SELF-CONSISTENT DETERMINATION OF IMPACT TIMESCALES BY GROWTH AND DIFFUSION KINETICS OF OLIVINE AND PYROXENE POLYMORPHS IN 3 HIGHLY SHOCKED L CHONDRITES

M. Ciocco[1] , M. Roskosz[1], M. Gounelle[1], G. Fiquet[1] and H. Leroux[2]
[1]IMPMC, CNRS, UMR 7590, Sorbonne Université, Muséum National d'Histoire Naturelle, UMR 7590 – 61 Rue Buffon, 75005 Paris, France. (E-mail : marine.ciocco@mnhn.fr)
[2]Univ. Lille, CNRS, INRAE, Centrale Lille, UMR 8207, Unité Matériaux et Transformations, 59000 Lille, France.

Introduction: The early Solar System dynamical history can be documented through the formation of high pressure polymorphs during asteroidal collisions [1-5]. However, the different methods used to bridge the gap between mineralogy and shock properties, based either on crystal growth kinetics or the associated chemical diffusions, typically yield shock timescales spread over several orders of magnitude. Furthermore, most studies tend to focus on only one single olivine high pressure polymorph, namely ringwoodite (especially ringwoodite lamellae). The aim of this study is to characterize three shocked L chondrites (Tenham, Sixiangkou, and Acfer 040) using growth and diffusion kinetics on the same samples, and focusing on both ringwoodite and pyroxene's main high pressure polymorph, akimotoite. This would offer stronger constraints on shock durations and let us build a method able to provide a better estimate of the shock conditions, especially for meteorites in which ringwoodite lamellae are not observed.

Analytical Methods: Samples were first studied by optical microscopy and Raman spectroscopy to identify HP polymorphs. Scanning Transmission Electron Microscopy (STEM) was then used to study microstructures and transformation/growth mechanisms. Combined STEM-EDX and NanoSIMS chemical maps were finally acquired on the same FIB sections in order to compare both approaches and determine the effective spatial resolution of the nanoSIMS equipped with a new RF Plasma source.

Results: In the three studied meteorites, several high pressure assemblages exhibiting various microstructures are observed. The most common consists of polycrystalline aggregates of ringwoodite. Ringwoodite is also present as lamellae in Tenham and Sixiangkou. Their thicknesses range from 1 to 3 µm and are associated to Mn depletion with diffusion lengths extending over 1.5 to 3 µm towards the host olivine. Akimotoite is present in all the samples. In Tenham, akimotoite is in rare cases in the form of lamellae embedded in pyroxene. The akimotoite lamellae are overall thinner than ringwoodite lamellae, around 0.9 µm wide at best, associated with enrichments in Fe, Ca and Na up to 1.8 µm wide. In Acfer 040, no lamellae were observed on the studied section. Yet partially vitrified patches of pyroxene composition speckled with akimotoite crystals are commonly found. These assemblages are strongly fractionated: Ca, Na, Fe and Mn are all depleted in akimotoite while Mg and Si are enriched in this phase. The partition is likely due to segregation of the elements during crystallization of akimotoite from a melt. This texture was also found in other meteorites, such as Grove Mountains 052082 [6], but only depletion in iron was investigated.

Discussion: The comparison between nanoSIMS and STEM-EDX measurements reveals that while the spatial resolution of the STEM is higher, the nanoSIMS is still viable to depict diffusion profiles. The nanoSIMS profiles can be slightly larger than STEM profiles. Nevertheless, they can be used to determine shock timescales.

In Sixiangkou, Mn diffusion distances are equal within error to the size of the ringwoodite lamellae. Conversely, in Tenham, the chemical gradients spread outside the borders of the lamellae. This difference could originate from the transformation mechanisms involved. Indeed, the lamellar ringwoodite in Sixiangkou appears discontinuous and straight. Therefore, a heterogenous nucleation is likely the transformation mechanism. On the other hand, in Tenham, several types of lamellae are visible in TEM: straight, submicrometric and oriented ones, as well as larger lamellae surrounded by a polycrystalline layer. This second microstructure is associated with complex diffusion profiles. Finally, in Acfer 040, most glassy assemblages have chemical gradients extending outside the minerals. All these chemical partitions enable us to estimate shock duration as function of diffusion length.

As an exemple of self-consistency, we note that the shock timescale estimated through diffusion profiles over akimotoite lamellae in Tenham matches the ringwoodite growth time calculation using the values in [7]. The diffusion of Mn in ringwoodite lamellae yields close results, albeit slightly higher.

Conclusion: The extensive chemical redistribution between akimotoite and glass could be used to constrain shock timescales in meteorites. However, more work is needed on the transformation and diffusion rates of this mineral. Our first attempt suggests that consistently taking akimotoite into account would enable us to characterize a larger number of meteorites, which would in turn enlighten our understanding of a wider variety of asteroidal impacts and refine our knowledge of the shock history of the chondrites parent body.

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