Current strengths and limitations of synchrotron X-ray microtomography in revealing and quantifying deformation and metamorphic processes in crystalline rocks at the microscale

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Summary: In this contribution we describe an application of synchrotron X-ray microtomography in revealing and quantifying deformation and metamorphic processes in crystalline rocks. Strengths and limitations will be discussed, highlighting the combined LPO and SPO approach when studying a deformed metagranites, constituted by quartz, mica and feldspar, relatively simple geological material but still challenging for tomography studies.

1. INTRODUCTION

To reveal and quantify the evolution of a basement rock that undergone metamorphic processes, a fundamental parameter is the quantitative analysis of mineral preferred orientations (PO's). In the description of PO of minerals, two different concepts can be used: lattice (i.e. LPO) and shape (i.e. SPO). LPO analysis is performed using diffraction techniques (e.g. electron, neutron and X-ray) that permit to obtain LPO information from the micron scale (e.g. Electron Back-Scattering Diffraction, X-ray diffraction) up to the centimeter scale (neutron diffraction). These approaches have now reached a remarkable flexibility in field of view and resolution requirements, allowing the investigation of LPO of large volumes of rocks (a few cm^3) and active slip systems during geological processes (e.g. sedimentary, igneous, and tectonic). SPO analysis is currently approached by 2D imaging and aided by stereological techniques, but 3D tomographic tools, primarly using X-ray and neutron sources are rapidly growing since they easily overcome the intrinsic issues of 2D techniques. LPO and SPO analyses have been also successfully combined [1] even if some limitations are still reducing the effective acquisition of SPO data. Those limitiations are mainly related to phase recognition and grain boundary definition issues when the X-ray attenuation contrast of different mineral phases is low or -even worst- when rocks are constitued by polycrystalline monophasic layers, which is common in most geological processes. This contribution will address these issues, and highlight the strength and limitations of combined LPO and SPO approach, studying a relatively simple geological material as a deformed metagranite, constituted by quartz, mica and feldspar.

2. EXPERIMENTAL METHOD

The investigated specimen is a deformed granite sampled within the Alpine belt (Val D'Ossola, Italy). It is part of the Monte Rosa Unit, a continental crust slice, involved in the subduction that led to the building of the Alps. The granite protolith has a Permian age, while its oriented fabric is related to the subduction process, which took place during Cenozoic Europe-Africa convergence [2].
The sample is a mylonitic (i.e. highly strained) rock where main mineral phases, recognized by using a petrographic optical microscope (Fig. 1A) or SEM analisys (Fig.1B) are quartz, white mica, biotite, feldspar and plagioclase. They are all characterized by a strong preferred orientation both for shape (SPO) and lattice (LPO). This preferred orientation developed at temperature $T \approx 400\text{-}500°C$ and pressure $P \approx 0.5\text{-}0.12$ GPa [3, 4].
Synchrotron X-ray microtomography measurement were performed at the SYRMEP beamline of the the Elettra synchrotron facility (Trieste, Italy). Experiments were carried out using a monochromatic X-ray beam (energy of 28 keV) and working in phase-contarst mode setting the sample-to-detector distance at 500 mm. We acquired 1800 projections over a 180° rotation with an exposure time/projection of 1s. Projections were recorded with a 12 bit, water-cooled CCD camera (4008 x 2672 pixels, 9.0 µm effective pixel size).
Slice reconstruction was performed using the SYRMEP Tomo Project sw, custom developed at Elettra [5]. The same data sets has been then reconstructed applying to the sample projections a single-distance phase-retrieval algorithm [6]. The consequence of this pre-processing is generally a slight blurring of the reconstructed images; for that reason, the algorithm parameters (γ ratio) were tuned in order to obtain a good compromise between contrast and spatial resolution. Both 'as reconstructed' and 'phase-retrieved' slices were segmented by using a 3D k-means clustering algorithm.

