Shear Faulting Mechanism of Deep-Focus Earthquakes: Experimental Evidence from Deformed Mn$_2$GeO$_4$
undergoing the Olivine – Wadsleyite Phase Transformation

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**Background and Motivation**

- One hypothesis for deep-focus earthquakes is transformational faulting (Fig. 3). Experimentally, metastable olivines deformed in high-pressure stability field exhibit a brittle behavior only within a certain temperature range (Fig. 2), marked by an abrupt transition between ductile and brittle responses.
- Micro-mechanisms of shear localization due to syn-formational transformation from olivine to wadsleyite or equivariant olivine are poorly studied.
- We investigate microstructures in experimentally faulted Mn$_2$GeO$_4$, Mg$_2$GeO$_4$, and (Mg,Fe)$_2$SiO$_4$ olivines, which transition to β, ε, and χ phases, respectively.

**Experimental**

- Pre-synthesized polycrystalline Mn$_2$GeO$_4$ and Mg$_2$GeO$_4$ olivine samples were deformed in the DDA apparatus with acoustic emission (AE) monitoring (Fig. 3), under pressure and temperature conditions corresponding to the respective high-pressure phase stability fields.
- All the metastable olivine samples deformed in the brittle fields shown in Fig. 2 emitted numerous AE signals and succeeded samples contain macroscopic failures (Fig. 4). In all cases, maximum axial strain axes are on the order of 25–50%.
- Microstructural characterizations were achieved using microscopy, SEM, and TEM on recovered samples.

**Results**

SEM and EBSD show that newly nucleated β-Mg$_2$GeO$_4$ forms extensively thin linear zones, often encasing olivine grains into subparallel bands, which have the characteristics of kink bands. Within the β-Mg$_2$GeO$_4$ phase zone, grain size is extremely fine, typically 100 nm or less.

**Discussion**

Olivine has insufficient independent slip systems to satisfy von Mises criterion of plastic deformation. In Fig. 11a & b, the easy slip plane in grain (2) is parallel to the maximum shear stress, whereas the slip system in grain (1) cannot be activated. Slip in grain (2) creates stress concentration (red triangle in the circle), generating geotectonically necessary dislocations (SDOs, red + symbols) in grain (1). Kink bands are a result of production and propagation of NGDs (Figs. 11b, 11h).

Conjugate kink bands in deforming metastable olivine are the nucleation sites for the high-pressure phases (wadsleyite and ringwoodite). Nanometric high-pressure phases grow in kink band boundaries to form a network of nano-scale shear zones (NSZs). The weak nanometric grains and latent heat released by the phase transformation focus deformation to the NSZ-network, promoting macroscopic shear failure. We have documented this mechanism in experiments on two olivines Mn$_2$GeO$_4$ and Mg$_2$GeO$_4$, which transform to wadsleyite and ringwoodite structures, respectively. This may be a vital mechanism for the nucleation of deep-focus earthquakes.

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**References:**