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Physical processes of quartz amorphization due to friction

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Solid state amorphization of minerals occurs in indentation and shock experiments, and has been observed in high pressure metamorphic rocks. A production of amorphous material is also reported in experimentally created silicate gouges (Yund et al., 1990), and in San Andreas Fault core samples (Janssen et al., 2010). Rotary-shear friction experiments of quartz rocks imply dynamic weakening at seismic rates (Di Toro et al., 2004). These experiments have suggested that weakening is caused by formation and thixotropic behavior of a silica gel layer which comprises of very fine particles of hydrated amorphous silica on fault gouges (Goldsby & Tullis, 2002; Hayashi & Tsutsumi, 2010). Therefore, physical processes of amorphization are essential to better understand the weakening mechanism of quartz bearing rocks. In this study, we conducted pin- and ball-on-disk friction experiments to investigate details of quartz amorphization (Muto et al, 2007). Disks were made of single crystals of synthetic and Brazilian quartz. The normal load F and sliding velocity V were ranged from 0.01 N to 1 N and from 0.01 m/s to 2.6 m/s, respectively. The friction was conducted using quartz and diamond pins (curvature radii of 0.2 ~ 3 mm) to large displacements ($>$ 1000 m) under controlled atmosphere. We analyzed experimental samples by Raman spectroscopy and Fourier transform infrared spectroscopy FT-IR. Raman spectroscopy (excitation wavelength 532.1 nm) provides lattice vibration modes, and was used to investigate the degree of amorphization of samples. Raman spectra of friction tracks on disks show clear bands at wavenumbers of 126, 204, 356, 394, and 464 cm^{-1}, characteristics of intact a-quartz. Remarkably, in experiments using diamond pins (F = 0.8 N, normal stress calculated by contact area = 293 ~ 440 MPa, V = 0.12 ~ 0.23 m/s), the bands at 128, 204 and 464 cm^{-1} gradually broaden to reveal shoulders on the higher-wavenumber sides of these peaks. Especially, three distinguished peaks at 490, 500 and 515 cm^{-1} and a weak broad peak at 606 cm^{-1} appear sporadically on the track after the slip distance of $>$ 7 m. Moreover, in experiments using quartz pins (F = 1 N, normal stress calculated by contact area = 1 MPa, V = 0.01 ~ 2.6 m/s) after a large displacement ($>$ 78 m), the frequency shifts or appearance of new distinguished peaks similar to those in experiments using diamond pin are found. The bands at 490 and 606 cm^{-1} can be assigned to the symmetric stretching of four-membered SiO_4 ring (D1 band) and planar three-membered SiO_4 ring (D2 band) in amorphous silica, respectively. The peaks at 500 and 515 cm^{-1} correspond to the strongest moganite A1 mode and the strongest coesite A1 mode, which arise from four-membered SiO4 ring structure. These results indicate that quartz change intermediate range structure of SiO_4 network during friction, and four or three-membered SiO_4 rings gradually increase in six-membered quartz. The results of FT-IR analyses on friction tracks showed the presence of a broad peak at 3000 -3600 cm^{-1} only at frictional tracks, which indicates the ?OH symmetric stretching band of molecular H_2O. It shows that hydration of quartz occur only on friction tracks due to friction. The results of Raman spectroscopy and FT-IR as well as flow like structure of wear materials observed by SEM analyses imply that Si-O-Si bridging of strained rings preferentially react with water to form hydrated amorphous silica layer on friction surface. The formation of silica gel layer that occurs locally at real asperity contacts is likely to cause fault weakening observed by pin-on-disk friction experiment.

Keywords: quartz amorphization, friction experiment, fault weakening, raman spectroscopy