NANOSCALE HETEROGENEITIES IN SILICATES FROM SUTTER'S MILL

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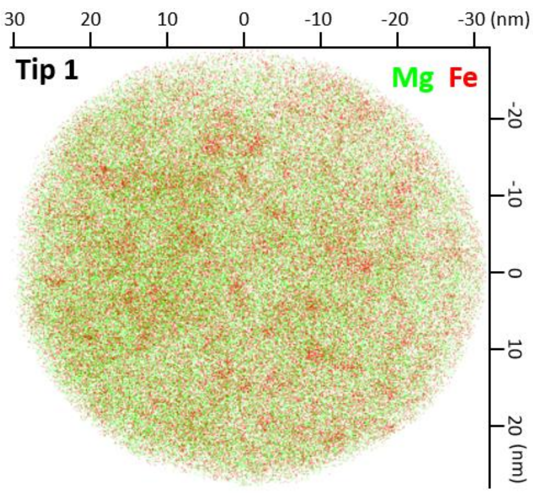

Fig 1. Atom-probe tomographic (APT) reconstruction of matrix minerals in Sutter's Mill, with individual atoms shown as dots (Mg in green, Fe in red). Fe shows clustering, Mg is relatively homogenous.

Introduction: Sutter's Mill is a CM chondrite regolith breccia (fall; April 22, 2012), with lithologies ranging from CM 2.0 to 2.1 [1]. The meteorite has experienced varying degrees of aqueous and thermal alteration, and contains clasts of non-CM material, making this meteorite complex on the macroscale [2]. On a microscale, understanding the fine-grained mixture of hydrated and thermally altered components requires characterization techniques with high-spatial analytical resolution. Here, we use atom-probe tomography (APT) to analyze the matrix minerals in Sutter's Mill at near-atomic resolution in 3D in order to enhance our understanding of this unique meteorite with minimal sample consumption.

Samples and Methods: We studied a polished section of the SM47 specimen (FMNH Me 5799.4). The section contains abundant grains of olivine, pyroxene, troilite, pentlandite, sulfide and calcite. Some of the olivines were strongly zoned (Fa_{14-36}), others, occurring as individual grains in the matrix are almost pure forsterite [1].

We prepared two microtips from the matrix using the Tescan Lyra3 FIB-SEM microscope at the University of Chicago. The area of interest was coated with Pt to protect the mineral surface from Ga ion implantation. Several spokes were prepared with our method developed for APT of lunar ilmenite [4]. Total sample consumption in the production of one tip was ~20 μm^3. A sample of the San Carlos olivine (FMNH Me 7688.2) served as a reference material.

The tips were analyzed with a LEAP 5000X Si atom probe tomograph at the NUCAPT facility of Northwestern University. In APT, atoms of the sample surface are field field-evaporated, assisted by UV laser pulses, and field-ionized, ifrom the sample surface in a high electric field using UV laser pulses. The ions' times-of-flight and positions are detected with a multimicro-channel plate detector. APT records elemental and isotopic compositions and the 3D distribution of atoms in the sample. The current detection efficiency is ~80% which makes it ideal to study small volumes [3]. We used CAMECA's IVAS software to reconstruct the tomographic dataset for each sample.

Results and Discussion: We obtained 5.5 million atoms for Tip 1 and 1 million for Tip 2. Both samples were forsteritic olivine that exhibited compositional variations on the nanoscale. The composition of a ~5 x 5 x 15 nm representative volume within Tip 1 ($Fa_{0.13-0.18}$) is similar to olivine of Type I chondrules. In a volume with the same size, Tip 2 has a higher compositional variability ($Fa_{0.03-0.70}$). This intrachondrule variability is smaller than the interchondrule variability ($Fa_{0.5-2}$), reported in [5].

In Tip 1 we observed nanoclusters with $[Fe]^{++}$ and $[FeO]^{+}$ enhanced by up to 2× (~4 wt%) compared to the surrounding volume. The clusters measured 1.5 to 8 nm (average ~3 nm, Fig. 1) on the long axis. Mg and O were homogeneously distributed. Similar nanoclusters were observed in Tip 2. None of this nanoscale variability was observed in our San Carlos olivine reference material that we analyzed with similar analytical conditions. We therefore conclude that this compositional nanoscale variability is intrinsic to the Sutter's Mill olivines. These clusters are similar in size to the nanophase Fe particles observed in the surfaces of lunar ilmenite [4], but likely have a different origin. Characterization of this fine-grained material is important for better understanding C-chondrites, including materials expected from the Hayabusa 2 and OSIRIS-Rex sample-return missions.

References: [1] Jenniskens, P. et al. (2012) *Science,* 338:1583-1587. [2] Zolensky, M. et al. (2014) *Meteoritics & Planetary Science,* 49:1997-2016. [3] Kelly, T. F. and Lawson, D. J. (2012) *Annual Review of Materials Research,* 42:1-31. [4] Greer, J. et al. (2017) *80th Annual Meeting of the Meteoritical Society,* Abstract #1987. [5] Nagashima, K. et al. (2012) *75th Annual Meeting of the Meteoritical Society,* Abstract #5160. [6] Schrader, D. L. and Davidson, J. (2017) *Geochimica et Cosmochimica Acta,* 214:157-171.