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A large amount of fluid percolates along faults formed at brittle-ductile transition zones

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In mobile belts such as the Japanese islands and California, inland earthquakes most frequently occur at the depth range between 10-15 km, and few earthquakes occur below 15 km. Assuming that upper crustal rheology is controlled by that of quartz, the depth of brittle-ductile transition (B-D transition hereafter) is inferred to be located at the depth of 10-15 km based on deformation experiments of rocks. Accordingly, the lower limit of depth of hypocenters well coincides with the depth of B-D transition, and hence it is inferred that inland earthquakes most frequently occur in the basal part of brittle region (here referred to as B-D transition zone).

Recently, there seem to be increasing interest among researchers in studies on shear zone formation and strain softening at the B-D transition zone, and in some studies, weak faults are directly linked to elevated pore-fluid pressure (Faulkner et al., 2006, Nature). In fact, it has been inferred that a large amount of fluid exists around hypocenters below inland active faults, based on measurements of electrical conductivity. Although many researches have been conducted on fluid migration in exhumed and fossil deeper parts of the crust, not many of them are directly related with the B-D transition zone.

High-grade parts of the Sambagawa metamorphic rocks, which we have been studying for many years, form at the depth of ca. 30 km, and then experience a large amount of ductile deformation during the exhumation to the level of B-D transition (D1 phase). However, we have recently found that these rocks further experience pervasive normal faulting during D2 phase, when they are elevated crossing the B-D transition zone (Takeshita and Yagi, 2004, GS London, Special Pub.; El-Fakharani and Takeshita, 2008, J. Asian Earth Sciences). Not only because quartz veins, which are closely associated with normal faults, plasitically deform at low-temperature conditions, but because they are also cracked, it is inferred that these normal faults form at the temperature conditions of B-D transition. Furthermore, this inference is also evidenced by the fact that some fault rocks consisting mostly of actinolite show mineral assemblages of actinolite+talc+chlorite, indicating metamorphism of peridotite at sub-greenschist conditions.

One important fact is that the normal fault zone is accompanied by a thick damage zone, where shear bands (micro-normal faults) are pervasively developed in rocks. Along shear bands, not only phengite and chlorite newly grow, but also quartz crystals become fine-grained, forming micro-shear zones. The fact that phengite and chlorite newly grow along anastomosing conjugate shear bands indicates that fluid migration is pervasive at a sample scale. In particular, chlorite, the chemical formula of which is expressed as $(Mg, Fe)_{10}Al_4Si_6O_{20}(OH)_{16}$=10(Mg, Fe)O, 2Al2O3, 6SiO2, 8H2O, contains crystal-bound water of 10-13wt.% . In mafic schist strain fringes with higher aspect ratios than 10 in some cases densely develop, and chlorite rocks occur in another case, where matrix amphibole and epidote are almost totally replaced by chlorite. For the latter case, it is roughly inferred that water of ca. 5 wt.% is added to the chlorite rocks, which may be far less than the actual volume of migrating fluid. Furthermore, a large-scale metasomatism must have occurred during the formation of chlorite rocks, where Ca and Si are extracted and Mg and Fe are added.

In summary, it is inferred that pervasive fluid migration occurs in fault zones under the conditions of B-D transition, and the volume could be of great amount. In the future, the relationship between fluid migration and deformation processes and mechanisms must be analyzed, and the role which fluid migration plays in the generation of inland earthquakes.