

**BIO-WEATHERING OF LUNAR AND MARTIAN ROCKS BY CYANOBACTERIA: A RESOURCE FOR MOON AND MARS EXPLORATION.** I.I. Brown<sup>1</sup>, S.A. Sarkisova<sup>1</sup>, D.H. Garrison<sup>1</sup>, K. Thomas-Keprta<sup>1</sup>, C.C. Allen<sup>1</sup>, J.A. Jones<sup>1</sup>, C. Galindo Jr.<sup>1</sup>, D.S. McKay<sup>1</sup> <sup>1</sup>ARES, NASA JSC (Mail code: KA, 2101 NASA Road One, Houston, TX, 77058; igor.i.brown.@nasa.gov; david.s.mckay@nasa.gov

**Introduction:** Contemporary cyanobacteria (CB) began to occupy different ecological niches in the Precambrian Earth about 3 billion years ago and they are still the leading producers of terrestrial organic matter and oxygen [1]. CB have survived many terrestrial ecological catastrophes, including meteorite bombardment [2] and “Snowball” glaciation [3]. Some cyanobacteria, e.g. *Spirulina*, demonstrate significant resistance to gamma radiation [4]. Other cyanobacteria have been shown to survive the desiccating, freezing conditions of space in orbital experiments [5].

The release of the NASA Lunar Architecture Team lunar mission strategy appears to be very timely and relevant for the development of bio-technologies for long term outpost resource utilization. A more efficient, and lower energy air bioregeneration technique based on the metabolism of lower order photosynthetic organisms with a high capacity of CO<sub>2</sub> scrubbing and O<sub>2</sub> release may prove beneficial. Other, direct and indirect products of bioweathering could provide fuel production, biomass, nutrients, and feed stock for biological and chemical reactions [6]. One such concept is the European Micro-Ecological Life Support System Alternative (MELiSSA) which is an advanced concept for organizing a bioregenerative system for long term space flights and extraterrestrial settlements. The high level of photosynthesis, antioxidant potential and immunocorrection ability of *Spirulina* make this cyanobacterium a key component in the MELiSSA life support loop [7].

Cyanobacteria are also known as very effective litholiths [8, 9]. Given this trait, bioweathering of rocks by extracellular products of microbes (bioweathering) seems to be applicable to ISRU needs on the Moon. Using organic acids, bacteria are able to dissolve different rocks, including such hard rocks as volcanic glass [10], granites, hornblende, and basalts ([11]). Bioweathering of lunar regolith has been considered in studies on the preparation of lunar-derived soil [12]. Because the Moon is practically free of organic compounds but is rich in inorganic elements, it makes sense to use autotrophic cyanobacteria for future extraterrestrial biotechnologies [6]. Cyanobacteria are free of oxygen-motivated respiration upon illumination [13] and are not, therefore, potential consumers of oxygen produced in situ either on the Moon or Mars.



**Figure 1.** *Cyanobacterium JSC-12 growing on ilmenite grains. Single green flakes are biofilm detached from ilmenite grains.*

Numerous species of cyanobacteria have established genetic systems and allow genetic manipulations for enhanced metabolic capabilities [14, 15].

Here we describe our results on the interaction of siderophilic CB with analogs of lunar and martian soils.

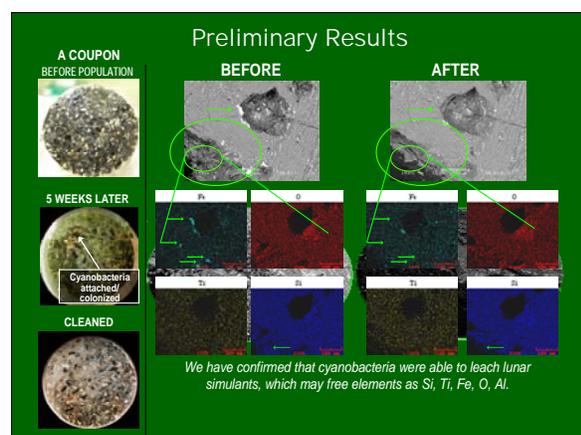
**Results:** We have used several species of siderophilic CB isolated from iron-depositing hot springs in Yellowstone National Park (Brown et al., 2007) to characterize their bioweathering activity. Severe reduction of iron and trace elements in incubation media led to the depression of CB growth while the presence of any analog of either lunar or martian soil in culture media stimulated the growth of CB. In parallel, it was found that rocks stimulated the production of 2-ketoglutaric acid by several species of siderophilic CB. This result led to the hypothesis that the bioweathering activity of CB is bound to the secretion of natural chelators as organic acids. Further studies showed that the efficiency of different cyanobacterial species to break down minerals in lunar simulants varied considerably depending on the species. The selection of the most efficient “biominers” within our collection of siderophilic cyanobacteria was carried out. In particular, the cyanobacterial isolate JSC-12 (previously unidentified species) demonstrated the highest bioweathering activity in comparison to the different isolates. We also carried out a stepped (graduated) selection of the population of endogenous mutants of JSC-12 isolate with elevated resistance to dissolved iron and titanium. As a result, filaments of JSC-12 culture were able to grow directly on the surface of the ilmenite grains composed of about 50 percent iron and titanium (figure 1).

The model for studying the bioweathering of lunar simulants was elaborated by further experiments. Grains of either Minnesota basalt or ilmenite were imbedded in epoxy. Solidified coupons were polished and were studied by scanning electron microscopy (SEM) and energy-dispersive x-ray spectroscopy

(EDS) before and after treatment with cyanobacteria (figure 2, left vertical panel). Figure 2 (right upper panel) demonstrates the physical decrease of the size of a Minnesota basalt grain after dissolution by a cyanobacterium (compare the shape of the same grain in the left lower corner). Elemental maps of iron distribution confirmed iron removal from iron-bearing mineral grains (white on black and white pictures and bright blue-green on maps for iron). TEM studies revealed that siderophilic CB accumulate colloidal iron in or on cyanobacterial cells rather than in a cultivation medium.

**Conclusion:** Preliminary results suggest that it would be reasonable to use the bioweathering potential of litholithic CB for the transition of different chemical elements from extraterrestrial rocks to an aqueous phase where they will be available for different applications, such as the preparation of substrates for hydroponic cultivation. Further studies of the bioweathering activity of litholithic CB should identify the list of chemical elements which can be extracted from rocks by CB. A no less important task will be to identify patterns in the distribution of released elements between the aqueous phase and bacterial cells, as well as the resorption of release elements on solid phases. The level of our knowledge about the interaction of CB with extraterrestrial minerals is rapidly increasing, but is currently at a low technology readiness level. It is clear that the development of CB bioweathering to industrial levels will require considerable efforts of taxonomists, physiologists, geochemists, and molecular biologists.

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**Figure 2.** Bioweathering of Minnesota basalt grains by siderophilic CB JSC-12. Explanations are in text.

**References:** [1] Tomitani A. et al. (2006) PNAS U S A, 103, 5442-5447. [2] Cockell CS. (2006) Philos.