3. RESULTS

The results (Figs. 1C-1F) show an evident improvement in the phase separation of quartz and feldspar after phase-retrieval. The phase separation could strongly benefit from images acquired at higher spatial resolution. In the near feature, we plan to perform new synchrotron X-ray microtomography experiments on the same type of samples with a spatial resolution at the micron scale in order to keep an investigated representative sample volume (a compromise between spatial resolution and size of the probed sample volume constituting an essential requirement in these studies). This should allow to obtain a better visibility of the interfaces between the different phases and to segment and quantify in a more accurate way the 'low-contrast' phases present in the sample, especially feldspar and quartz. Moreover, complementary experiments by using Diffraction Contrast Tomography [7] could permit grain separation in monophasic layers.

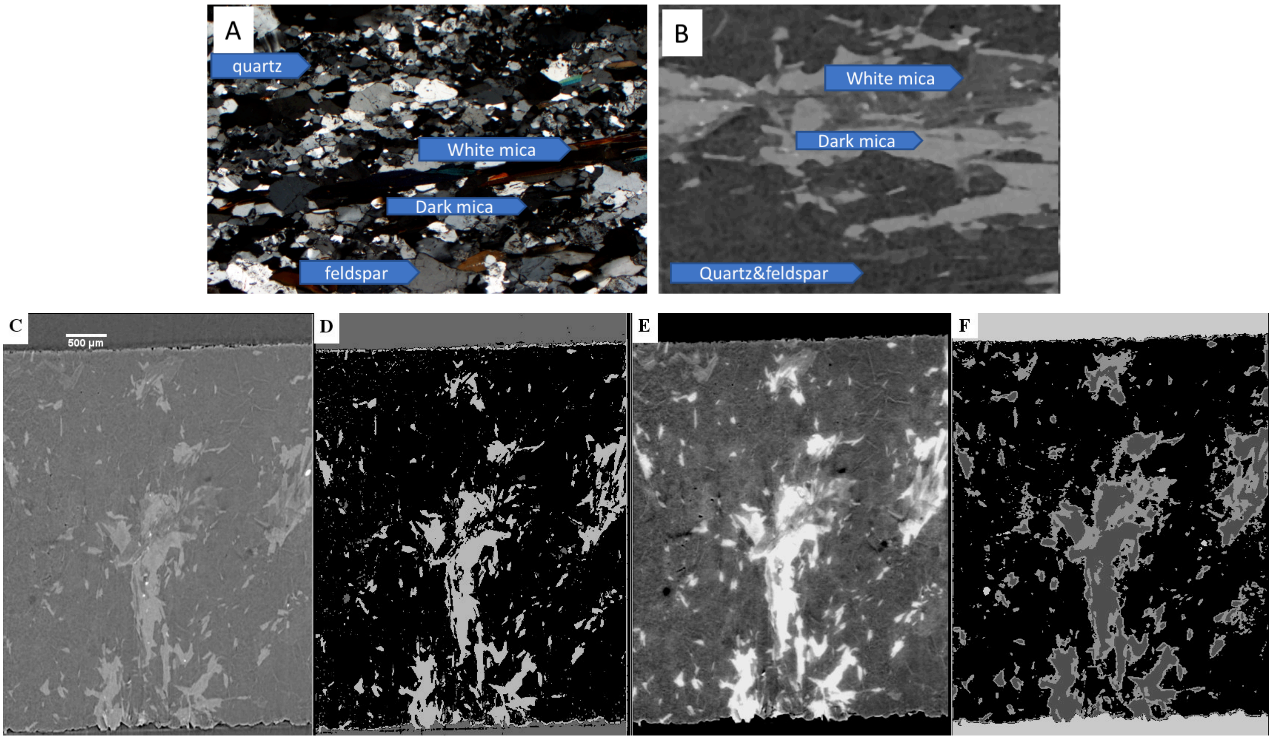

Figure 1. A) Optical and B) SEM images of the mylonitic metagranite (long side of the photograph = 1 mm). A sagittal section of the sample investigated by synchrotrn X-ray microtomography (isotropic voxel size = 9 μm): C) as reconstructed, D) k-means clustering segmention of the image reported in D), E) after phase-retrieval and F) k-means clustering segmention of the image reported in E).

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