IN-SITU HEATING EXPERIMENTS OF THE TARDA METEORITE: EFFECTS OF THERMAL PROCESSING ON ACQUEOUSLY-ALTERED CARBONACEOUS CHONDRITE.

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Introduction. Asteroids and comets give us the opportunity to study the original materials that formed the planets in the protoplanetary disk. They contain bio-essential components, *e.g.,* organics and water-bearing phases, that we think contributed water and the ingredients that helped life emerge of life on Earth. Laboratory analysis of meteorites shows that these components are intimately mixed at the nanoscale [1]. To constrain whether asteroids delivered bio-ingredients to the Earth, it is first important to retrace their origins and evolution histories. The response of fine-grained materials to secondary alteration is important for understanding active processes (e.g., melting, volatile loss, elemental diffusion between grains, and driving hydrothermal processing) affecting volatiles on the surfaces of and within the parent asteroids to chondritic meteorites [1]. The presence of hydrous minerals in many carbonaceous chondrites provides evidence of low-temperature hydrothermal on asteroids [2]. Constraining the effects of these different thermal processes is critical to understanding past and ongoing processing of asteroids.

To further investigate the effects of thermal processing on carbonaceous and hydrated materials, we report new results from in-situ heating (400-700°C; Fig. 1) of fine-grained materials from the Tarda meteorite.

Sample and Methods. The Tarda meteorite fell in southern Morocco near the village of Tarda on August 25, 2020. A total mass of ~4kg, including many stones, has been recovered so far [3]. Based on the initial data, Tarda was classified as a C2 ungrouped carbonaceous chondrite. Its O isotopic composition is similar to CI-chondrite and Yamato-type values. Marrocchi et al. [4] showed that Tarda shares petrographic and isotopic similarities with the Tagish Lake chondrite, suggesting that it might also be related to D-type asteroids.

Fine-grained material of Tarda was crushed into a powder in an agate mortar and drop-casted onto supporting SiN films (Norcada) for in-situ heating and analysis (Fig. 1). The films consist of a microelectromechanical systems (MEMS) platform to provide uniform heating. The chip was then loaded to a Hitachi Blaze heating and electric bias sample holder. We carried out using the 200 keV aberration-corrected Hitachi HF5000 scanning TEM (S/TEM) in the Kuiper Materials Imaging and Characterization Facility (KMICF) at the University of Arizona. It is equipped with STEM-based secondary electron (SE), bright-field (BF), and dark-field (DF) imaging detectors, as well as an Oxford Instruments X-Max^N 100 TLE energy dispersive X-ray spectroscopy (EDS) system with dual 100 mm^2 windowless silicon-drift detectors (solid angle of 2 sr).

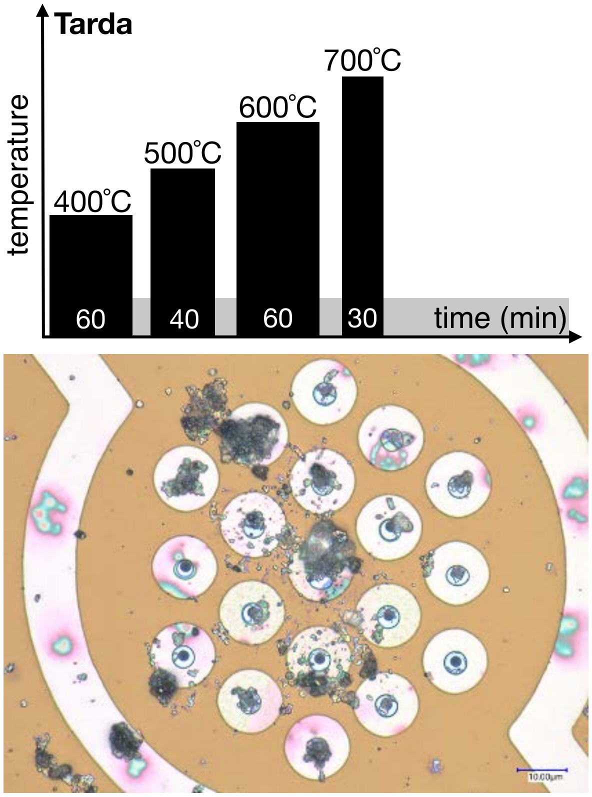

Fig. 1. Heating regiment (top) and chip loaded with the Tarda meteorite particles (bottom). Scale is 1 mm.

Previous Heating Experiments. Apart from a few studies [5-7], most previous heating experiment studies were static with the acquisition of the imaging, chemical and/or structural data only before and after the heating regimen. While they provided important information on the effects of thermal processes, these experiments [8-11] lacked the ability to monitor progressive changes in the chemistry and microstructure of the sample in real-time during the simulated heating event directly inside the TEM.

