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Strain-dependent evolution of garnets in a high pressure ductile shear zone using Synchroton x-ray microtomography

Alice Macente (1), Florian Fusseis (2), Luca Menegon (3), and Timm John (4)

(1) School of Geosciences, University of Edinburgh, Edinburgh, United Kingdom (alice.macente@ed.ac.uk), (2) School of Geosciences, University of Edinburgh, Edinburgh, United Kingdom (ffusseis@staffmail.ed.ac.uk), (3) School of Geography, Earth and Environmental Sciences, Plymouth University, Plymouth, United Kingdom (luca.menegon@plymouth.ac.uk), (4) Institut für Geologische Wissenschaften, Freie Universität, Berlin, Germany (timm.john@fu-berlin.de)

Synkinematic reaction microfabrics carry important information on the kinetics, timing and rheology of tectonometamorphic processes. Despite being routinely interpreted in metamorphic and structural studies, reaction and deformation microfabrics are usually described in two dimensions. We applied Synchrotron-based x-ray microtomography to document the evolution of a pristine olivine gabbro into a deformed omphacite-garnet eclogite in 3D. In the investigated samples, which cover a strain gradient into a shear zone from the Western Gneiss Region (Norway) previously described by John et al., (2009), we focused on the spatial transformation of garnet coronas into elongated clusters of garnets. Our microtomographic data allowed us to quantify changes to the garnet volume, their shapes and their spatial arrangement. We combined microtomographic observations with light microscope- and backscatter electron images as well as electron microprobe- (EMPA) and electron backscatter diffraction (EBSD) analyses to correlate mineral composition and orientation data with the x-ray absorption signal of the same mineral grains. This allowed us to extrapolate our interpretation of the metamorphic microfabric evolution to the third dimension, effectively yielding a 4-dimensional dataset. We found that:

- The x-ray absorption contrast between individual mineral phases in our microtomographic data is sufficient to allow the same petrographic observations than in light- and electron microscopy, but extended to 3D.
- Amongst the major constituents of the synkinematic reactions, garnet is the only phase that can be segmented confidently from the microtomographic data.
- With increasing deformation, the garnet volume increases from about 9% to 25%.
- Garnet coronas in the gabbros never completely encapsulate olivine grains. This may indicate that the reaction progressed preferentially in some directions, but also leaves pathways for element transport to and from the olivines that are unobstructed by reaction products.
- Neighbouring garnet coronas are interconnected, i.e. in direct contact to each other. From a mechanical point of view, we interpret touching garnet coronas that form a rigid, potentially load-supporting framework to affect the rheology of the rock.
- In the most highly deformed eclogites, the oblate shapes of elongated garnet clusters reflect a deformational origin of the microfabrics. The clusters define a foliation, whose orientation and intensity we quantified using a star volume distribution algorithm. We interpret the aligned garnet clusters to direct synkinematic fluid flow and consequently influence the transport of dissolved chemical components.
- EBSD on garnets shows that, there is no evidence for crystal plastic deformation and all the garnets are internally strain free and show a near-random crystal preferred orientation. There is, however evidence for minor fracturing. We interpret these observations as pointing to a mechanical disintegration of the garnet coronas during strain localisation, and their rearrangement into individual clusters. This process will have been supported by pressure solution/reprecipitation processes.

Our study clearly demonstrates what 3- or even 4-dimensional data from reaction microfabrics can add to the understanding of metamorphic processes.