IMPACT VAPORIZATION AND CONDENSATION: LASER IRRADIATION EXPERIMENTS WITH NATURAL PLANETARY MATERIALS. C. Hamann[1,2], L. Hecht[1,2], S. Schäffer[3], D. Heunoske[3], T. Salge[4], A. Garbout[4], J. Osterholz[3], and A. Greshake[1], [1]Museum für Naturkunde, 10115 Berlin, Germany (christopher.hamann@mfn–berlin.de), [2]Institut für Geologische Wissenschaften, Freie Universität Berlin, 12249 Berlin, Germany, [3]Fraunhofer-Institut für Kurzzeitdynamik, Ernst-Mach-Institut, 79104 Freiburg, Germany, [4]Imaging and Analysis Centre, Natural History Museum, London SW7 5BD, United Kingdom.

Introduction: Hypervelocity impacts of asteroids or comets onto planetary surfaces typically induce melting and partial to complete vaporization of the involved materials close to the point of impact [e.g., 1], and may produce a vapor plume above the impact crater that subsequently condenses after it reaches the liquid–vapor coexistence curve [2,3]. Compared to impact melts and owing to their rarity, natural products of impact vaporization and condensation have scarcely been studied [e.g., 4–7]. Moreover, previous experiments that focused on impact vaporization and condensation have either used numerical modeling to predict physical (e.g., spherule size) and thermodynamic (e.g., temperature, oxidation state) characteristics of vaporized and condensing materials [e.g., 2,3], or directly investigated physicochemical properties of experimentally generated vapor plumes using spectroscopic techniques [e.g., 8]. The products of impact vaporization and subsequent condensation have, however, rarely been studied [e.g., 9].

Here, we present a petrographic-geochemical characterization of vapor condensates produced by laser irradiation of planetary materials [cf. 10] of chondritic, basaltic, dioritic, and granitic compositions to constrain mineralogy and composition of impact condensates formed from similar materials.

Methods: We used a continuous-wave (CW) fiber laser with a wavelength of 1.07 µm at Fraunhofer Institut für Kurzzeitdynamik, Freiburg, Germany [cf. 10], to irradiate pieces of the H5 chondrite Hammadah al Hamra 077 (HaH 077) as well as terrestrial rocks of basaltic, dioritic, and granitic composition in ambient air at 1 bar and room temperature (Fig. 1).

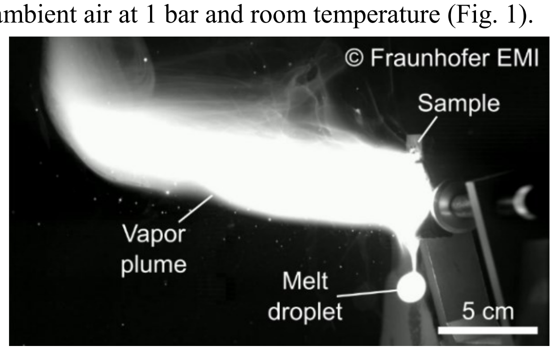

Figure 1: Laser irradiation of andesite. (Exemplary image to illustrate experimental setup; witness plates were not used here to fully observe the vapor plume.)

The CW fiber laser emitted a power of 8 kW over a specified time (5–10 s) during which the target was moved either vertically or horizontally. The profile of the laser beam was close to a Gaussian distribution with a $1/e^2$ diameter of 2 mm on the target. The average laser intensity within the $1/e^2$ diameter was 2.2×10^5 W/cm^2 and the laser–matter interaction zone was observed using a similar setup as described in [10].

The vapor plumes were sampled by witness plates of aluminum metal or ceramics that had a horizontal, 5 mm wide slit machined into the material to allow passage of the laser beam. The witness plates were positioned opposite and parallel to the target surface at distances between 1 and 3 cm, and sampled a mixture of condensate precipitates and melt droplets that were excavated from the irradiation zones. Textural and compositional characterization of condensates employed field-emission scanning electron microscopy (SEM), low-voltage energy dispersive spectroscopy (EDX), and 3D X-ray microscopy (CT) at the Imaging and Analysis Centre, Natural History Museum, London, UK.

Results: Direct CW laser irradiation of the samples in the parameter region considered here resulted in formation of self-luminous vapor plumes (Fig. 1) that precipitated onto the witness plates macroscopically white (silicate starting materials) or tan to dark brown (HaH 077 starting material), fine-grained, fluffy coatings or layers. In addition, the laser excavated melt droplets of sub-micrometer to millimeter diameters that were ballistically transported to the witness plates; if deposited early, these melt droplets were also coated by thin condensate layers.

SEM analysis obtained from the surfaces of the condensate films reveals that the condensate coatings consist of fluffy, dust-like, globular, ~100-nm-diameter nanoparticles (Fig. 2a,b) that accreted to continuous, chemically alternating sequences or layers (Fig. 2c–e). Individual condensate sub-layers seem to evolve from more refractory to more volatile compositions (e.g., from Si-rich to Na-rich composition) with decreasing depth (i.e., from bottom to top; Fig. 2e). Moreover, platy to acicular, idiomorphic crystallites (presumably sodium sulfate) of 2–5 µm size were found interbedded into rod-shaped aggregations of nanoparticles in some experiments (e.g., gabbroic starting composition; Fig. 2b), indicating that the vapor plume precipitated a mixture of presumably amorphous nanoparticles and crystallites.

Discussion: Following methods outlined in [8] and [10], we estimate that the irradiation intensities used in our study result in entropy increases that correspond to impact velocities in the range of 10 to some 25 km/s and, thus, are capable of simulating impact vaporization of planetary materials (i.e., typical silicate rocks and chondrites).

The experimentally generated condensate deposits share similarities to condensates formed in previous experiments that used pulsed laser irradiation [e.g., 9,11]. The chemical zoning of individual condensate layers observed here likely reflects slight changes in temperature and, thus, composition [12] of the vapor plume of a given experiment. As irradiation was continuous over several seconds, continuously "replenishing" plumes were formed that precipitated several sequences of alternating composition, whereat each sequence seems to reflect a specific (and rhythmically recurring) temperature interval.

In future work we plan to extend our characterization of our experimental vapor condensates to the nanometer scale using transmission electron microscopy, and to perform similar experiments in vacuum to simulate impact vaporization on atmosphere-less bodies.

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Figure 2: **a** Condensate nanoparticles on the surface of a condensed film (HaH 077 starting material); secondary electron (SE) image. **b** Idiomorphic crystallites, presumably sodium sulfate, interbedded into aggregates of condensate nanoparticles (gabbroic starting material); SE image. **c** Representative CT slice of condensate layers and silicate melt droplets (granitic starting material). The dashed white line indicates the position of an aluminum witness plate (removed before CT imaging). **d** Back-scattered electron image of two condensate layers featuring various sub-layers adhering to a silicate melt droplet. **e** Elemental distribution of Na, Si and Al of alternating condensate layers deposited onto an aluminum witness plate (removed before sectioning; position indicated by dashed white line) and silicate melt droplets. Note that each layer evolves from Si-rich, more refractory to Na-rich, more volatile compositions.