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Rock Elastic Anisotropy Study by X-ray Synchrotron, Neutron Diffraction and Ultrasonic Methods

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Abstract

We present a combined study of a classical rock sample from Val Malenco, Italy, by investigating the microstructure and texture with state-of-the art synchrotron X-ray, neutron diffraction methods and measuring ultrasonic velocities both with a multianvil apparatus and a novel instrument to measure P and S velocities on spheres. Petrological properties were studied by thin section analysis in three basic structural planes. We discuss advantages and disadvantages of texture measurements and compare them with ultrasonic velocities results. Elastic tensor properties (Cij parameters) can be derived from spherical velocities by inversion. From quantitative texture measurements, elastic properties can be modelled by self-consistent averaging. Comparison of experimental and model Cij parameters is done based on microstructures. Good agreement between the velocity and microstructural models is observed. Similar methods can now be applied to more complex geological materials, where anisotropy is more significant.

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1. Introduction

The goal of this contribution is to quantify the microstructure and particularly crystallographic preferred orientation (CPO) in serpentinate with modern diffraction methods, time-of-flight neutron diffraction

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and synchrotron X-ray diffraction. We will then compare ultrasonic velocity measurements in three orthogonal directions on cubes with new 3D velocity determinations on spheres. The samples used for the seismic as well as for the texture measurements were prepared from the same block of serpentinite. Finally, we will predict elastic properties of the serpentinite based on CPO data and compare them with those that were actually measured.

2. Sample, experimental techniques and results

2.1. Sample

The sample is a serpentinite from Val Malenco, N-Italy, where ultramafic rocks constitute the subcontinental mantle of the Adriatic lithosphere [1]. The serpentinite is mined in a quarry near the locality Castellaccio. The sample displays a pronounced foliation and lineation. Antigorite is the main component with flat grains (e.g. Fig. 1A). There are some relic olivine grains from which antigorite transformed. Fragments of sheared olivine grains are observed locally, and small relics of olivine grains are distributed throughout the antigorite matrix. Aspect ratios of antigorite grains obtained from length of minor and major axes are in the range 0.3 –0.1 . At ambient conditions bulk density of the serpentinite, as derived from the volume and the mass of the sample cube, is 2.71 g/cm^3. The optically identified minerals are antigorite, olivine, magnetite, and chromite. Magnetite and chromite compose less than 5 % of the volume.

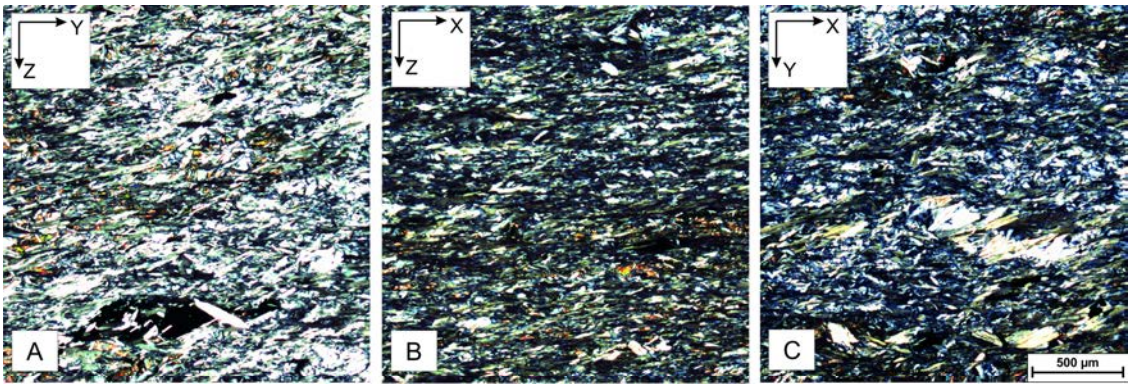

Fig. 1. Petrographic thin sections of the sample illustrating the microstructure in different directions: A – X-lineation direction; B –Y – foliation plane, perpendicular to X; C – Z – normal to the lineation.

2.2. Texture measurements

Quantitative studies have been done with diffraction methods [e.g. 2]. The low symmetry of antigorite and microstructural complexities pose additional complications and synchrotron X-rays and neutron diffraction appeared to be most applicable. Results from the two methods will be compared

2.2.1. Synchrotron X-rays

For the synchrotron experiment the sample is a cylinder, 2 mm in diameter and 10 mm long. The advantage of cylinders is that it provides full pole figure coverage with data. The cylinder was drilled perpendicular to the foliation. Experiments were performed at the high energy beamline ID-11C of the Advanced Photon Source at Argonne National Laboratory Wenk et al. [3]. The X-ray beam size was 0.7 mm x 0.7 mm, with a monochromatic wavelength of 0.10803 A. The sample is mounted on a goniometer with the axis perpendicular to the incoming X-ray. During the 28 s exposure the sample was translated 7.5 mm parallel to the cylinder axis to provide a better volume average over ~ 7 mm^3. A typical image is shown in Fig. 2A. The sample was rotated in increments of 15° from -90° to +90°.