Goldschmidt 2022 Abstract
https://doi.org/10.46427/gold2022.12543

Atom by Atom: Investigating phosphorus in olivine using atom probe tomography

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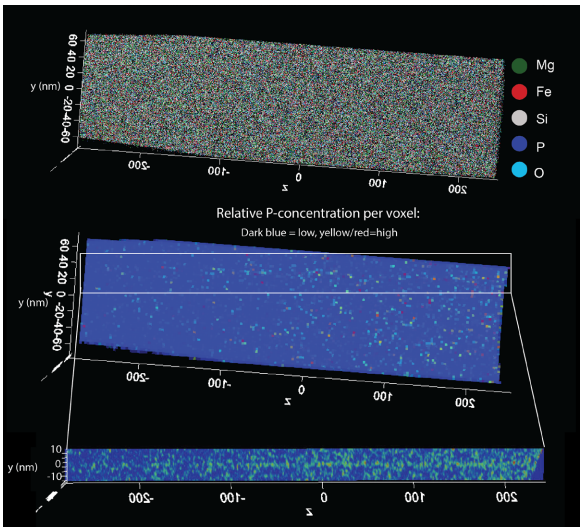

Olivine is one of the most common minerals in the solar system. Chemical heterogeneities in this mineral can be leveraged to reveal information about the formation history of the host rock. However, many of these heterogeneities are diffusively homogenized relatively quickly, obscuring the early crystallization histories of many samples. A notable exception is the near-ubiquitous observation of heterogeneous distributions of phosphorus (P) in olivine. P is a slow diffusing trace element in olivine, presenting as skeletal heterogeneities that could provide significant information on these crystals' early cooling and crystallization histories. However, the behavior of phosphorus in olivine is still poorly understood. For example, P-rich lamellae are often exceedingly thin, down to the spatial resolution of field emission gun electron probe microanalysis (EPMA). Further, there is still significant uncertainty on how P behaves in olivine: where in the lattice is it typically accommodated, and how is charge balancing maintained? A first step to answering either of these questions is determining the correlation and anticorrelation of other elements with respect to P.

The spatial scale of these lamellae precludes the use of EPMA to answer these questions and requires an instrument with finer spatial resolution. Atom Probe Tomography (APT) is uniquely suited for this task. After a sample is carved into a very fine needle, individual atoms (or small groups of atoms) are ionized, then identified by a time of flight mass spectrometer. The position and mass of each ion are recorded, allowing for the reconstruction of a 3D model of the sample. The model is then analyzed to determine how each element spatially correlates with P and the spatial distribution of P in the needle. We find a striking anticorrelation of P with silicon (Si), corroborating previous arguments that P occupies the Si site in olivine's lattice. Further, an anticorrelation of P with magnesium (Mg) suggests that Mg vacancies in the olivine lattice could offset the net positive charge created by P occupying the Si site. Finally, we find P lamellae can be thinner than 5 nm, which will need to be addressed in future diffusion chronometry studies involving this system.