

MICROCRATERS IN DISAGGREGATED REGOLITH-BRECCIA METEORITES R. C. Ogliore¹, J. B. Malaer¹. ¹Department of Physics, Washington University in St. Louis, St. Louis, MO 63117, USA.

Introduction: Space-weathering features such as micrometeoroid impact craters, splash melt, and solar-wind blistering have been identified in lunar soil grains [1] and surface regolith returned from asteroid Itokawa [2, 3]. Regolith-breccia meteorites [4] likely contain particles that were directly exposed on the surface of airless bodies mixed with many particles that were never exposed to space. If space-exposed particles can be identified, they can be further studied by FIB-TEM to determine, e.g., the characteristics of nanophase Fe rims compared to regolith grains from the Moon and Itokawa. Analyses of these grains from regolith-breccia meteorites would extend our understanding of space-weathering to other airless bodies in the Solar System: the parent bodies of CI, CM, CR, and CH carbonaceous chondrites; H, L, and LL ordinary chondrites; R and E chondrites; and the ureilites, howardites, and aubrites.

A few micrometeoroid impact craters have been identified in regolith-breccia meteorites: the howardite Kapoeta [5] and CM chondrite Murchison [6]. Melt products were reported in thin sections of Fayetteville (H chondrite) and Kapoeta [7].

Here we describe our method to gently disaggregate regolith-breccia meteorites and search for micrometeoroid impact craters, and the initial results of this search on particles from Adzhi-Bogdo (stone) (LL3–6, [8]) and Murchison (CM2). These two meteorites were chosen for this investigation because they are both enriched in solar-wind gases [9] and characterized as regolith-breccias [4]. Additionally, Adzhi-Bogdo is of similar classification as the Hayabusa samples from Itokawa [10], and Murchison meteorite is an appropriate meteorite analog for the samples that will be returned from asteroid Bennu by the OSIRIS-REx mission [11].

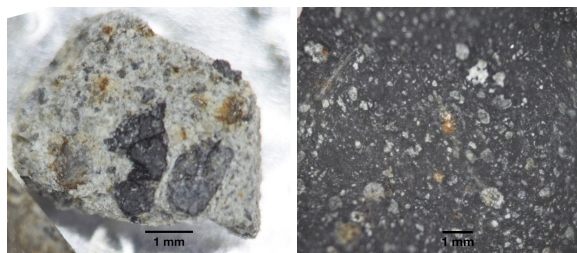


Figure 1: Left) Adzhi-Bogdo chunk before disaggregation—dark lithology is where noble gases are concentrated [9]. Right) Murchison before disaggregation.

Methods: We disaggregated ~0.5 g of Adzhi-Bogdo and Murchison using an automatic freeze-thaw device that we designed and built. This device uses

electronically controlled Peltier coolers to freeze and thaw six samples simultaneously (Fig. 2). Samples were subjected to ~3000 freeze-thaw cycles which took ~38 days (one freeze-thaw cycles takes ~18 minutes).

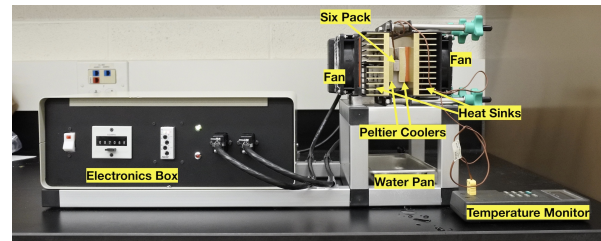


Figure 2: Automatic freeze-thaw system.

After disaggregation, the water was evaporated and the meteorite powder was deposited with a paintbrush onto carbon tape on half-inch SEM stubs. Each sample was coated with ~5 nm of Au-Pd for electrical conductivity. The disaggregated particles were then imaged with a Tescan MIRA-3 FEG-SEM using 1–2 kV accelerating voltage to maximize surface sensitivity of the secondary electrons. Secondary electron images (with a 50 μm field of view and 1536 \times 1536 pixels) were automatically acquired with gain and focus automatically adjusted for each image. Each SEM stub took ~2 weeks to image and yielded ~15,000 images. These images were then searched individually by human eye for impact craters. We are developing a crowd-sourced website to enlist volunteers to help us with the search.

Results: We identified dozens of potential craters in Adzhi-Bogdo. Three of the most promising examples are shown in Fig. 4. These clustered craters are relatively shallow (small depth/diameter ratios). The Adzhi-Bogdo disaggregated samples had many grains with clean surfaces that are well-suited for crater searches.

Microcraters were more difficult to identify in Murchison due to fine-grained adhering material (matrix grains, organics, or oxidation products created during freeze-thaw disaggregation). Nonetheless, we identified a few potential microcraters in Murchison, one of which had a prominent raised rim (Fig. 3).

Discussion: The microcraters we observed Adzhi-Bogdo are clustered, shallow and usually have crater lips and some melt residue. We did not observe any craters will spall zones around the central pit that are characteristic of most hypervelocity impacts [12]. We interpret these clustered craters as secondary ejecta impacts from a hypervelocity impact on the parent asteroid. We did not observe clustered microcraters in Murchison, though analyses of Murchison were chal-

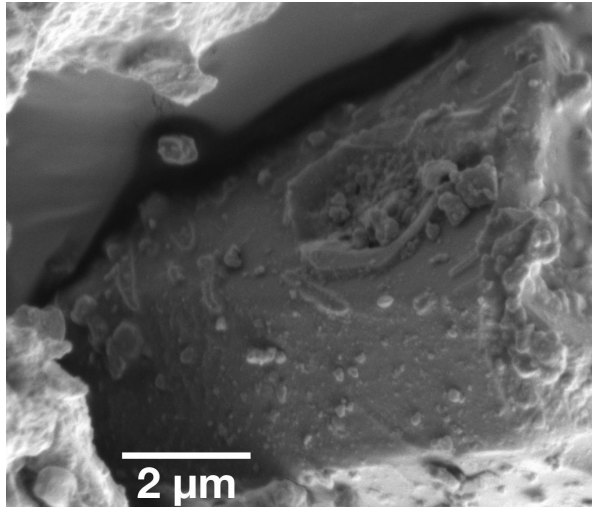


Figure 3: Secondary electron image of crater-like feature in Murchison.

lenging due to the scarcity of clean grain surfaces in our disaggregated sample.

