From the solar nebula to planetary interiors: two applications of 3DED

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Minerals are the building blocks of rocky bodies in the Solar System. By definition, they are normally crystalline [1], meaning that, ideally, their atomic structure is ordered and periodic. In fact, real crystals often show short-range disorder and reduction in crystallinity, but these local features are usually averaged in a sufficiently long range. However, natural processes, like rapid cooling, often produce heterogeneous aggregates of sub-micrometric crystals where even such small imperfections may become significant. These features prevent the use of conventional crystallographic techniques like single-crystal X-ray diffraction. In contrast, transmission electron microscope (TEM) techniques, like selected area electron diffraction, are capable to analyse such challenging samples, but they only produce 2D sections of the reciprocal lattice. Three-dimensional electron diffraction (3DED) [2] combines the high spatial resolution of TEM with a 3D reconstruction of the reciprocal lattice, enabling deep micro-structural investigations of minerals formed in extreme environments. Here we present two applications of 3DED that cover different topics in planetary sciences.

1. Ca-Al-rich inclusions (CAIs) are thought to be the oldest solids formed in the solar nebula, recording the early evolution of the Solar System [3]. 3DED was performed to study mineralogical transformations in altered CAIs from the metasomatized type 3 Ornans-type carbonaceous chondrite (CO3) Frontier Mountain 90006. Particular attention was paid to those involving 1) hibonite and hercynite, 2) clinopyroxenes with variable Al-Ti-Mg contents and 3) anorthite and nepheline. The combination of TEM imaging, nanoscale energy-dispersive X-ray spectroscopy and 3DED guarantees a robust petrographic investigation, allowing to resolve cryptocrystalline and polyphasic matrices which contain information about both primary crystallization and secondary metamorphic reactions at non-equilibrium conditions.
2. Tranquillityite, currently defined as $Fe^{2+}_8Zr_2Ti_3Si_3O_{24}$, is a rare silicate first discovered in Apollo 11 samples [4] and subsequently found in lunar and Martian meteorites [5,6] and as an accessory phase in terrestrial mafic rocks [7]. To date, a description of its crystal structure is still missing. By combining 3DED with electron backscatter diffraction data, we managed to solve and refine, for the first time, the structure of tranquillityite from the Martian shergottite Northwest Africa 856.

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