

## Sliding history and energy budget recorded in a frozen mantle earthquake in Balmuccia, Italian Alps

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In the Balmuccia massif (NW Italy), pseudotachylytes (PST) are found within a spinel lherzolite. Coming from the solidification of the melt generated during seismic rupture, these rocks constitute a geological record of fossilized earthquakes. Here, combining field observations, Raman spectrometry and Electron Back-Scattered Diffraction (EBSD), we decipher the sliding history of an ancient  $M_w > 6$  earthquake. The earthquake fault displays a 1-1.2 m strike-slip component. The average width of the principal fault plane is about 5 mm. A dense network of thin (20-200  $\mu\text{m}$ ) faults and injection veins decorates this principal slip surface. Ultramylonitic faults, filled with olivine (0.2-2  $\mu\text{m}$ ), pyroxenes and Al-spinel exhibit strong olivine fabric, with (010) planes parallel to the sliding of the fault and [100] direction parallel to the slip direction. The EBSD pole figure for the [100] direction shows an angle of about  $40^\circ$  with respect to Z-axis, indicating a non-negligible dip-slip component of 1.2-1.5 m, i.e. a probable total relative displacement of 1.6-1.9 m. The olivine fabric is consistent with partial melting and/or high temperature ( $>1250^\circ\text{C}$ ) diffusion-accommodated grain boundary sliding, which proves: 1) that the ultramylonite originates from a recrystallized melt; 2) that the earthquake occurred at a depth greater than 35 km (stable Al-spinel, no plagioclase). Raman spectrometry in micrometric injectites reveals amorphous material, with water content of 1-2 wt%, structurally bounded. Assuming a peak temperature of 1600-1800°C during sliding, the melt viscosity was  $< 1 \text{ Pa s}$ .

Fracture surface energy and thermally dissipated energy are estimated from fracture density and melt volume (including injected volume) around  $5 \cdot 10^4$  and  $5 \cdot 10^7 \text{ J m}^{-2}$  respectively. Considering a metric displacement, an average melting width of 1 cm and high normal stress,  $> 1 \text{ GPa}$ , this yields a dynamic friction coefficient  $\ll 0.1$ , which demonstrates that complete fault lubrication occurred during co-seismic sliding. We argue however, that lubrication is transient, as the melt could rapidly flow ( $2\text{-}10 \text{ m s}^{-1}$ ) into tensile fractures. Melt injection within the fracture led to rapid cooling and may have promoted strength recovery and sliding arrest. Post-seismic slip is nevertheless recorded in the main PST axes, which are mylonitized, contrary to the thin fault network. Finally, the finding of water fossilized in a frozen mantle earthquake strongly suggests that fluid and/or hydrous minerals were present and emphasizes the need for a better understanding of their role in the mechanics of earthquakes.

Keywords: Earthquakes, Péridotite, Pseudotachylyte, Intermediate-depth, Mantle, Water

