Weakening of quartz rocks at subseismic slip rates due to frictional heating

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Quartz rocks are known to show weakening commonly at subseismic slip rates of 0.1–10 cm/s, in contrast to other rocks in which weakening commonly occurs at seismic slip rates of ≧10 cm/s. We show by experiments and theoretical considerations that weakening of quartz rocks at subseismic slip rates occurs due to frictional heating.

We conducted rotary-shear friction experiments on intact agate and silica-gel gouge at a normal stress of 1.5 MPa and equivalent slip rates (V_{eq}) of 0.1–10 cm/s monitoring temperature (T) adjacent to the slip surface or the gouge layer. It should be noted that the actual slip-surface or gouge temperature during the experiment was much higher than T. Steady-state friction coefficient μ_{ss} of both intact agate and silica-gel gouge decreased with increasing V_{eq} from 0.6–0.7 at V_{eq} = 0.1 cm/s to 0.03–0.2 at V_{eq} = 10 cm/s, while T increased with increasing V_{eq} from ≈25˚C at V_{eq} = 0.1 cm/s to 88–105˚C at V_{eq} = 10 cm/s. Spikes of high friction followed by T maxima and subsequent weakening suggest that slip at strong asperity contacts induced frictional heat, which in turn resulted in weakening. These results indicate that the frictional strength of intact agate and silica-gel gouge at slip rates of 0.1–10 cm/s is controlled by temperature, which increases by frictional heating.

Based on the flash-heating model of Rice (2006), temperature increase ΔT (˚C) by flash heating at an asperity contact can be described as follows:

$$\Delta T = \mu_p (4 S_i^3 V^2 \sigma A / \alpha^2 \pi^3)^{1/4} / \rho c_p$$

where μ_p is peak friction coefficient, S_i is indentation strength, V is slip rate, σ is normal stress, A is slip surface area, ρ is density, c_p is heat capacity, and α is thermal diffusivity. Because μ_p, ρ, c_p and α are not much different among rocks, the above equation implies that at a given condition of V, σ and A, ΔT depends primarily on S_i and is proportional to $S_i^{3/4}$. Although only limited S_i data are available at present, indentation hardness H_i can be correlated with S_i, and H_i value of quartz (12 GPa) is much larger than those values of other common rock-forming minerals, e.g., 6 GPa for feldspars, 3.4–5 GPa for amphiboles, 3.4–6.5 GPa for pyroxenes, 6.5–8.4 GPa for olivine, 1.5 GPa for calcite, and 1–2 GPa for micas (Spray, 2010). Thus at a given condition of V, σ and A, ΔT of quartz rocks would be much higher than those of other rocks so that much more amount of frictional heat would be induced at asperity contacts in quartz rocks than in other rocks, which must be responsible for weakening of quartz rocks at subseisimic slip rates.

Keywords: quartz rocks, frictional heating, weakening, subseismic slip rates

