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Three dimensional rock microstructures: insights from FIB-SEM tomography

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Most studies of rock microstructures investigate two-dimensional sections or thin slices of three dimensional grain structures. With advances of X-ray and electron tomography methods the 3-D microstructure can be(relatively) routinely investigated on scales from a few microns to cm. 3D studies are needed to investigate the connectivity of microstructures and to test the assumptions we use to calculate 3D properties from 2D sections.

We have used FIB-SEM tomography to study the topology of melts in synthetic olivine rocks, 3D crystal growth microstructures, pore networks and subgrain structures. The technique uses a focused ion beam to make serial sections with a spacing of tens to hundreds of nanometers. Each section is then imaged or mapped using the electron beam. The 3D geometry of grains and subgrains can be investigated using orientation contrast or EBSD mapping. FIB-SEM tomography of rocks and minerals can be limited by charging of the uncoated surfaces exposed by the ion beam. The newest generation of FIB-SEMs have much improved low voltage imaging capability allowing high resolution charge free imaging. Low kV FIB-SEM tomography is now widely used to study the connectivity of pore networks. In-situ fluids can also be studied using cryo-FIB-SEM on frozen samples, although special freezing techniques are needed to avoid artifacts produced by ice crystallization. FIB-SEM tomography is complementary, in terms of spatial resolution and sampled volume, to TEM tomography and X-ray tomography, and the combination of these methods can cover a wide range of scales.

Our studies on melt topology in synthetic olivine rocks with a high melt content show that many grain boundaries are wetted by nanometre scale melt layers that are too thin to resolve by X-ray tomography. A variety of melt layer geometries occur consistent with several mechanisms of melt layer formation. The nature of melt geometries along triple line junctions and quadruple points can be resolved. Quadruple point junctions between four grains cannot be investigated in 2D studies. 3D microstructural studies suggest that triple lines and quadruple points are important sites for the initiation of recrystallization, reaction and fracture.