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Space weathering of Fe-poor silicate regoliths: Reflectance spectra and SEM/TEM studies of laser-irradiated andesine-labradorite

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Abstract

To assess possible effects of micrometeorite bombardment on Fe^{2+}-poor regoliths, we performed spectral reflectance and SEM/TEM studies of a natural plagioclase (andesine-labradorite) irradiated with a nanosecond pulsed laser. Our results suggest that ~0.8 wt.% FeO in the target is insufficient to produce optical darkening and reddening associated with the formation of nanophase Fe^0 (np Fe^0) inclusions.

1. Introduction

Surfaces of airless solar system bodies are optically modified by space weathering processes, including micrometeorite bombardment and interaction with solar wind plasma. Fe-bearing silicates darken and redden due to reduction of their Fe^{2+} or Fe^{3+} to Fe^0, which is well documented for targets with ~10 wt.% FeO. However, some regoliths, e.g., on Mercury and some asteroids, may contain very little FeO, and it is important to understand, to what extent their albedos and spectra may be modified by space weathering.

2. Samples and Experimental Procedures

A well-characterized [1] natural andesine-labradorite (An_{47-52}) sample was magnetically separated and carefully hand-picked to remove magnetic and visually-detectable accessories such as biotite and ilmenite. After these procedures, the bulk chemistry of the sample shows 0.77 wt.% FeO, while the pure andesine-labradorite grains contain <0.08 wt.% FeO [1]. The major sources of FeO in the sample are traces of mica, ilmenite and enstatite (En_{71-74}). To simulate micrometeorite bombardment on an FeO-poor target comparable with the hermean regolith and other FeO-poor silicate targets, two pressed pellets of the powdered andesine-labradorite were irradiated with nanosecond laser pulses (see [2] for details). Biconical reflectance spectra were acquired from 0.45 to 18 μm at i=e=20° using a Bruker IFS88 FTIR-spectrometer equipped with a "Seagull™" reflectance accessory. A Zeiss 1540 XB Focused Ion Beam-Scanning Electron Microscope (FIB-SEM)

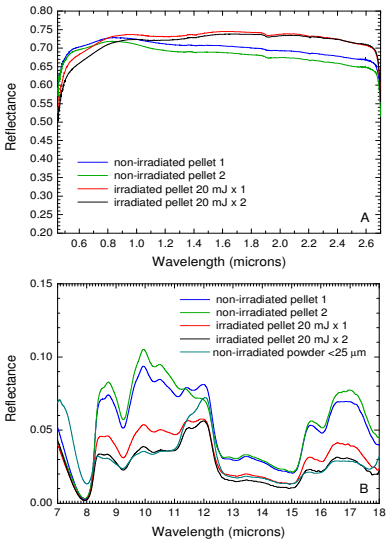

Figure 1: Reflectance spectra of non-irradiated and irradiated areas of the plagioclase pellets

was used for cutting out a lamellae perpendicular the surface of a labradorite grain. A part of the pressed pellet was carbon coated before the FIB-SEM studies. Transmission electron microscopy was carried out using a Zeiss Libra 200FE TEM operating at 200 kV.

3. Reflectance Spectra

Fig. 1 shows average spectra of non-irradiated areas of the two andesine-labradorite pellets, compared to those of the pellet areas exposed to single (20 mJ x 1) and double (20 mJ x 2) scanning irradiation. No darkening is evident. This is similar to earlier reported results on laser-irradiated anorthite pellets [3]. Mild spectral reddening is observed in the NIR (Fig. 1). The TIR spectra of the irradiated pellet surfaces show more prominent Transparency features and weaker Reststrahlen bands compared to the non-irradiated areas of the pellets. Analysis of the spectra and their comparison with those of a fine powder indicate that the described effects are largely due to surface roughness changes – e.g., laser-induced "gardening" the originally smooth pellet surface.

4. SEM/TEM results

The surface studies of the pellet under the SEM show significant melting of the grain surfaces. In the FIB cut section, a 2-4 µm-thick melt layer is seen over the plagioclase grain (Fig. 2). The melt layer contains unmelted plagioclase clasts and many vesicles (500 nm – 1 µm in diameter. No $npFe^0$ particles were detected within the melt layer during preliminary TEM studies. Two melt droplets (10-15 µm in diameter) and many small (~1 µm) melt spherules of ilmenite composition were found between plagioclase grains in the pellet. These findings are similar to the recently reported TEM study of laser-irradiated meteorites [4] but the lack of $npFe^0$ didn't allow us to detect a vapor deposit layer, if present.

5. Conclusions

The irradiation with a nanosecond pulsed laser did not produce darkening and significant reddening of a natural andesine-labradorite sample. The mild spectral alteration is probably caused by textural effects. The lack of nanophase Fe^0 inclusions within the irradiated surface areas studied by TEM support this interpretation. Our results indicate that the nanosecond laser irradiation produces a vesicular melt layer up to several micrometers thick. The described effects differ from those observed after irradiation with a pulsed laser of FeO-richer (~10 wt.% FeO) targets [e.g., 2] and show that the presence of Fe in target minerals is crucial to produce space weathering-induced darkening and reddening of planetary regoliths. As less as 0.77 wt.% FeO in the Hermean regolith would probably be insufficient to produce low albedo and reddish color of Mercury by micrometeorite bombardment.

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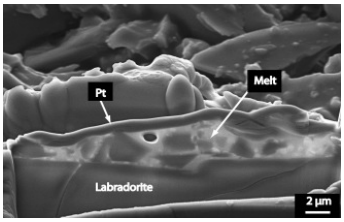

Figure 2: SEM image of the FIB section cut perpendicular to a plagioclase grain. A layer of platinum (Pt) was deposited over the FIB lamellae.