Mineralogical complexity of altered kamacite in Sutter's Mill (SM3, pre-rain): insights into asteroidal dehydration
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Introduction: The Sutter's Mill meteorite fell on April 22nd 2012. Only three stones (totaling 14.6 g) were collected before heavy rains fell over the fall site, one of which (SM3, 5.0 g) was obtained by Arizona State University's Center for Meteorite Studies. A bulk powder X-ray diffraction investigation of SM3 shows that it is dominated by olivine [1], and thermogravimetric analysis shows that it is largely anhydrous, with mass loss of ~3 wt%. It also contains Fe-sulfides, magnetite, oldhamite, and minor enstatite. Reflected-light observations show a hetergenous distribution of clasts, sulfides, bluish-white grains of $Ca(OH)_2$ and few chondrules embedded in a dark fine-grained matrix. This investigation focuses on a grain of kamacite surrounded by concentric rings of alteration products embedded within the matrix.

Materials and Methods: A 5-mm chip of SM3 was embedded in epoxy (fragment SM3-1), and dry polished to prevent contamination of the sample with liquids. Backscatter electron images (BSE) (Fig. 1), x-ray maps (Fig. 2), and WDS data of the metal grain and surrounding phases were acquired with a CAMECA SX100 electron microprobe at the University of Arizona's Michael J. Drake Electron Microprobe lab.

Results: The metal grain and surrounding area will be discussed as four separate regions; center, middle, outer aureoles and exterior, which is readily visible in the optical image and Fe map (Fig. 2).

Center: The center is characterized by an irregular 150 μm diameter metal grain. The central grain has a 93:6 Fe:Ni ratio with 0.2 wt% Co and minor Cr and P, consistent with kamacite.

Middle: Surrounding the central kamacite grain are numerous ~5 μm irregularly shaped angular grains (IAG's). The junction between the IAG's and the kamacite is sharp (figure 1). The IAG's have Fe:Ni ratio of 68:29, with 1.2 wt% Co and minor Cr, consistent with taenite. Reflected-light imaging shows the interstitial area of the IAG's to be composed of grey and black phases. X-ray maps indicate the presence of abundant Fe and Ni with minor S, P, and Mg. Quantitative WDS within interstitial areas shows the presence of O at ~20 wt%. Figure 2 details the compositional heterogeneity surrounding the kamacite grain.

Outer aureoles: Beyond the area where IAG's are present there are two distinct nearly concentric rings with different compositions. The first ring is light grey in reflected light, rich in Fe, low in Ni, with ~20 wt% O yielding a composition of $Fe_{0.9}O$, consistent with non-stoichiometric wustite. The next ring is golden in reflected light and composed of Fe (52 wt%), S (19 wt%), Si (4 wt%), Mg (3.5 wt%), and Ni (0.5 wt%).

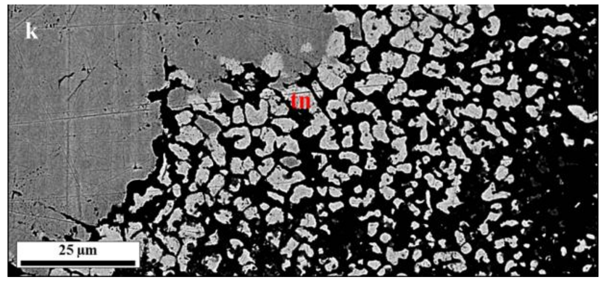

Figure 1: BSE image showing the boundary between the central kamacite (k) grain and irregularly shaped taenite (tn) grains.

Exterior: The exterior of the area represents the boundary between the dark meteoritic groundmass and the kamacite alteration rings. X-ray maps show that S is diffused into the groundmass radially. WDS and reflected-light observations reveal Fe-Ni sulfides and several euhedral silicates (olivine) surrounding the metal grain in a nearly concentric fashion.

Discussion: SM3 is largely anhydrous and dominated by Fe-rich olivine [1], though it has features suggesting that is was clay-rich and hydrated, similar to CM2 meteorites. These observations suggest that SM3 experienced temperatures ~700°C [2,3]. In CM chondrites, low-temperature aqueous alteration of kamacite in the presence of S leads to the formation of tochilinite and Fe sulfides [4]. At the higher temperatures experienced during the SM3 heating, the tochilinite surrounding the kamacite would begin decomposing to Fe-Ni sulfides and Mg-Fe (hydro-) oxides around 250°C. This would be nearly complete ~700°C. One possibility is that the Fe-Ni sulfides would further alter to the Fe-Ni IAG's and interstitial Fe-Ni-O rich material. The presence of concentric rings could be due to the formation of Fe-rich aureoles via dissolution and precipitation reactions occurring in a limited spatial area with chemical conditions differing from the surrounding groundmass [5]. The incomplete reaction, as evidenced by the presence of the kamacite core, results in a radially complex mineralogical assemblage.

