



Regolith weathering thorough heating samples under reducing conditions for Phobos surface studies

Jérémie Lasue, Patrick Pinet, Michael J. Toplis, Pierre Beck, Loise Cao, Pascal Munsch

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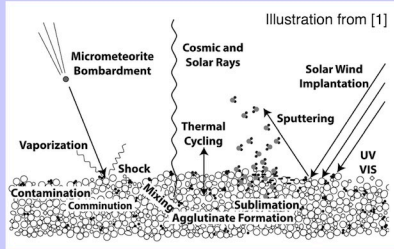
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Introduction

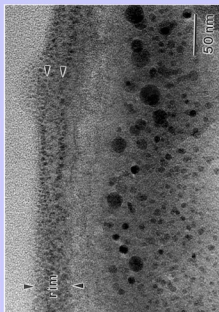
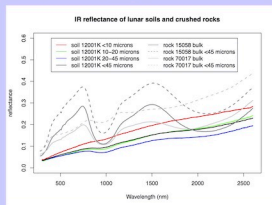
Atmosphereless bodies of the Solar System present surface evolution under the conditions of space weathering. Their regolith is exposed to thermal cycling, cosmic and solar rays irradiation, solar wind sputtering and micrometeorites bombardment and vaporization.



With time, the regolith accumulates optically active opaque particles such as nanophase metallic iron particles on the surface or rims of dust grains. The density increase in iron particles modifies the spectral properties of the material with a reduced albedo, and absorption bands generally associated with a global reddening of the spectral slope [1, 2].

Previous studies have shown that nanophase iron particles inducing weathering spectral properties will accumulate at the surface of olivine and pyroxene minerals under heating conditions simulating micrometeorite impacts by pulsed laser [3].

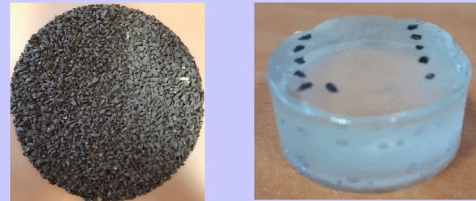
Comparison of IR reflectance for lunar soils and crushed rocks with different fractions showing the reddening effect of npFe⁰ in the lunar soil fine fractions (adapted from [4, 5]).



TEM image of lunar agglutinate illustrating the presence of npFe⁰ forming two layers within the rim but larger Fe⁰ in the interior of the grain, from [1]

Experimental setup and samples

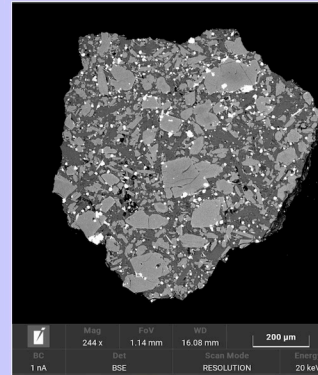
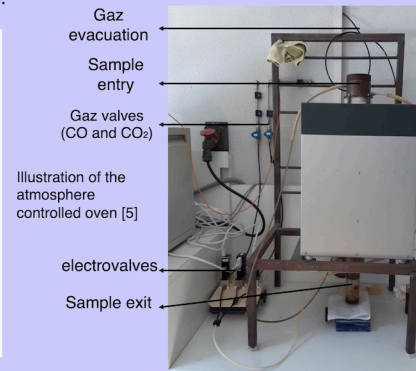
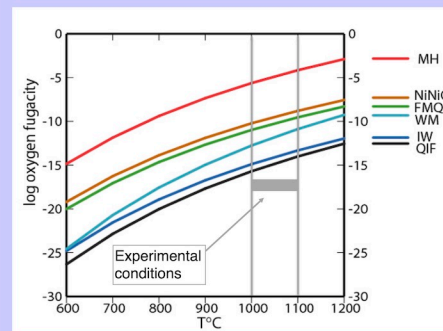
We prepare **laboratory weathered analogues** samples from a basalt lunar analog used previously for laboratory studies on the lunar regolith optical and spectrophotometric behavior (Pic d'Ysson basalt) [6]. The basalt grains are crystalline (as shown on the figure, with minerals of olivine, pyroxene, plagioclase and ferroilmenite). The sample granulometry has been sieved to a range from 0.5 to 1mm, which is the most abundantly available for the study.



