LASER-IRRADIATION OF AN ORDINARY CHONDRITE: SIMULATION OF ATMOSPHERIC ENTRY OF CHONDRITIC MATERIALS AND LINKS TO THE FORMATION OF MICROMETEORITES.

C. E. Kampf[1,2], C. Hamann[1], S. Schäffer[3], D. Heunoske[3], T. Hasse[1], L. Hecht[1,2], A. Greshake[1], and J. Osterholz[3], [1]Museum für Naturkunde Berlin, Germany (clara.kampf@mfn.berlin), [2]Institut f. Geologische Wissenschaften, Freie Universität Berlin, Germany, [3]Fraunhofer-Institut für Kurzzeitdynamik, Ernst-Mach-Institut, Freiburg, Germany.

Introduction: Atmospheric entry of asteroidal or cometary planetary materials typically involves fragmentation, melting, evaporation, mass loss, metal–silicate segregation, sudden changes in oxygen-fugacity (fO_2) conditions, and finally subsequent rapid quenching of superheated melts. Typically, this leads to the formation of fusion crusts around meteorites (e.g., [1,2]) and the formation of micrometeorites or cosmic spherules that form by partial to complete melting of cosmic dust (e.g., [3,4]). Particularly in primitive, highly reduced chondritic materials, atmospheric entry and the associated flash heating induces significant changes in chemical and mineralogical compositions [2,5]. Since our understanding of the formation, evolution, and composition of planetary bodies in the solar system relies in part on micrometeorites, understanding of the processes and products of flash heating during atmospheric entry is needed for their unbiased interpretation. Here, we present a comparison of the melts produced in a laser-irradiation experiment performed with the H5 ordinary chondrite Hammadah al Hamra (HaH) 077 against a subset of pristine urban micrometeorites [6] and fusion crusts developed around ordinary chondrites [2]. Our aim is to test whether our experiments allow faithful simulation and detailed investigation of melt-forming processes during atmospheric entry of planetary materials. In addition, such experiments have general relevance for the understanding of silicate–metal fractionation.

Materials and Methods: We used a continuous-wave infrared fiber laser at Fraunhofer-Institut für Kurzzeitdynamik to irradiate a piece of HaH 077 in air at 1 bar, using methods and instrument parameters described in [7]. Laser-induced flash heating of the chondrite resulted in formation of massive, tens of millimeters sized lumps of melt on the sample surface as well as millimeter to submillimeter sized spherules of melt that were ejected away from the irradiation zone. Thermal imaging by an infrared pyrometer suggests that peak surface temperatures were >2100 °C for about 5 s and that the melts quenched to room temperature within a few seconds after cessation of laser irradiation. A petrographic characterization of the laser-produced melts as well as the subset of recently described, pristine urban micrometeorites [6] was done using SEM/EDS and EMPA methods.

Results and Discussion: Flash heating of the chondrite produced metal–silicate emulsions that quenched to sulfide–metal assemblages and hypocrystalline silicate domains, respectively. The silicate melts quenched to a mixture of hopper-shaped, acicular, or tabular, distinctly zoned ($Fa_{\sim15–40}$) olivine quench crystals set in a glassy matrix that contains dendritic or skeletal magnetite crystals, a second generation of olivine nanocrystals, and occasionally chromite grains, botroidal or spherical troilite and FeNi metal droplets. The observed microtextures and modes of the quenched silicate melts are similar to those recently described by [5] and to fusion crusts developed around H chondrites such as Asuka (A) 09004 and 09502 [2]. Reminiscent of the fusion crusts on A 09004 and A 09502, relict forsteritic olivine clasts ($Fa_{\sim19–22}$) disseminated in the experimentally produced silicate glasses are overgrown by subhedral to euhedral rims of olivine that often, but not exclusively, show inverse zoning to the host olivine. In these cases, the overgrowths may start with more forsteritic compositions ($Fa_{\sim13–16}$) than the host olivine and then grade to increasingly fayalitic compositions ($Fa_{25–41}$); however, normal zoning in olivine was also frequently observed. Similar microtextures and comparable phase compositions were observed in some of the urban micrometeorites studied here. For instance, a relict forsterite clast (Fa_2) in porphyric sample THMM461 is surrounded by a rim of more fayalitic, anheral to subhedral, zoned olivine (Fa_{25}–$_{42}$). Other samples (e.g., THMM392) lack relict mineral clasts and are similar to clast-free quenched silicate melts in the experiment. In the experimentally produced melts, olivine crystals that are close to FeNi metal domains have more fayalitic, but rather Ni-poor compositions ($Fa_{72–90}$; Ni < 0.1 wt%) than the more forsteritic olivine crystals in the metal-poor regions. In addition, preliminary data on FeNi metal compositions suggest that metals in the laser-irradiated regions change to more Ni-rich compositions (from Fe/Ni ~15 in the chondritic metal to Fe/Ni ~5–12 in the quenched metal droplets), suggesting selective oxidation and fractionation of Fe from FeNi metal into the nearby silicate melt (cf. [8]). Likewise, surfaces of FeNi metal melts in contact with ambient air during quenching typically show iron oxide rims. Similar observations were also reported by [5] and [6], which further corroborates that redox conditions and thermal histories are comparable between the laser-irradiated materials and chondritic materials that experienced atmospheric entry. Further analyses are forthcoming to investigate possible fractionation of other elements as well as to evaluate the role of evaporation of volatile elements at high temperatures.

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