References: [1] Garvie L.A.J. (2013) 44th LPSC #2148 [2] Haberle, C. W. (2013) AGU fall mtg., #1804507. [3] Haberle, C. W. (2013) 44th LPSC #2810. [4] Palmer, E. E. (2010) 41st LPSC #2211. [5] Hanowski, N. P. (2000) Met. and Pl. Sci., 35, 1291-1308

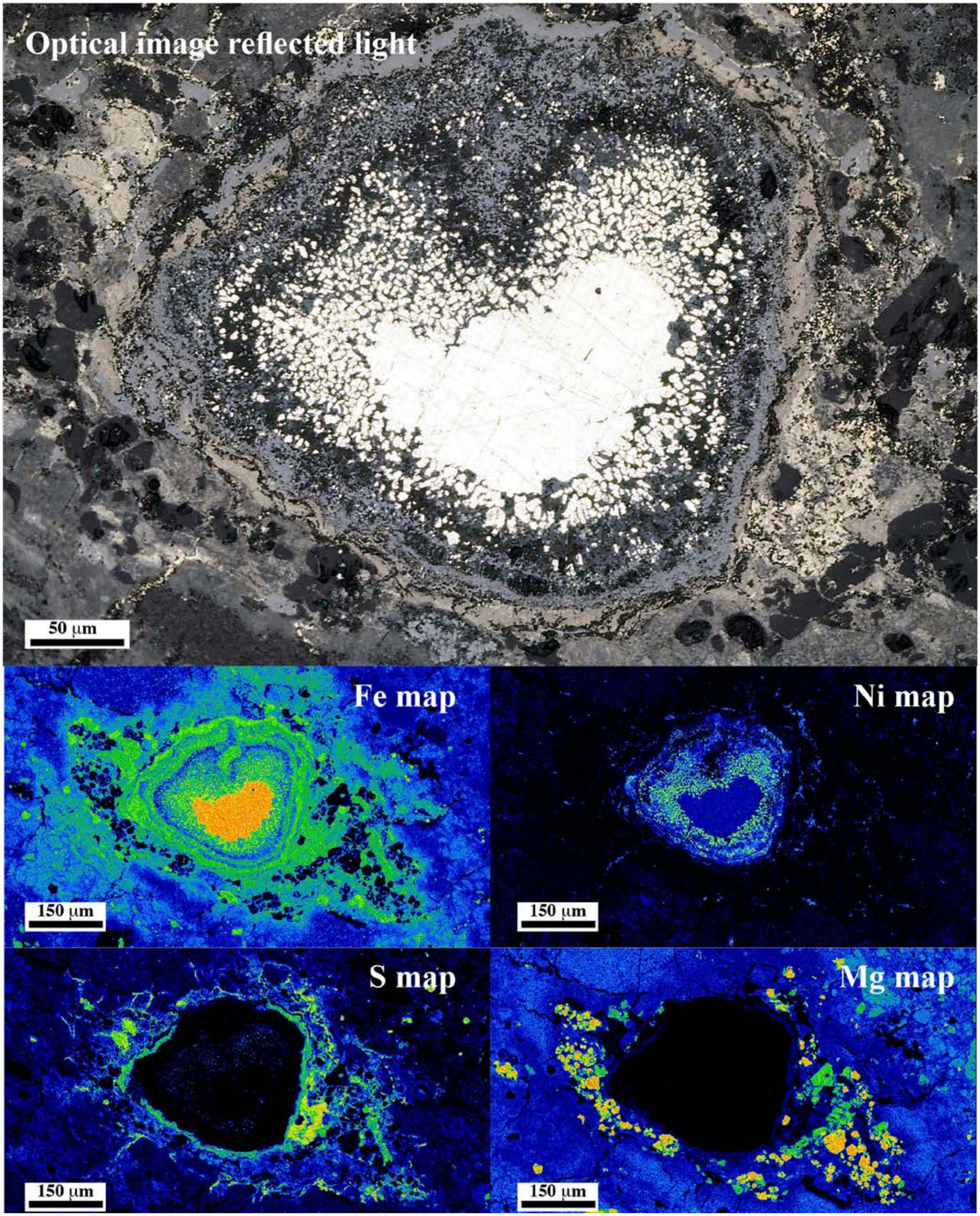

Figure 2: Reflected light image of the area of investigation with corresponding X-ray maps showing elemental distribution for the elements; Fe, Ni, S and Mg.