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Fault lubrication by graphitic fault gouge; implications for fault creep along the Atotsugawa fault system

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Graphite often contained within the fault gouge associated with its geological background (e.g., Zulauf et al., 1990, Manatschal, 1999, Craw, 2002), has a significantly low friction coefficient. Graphite-bearing natural fault gouges are often composed of finely crushed quartzo-feldspathic fragments and highly crystallized graphite with minor accessory clay minerals. Although the graphite content varies depending on faults, most of the blackish fault gouge contains about 3-10 wt% of graphite (particles size of $<$ 10 um) in bulk fault gouge. Oohashi et al. (2011) revealed that graphite shows very low friction coefficient ($u < 0.2$) over a wide range of slip rates of 50 um/s to 1.3 m/s. Consequently, the presence of graphite, even if its proportion is small, possibly reduce the fault strength efficiently.

Effect of weak mineral for strength of natural fault zone is examined to conduct bimineralic gouge experiment. Thus, we conducted frictional experiments with graphite-quartz mixture gouges to determine how amount of graphite is needed to reduce the frictional strength, and textural contribution for weakening. Experimental results clearly indicated that the friction coefficient of the mixture gouge decreases with graphite content according to the power-law relations irrespective of slip-rate; it starts to reduce at the graphite fraction of 5 vol% and reached to the almost same level of pure graphite gouge at the fraction of $>$ 28 vol%. The weakening of mixture gouges $<$ 10 vol% of graphite is associated with slip localization and partial connection of graphite matrix along the surface. On the other hand, $>$ 28 vol% of mixture shows diffused graphite-matrix flow within the slip localized zone due to the development of through-going connection of graphite parallels to the Y and P surfaces. These non-linear, power-law dependency of friction on content which is differ from almost linear trend of clay minerals (e.g., Tembe et al., 2010, Moore and Lockner, 2011) demonstrates that the potential importance of graphite for weakening agent on mature faults even small amounts.

Comparison on graphite content and textural features with our experimental results and natural graphite-bearing faults revealed that the weakening by graphite can be possible in natural fault zones as a consequence of greater displacement. Although shallow faults often contains some extent of clay minerals, effectiveness of graphite for fault weakening surely exceeds that of clay minerals because the weakening effect of 10 % content of graphite is equivalent to that of 30-60 % of montmorillonite and more than 65 % of illite and kaolinite. This weakening may be more effective at depths where smectite could not exist anymore. The weakness of graphite even at low slip-rates may promotes creeping fault motion or afterslip and one of the candidates for long-term fault weakening.

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