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Processed meteorites and weathered asteroid spectra analysis for low cost cubesat detector optimization

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Artificial space weathering tests on NWA 10580 CO3, NWA 11469 CO3, NWA 5838 H6, NWA 4560 LL3.2, and Dho 007 Eucrite meteorites using solar wind relevant proton irradiation were performed. The experiments revealed increased iron content, amorphization, water loss, and structural changes that typically reduce the mechanical hardness of the outermost surface layer. Results support both meteorite-asteroid linking and optimization of future infrared detector channel arrangement for cubesat asteroid missions.

Introduction

Artificial space weathering tests in the laboratory of ATOMKI on meteorites using solar wind relevant proton irradiation were performed. The simulation corresponded to 10-100 million years of space weathering exposure, and the resulting changes were detected by infrared, Raman, SEM and XRD measurements before and after the irradiation actions. The aim was to better understand the modifications by surveying the sample with different methods and interpreting the results jointly. The findings are expected to support a better understanding of asteroid spectra, the linking of meteorites to source asteroids, and improved detector band localization for upcoming missions.

Simulated solar wind can induce mineral amorphization, detectable by infrared (IR) spectroscopy (Demyk et al. 2004; Lantz et al. 2015) and Raman spectroscopy (Brucato et al. 2004; Demyk et al. 2004), through band shifts in silicates and compositional changes (Hapke et al. 1975). Nanophase iron-nickel particles have also been identified in CV and CO chondrites post-irradiation (Zhang et al. 2023). These effects are primarily analyzed using Fourier Transform Infrared (FTIR) spectroscopy on bulk samples (Lantz et al. 2017; Brunetto et al. 2014, 2020), and Raman spectroscopy (e.g., olivine: Lantz et al. 2017; polystyrene and olivine: Kanuchova et al. 2015). Beyond scientific interest, understanding the composition and mechanical properties of Near Earth Asteroids - potentially influenced by surface modification of grains within rubble pile structure objects - is essential for developing effective mitigation strategies and improving the spectral correlation with meteorites.

Methods

The meteorite samples (NWA 10580 CO3, NWA 11469 CO3, NWA 5838 H6, NWA 4560 LL3.2, and Dho 007 Eucrite) were irradiated with 1 keV H^+ protons produced by the ECR ion source (Biri et al. 2021) at the ATOMKI institute under vacuum conditions, up to a fluence of 10^{17} ion/cm^2. The samples were analyzed before and after irradiation actions using the following facilities. For sample analysis FTIR spectroscopy was performed using a Vertex 70 spectrometer with 32 scans in the

400–4000 cm^{-1} range, measured for 30 s at 4 cm^{-1} spectral resolution, processed using Bruker Optics' Opus 5.5. software. Raman spectroscopy was applied using a Morphologi G3-ID instrument (Malvern Instruments; Garzanti et al. 2015) and a Kaiser Optical Systems Inc. Raman Rxn1 Spectrometer with NIR Laser Diode at 785 nm wavelength. Measurements were taken with an exposure time of 30 s at 10 mW laser power over the 150 - 1150 cm^{-1} range. The laser spot size was 3 μm at 50× magnification, with a spectral resolution of 1 cm^{-1} and a focal depth of 1.82 μm. The Scanning Electron Microscope (SEM) used was a JEOL JSM-IT700 HR, operated at a 20 keV voltage and 6 nA beam current, with a 40 s point integration time and 100 s areal integration time.

Results

A range of changes was observed in peak positions, FWHM values, and the disappearance of minor bands, indicating the following sequence of alterations during the series of irradiation and measurement sequences.

- Metastable phases may form ephemerally under conditions differing from those of stability, as shown by Lindsley et al. (1972) in their identification of metastable pyroxferroite related to smectites in cosmic materials, or in specific mineral-like alloys(Lilienfeld et al., 1987), where irradiation modified grain boundaries and dislocations (Chesser et al., 2024). However, such effects have rarely been explored in irradiated meteorites.
- Defect production occurred in the crystalline lattice during the next phase, where vacancy migration was likely influenced by temperature (Campbell et al., 2002,). These defects could reduce band strength and increase FWHM in general.
- Element migration, replacement, and ion integration occurred, particularly affecting olivine composition, which changed from Fo-50–60 (Hamilton 2010) to Fo-30–35 after irradiation in Frontier Mountain 95,002 and Lancé meteorites (Brunetto et al., 2020), as well as in Tagish Lake sample following ion irradiation (Dukes et al., 2015). We also observed an increase in the Fe/Si ratio during the later stages of the tests at elevated irradiation fluence.
- Amorphization and mineral decomposition were characteristic of the later phase of the tests, occurring at higher levels of irradiation. Excessive defect formation and element loss or implantation were observed. In silicates, depolymerization of SiO_4 tetrahedra and lattice decomposition led to the weakening, and disappearance of spectral bands.

We also evaluated mineral identification possibilities using different spectral resolution, as onboard cubesats simple detectors are expected to be used for asteroid missions frequently in the near future. Spectral coarsening, achieved by artificially lowering the resolution with averaging data points, leads to flattening on a smaller scale. Smaller peaks tend to disappear quickly with the worsening resolution.

Discussion and Conclusion

The experiments revealed increased iron content, amorphization, water loss, and structural changes that typically reduce the mechanical hardness of the outermost surface layer, supporting the linking of meteorites to asteroids; however, one major further step remains: the inclusion of laser-shot-simulated microscopic impact effects, resulting melting, darkening and nanophase iron formation. The major infrared spectra bands are more strongly influenced by spectral coarsening than by space weathering, although both effects should be considered.

A further unexplored topic is the possible mechanical and thermal consequences of space weathering. It may be worth evaluating whether irradiation-induced grain surface alteration (particularly mechanical weakening and reduced heat conduction capacity) could affect the collective behaviour of grain assemblages under YORP-induced forces, where grains are moving next to each other. These forces gradually reshape asteroid bodies and mix their components. The results suggest that both mineralogical and morphological changes may occur over timescales of 10–100 million years. Theoretical implications and open research questions are also discussed.

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