MEASURING THE SHOCK STAGE OF ASTEROID REGOLITH GRAINS BY ELECTRON BACK-SCATTERED DIFFRACTION. Michael Zolensky[1], James Martinez[2], Scott Sitzman[3], Takashi Mikouchi[4], Kenji Hagiya[5], Kazumasa Ohsumi[6], Yasuko Terada[6], Naoto Yagi[6], Mutsumi Komatsu[7], Hikaru Ozawa[5], Yuta Taki[5], Yuta Yamatsuta[5], Atsushi Takenouchi[4], Hikari Hasegawa[4], Haruka Ono[4], Kotaro Higashi[4], Masaki Takata[6], Arashi Hirata[5], Ayaka Kurokawa[5], Shoki Yamaguchi[5]. [1]ARES, NASA JSC, Houston, TX USA (michael.e.zolensky@nasa.gov); [2]Jacobs, Johnson Space Center, Houston TX USA; [3]Aerospace Corporation, El Segundo, CA USA; [4]School of Science, Univ. of Tokyo, Tokyo, Japan; [5]Graduate School of Life Science, Univ. of Hyogo, Hyogo, Japan; [6]Japan Synchrotron Radiation Research Institute, Hyogo, Japan; [7]SOKENDAI, Graduate University for Advanced Studies, Hayama, Japan.

Introduction: We have been analyzing Itokawa samples in order to definitively establish the degree of shock experienced by the regolith of asteroid Itokawa, and to devise a bridge between shock determinations by standard light optical petrography, crystal structures as determined by electron and X-ray diffraction [1,2,3,4]. These techniques would then be available for samples returned from other asteroid regoliths.

Techniques: We are making measurements of olivine crystal structures and using these to elucidate critical regolith impact processes. We use electron back-scattered diffraction (EBSD) and synchrotron X-ray diffraction (SXRD). We are comparing the Itokawa samples to L and LL chondrite meteorites chosen to span the shock scale experienced by Itokawa, specifically Chainpur (LL3.4, Shock Stage 1), Semarkona (LL3.00, S2), Kilabo (LL6, S3), NWA100 (L6, S4) and Chelyabinsk (LL5, S4). In SXRD we measure the line broadening of olivine reflections as a measure of shock stage.

EBSD: In this presentation we concentrate on the EBSD work. We employ JSC's Supra 55 variable pressure FEG-SEM and Bruker EBSD system. We are not seeking actual strain values, but rather indirect strain-related measurements such as extent of intra-grain lattice rotation, and determining whether shock state "standards" (meteorite samples of accepted shock state, and appropriate small grain size) show strain measurements that may be statistically differentiated, using a sampling of particles (number and size range) typical of asteroid regoliths.

It is absolutely critical to optimize an EBSD system before routine use, since every EBSD detector/software package/SEM combination is so different. Using our system, we determined that a column pressure of 9 Pa and no C-coating on the sample was optimal. We varied camera exposure time and gain to optimize mapping performance, concluding that 320x240 pattern pixilation, frame averaging of 3, 15 kV, and low extractor voltage yielded an acceptable balance of hit rate (>90%), speed (11 fps) and map quality using an exposure time of 30 ms (gain 650). We also varied camera binning parameters. Figure 1 shows a comparison of EBSD mapping of the same Semarkona chondrule before and after our system optimization.

We found that there was no strong effect of step size on Grain Orientation Spread (GOS) and Grain Reference Orientation Deviation angle (GROD-a) distribution; there was some effect on grain average Kernel Average Misorientation (KAM) (reduced with smaller step size for the same grain), as expected. We monitored GOS, Maximum Orientation Spread (MOS) and GROD-a differences between whole olivine grains and sub-sampled areas, and found that there were significant differences between the whole grain dataset and subsets, as well as between subsets, likely due to sampling-related "noise". Also, in general (and logically) whole grains exhibit greater degrees of cumulative lattice rotation. Sampling size affects the *apparent* strain character of the grain, at least as measured by GOS, MOS and GROD-a. There were differences in the distribution frequencies of GOS and MOS between shock stages, and in plots of MOS and GOS vs. grain diameter (Figs. 2-5). These results are generally consistent with those reported last year [5]. However, it is unknown whether the differences between samples of different shock states exceeds the clustering of these values to the extent that shock stage determinations can still be routinely made with confidence. We are investigating this by examination of meteorites with higher shock stage 4 to 5, and Itokawa samples (reported at LPSC). Thus far it appears that EBSD can be used to determine regolith grain shock state of regolith grains as long as at least 25 grains are characterized (see Fig. 5).

Implications: Our research will improve our understanding of how small, primitive solar system bodies formed and evolved, and improve understanding of the processes that determine the history and future of habitability of environments on other solar system bodies. The results will directly enrich the ongoing asteroid and comet exploration missions by NASA and JAXA, and broaden our understanding of the origin and evolution of small bodies in the early solar system, and elucidate the nature of asteroid and comet regolith.

