest as technology and engineering needs progress.
- Most of the properties are not unique (“invertible”) to a specific material. For example a dielectric constant might match sawdust, ground rock, ceramics, etc.
- Divide the properties into two groups: “primary” vs. “derived”. The terms are notional/conceptual, not definitive.
- Attributes of good primary properties -
  - As few as practical
  - Definitive (I.e. invertible)
  - Practical
  - Measured via defined techniques
  - Compare terrestrial simulants to lunar samples (Lunahkod and Apollo)

# Approach

- Fixed method of comparing lunar and terrestrial materials.
- Expressed as a computer algorithm. This eliminates ambiguity and enforces rigor.
- Attributes of good primary properties -
  - As few as practical
  - Definitive (I.e. invertable)
  - Practical
  - Measured via defined techniques
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# Figures of Merit

- Four characteristics
  - Composition
    - •Lithic Fragments
    - •Mineralogy
    - •Glass
    - •Agglutinate
  - Size Distribution
  - Shape (may subdivide this)
  - Density
- As needs change, requirements and FoMs may be added, deleted or modified.
- Equations have been published, STAIF, Albuquerque, New Mexico, Feb. 2007
- Code already implemented and will be demonstrated in June in Sudbury, Canada.

# Publications

National Aeronautics and
Space Administration

MSFC-RQMT-3503
DRAFT
EFFECTIVE DATE: 08-31-2006

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

**MSFC-RQMT-3503**

**Lunar Regolith Simulant Requirements**

**Pre-Decisional**

**DRAFT**

**For Review Only**
**Not For Public Release**
**Not to be used for production**

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May 21, 2007 6:07

# Figures of Merit, Commentary

- Expressed as a computer algorithm with fixed inputs.
- Designed to be extensible in response to new knowledge or needs
- Many, many practical virtues
  - Can compare between simulants
  - Standardized, objective method
  - Users do not have to understand the all the details of the background skills which go into making the simulant
  - Producers shielded from vague specifications

# Vector Expression

The composition of a material (reference or simulant) may be viewed as a vector of the fractions of the various constituents of the material.

**Observation 1** - The elements of a composition vector must necessarily sum to unity (the sum of the fractional parts must equal the whole) **excluding** contaminants. Mathematically, this may be stated as the L1-norm of a composition vector is always 1.

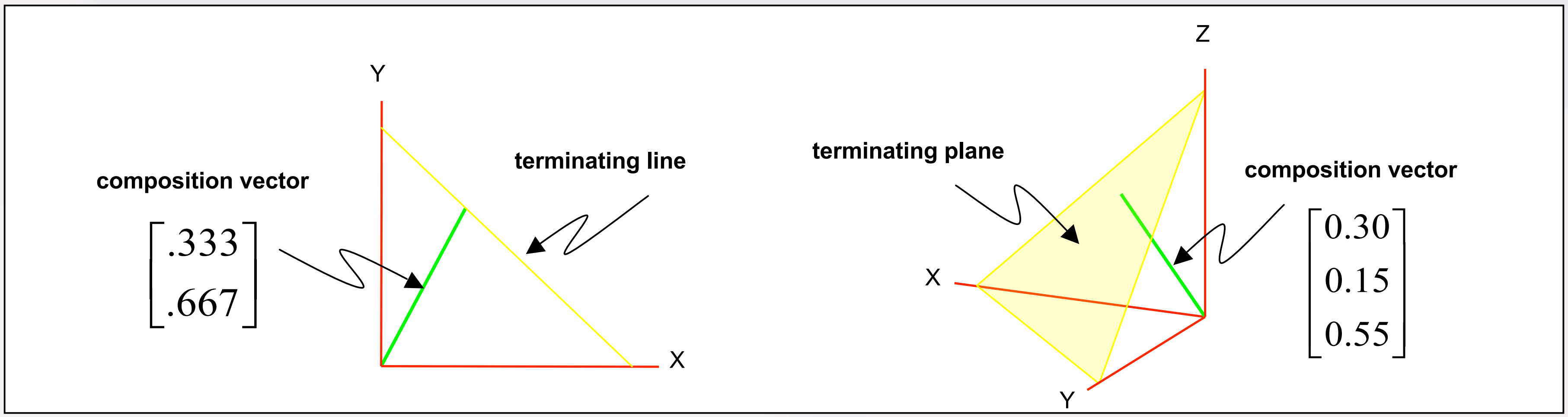
**Observation 2** - A composition vector always terminates on a line (2 dimensions), a plane (3 dimensions) or hyper-plane (4 or more dimensions) which intersects the composition space coordinate frame axes at the unity coordinate points. This follows from the fact that we may write the following equation for the L1 norm of the composition vector:

$$x+y+z = 1$$

where x is the fraction of the $1^{st}$ component, y is the fraction of the $2^{nd}$ component, z is the fraction of the $3^{rd}$ component… which is the defining equation for a hyper-plane.

