LASER SPACE WEATHERING OF POSSIBLE (1) CERES ANALOGS.

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Introduction: Spectral studies of mineral and meteorite analogs for (1) Ceres [1-5] are done on non-space weathered materials. Linking these analog materials with (1) Ceres spectrally is made complicated by space weathering (SW). Two principal SW processes that affect regoliths on airless bodies are solar-wind irradiation and micrometeorite impacts. Together these processes serve to generally darken, redden (i.e., the Vis-NIR continuum slope steepens), and reduce diagnostic absorption features of the minerals as a function of exposure [6,7].

Spectra of fresh and laser space weathered (1) Ceres analog materials are compared to assess which spectral bands persist and which are more easily erased during micrometeorite related SW. The aim is of this research is two-fold: (1) Disclose which absorption bands persist and can therefore be used reliably for mineral identification; and (2) Document bands that shift band center or are easily erased during SW.

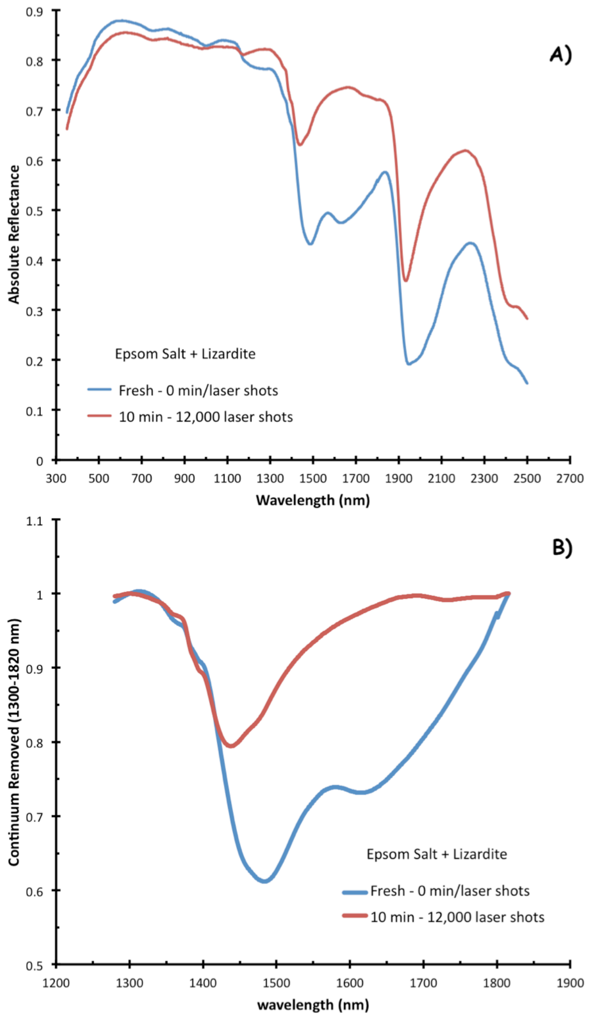


Fig. 1 Fresh and laser space weathered epsom salt mixed with lizardite A) absolute reflectance and B) continuum removed spectra.

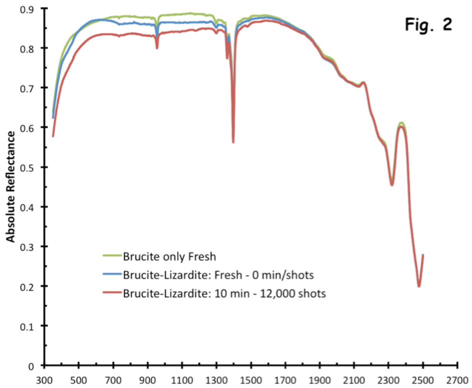
Methods: Laser irradiation experiments were performed on (1) Ceres-like mineral analogs: brucite (MgO), epsom salt ($MgSO_4{\cdot}7H_2O$), lizardite ($Mg_3[Si_2O_5](OH)_4$), siderite ($FeCO_3$), cronstedtite $Fe^{2+}{}_2Fe^{3+}(Si,Fe^{3+}O_5)(OH)_4$, Murchison, and mixtures of these components. The samples were ground in a quartz mortar and pestle. Samples were then dry-sieved to a grain size was <75 µm. In order to characterize experiment reproducibility, three 0.3 g aliquots each uncompressed powdered sample were used for pulsed laser irradiation experiments.

Micrometeorite impact heating was replicated using a Nd:YAG (1064 nm), pulsed (20 Hz) laser. Pulse duration is 5–7 ns, which is comparable to the timescale of micron-sized micrometeorite impacts. Pulse energy was 30 mJ. Irradiations were done in 1,200 pulses or 1-minute increments using a rastered beam, for a total of 12,000 laser shots or 10 minutes. These experiments simulate approximately 1.2×10^{8} years of micrometeorite exposure. Laser weathering experiments were performed under vacuum of $\sim1\times10^{-6}$ torr using an oil-free turbo/roughing pump combo.

