DEVELOPMENT ISSUES FOR LUNAR REGOLITH SIMULANTS

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Introduction: Significant challenges and logistical issues exist for the development of standardized lunar regolith simulant (SLRS) materials for use in the development and testing of flight hardware for upcoming NASA lunar missions. A production program at Marshall Space Flight Center (MSFC) for the deployment of lunar mare basalt simulant JSC-1A is underway. Root simulants have been proposed for the development of a low-Ti mare basalt simulant and a high-Ca highland anorthosite simulant, as part of a framework of simulant development outlined in the 2005 Lunar Regolith Simulant Materials Workshop held at MSFC. Many of the recommendations for production and standardization of simulants have already been documented by the MSFC team [1]. But there are a number of unanswered questions related to geology which need to be addressed *prior to* the creation of the simulants.

Example Questions: Some questions are remarkably basic. For example, what is the average composition of specific areas of the moon? Estimates for a "typical" Lunar Highlands rock range from hypersthene basalts to strict anorthosites [3,4]. The calcium content of the plagioclase, mechanical and chemical shock-induced features, impact glass and agglutinates are known, in a quantitative sense, to be important [1,2]. This is also true for some minor minerals, such as the spinels, apatite and Ti bearing phases. The oxidation state of iron in the ilmenite and the precise crystallography of Ti-bearing phases are probably important.

Other questions exist because terrestrial sources do not match lunar material in some critical aspects. For example, the grain size of Archean anorthosites or layered intrusives [4] is much too coarse to reproduce the percentage of lithic fragments as a function grain size found in the lunar material during grinding. Most terrestrial sources include minerals containing hydroxyl or water, either as primary or secondary minerals. These will definitely affect melt behaviors and are absent on the Moon. Even the heterogeneity of the regolith is outside that of most terrestrial geologic materials [5,6].

Mining Impacts: Mining and milling of the terrestrial source material will also introduce unwanted or uncontrolled features. What these are and their significance must be established. As an example, ball milling introduces significant variables that include time, velocity of the mill, radius of the mill, characteristics of the feed stock, size and composition of the balls, and additional media (water, gases, vacuum). The mining method used will be important as well. For example, most open pit operations use Ammonium Nitrate and Fuel Oil (ANFO) as explosive. This, of course, introduces carbon and nitrogen contamination. Underground operations use other explosives and quarries may or may not blast at all, depending on the commercial use of their product.

The "environment" of the mine will also introduce features. Most operations involve the use of water, if only for dust control. Human waste can also be an element in run-of-mine material.

Quantification: No simulant can be a perfect reproduction of the Lunar regolith. Questions such as the ones we raise here have to be evaluated but the answers are not really scientific. Rather they are driven by engineering considerations that require quantification when ever possible. One may ask, for example, how much does NASA and its projects would gain by raising the feldspar from An75 to An95 to match lunar compositions more closely?

To describe how well any simulant models the regolith, the MSFC team is considering the use of "Figures of Merit". A Figure of Merit could quantify how closely the simulant reproduces a specific attribute of a hypothetical ideal or specific lunar sample. A suite of these values would tell the user how close the simulant comes to reproducing many properties. Mathematically, each Figure of Merit can be treated as a vector, which makes expression, manipulation and analysis much easier.

The choice of which properties of the regolith to duplicate is based on the needs of the end users and their sensitivity to the level of fidelity of the simulant. This approach requires a methodology to characterize quantitatively both the original source material to be used as a simulant and the effects of processing on the final properties of the delivered material. It is therefore critical that close attention be paid to the constraints placed on materials by terrestrial geology as well as the known limitations of current processing techniques for large quantities of mineral materials. Such exercise is unavoidable if one desires to define reasonable requirements rooted in reality for these standard lunar regolith simulants in terms of bulk chemistry, mineralogy (modal variations, variations in a grain size fraction, and mineral chemistry), grain size, grain shape, angularity, sphericity, glass content, agglutinate fraction, shock features, ion implantation, and other details that have been observed in highland materials.

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