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References: [1] Zolensky et al. (2012) *Lunar and Planetary Science*, XLIII, #1477, Lunar Planet. Inst., Houston (CD-ROM); [2] Zolensky et al. (2014) *Hayabusa 2014: 2nd Symposium of Solar System Materials. Abstracts*.; [3] Zolensky et al. (2016) *Hayabusa 2016 Abstracts*; [4] Hagiya et al. (2016) *Abstracts, 79th Annual Meeting of the Meteoritical Society*; Ruzicka and Hugo (2017) *80th Annual Meeting of the Meteoritical Society*, 6368.

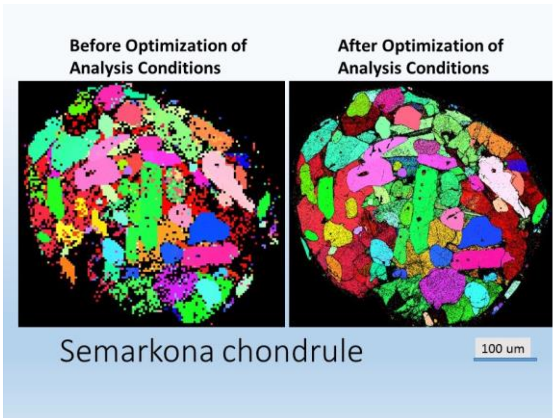

Figure 1. Before (left) and after (right) optimization of EBSD maps of a Semarkona chondrule.

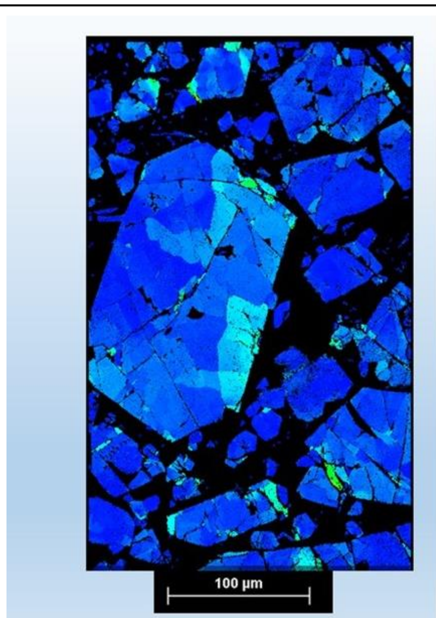

Figure 2. EBSD map of Semarkona, shock stage S2. Well crystalline regions have color, poorly crystalline regions are black. Mosaicism is exhibited by color variations within crystals (mainly olivine). Scale bar measures 100 µm.

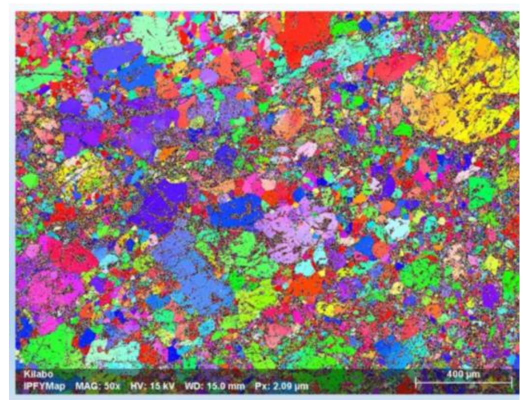

Figure 3. EBSD map of Kilabo, shock stage S3. Compare to Figure 2. Scale bar is 400 µm.

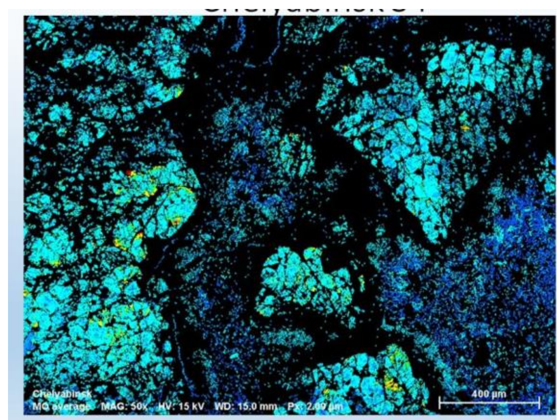

Figure 4. EBSD map of Chelyabinsk, shock stage S4. Compare to Figures 2 & 3. Scale bar is 400 µm.

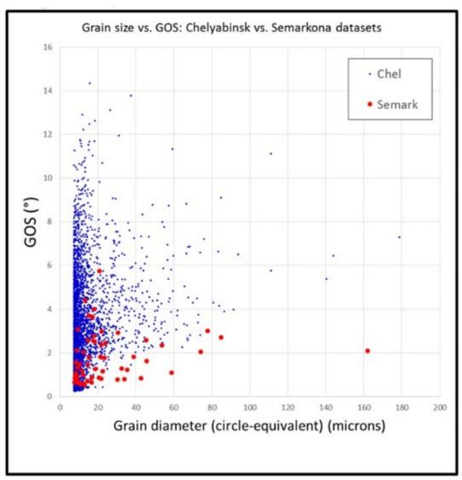

Figure 5: Grain size vs GOS for Semarkona and Chelyabinsk, showing significant differences.