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Editorial

Editorial for Special Issue "Lattice-Preferred Orientation and Microstructures of Minerals and Their Implications for Seismic Anisotropy"

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The lattice-preferred orientation (LPO) of minerals is important for interpreting seismic anisotropy [1–5], which occurs in the Earth's crust and mantle [6,7], and for understanding the internal structure of the deep interior of the Earth [6–8]. The characterization of microstructures, including LPO, grain size, grain shape, and misorientation, is important to determine the deformation conditions, deformation histories, kinematics, and seismic anisotropies in the crust and mantle [1,2,9]. LPOs develop in minerals in the crust, mantle, and subduction zones [1,2], where the rocks are deformed under high pressure and temperature [1–5].

This Special Issue [10–18] contains contributions pertaining to the LPOs of various minerals, including olivine, pyroxene, garnet, omphacite, muscovite, lawsonite, epidote, glaucophane, and natural ice in different settings in the crust, mantle, and subduction zones.

The articles published in this issue are divided according to the different rock types occurring in the mantle, subduction zones, and crust. The articles by Park et al. [10], Liu et al. [11], and S. Jung et al. [12] are case studies that investigate the microstructures, LPOs, and seismic properties of mantle peridotites.

Park et al. [10] have reported the deformation microstructures and LPOs of olivine and pyroxenes with respect to the petrogenesis of upper mantle xenoliths beneath the Baekdusan volcano, North Korea. Based on the petrographic features and deformation microstructures, they identified two textural categories for the peridotites: coarse and fine-grained harzburgites (CG and FG Hzb). They found that mineral composition, equilibrium temperature, LPO of olivine, stress, and extraction depth varied considerably with texture. Accordingly, they suggested that the A-type LPO of olivine in CG Hzb samples may be related to the pre-existing Archean cratonic mantle fabric (i.e., old frozen LPO) formed under anhydrous, high-temperature, and low-stress conditions. Conversely, they suggested that the D-type LPO of olivine in FG Hzb samples likely originated from later localized deformation events under low-temperature, high-stress, and anhydrous conditions after a high degree of partial melting.

Liu et al. [11] have carried out a comprehensive petro-structural and geochemical study to better elucidate the thermo-structural evolution of the Val Malenco peridotites in Italy. Their results showed that the Val Malenco serpentinized peridotites recorded both pre-alpine extension and alpine convergence events. The pre-alpine extension was recorded by microstructural and geochemical features preserved in clinopyroxene and olivine porphyroblasts, including partial melting and re-fertilization and high-temperature (900–1000 °C) deformation, followed by cooling and fluid–rock interactions. The following alpine convergence that occurred in a supra-subduction zone setting was documented by subduction-related prograde metamorphism that was preserved in the coarse-grained antigorite and olivine in the less-strained olivine-rich layers, with later low-temperature

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(<350 °C) serpentinization of the fine-grained antigorite in the more strained antigorite-rich layers.

Jung et al. [12] have studied the microstructure of amphibole peridotites from Åheim, Norway, to understand the evolution of the LPO of olivine throughout the Scandian orogeny and its implications for seismic anisotropy in the subduction zone. Detailed microstructural analysis of the Åheim peridotites revealed multiple stages of deformation. The coarse grains showed an A-type LPO of olivine, which can be interpreted as the initial stage of deformation. The spinel-bearing samples showed a combination of B-type and C-type LPOs of olivine, which is considered to represent deformation under hydrous conditions. The recrystallized fine-grained olivine displayed a B-type LPO, which can be interpreted as the final stage of deformation. The microstructure and water content of olivine indicated that dislocation creep under hydrous conditions was the dominant deformation mechanism in olivine with B-type LPO. They found that the occurrence of the B-type LPO of olivine to be vital for trench-parallel seismic anisotropy in the mantle wedge. Moreover, the calculated seismic anisotropy of tremolite showed that tremolite could contribute to trench-parallel seismic anisotropy in the mantle wedge.

Several studies have focused on the LPOs of minerals and microstructures of eclogites and blueschists in subduction zones. Two articles in this issue pertain to eclogites (Lee et al. [13], Cao et al. [14]), while two focus on blueschists (Park et al. [15], Choi et al. [16]).

Lee et al. [13] have investigated retrograde eclogites from Xitieshan, northwestern China, to understand the seismic velocity, anisotropy, and seismic reflectance in the upper part of the subducting slab. In their study, S-type LPO of omphacite was observed in three samples. The LPOs of amphibole and omphacite were found to be similar in most samples. The misorientation angles between amphiboles and their neighboring omphacites were small, with a lack of intracrystalline deformation features in the amphiboles. This indicates that the LPO of amphibole was formed by its topotactic growth during the retrogression of eclogites. The seismic properties of retrograde eclogites and amphibole were similar, indicating that they were strongly affected by the amphibole growth. The contact between serpentinized peridotites and retrograde eclogites showed a high reflection coefficient, indicating that a reflected seismic wave could be easily detected at this boundary.

