# Particle track densities in olivine of the heated Jbilet Winselwan CM2 chondrite: Constraints on regolith heating?

Dennis Harries[1] and Philip Wild[1]

[1]*Institute of Geosciences, Friedrich Schiller University Jena, Carl-Zeiss-Promenade 10, 07745 Jena, Germany (Email: dennis.harries@uni-jena.de).*

Sample-return missions underway to the near-Earth objects 101955 Bennu (OSIRIS-REx) and 162173 Ryugu (Hayabusa 2) are expected to return surface regolith from two primitive C-group asteroids for laboratory study. Spectroscopically the C-group asteroids share similarities with CI and CM chondrites and are likely parent bodies of these meteorite groups. Material returned from the Moon and S-type asteroid 25143 Itokawa has shown that phenomena related to space weathering are well-recorded on the surface of silicate grains [1]. The degree (or maturity) of space weathering can potentially provide insights into the evolution of regoliths and, therefore, shed light on the dynamical evolution of near-Earth asteroids and their orbits [2,3,4]. Olivine is a good candidate for comparative taxonomy of space weathering due to its wide-spread occurrence in lunar and asteroidal samples and its experimentally extensively studied properties. If C-group asteroids are indeed related to CI and CM chondrites, olivine is expected to be a significant mineral in their regoliths. However, aqueous and thermal alteration processes recorded in CI and CM chondrites potentially leave morphological and chemical signatures on mineral surfaces, onto which space weathering would be superposed. This motivated us to investigate olivine grains of the Jbilet Winselwan (JW) meteorite, a moderately heated (tentatively <500 °C) CM2 chondrite [5]. In particular, we try to understand how olivine grains and the phyllosilicate mineralogy of JW can be used to constrain the heating event, which may have taken place in a number of different settings, e.g., deep in the CM2 parent body, in the regolith of a rubble-pile asteroid, or during the meteoroid stage of JW's travel towards the Earth.

**Material and Methods**: A 37.6 gram fragment of JW was sliced using a diamond wire saw and interior slices were used to produce two polished petrographic sections (~20×30 $mm^2$) and cuboidal subsamples (~10×7×7 $mm^3$). The cuboids were subjected to 100 to 150 cycles of freeze-thaw disaggregation in high-purity water. After drying, olivine crystals were separated by hand-picking and mounted onto SEM stubs or epoxy-embedded and polished. The grain mounts and polished petrographic sections were studied by field-emission SEM. The polished grain mounts were etched in WN solution in order to reveal damage tracks produced by ionizing, high-energy particles [6].

**Results and Discussion:** SEM imaging of the JW petrographic sections indicates subtle textural heterogeneities, most evident by variations in the abundance of serpentine/tochilinite-like aggregates. There is no obvious brecciation as seen in other CM2 chondrites [7] and specimens of JW [8]. Many components (dominantly chondrules) are surrounded by fine-grained rims, and the general texture resembles a primary accretionary rock [7]. The freeze-thaw disaggregated material is a black, non-cohesive powder (~80% <100 µm, ~50% <50 µm).

Euhedral to subhedral olivine crystals are optically prominent objects in the powder. The hand-picked olivine grains have median sizes of ~240 µm and a size range of 100 to 600 µm. Comparison with the petrographic sections suggests that the larger grains often occur as single grains within the meteorite. The smaller ones are most probably derived from porphyritic chondrules. The surface morphologies show a large diversity and can be subdivided into 'as-grown' crystal surfaces and fractured surfaces. Pristine surfaces are smooth and featureless, fresh fracture surfaces are typically characterized by step-like hackle marks. Altered surfaces have developed significant roughness through dissolution and the formation of secondary mineral scales. Such features superposed on surfaces with hackle marks suggest that fracturing had occasionally occurred before aqueous alteration.

We have studied a total of 81 olivine grains from three interior cuboids of JW for particle tracks, and etching has revealed tracks in 65 of them. In all cases the track densities are $<5\times10^4$ tracks/$cm^2$ (Fig. 1), and the median is ~9400 tracks/$cm^2$ (~6500 tracks/$cm^2$, if upper limit track densities for track-free grains are considered). The maximum track densities found in two grains are approximately consistent with the background track densities due to galactic cosmic rays (GCR) in typical CM2 chondrites [7]. However, the median values are much lower than typical GCR background track densities. The absence of brecciation and track-rich grains ($>10^6$ tracks/$cm^2$, from irradiation by solar flare ions) indicates that the material of our JW specimen was never exposed in the upper few millimeters of a regolith. This is corroborated by the absence of solar wind noble gases in other samples of JW [9]. However, JW's unusually long Neon exposure age of 6.6±1.7 Ma [9] and the very low GCR track count suggests that GCR tracks may have been partially annealed by the, so far unidentified, heating event.

