THE OCCURRENCE OF COMPLEX MICROSTRUCTURES AND ZONATIONS IN CARBONATES FROM A HYDRATED FINE-GRAINED ANTARCTIC MICROMETEORITE.

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Introduction: Carbonates in micrometeorites have been studied previously [1-2]. However, they have not received a close examination by transmission electron microscopy (TEM), although scanning electron microscopy (SEM) and electron microprobe studies have been performed. The observations presented here focus on the occurrence of complex microstructures and zonations in carbonates (dolomite and ankerite) from one particular hydrated fine-grained Antarctic micrometeorite (H-FgMM, 03-36-46) that was previously described in a combined mineralogical and oxygen isotopic study [2-3]. Our TEM analysis of carbonates aims to understand a more detailed picture of carbonate formation and evolution of rarely analyzed hydrated micrometeorites. We examine the implications for the presence of compositional and microstructural features and their possible role in interpreting their formation.

Methods: Four focused ion beam (FIB) sections were studied using a variety of TEM techniques, including scanning transmission electron microscopy (STEM) imaging, nanodiffraction, and energy-dispersive X-ray spectroscopy (EDS). All imaging and analysis were carried out at 300 kV using the Titan G2 analytical (S)TEM. Additional EDS hyperspectral maps were performed at the Molecular Foundry, Lawrence Berkeley National Laboratory using a 200 kV TitanX "ChemiSTEM" with four windowless X-ray silicon drift detectors (~0.7 sr solid angle).

Results: In the H-FgMM analyzed, we identified two distinct regions containing non-stoichiometric carbonates (dolomite and ankerite) found at ~20 µm distance. Detailed TEM observations show the presence of fine microstructural features called modulations in carbonates from both regions (Fig. 1). These modulations appear as near-parallel lamellae or domains alternating dark/light contrast when imaged with a small convergence angle (0.1-0.3 mrad) in the STEM mode. The modulations affect the entire crystals and show multiple orientations (Fig. 1). The EDS analysis indicates that these modulations correspond to local, nanometric compositional variations in manganese up to 2.0 wt% MnO. Additionally, the interface between the two crystals in the cluster displays a moiré pattern formed by the superimposition of two periodical structures. Extra peaks due to the two dolomite crystals (relative rotation angle of ~4°) forming the moiré structure are apparent in the fast Fourier transform (FFT) diffraction pattern made at the boundary between the two crystals (Fig. 1).

Discussion: Compositionally zoned carbonates are commonly observed in Martian and chondritic meteorites with variations at scale ranging from submicron to tens of micrometers [4-6]. Similarly, carbonates in the H-FgMM analyzed in this study exhibit large, localized, compositional variations identified at both micrometer and nanometer scales. Furthermore, it has been suggested that these chemical variations are ubiquitous in carbonates, regardless of the morphology and sample, indicating changes in fluid composition during their formation [e.g., 6]. More precisely, this study shows that the composition of fluids responsible for the alteration of this AMM have varied locally during carbonates growth and was enriched in Mn and Fe, indicating reducing conditions in the fluid. In addition to the compositional variability, microstructural features are pervasive in these carbonates, similar to those described in heavily shocked meteorites [4]. Previous studies suggest that these features result from rapid growth, though some doubt remains about its origin. Further systematic analysis is needed in carbonates characterized by different shock stages to understand these complex microstructural features.

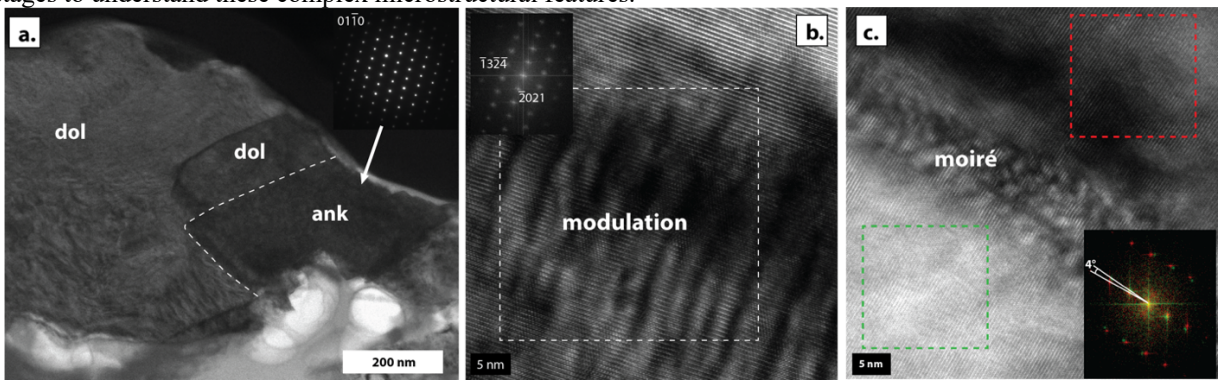

Figure 1. TEM micrographs and diffraction patterns showing the complex microstructure of a cluster of dolomite (dol) and ankerite (ank) crystals from the H-FgMM analyzed in this study.

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