

Frictional properties of fault rocks developed along the Median Tectonic Line

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We investigated frictional properties of fault rocks exposed along the Median Tectonic Line (MTL), at realistic physical conditions, i.e. high-temperature ($\sim 300^\circ\text{C}$), high-pressure (normal stress of 300 MPa) and high-pore pressure (pore fluid pressure up to 240 MPa), using the hydrothermal ring shear apparatus at Utrecht University. The MTL is the largest fault in Japan that has been defined as the boundary fault between the Ryoke and the Sambagawa belts of southwest Japan. Experiments were performed on simulated gouges derived from two cataclasite and one protomylonite samples in the Ryoke belt. Both cataclasites contain ~ 30 wt.% clay minerals. One contains ~ 14 wt.% white mica and the other ~ 14 wt.% chlorite.

From chemical analyses of chlorite grains in chl-cataclasite and protomylonite, we estimated the natural deformation temperature using the chlorite geothermometer proposed by Bourdelle *et al.* (2013 CMP). Results for the protomylonite show a bimodal distribution ($230\text{--}240^\circ\text{C}$ and $290\text{--}340^\circ\text{C}$) with most of the low temperature chlorite grains existing as blobs ($\sim 1\text{--}2$ mm) containing with lamella of white mica. These chlorite grains may have developed as pseudomorphs of biotite in the original tonalite. On the other hand, the high temperature chlorite grains do not coexist with white mica and have developed at grain boundaries or fracture surfaces in the original tonalite. The chlorite grains which show low temperature might have been formed by alteration, so that we estimate that the estimated high temperature of $290\text{--}340^\circ\text{C}$ is the deformation temperature when fracture surfaces were formed in the protomylonite. Chl-cataclasite also shows a bimodal distribution of temperatures ($180\text{--}220^\circ\text{C}$ and $240\text{--}300^\circ\text{C}$) but these different peaks cannot be assigned to different microstructures.

To prepare simulated gouges for friction experiments, the starting samples were crushed and sieved to $< 50 \mu\text{m}$ and the powders pressed into a ring shape with a small amount of distilled water. The friction coefficient obtained for the protomylonite at steady state was ~ 0.68 . That for the Ms- and Chl-cataclasites varied with pore fluid pressure, increasing from ~ 0.65 and ~ 0.56 at 120 MPa to ~ 0.87 and ~ 0.66 at 240 MPa, respectively. Velocity stepping experiments at sliding velocities from 0.001 mm/s to 0.1 mm/s, yielded velocity-weakening or neutral behaviour in all experiments. These results suggest that earthquakes can nucleate in all gouges types studied at ~ 10 km depth (normal stress of 300 MPa) at a temperature of 300°C . Furthermore, we also performed frictional experiments on pure chlorite (clinochlore), a phyllosilicate that is widely considered to contribute to weakening of fault-zone. Friction coefficients obtained varied only with temperature, increasing from $\sim 0.20\text{--}0.30$ below 400°C to $\sim 0.30\text{--}0.40$ above 500°C . Velocity strengthening behaviour was observed at almost all experimental conditions at slip velocities from 0.0003 mm/s to 0.1 mm/s. Unlike our results for the gouges studied, this finding suggests that earthquakes will not nucleate in gouge formed at the depths and temperatures where chlorite is abundant and stable. In summary, our results show that chlorite can contribute to the low strength of fault-zones but that the amount of chlorite of ~ 14 wt.% in the fault rocks of the MTL is not enough to influence whole gouge strength (friction coefficient). In other words, when the content of chlorite increases in fault rocks or localization of deformation occurs within the chlorite, the strength of the fault zone will decrease but the velocity-strengthening nature of the chlorite should tend to inhibit

initiation and propagation of large rupture events.

Keywords: Frictional property, Fault rock, Chlorite, High-pressure hydrothermal condition, Median Tectonic Line