In this study we only identified a few $\sim 100 \mu\text{m}^2$ areas of space-exposed grains in millions of μm^2 areas of disaggregated grains that we searched in Murchison and Adzhi-Bogdo. It is likely that searches of thin sections of the regolith-breccia meteorites of Fayetteville (H4) and Kapoeta (howardite) [7] did not identify nanophase-Fe bearing rims because intact space-exposed grain surfaces are rare in regolith-breccia meteorites and difficult to identify in cross-section.

Future Work: We will extract electron-transparent lamellae of the craters and nearby grains surface using the FEI Quanta 3D FIB at Washington University in St. Louis for subsequent TEM analysis. In cross-section, the mineral below the craters should show shock deformation if these are truly impact craters [13]. We will then characterize the surfaces of space-exposed grains by TEM and compare with space-weathered regolith grains from the Moon and asteroid Itokawa.

References: [1] F Hörz, J. Hartung, and D. Gault. *Journal of Geophysical Research* 76.23 (1971), 5770–5798. [2] T. Noguchi et al. *Meteorit. Planet. Sci.* 49.2 (2014), 188–214. [3] E Dobrică and R. Ogliore. *Earth Planet. Sp.* 68.1 (2016), 21. [4] A. Bischoff et al. *MESS-II* (2006), 679–712. [5] D. Brownlee and R. Rajan. *Science* 182.4119 (1973), 1341–1344. [6] J. Goswami, I. Hutcheon, and J. Macdougall. *LPSC*. Vol. 7. 1976, pp. 543–562. [7] S. K. Noble, L. P. Keller, and C. M. Pieters. *Meteorit. Planet. Sci.* 45.12 (2010), 2007–2015. [8] A Bischoff et al. *Meteorit. Planet. Sci.* 28.4 (1993), 570–578. [9] L. Schultz and L. Franke. *Meteorit. Planet. Sci.* 39.11 (2004), 1889–1890. [10] D. Nakashima et al. *Earth Planet. Sc. Lett.* 379 (2013), 127–136. [11] D.

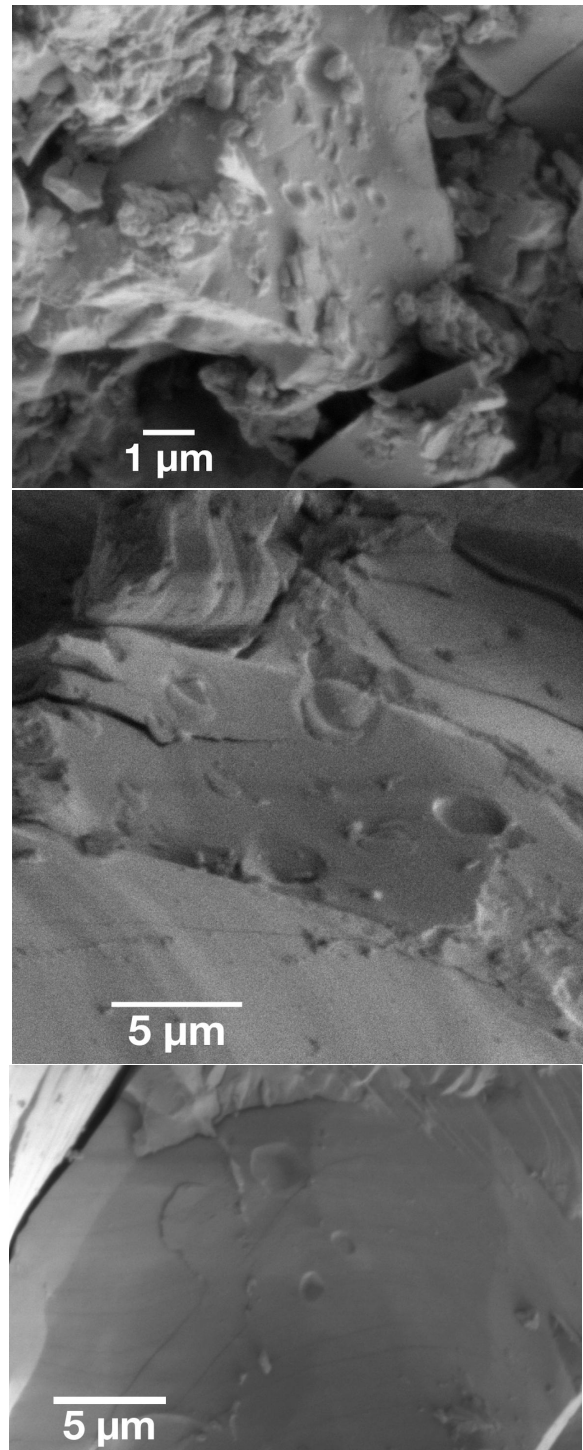


Figure 4: Secondary electron images of crater-like features in Adzhi-Bogdo.

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