FORMATION OF S-, I-, AND G-TYPE COSMIC SPHERULES FROM ORDINARY CHONDRITE MATERIAL: INSIGHTS FROM LASER-IRRADIATION EXPERIMENTS.

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Introduction: Micrometeorites (MMs) are extraterrestrial dust particles mostly between ~10 µm and 2 mm across that survive atmospheric entry and arrive on Earth's surface [1,2]. Depending on their velocity, entry trajectory, and mass, MMs suffer variable degrees of flash heating. Especially the larger ones >100–200 µm undergo extensive melting and vaporization during atmospheric entry [3,4], which modifies their initial texture, mineralogy, and composition and results in formation of cosmic spherules [1,2]. Due to their small sizes and their significant modification during atmospheric entry, the mineralogical and compositional properties of MMs are unlikely to represent those of their parent bodies [1]. However, MMs may inform about the nature of their parent bodies if a link between certain groups of MMs can be established to certain types of parent bodies as well as their individual components and if the modification of MMs during atmospheric entry is understood. Here, we show by petrographic investigation of melt spherules produced by laser-induced flash heating of the H5 ordinary chondrite Hammadah al Hamra (HaH) 077 that most mineralogical and compositional properties of the most common types of micrometeorites can be produced from a single ordinary-chondrite sample, which has implications for the identification of potential parent bodies of MMs [5].

Materials and Methods: We used a continuous-wave infrared fiber laser to irradiate a piece of HaH 077 in air at 1 bar using methods described in [6]. Flash heating of HaH 077 produced massive, tens of millimeters sized lumps of melt on the irradiated surfaces [7] as well as melt spherules comparable in size (between ~10 µm and ~4 mm; typically 50–300 µm) to MMs. The melt spherules were ejected from the irradiation zone in the form of a fine melt spray that was sampled by a ceramic witness plate. Peak surface temperatures of the massive melts were >2100 °C for about 5 s [7]; quenching was facilitated in ambient air. Similar peak temperatures are assumed here for the fine melt spay. Characterization of the laser-produced melts by optical microscopy, µXRF, SEM-EDS, and EMPA is ongoing.

Results and Discussion: We identified several sub-types of spherules among our laser-generated melts that closely resemble S-type, I-type, and G-type melted MMs or cosmic spherules as well as partially melted or scoriaceous MMs [1,2]. Most abundant among the investigated melt spherules were glassy as well as cryptocrystalline silicate spherules, the latter consisting of olivine microcrystals, silicate mesosatsis, and magnetite dendrites and often having knobby surfaces resembling 'turtleback' cryptocrystalline S-type MMs [1,2]. In addition, silicate spherules dominated by equant microphenocrysts or skeletal to hopper-shaped olivine microcrystals set in glassy matrix that resemble porphyritic S-type MMs as well as complex, often highly vesicular, spherical or irregular silicate droplets that resemble scoriaceous MMs [1,2] also occur among the laser-produced melts. The silicate spherules occasionally contain FeNi metal blebs or beads with highly variable Ni abundances (~10–90 wt% Ni) that form sub-spherical domains in the glass; others contain Ni-poor (typically <10 wt% Ni) wüstite or magnetite blebs or coatings that often contain Ni-rich FeNi metal blebs in their interior parts (i.e., away from the silicates). Spherules dominated by Ni-bearing wüstite or magnetite, or entirely consisting of iron oxides, also exist; these spherules resemble I-type MMs [8]. We also observed rare composite blebs of FeNi metal and sulfides which typically occur in the form of deformed objects or melt splashes. We semi-quantitatively determined the bulk compositions of the laser-generated spherules by SEM-EDS analysis of carbon-coated spherule exteriors, following methods outlined in [9]. The bulk compositions of the laser-generated melts can be explained by melting and mixing of the individual components of HaH 077 under oxidizing conditions. In binary plots such as Si–(Fe + Ni) or Mg–(Fe + Ni) as well as in ternary plots such as Si–Mg–(Fe + Ni), most bulk compositions plot onto mixing lines spanned by either HaH 077 olivine ($Fa_{\sim20}$), pyroxene ($Fs_{\sim18}$), and oxidized FeNi metal (i.e., FeO), whereas the FeNi metal spherules reflect highly fractionated, Fe-depleted kamacite or taenite starting compositions. Overall, the compositional range spanned by the laser-generated melts is consistent with the range spanned by average compositions of I-, G-, and S-type cosmic spherules [1,2,8,9].

Conclusions: Typical shapes, mineralogies, and bulk compositions of I-, G-, and S-type cosmic spherules were reproduced in melt spherules formed by laser-induced flash heating of an H5 ordinary chondrite. Our results shed light onto mixing trends typically documented in these cosmic spherules and illustrate how a suite of compositionally/mineralogically diverse suite of MMs can be produced from compositionally complex chondritic starting material.

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