Brittle-plastic transition of experimentally simulated quartz-feldspar aggregates

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The brittle-plastic transition zone of the upper crust, where the crustal strength estimated based on rock mechanics reaches the maximum, often nucleates major continental earthquakes. Therefore, it is crucial to reveal the deformation mechanism there for understanding the process of earthquake nucleation. However, deformation experiments for actual constituents of the continental crust are lacking. To illuminate the microphysical process, we conducted a series of rock deformation experiments under conditions spanning the brittle-plastic transition zone.

Experiments were carried out using a Griggs-type solid medium apparatus installed at Tohoku University. The sample was composed of quartz and albite powder, with a mass ratio of 1:1. Median diameters of the initial grain were ~30 μm for the quartz and ~50 μm for the albite. Temperature and pressure conditions were chosen by assuming a geothermal gradient of 30 °C/km and a granite density of 2700 kg/m^3, respectively. The experimental conditions simulating the depth of 7, 8, 10, 13, 18, 24, and 30 km were confining pressure ranging from 185 MPa to 870 MPa and temperature ranging from 210 °C to 900 °C. Shear strain rates were repeatedly changed between ~10^{-3} and ~10^{-4} /s during deformation. Mechanical results show that the shear strength increased as equivalent depth increased from 7 to 24 km. This implies the brittle deformation because the strength increases in proportion to the pressure. On the contrary, the strength dropped by about 550 MPa as the depth increased from 24 to 30 km. The remarkable decrease in strength even under the elevated pressures implies the plastic deformation in this condition. Microstructure in samples deformed at the shallower depth conditions (< 10 km depths) shows short cracks with finely crushed grains, which also suggests the brittle deformation in the condition. Samples deformed at the equivalent depth > 13 km show flow structures distributed between patches of fine-grained aggregates. Furthermore, the aggregates formed under conditions at 13, 18, and 24 km depth consist of fine angular grains and pores, while those at 30 km depth condition exhibit tightly packed, polygonal grains of ~1 μm. We speculate that the small polygonal grains were formed by dynamic recrystallization. Since the sample was composed of quartz and albite, stress was heterogeneously concentrated on quartz, which is the stronger phase (Tullis et al., 1991). This results in subgrain boundaries forming inside the quartz grains. As temperature increased to 900 °C, dislocations climb was activated, and the small polygonal grains were formed by recrystallization, as suggested by Gonçalves et al. (2015). These microstructural observation indicates that the shallower depth samples (< 10 km depths) deformed in brittle behavior while the sample at 30 km depth condition deformed in plastic behavior. At 13, 18, and 24 km depths conditions, the samples deformed in brittle-plastic transitional behavior. Moreover, image analyses showed a change in feature of the cracks with increasing the equivalent depth from 8 to 18 km: short and random oriented cracks at the equivalent depth of 8 km while long cracks forming R_1- and Y- shears at the equivalent depths > 10 km. This change implies that short cracks are connected in the kinematically favored orientation for slip with increasing pressure and temperature. Since the samples deformed at 13 and 18 km depth conditions are within the brittle-plastic transition regime, the crack coalescence is a possible cause for major continental earthquakes nucleating at the brittle-plastic transitional zone.

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