Characterizing Ejecta Fragments from Impact Experiments into Meteoric Iron using Scanning Electron Microscopy (SEM). J. M. Christoph (jmchri17@asu.edu)[1], T. Sharp[1], S. Marchi[2], and L. T. Elkins-Tanton[1] [1]School of Earth & Space Exploration, Arizona State University, Tempe, AZ 85287, [2]Southwest Research Institute, Boulder, CO 80302

Introduction: Ejecta generated by impacts has been recognized as a key component of regolith formation on airless planetary objects [e.g. 1]. While cratering experiments have been performed into metallic surfaces, we have not been able to find any previous study analyzing ejecta from such an experiment to describe a putative regolith on metallic planetary surfaces hypothesized for the asteroid 16 Psyche or an iron meteorite parent body [2]. Marchi et al. [3] previously performed impact cratering experiments into metallic samples from the Coahuila, Gibeon, and Santiago Papasquiero iron meteorites provided by the Center for Meteorite Studies at ASU. Here, we report preliminary results of electron microscope imaging and characterizing ejecta from these impact tests into Santiago Papasquiero (ASU#721). By examining the granular/sub-granular microstructure, fracture surfaces, and deformation features present in ejecta fragments, we can infer details about the shock mechanics and breakup processes occurring in the metal during impact, which may inform hypotheses about the properties of metallic impact-generated regoliths that may be testable by future spacecraft missions such as Psyche [2].

Ejecta Recovery and SEM Details: Fragments in this study came from Santiago Papasquiero shot #3.09, with a 6.350 mm Al projectile at 5.31 km/s at normal incidence and temperature 129 K (see Table 1 in [3]). Fragments were recovered by sweeping the impact chamber followed by magnetic separation [3]. Approximately 0.75 g of ejecta fragments were recovered, including ~40 fragments between 1 and 3 mm in diameter and a single fragment nearly 10 mm long, larger than 5 mm in all dimensions, and massing 0.45 g (see Fig. 12 in [3]). The ejecta fragments were mounted on a 25 mm diameter sample platen with carbon tape, then carbon-coated. The largest fragment was mounted on a separate platen to prevent it from shadowing nearby fragments from the electron beam.

We use the FEI XL-30 Field-Emission Environmental SEM in the Cowley Center for High-Resolution Electron Microscopy at ASU. The XL-30 is capable of high-resolution imaging at magnification exceeding 20,000X, operating at low electron beam voltage (2-5 kV) to minimize surface charging due to poor sample conductivity or nonconductive particles adhered to the surface. We took images using both secondary and backscatter electron detectors for comparison. Multiple images covering larger areas were manually mosaiced.

Images:

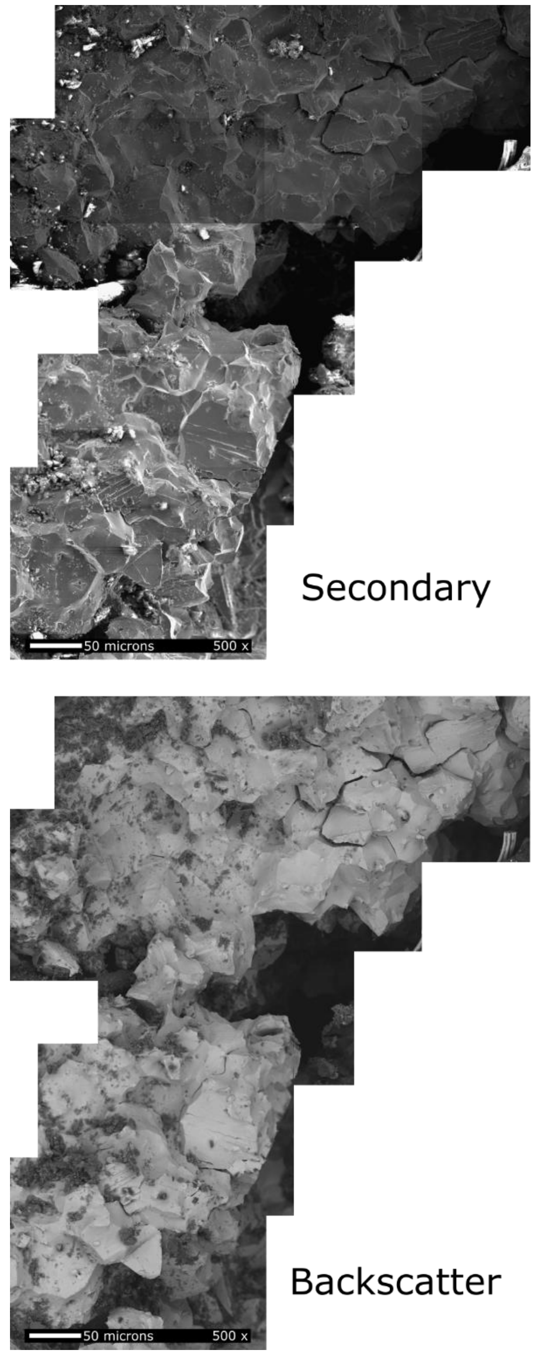
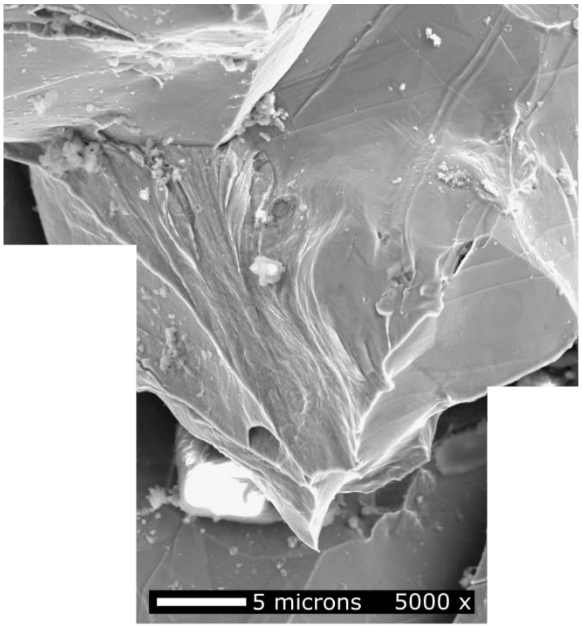
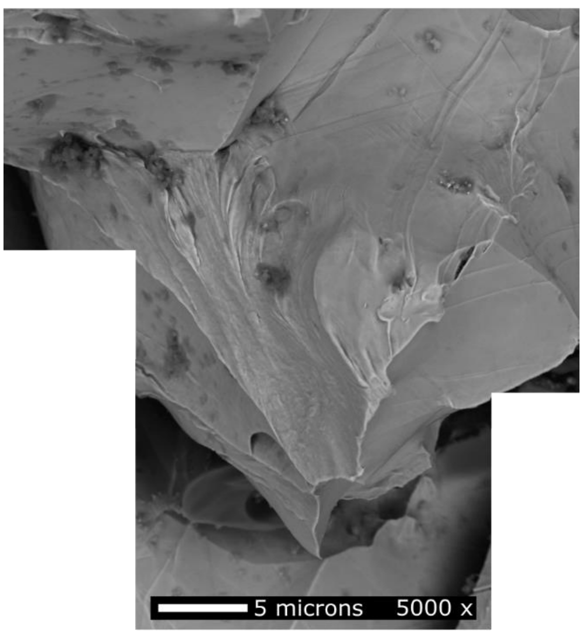