Cao et al. [14] have investigated the seismic velocity and seismic anisotropies of a unique olivine-rich eclogite from northwestern Flemsøya in the Nordøyane ultra-high pressure domain of the Western Gneiss Region in Norway. Detailed analyses of the seismic properties suggest that seismic anisotropy patterns of the Flem eclogite were largely controlled by the strength of the crystal-preferred orientation (CPO) and characterized by significant destructive effects of the CPO interactions, which together resulted in very weak bulk rock seismic anisotropies (AVp = 1.0–2.5%, max. AVs = 0.6–2.0%). The magnitudes of the seismic anisotropies of the Flem eclogite were similar to those of dry eclogite but markedly lower than those of gabbro, peridotite, hydrous phase-bearing eclogite, and blueschist. The average seismic velocities of the Flem eclogite were significantly affected by the relative volume proportions of omphacite and amphibole. The Vp (8.00–8.33 km/s) and Vs values (4.55–4.72 km/s) of the Flem eclogite were markedly larger than those of the hydrous phase-bearing eclogite, blueschist, and gabbro, but they were lower than those of dry eclogite and peridotite. The seismic features of the Flem eclogite can thus be used to distinguish olivine-rich eclogite from other common rock types (especially gabbro) in the deep continental crust or subduction channel when high-resolution seismic data are available.

Park et al. [15] have conducted deformation experiments on epidote blueschists in simple shear under high pressure (0.9–1.5 GPa) and high temperature (400–500 °C) to understand the LPO and deformation microstructures of blueschists occurring at the top of a subducting slab in a warm subduction zone. They discovered that the LPO of epidote and glaucophane changes with increasing shear strain. At low shear strain ($\gamma \leq 1$), the [001] axes of glaucophane were subparallel to the shear direction, and the (010) poles were subnormally aligned with the shear plane. At high shear strain ($\gamma > 2$), the [001] axes of glaucophane were subparallel to the shear direction, while the [100] axes were aligned subnormally to the shear plane. At a shear strain of $\gamma > 4$, the alignment of the (010) epidote poles altered from being subparallel to becoming subnormal to the shear plane, while the [001] axes were subparallel to the shear direction. Their experiments indicate that the magnitude of shear strain and rheological contrast between component minerals play an important role in the formation of LPOs for glaucophane and epidote.

Choi et al. [16] have investigated the effect of lawsonite twinning on the strength of CPO and seismic anisotropy in the lawsonite blueschists from Alpine Corsica (France) and the Sivrihisar Massif (Turkey). Lawsonite is an important mineral for understanding the seismic anisotropy of subducting oceanic crust due to its large elastic anisotropy and occurrence in cold subduction zones. The study concluded that twinned lawsonite could induce substantial seismic anisotropy reduction, particularly for the maximum S-wave anisotropy in lawsonite and whole rocks by up to 3.67% and 1.46%, respectively. This article was selected as the cover issue of *Minerals* on 11 April 2021.

One article focuses on the studies of LPOs and microstructures in crustal rocks (Han et al. [17]). Muscovite is a major constituent mineral in the continental crust that exhibits markedly strong seismic anisotropy. In this article, deformation microstructures of muscovite-quartz phyllites from the Geumseongri Formation in Gunsan, South Korea, were studied to investigate the relationship between muscovite and chlorite fabrics in strongly deformed rocks and the seismic anisotropy observed in the continental crust. Their results indicate that the modal composition and alignment of muscovite and chlorite significantly affect the magnitude and symmetry of seismic anisotropy. It was found that when their [001] axes are aligned in the same direction, the coexistence of muscovite and chlorite constructively contributes to seismic anisotropy.

Kim et al. [18] have reported the microstructures and fabric transitions of natural ice. They studied five ice core samples from the Styx Glacier, northern Victoria Land, Antarctica, and reported CPO changes in ice with depth. They interpreted that the change in CPOs at <140 m was related to a combination of vertical compression and shear on a horizontal plane, while the girdle CPOs at depths >140 m were the result of horizontal extension. Their results imply that, during burial, stress regimes are subject to changes due to external kinematic controls, such as the appearance of a small peak in the bedrock.

The articles in this Special Issue prove that studies of LPO and microstructures of minerals and rocks are a major research area and provide a foundation for interpreting seismic anisotropy in the crust, mantle, and subduction zones. Therefore, the authors hope that this Special Issue encompassing recent advances in the measurement of LPOs of different minerals under various tectonic settings will be a fundamental and valuable resource for the readers and researchers interested in exploring the deformation conditions of minerals and rocks as well as the interpretation of seismic anisotropy in the crust, mantle, and subduction zones.

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