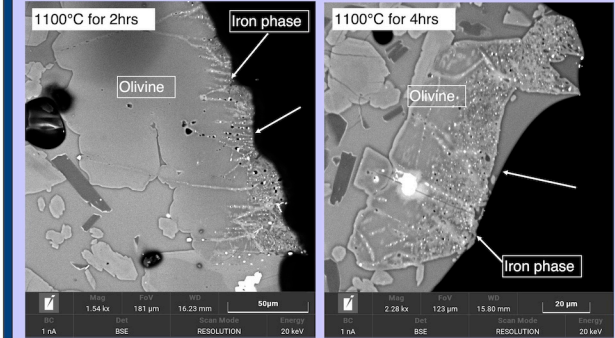
| SiO ₂ | Al ₂ O ₃ | Fe ₂ O ₃ | MnO | MgO | CaO | Na ₂ O | K ₂ O | TiO ₂ | P ₂ O ₅ |
|------------------|--------------------------------|--------------------------------|-----|------|-----|-------------------|------------------|------------------|-------------------------------|
| 42.8 | 11.5 | 12.9 | 0.3 | 15.3 | 9.6 | 2.7 | 1.2 | 2.1 | 0.6 |

Illustration of the Pic d'Ysson lunar basalt analog sample [6]

The sample is heated to **near melting temperature** (1000-1100°C) in an atmosphere controlled oven under **reducing conditions** [7]. A partial pressure of CO/CO₂ of 96% is used corresponding to an oxygen fugacity of about 10⁻¹⁷ mimicking the space environment alteration effects. Choosing this fugacity places us well below the Iron-Wustite (IW) buffer curve. The samples are altered for different exposure times ranging from 1 to 8 hours.

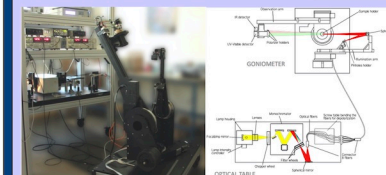
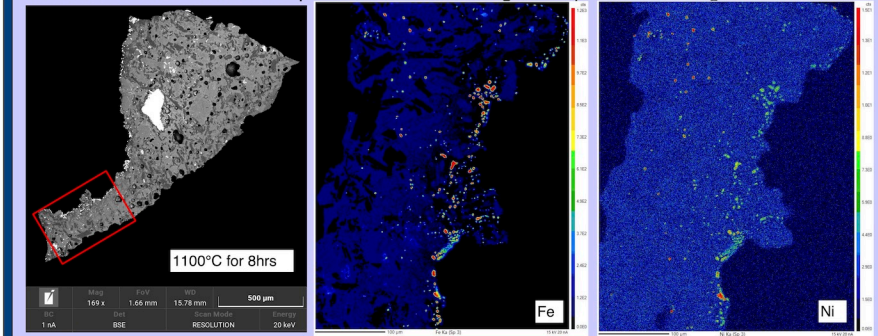


Results and future work



Submicronic metallic Fe, also referred to as nanophase iron particles (npFe⁰) [8] appear on the surface of the weathered samples analysed with SEM. The thickness varies with the duration of exposure to 1100°C (~10 microns for 2hrs, ~20 microns for 4hrs)

The iron phase dimensions vary. Nanophase iron is dominant in olivine grains, while pure iron phase grains of several microns can appear directly on the surface of basaltic matrix. A grain altered at 1100°C for 8hrs was analyzed with a scanning electron microprobe (Sx5ive Cameca). The iron phase is dominant in the grain, but the Ni / Fe ratio varies indicating that the alteration is not homogeneous (thickness of 50 to 100 microns). These experiments demonstrate the use of such a process to simulate long-term space weathering conditions.



Infrared reflectance spectra will be measured using the **SHADOWS spectro-gonio-radiometer available at IPAG** [9]. Bidirectional reflectance spectra are measured with a photometric accuracy below 1% in the 0.5–3.0 μm range with a sampling interval of 10 nm.

- Analogs for space weathering can be prepared in the laboratory by using short heating under reducing conditions.
- Exposure to such conditions generate nanophase iron particles on the surface of grains, changing their optical properties.
- Future studies will be made using different exposure times, and granulometry to study the infrared reflectance properties of grain samples and compare them with airless bodies, especially Phobos.

[1] Pieters, C.M., & Noble, S.K. (2016) JGR, 121(10), 1865-1884. [2] Hapke, B. (2001) JGR, 106(E5), 10039-10073. [3] Weber, I., et al. (2020) EPSC, 530, 115884. [4] Taylor, L.A., et al. (2001) JGR, 106(E11), 27985-27999 [5] Isaacson, P.J., et al. (2011) MAPS, 46(2), 228-251. [6] Souchon, A.L., et al. (2011) Icarus, 215(1), 313-331 [7] Toplis, M.J., & Corgne, A. (2002) Contributions to Mineralogy and Petrology, 144(1), 22-37. [8] Pieters, C.M., et al. (2000) Meteor. And Planet. Sci., 35, 1101. [9] Potin, S., et al. (2018) Applied optics, 57(28), 8279-8296.