We previously reported on in-situ flash- and step-heating experiments of matrix material of the Murchison (CM2), Tagish Lake (C2-ung.) and Acfer 094 (C2-ung.) chondrites inside a Hitachi SU9000 30 keV scanning transmission electron microscope (STEM) [12]. Our initial results from in situ heating of

Murchison and Tagish Lake fine-grained material indicate that significant changes to their microstructure and elemental compositions, such as melting and formation of Fe-Ni metal nanoparticles, occurred only after heating above 600°C (Fig. 2). Heating up to 1075°C caused a significant loss of volatiles (e.g., S) and the graphitization of the carbonaceous matter. [12].

Heating of the Tarda meteorite. Apart from the direct volatilization of a sodium chloride grain, no other significant change to sample was observed while heating the sample up to and while at 400°C.

Fe-Ni nanoparticles started to form when the sample was heated to 500°C and then to 600°C for 40 and 60 min, respectively. All the nanoparticles stayed very small (~10 nm).

Heating to 700°C for 30 min led to the formation of numerous Fe-Ni nanoparticles (including much larger ones) and the destructions of indigenous Fe sulfide grains. Unlike the Tagish Lake experiments, not all Fe sulfides were destroyed after heating to 700°C. We will also determine the functional chemistry of carbonaceous matter in unheated and heated Tarda to confirm whether heating to 700°C led to the graphitization of the organics in the sample.

Future heating experiments. We will explore the effects of lower temperatures (<300°C) on hydrated minerals, chlorides, carbonates and hydrocarbon compounds. Overall, this work will help constrain the temperature ranges affecting different volatile-bearing phases within hydrated carbonaceous chondrites analogous to those sampled by recent/ongoing space missions.

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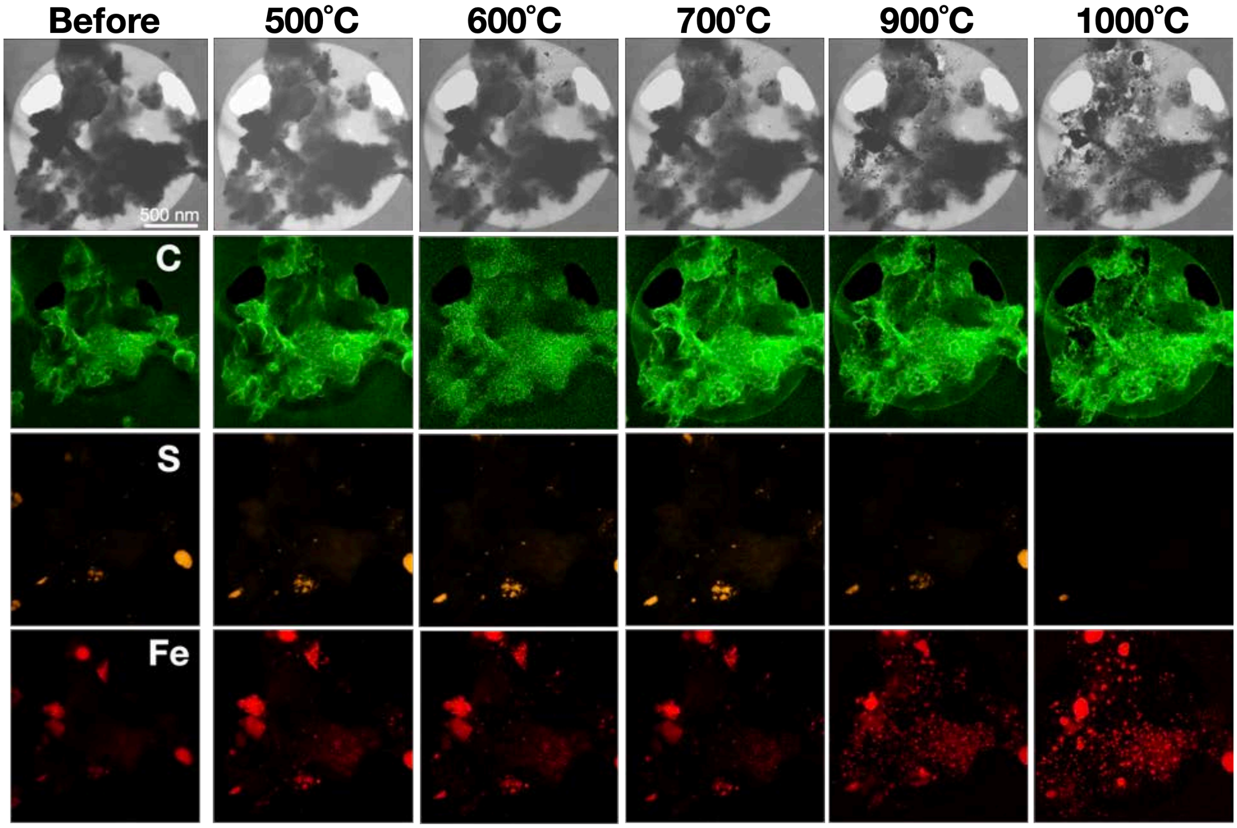

Fig. 2. Bright-field images and false-color EDS elemental maps during heating of a Tagish Lake sample.