Fig. 1: Mosaiced survey SEM images of a small portion of the largest fragment; even at low magnification both inter-granular and trans-granular fractures are visible.



Secondary



Backscatter

Fig. 2: Mosaiced high-resolution SEM images of a single grain within the region shown in Fig. 2, displaying evidence of both brittle fracture and ductile deformation and failure, and possibly also thermal alteration.

Interpretation: All of the fragments imaged so far exhibit significant variation across their exposed surfaces, suggesting heterogeneity in the pressure and temperature conditions throughout the target during impact. On the larger fragments (e.g. Fig. 1) multiple individual metal grains are apparent, consistent with ~0.1 mm equiaxial kamacite grains in unmodified Santiago Papasquiero described in [4]. The presence of these equiaxial grains, along with visible gaps between some grains, suggests intergranular brittle fracture as a major component of the overall failure mode. Higher magnification imaging reveals many of these kamacite grains are significantly deformed indicating ductile deformation and failure (Fig. 2). Many kamacite grains are also crossed by linear or planar features: smaller transgranular fractures (cleavage), or surficial breakaway features e.g. slickenlines. Smaller grains in between the kamacite crystals and consistent in diameter with taenite cyrstals described in [4] appear to be more heavily modified, consistent with either fast melting and recrystallization or strain accumulation in a manner similar to inclusion-nucleated fracture. On some fragments there are also extensive systems of parallel transgranular fracture (cleavage) across multiple grains.

Although many of these fracture and deformation surfaces superficially resemble those that can form in metals under familiar conditions to a metallurgist [5], the ultra-high strain rates characteristic of impacts require shock physics to accurately describe deformation and fracture behavior [6]. In multicrystalline materials, variables including composition and orientation can significantly vary the temperature and internal strain experienced by indivudal grains over multiple impact phases [6]. Previous shock physics modeling of impacts into metal-containing meteorites has demonstrated that metals can melt at shock pressures of 30-70 GPa [7], but principally where shockwave concentration or pore collapse localize stress to a particular grain, and remote grains remain unmelted [8]. The heterogeneity of deformation and fracture modes we observe in our ejecta fragments is consistant with similar meso-scale heterogeneities in shock. Thus, we hypothesize that a metallic regolith formed by impact processes may exhibit similar heterogeneity, resulting in a variety of regolith particle sizes and morphologies.

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References: [1] F. Hörz 1977 *Phys. Chem. Earth* 10. [2] L.T. Elkins-Tanton et al. 2020 *JGR Planets* 125. [3] S. Marchi et al. 2020 *JGR Planets* 125. [C] M. Meyers and K. Chawla 2009 Ch. 8 Fracture: Microscopic Aspects in *Mechancial Behavior of Materials 2nd Edition*, Cambridge. [4] Buchwald 1975 *Handbook of Iron Meteorites* p. 1418. [5] J.D. Clayton 2019 *Nonlinear Elastic and Inelastic Models for Shock Compression of Crystalline Solids*, Springer. [7] Moreau et al. 2017 *Met. Plan. Sci.* 52. [8] Moreau et al. 2018 *Phys. Earth Plan. Int.* 282.