SSS32-14 Room:315 Time:May 1 14:30-14:45

Shock compression experiment of olivine- Part 3: pulverization occurred before frictional melting

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Seismic waves may be generated by a rapid slip accompanied by a rapid drop of shear stress at or near the rapture tip that propagates rapidly. It is an important subject of seismology to identify the material changes occurring at the fracture tip. The inferred slip weakening has been ascribed to (1) frictional melting and lubrication, (2) thermal pressurization, (3) flash heating and melting, (4) powder lubrication, and the combinations of those above. High-speed rotary shear friction apparatus has played important roles in formulating the above hypothesis in the past, but in these experiments fault planes are already prepared and the formation of new fault planes cannot be studied. Moreover normal pressure cannot exceed few tens of mega-Pascal because of the instrumental limitation.

We performed a series of shock compression experiments using a keyed powder gun at Kumamoto University in order to investigate the focal mechanics of deep earthquakes. We used a single crystal of forsterite (Fo 94; shaped in a diskette of diameter 12 mm and thickness 3 mm nearly perpendicular to the olivine c-axis). The olivine disk is mounted in a steel capsule. Flyer speed was 1.5 km/s; applied pressure, 31 GPa; and shock wave velocity, ca. 7 km/s; particle velocity, ca. 1 km/s. After the shock experiment the capsule is recovered from the gun and cut perpendicular to the disk plane and polished thin sections were prepared for optical, SEM an TEM observations.

Many shear planes were generated. Olivine shows wavy extinctions and locally cataclastic texture. Shear planes (i.e., fault) are typically sharp and show up to 0.5 mm displacement. The TEM observation of the fault wall where 'spongy material is attached' revealed that the wall has a zonal structure as follows. Well inside the wall are developed densely spaced and tangles [001] screw dislocations. Outer 2-5 micron zone is polycrystalline olivine of average grain size 200-300 nm. The outermost rim is an aggregate of semi-rounded small olivine particles (ca. 200 nm) mounted in a matrix of glass of olivine composition, indicating that melting of olivine occurred here. It is important to note that the same dislocation structure remained in these olivine nano-particles. It is inferred from these structure that polygonization and pulverization of olivine has occurred before melting began near the fault wall (within a few microns). Such pulverization is possible at running fracture tip, where stress and strain rate are the highest (Reches and Dewer, 2005). The whole process occurred in a short duration of the order of 0.5 microsecond. The fracturing was probably propelled by the rapid sweep of shock waves running through the sample in our experiment. Apart from the role of the shock waves, the situation is considered to be analogous to natural earthquakes. Present experimental result sheds light on the long-lasting controversy on the formation of pseudotachylytes.

Reference: Reches and Dewers (2005) Gouge formation by dynamic pulverization during erthquake rupture. EPSL 235, 361-374.

Keywords: shock compression experiment, olivine, frictional melting, pulverization, fault, earthquake