Dust on the table. Developing lunar regolith for long-term colonization of the inner solar system

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On Earth, the terrestrial biosphere, including the entire of humanity is nourished through complex biogeochemical processes occurring in the thin layer of the upper continental crust we colloquially call soil. Soil continuously accumulates nutrients from weathered rock, distributes them in bioavailable forms to biota, and works as a repository and filter for biological byproducts. Soil is a critical part of our life support system, and it is continuously generated through biological weathering (Zaharescu et al., 2019). We envision that any long-term space-exploration endeavor will ultimately learn from and utilize the complex suit of functions that soil provides to sustain expanding colonies and incipient economies. We therefore need to start understanding how different planetary bodies can mediate the production of nutrients as soon as landing opportunities open. Mineral pools are abundant resources on surfaces of most of the inner Solar system bodies, and they can be used for developing a variety of life-support technologies, from water and oxygen extraction, to radiation protection, and fresh food production for the intrepid explorers. This is because of the main characteristic of regolith minerals: that they host the majority of chemical elements necessary for life.

Compositionally, soil is a mineral-organic aggregate comprising a suit of primary minerals – the source of nutrients, an organic matrix – acting as a temporary storage of bioavailable nutrients that microbes, fungi and plants can use to build up biomass, and a variety of secondary minerals, resulting from precipitation of excess ions, and the ultimate fate of chemical elements. A complex viral, microbial, and fungal ecosystem within the organo - mineral pore space gives soil the ultimate function of sustaining vascular plants and animals.

There are a variety of nutrient-rich soils on Earth, ranging from pure mineral on fresh volcanic fields, to purely organic, forming from the decomposition of the litter horizon in temperate forests (Brady and Weil, 2015). Simplified bio-engineered systems for plant growth, such as aeroponics and hydroponics, will always be sought in space colonization, as there will be systems that will make use of the complexity of natural soil environment to help transfer nutrients from local regolith to human use. Some of the advantages of the later is that it can provide CO_2 - removal capability, radiation shielding, help recycle nutrients from wastes, and possibly be a psychological benefit during long missions spent in unfamiliar environments. Nevertheless, astronauts should take advantage of the overly abundant crustal materials on the Moon to study it and obtain nutrients for their life support.

A number of fundamental science questions will have to be answered as soon as lunar landing opportunities open if we are to permanently settle our moon; and they will need to be further explored during subsequent missions to the Moon, Mars, and beyond. Here we succinctly describe a set of science objectives that will be imperative stepping stones in long-term settlement efforts. They meet the science and sustainability themes of the Lunar Exploration Roadmap LEAG, 2016), specifically objectives: Sci-A-3, Sci-D-7, Sci-D-9, Sci-D-12, Sci-D-13, Sci-D-17, Sci-D-20, Sci-D-21, FF-A-1, FF-A-4, FF-C-10, FF-C-11, Sust-B-9 and Sust-B-10.

Science Objectives

1. **Exploring the mineralogical and chemical composition of local regolith**. Many applications will require regolith, from answering fundamental questions about the origin of life on Earth (through preservation of unaltered Earth meteorites), to engineering habitat structures, extraction of propellants, and growing food. Analyzing the chemical and mineral abundances of regolith near landing sites is critical first step in evaluating the local nutrient and water stocks, as well as the potential presence of naturally-occurring contaminants (e.g. heavy metals) and metal resources of interest. Such characterizations are relatively simple to conduct using existing portable X-Ray Diffraction and X-Ray Fluorescence devices.
2. **Evaluating grain size distribution and physical structure with depth**, which should inform about mineral dissolution rates of fast (nanoparticles) and slow dissolving particles, permeability for microbial biofilms, fungi and plant root establishment. Such information will also inform about abrasive and engineering properties of the substrate, such as thrust resistance for landing vehicles.
3. **Measuring radiation absorption capacity of regolith.** This aspect is of critical importance not only for developing adequate radiation shielding for long-duration lunar settlement but also to understand the radiation-mineral-organic interactions on the lunar surface.
4. **Estimating lunar regolith – Terran seeds compatibility**. Keeping a lunar greenhouse may be a highlight of many long-duration missions; however, failures will be inevitable. Developing plant varieties adapted to the Lunar ground requires testing of a plethora of seeds. Suh tests will allow the first astronauts to start building up a knowledge base necessary for subsequent landings.
5. **Testing mineral – organic formulas** (biosolids, food leftovers). It is well known that early explorers that settled the widely dispersed volcanic islands of what is now known as Polynesia, used organic enrichment and rock fragmentation to increase the produce yield on basaltic materials. Such lithic 'mulching' practices were critical to the Rapanui of the Easter Islands, but they were also common in other native populations of Hawaii, Israel, China, Arizona (Hunt and Lipo, 2011). Similar to how the Rapanui created a thriving community on their 'moon-scape' island by learning to extract nutrients from local basaltic rock, astronauts can make use of the lunar regolith for sustainable habitation of their new world. We propose that astronauts of early Artemis missions test various organo-mineral mixtures to understand physical, chemical and microbial activity of new substrates that could aid in the long-term life support efforts.

References

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