Vis-NIR spectra were measured using a Analytical Spectral Devices Inc. FieldSpec 4 spectrometer. The spectral range is from 0.4–2.5 µm with 1 nm (Vis) to 10 nm (NIR) spectral resolution. Spectra were acquired using a standard 30° phase angle (30° incidence and 0° emission). Reflectance was measured relative to multiple Spectralon reflectance standards.

Results: Spectra for epsom salt+lizardite (95:5), brucite+lizardite (90:10), and siderite are present here. Laser weathering of brucite alone produced no changes in spectra. Spectra and conclusions based on laser weathered Murchison, cronstedtite, and lizardite were shown in previous studies [8-9].

Laser weathering of the epsom salt and lizardite mixture produced dramatic changes in spectral absorptions. The fresh mixture exhibited strong absorption bands at 1480, 1620 and 1935 nm and weak absorption bands at 730, 975, 1185 nm (Fig.1A). These absorption bands are attributed to epsom salt, absorptions associated with lizardite (i.e., 500 and a broad 1000 nm absorption) are not apparent. After 10 accumulated minutes or 12,000 laser shots, the 975, 1185, and 1620 nm bands disappeared (Fig. 1). The 1480 band center shifted to 1430 nm, the 1935 nm band center shifted to 1925 nm, and both became narrower. The visible continuum (350-700 nm) became slightly darker; from 700-1500 nm the spectrum became slightly darker and redder (but still a negative slope), and beyond 1500 nm the laser space weathered spectrum of epsom salt and lizardite became brighter than the fresh spectrum.



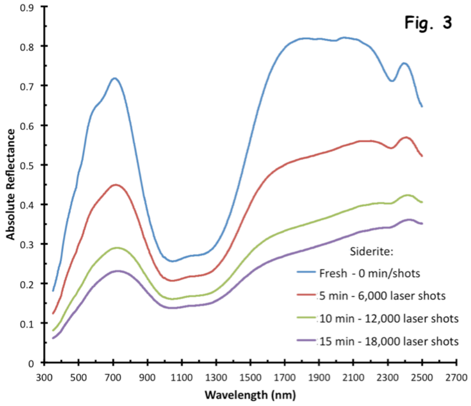


Fig 2 Absolute reflectance of brucite (fresh) and brucite mixed with lizardite (fresh and laser space weathered. **Fig 3** Spectra of siderite fresh and space weathered.

The mixture of brucite and lizardite showed less dramatic changes in spectra. Brucite exhibits very strong absorptions at 1400, 2310 and 2475 nm (Fig. 2). Absorption bands associated with lizardite are barely apparent (500 nm and a broad 1000 nm absorption). After 10 minutes or 12,000 laser shots, the visible-near-IR continuum of the mixture became slightly darker and redder. Beyond 1400 nm there is little no change in spectral properties between the fresh and weathered mixture.

Siderite also showed considerable spectral changes upon laser weathering (Fig. 3). Spectra of fresh siderite showed a steep slope in the visible, and broad 1200 nm band and a narrower 2325 nm band. With each increment of laser irradiation the spectrum became flatter/bluer, darker, the 1200 nm band decreased by about half and the 2325 nm band was nearly erased.

Discussion: These experiments illustrate how spectra of minerals and simple mineral mixtures change in response to micrometeorite simulated impacts. Spectral matching and radiative transfer modeling are powerful tools for understanding spectra of planetary surfaces. Experiments such as laser and proton irradiation are necessary because they yield chemical and physical changes that spectral matching with unirradiated and modeling cannot capture.

These experiments targeted possible analog materials observed in Dawn spectra of (1) Ceres. For instance, [1] used absolute reflectance and shape of the spectra from the Dawn framing camera to constrain the composition of the bright spots on the floor of Occator crater. The peak in reflectance for epsom salt mixture examined here is 560 nm, which is similar to maximum reflectance of 550 nm for bright spots [1]. Further, measurement by Dawns Visible-Infrared Mapping Spectrometer reveal (1) Ceres exhibits abundant absorption bands in the 2.5–4 µm region [2]. Unfortunately our data do not cover this portion of the NIR; however, we do plan to collect data at these wavelengths in the near future to assess whether diagnostic bands over this spectral shift or disappear like we observe for shorter wavelengths.

Conclusions: These laser irradiation experiments demonstrate some minerals appear resistant to space weathering (i.e., brucite), while diagnostic spectral bands of other minerals disappear and/or shift. For instance, the epsom salt mixture lost bands at 975, 1185, and 1620 nm; siderite lost a band at 2325 nm; and Murchison lost its phyllosilicate band at 700 nm [8]. Absorption bands for epsom salt + lizardite reveal shifts in two spectral bands (i.e., 1480 and 1935 nm) with laser exposure. These experiments also provide evidence as to weather spectra darken or brighten over some or the entire spectra range being measured (i.e., epsom salt mixture), and whether spectra become flatter/bluer or redder/steeper with irradiation (i.e., cronstedtite [9] and siderite. These data will help further our understanding of the surface composition of (1) Ceres.

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