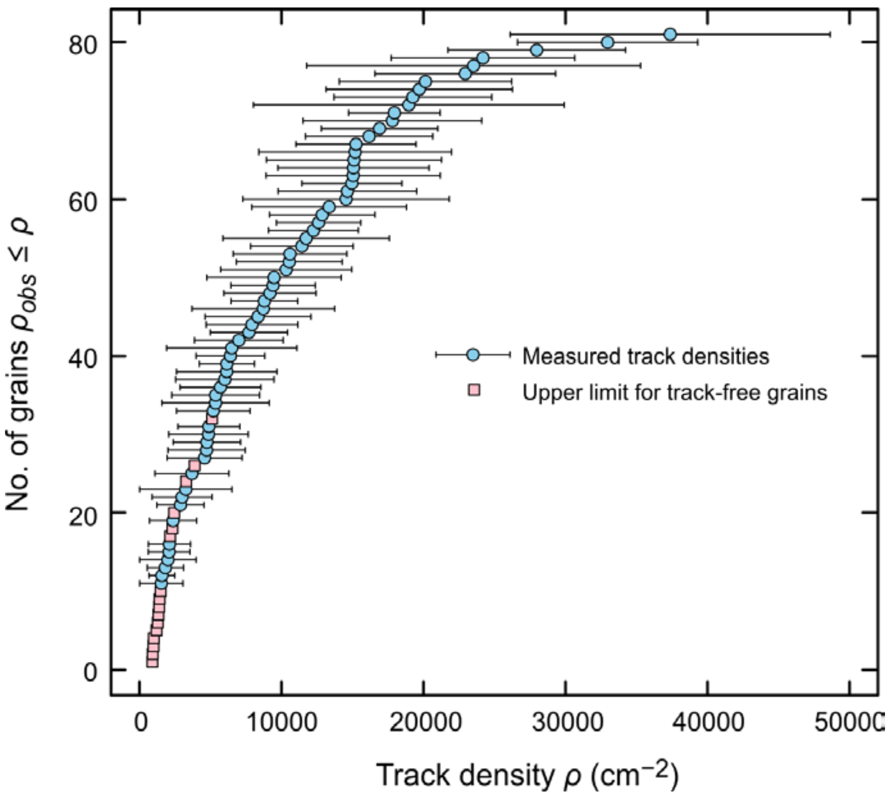


Figure 1. Cumulative plot of the particle track densities in Jbilet Winselwan olivines.

If JW was heated deep within its parent body, then GCR tracks and GCR-produced neon should have been acquired consistently during the meteoroid stage, unless the meteoroid that delivered JW to Earth was very large, and our specimen was deeply shielded within. The freshness of most JW specimens and the total known mass of JW meteorites of less than 10 kg (e.g., compared to >100 kg of Murchison) rule this possibility somewhat unlikely. Alternatively, JW may have been heated during a regolith residence or its meteoroid stage, e.g., by solar irradiation at low perihelion distances. If indeed solar heating can be made responsible for the mineralogical changes observed in JW (and possibly other heated CM and CM-like chondrites [10]), the implications for our understanding of space weathering phenomena in returned samples would be large, as heating and annealing may alter the exposure record of space-weathered grains (e.g., [3]).

**References**

[1] Noguchi T. et al. (2011) Science 333:1121–1125. [2] Conolly H. C. et al. (2015) Earth, Planets and Space 67:12. [3] Harries D. and Langenhorst F. (2014) Earth, Planets and Space 66:163. [4] Harries D. et al. (2016) Earth and Planetary Science Letters 450:337-345. [5] Nakamura T. et al. (2014) Antarctic Meteorites XXXVII, 54. [6] Krishnaswami S. et al. (1971) Science 174:287–291. [7] Metzler K. (2004) Meteoritics & Planetary Science, 39:1307–1319. [8] Zolensky M. E. et al. (2016) 47th Lunar and Planetary Science Conference, abstract #2148. [9] Meier M. M. M. et al. (2016) Meteoritics & Planetary Science 51:A455. [10] Harries D. and Langenhorst F. (2013) Meteoritics & Planetary Science 48:879-903.

**Acknowledgements**

We acknowledge funding from Friedrich Schiller University Jena (DRM/2016-01). The SEM facility at U Jena is supported by the DFG (grant LA 830/14-1 to F. Langenhorst).