# Vector Expression, part 2

**Observation 3** - The components of the composition vector are always positive (negative fractions of composition are not allowed), which results in the terminating hyper-plane always lying in the first quadrant. These observations are shown geometrically for the case of 3 dimensions.



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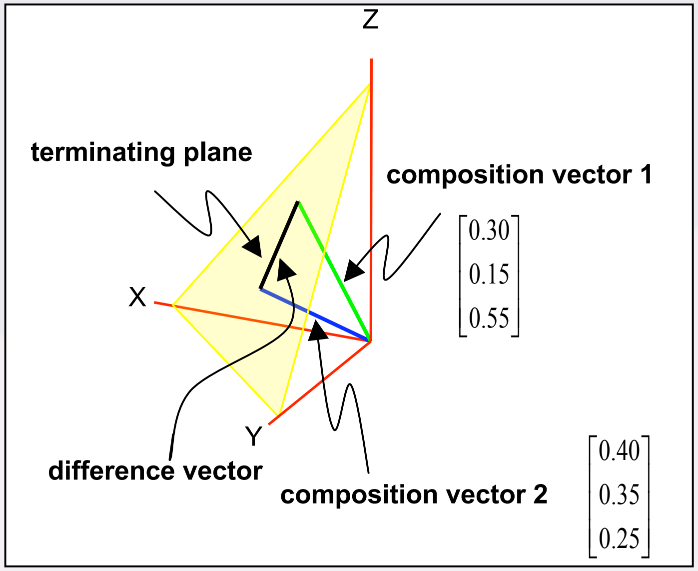
# Graphical Representation

Remember a *Figure of Merit* is a comparison of a reference material to an actual material or better, the comparison of two materials.

The *Figure of Merit* (r) is defined as the normalized difference of two composition vectors subtracted from unity. Normalization forces the difference of two composition vectors to lie between 0 and 1, and subtraction from unity results in a *Figure of Merit* of 1 for a perfect match to 0 for no match at all (as opposed to the other way around).

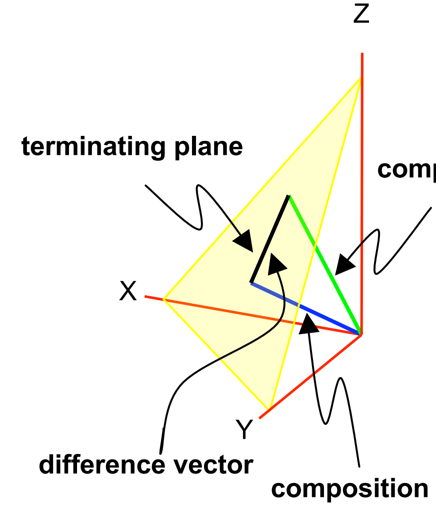


# Normalization

The difference of two composition vectors must always lie in the terminating hyper-plane (because this is where both vectors terminate).

It is obvious that the maximum difference between two vectors results if one material is entirely of one composition, and the other entirely of another. The two composition vectors for such a case would lie along any two of the coordinate frame axes defining the composition coordinate space (and would necessarily be orthogonal).

Two such vectors form the sides of an isosceles triangle, whose hypotenuse is of length $\sqrt{2}$ since the length of each composition vector is 1. Thus the maximum difference between any two composition vectors is $\sqrt{2}$ and this is the normalization factor for their difference.




$$\begin{bmatrix} 0.30 \\ 0.15 \\ 0.55 \end{bmatrix}$$

$$\begin{bmatrix} 0.40 \\ 0.35 \\ 0.25 \end{bmatrix}$$



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# Weighting

The *Figure of Merit* defined for composition also has a weighting vector to weight the composition vector difference. This allows favoring certain components of composition over others. This is equivalent to scaling the axes of the composition space, which has the result that the maximum difference between two different compositions may be other than $\sqrt{2}$.

However, it may be shown that in this case the maximum difference between two different composition vectors is the square root of the sum of the squares of the two largest weights:

$$\textit{normalization factor} = \sqrt{\max_1{}^2(w) + \max_2{}^2(w)},$$

Where $\max_1{}^2(w)$ is the $i^{th}$ largest element of the weighting vector *w* whose weighted square will be computed for the *Figure of Merit*



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# Topics Not Addressed Here

- Contamination
- Measurement technology
- FoM for Shape



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# Implications and Comments

FoMs are critical to defensible specifications for procurement of simulant. Some users will need higher FoMs than others. Note a FoM is a tolerance.

- Numbers approaching 1 are better reproductions of the reference material. This implies:

    - closer tolerances
    - additional quality control in
        - collection, processing, and blending,
    - and particular attention to minimizing contamination.

- Potential vendors may use offsite analytical techniques to verify the simulant FoMs.

- Tighter production tolerances or secondary processing are expected to drive higher costs to the end user.