FIB-TEM ANATOMY OF A SUB-MICROMETER IMPACT CRATER ON A HAYABUSA GRAIN.

D. Harries[1], S. Yakame[2], M. Uesugi[3] and F. Langenhorst[1]. [1]Institute of Geoscience, Friedrich Schiller Univerity Jena, Germany. E-mail: dennis.harries@uni-jena.de. [2]Department of Earth and Planetary Science, The University of Tokyo, Japan. [3]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (JAXA).

Introduction: The Hayabusa mission to near-Earth asteroid 25143 Itokawa returned regolith particles, which provide unique insights into the surface processes operating on small bodies of the inner Solar System [1,2]. Effects of space weathering result from both particle radiation and high-velocity impacts of small solid bodies. Crater-like features with sizes on the order of 100 to 200 nm have been reported, and are interpreted to be due to the impact of nanometer-sized, high-velocity projectiles [3]. We investigated Hayabusa grain RA-QD02-0265 which was found to contain a cluster of sub-micrometer-sized crater-like features [4].

Previous work: RA-QD02-0265 is a particle of originally 24 µm longest dimension, consisting of high-Ca pyroxene/diopside and minor olivine and plagioclase. It was sectioned by FIB [5] for FE-EPMA, which showed its similarity to highly equilibrated particles described previously [1]. Besides adhering grains and FeS melt patches, the grain's surface showed 15 crater-like features measuring 210 to 500 nm in diameter. Nine of them were found clustered in an area of approximately 5×5 μm^2 [4].

FIB-TEM study: We have sectioned the remaining grain across the largest crater-like feature (500 nm) by FIB. The bulk high-Ca pyroxene contains abundant 20 to 300 nm wide twin lamellae parallel to (100). The twin boundaries are frequently decorated by (partial) dislocations, indicating a mechanical origin of the intense twinning, most likely by a large-scale, pervasive shock event. The twin lamellae are responsible for a striated appearance of the external surface of the grain.

The 500-nm-crater exposed on the striated surface is relatively shallow with a depth-to-diameter ratio of ~1:10. During specimen tilting the volume below the crater floor shows distorted Bragg contours, indicating strain of the crystal down to a depth of about 400 nm. The likely sources of this strain are dislocations emitted during crater formation. A partially amorphous, radiation damaged rim of 20 to 30 nm thickness is present on the exposed surface and appears absent or greatly reduced in thickness below the crater floor, suggesting a late formation of the crater. Several Fe,Ni metal particles <60 nm are embedded in the crater floor and clearly indicate that the crater formed from the impact of a natural, metal-bearing particle (and not spacecraft exhausts). The density of solar flare tracks is relatively low ($\sim 10^9$ cm^{-2}) and suggests, in accordance with a simple space weathering rim and absence of surface abrasion, that the grain experience no exceptionally long surface exposure. The cluster of craters therefore is most likely due to secondary impacts of particles generated by an nearby (micro-)impact event, postdating the pervasive shock event recorded by the intense twinning.

References: [1] Nakamura T et al. 2011. *Science* 333:1113–1116. [2] Tsuchiyama A. et al. 2011. *Science* 333:1121–1125. [3] Nakamura T. et al. 2013. *PNAS* 109:624–629. [4] Yakame S. et al. 2013. Hayabusa 2013 Symposium. [5] Uesugi M. et al. 2014. *MAPS* 49:1186–1201.

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