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Seismicity triggered by the olivine-spinel transition: new insights from combined XRD and acoustic emission monitoring during deformation experiments in Mg2GeO4

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Polycrystalline Mg2GeO4-olivine has been deformed (strain rates from 2.10-4/s to 10-5/s) in the deformation-DIA in 13-BM-D at GSECARS (Advanced Photon Source) at ca. 2 GPa confining pressure for temperatures between 973 and 1573 K (i.e. in the Mg2GeO4-ringwoodite field). Stress, advancement of transformation, and strain were measured in-situ using X-ray diffraction (XRD) and imaging, and acoustic emissions (AE) were recorded simultaneously.

When differential stress is applied (ca. 1- to 2 GPa) and temperature is increased, the very beginning of the transformation to the ringwoodite structure (as evidenced by in situ XRD) is accompanied by AE bursts which locate within the sample. At high strain rates (>10-4/s) and low temperatures (800-900 degrees C), the number of AEs is comparable, if not larger, to that observed during the cold compression of quartz grains. The largest events always occur at a temperature slightly below that of appearance of the ringwoodite-structure phase on the XRD images patterns. This suggests that AEs are generated while the transition is still nucleation controlled (pseudo-martensitic stage). During stress-relaxation periods, the rate of AE triggering decreases, but does not completely vanish. Importantly, we still observed very large AEs at strain rates as low as approx. 10-5/ s, while at these early stages of the transformation, the samples did not show any macroscopic rheological weakening.

Focal mechanism analysis of the largest AEs showed that they are all of shear type, some being even pure double couple. They radiate about the same amount of energy as typically recorded during fast crack propagation in amorphous glass material. Microstructural analysis (SEM, EBSD and TEM) highlights the presence of thin transformation bands, with plausible evidence of shear (grain distortion and grain size reduction). These bands are made of incoherent spinel and olivine nano-grains which run across germanium-olivine grain boundaries. These bands are all oriented near perpendicular to the principal compressive
stress. In samples for which no AEs were recorded (hydrostatic conditions and higher temperatures and reaction progress), microstructure is different with incoherent grain growth at GB (hydrostatic conditions) and spinel-lamellae within a single germanium olivine crystal (fast reaction rate under deviatoric stress).

Our observations point out that under high deviatoric stress, the olivine – spinel transition is a source of mechanical instability, which produces nano-seismicity. This may have important consequences for the understanding of deep-focus earthquakes occurring in cold and metastable olivine within the transition zone.