A project to re-evaluate the deformation processes and mechanisms in the brittle-ductile transition zone of upper crust

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For inland earthquakes, which frequently occur in Japan, it has been believed that the depth of brittle-ductile transition in the upper crust determines the lower limit of depth of hypocenters for the case of quartz-controlled upper crustal rheology. However, there is a problem that the calculated differential stresses are too large, using the experimentally determined values (e.g. 480 MPa at the depth of 13 km, assuming thrusting and the pore-fluid pressure equal to the hydrostatic pressure). Such high differential stresses have not been observed with both geophysical and geological methods. Beaumont et al. (2004, JGR) have numerically shown that thrust extrusion of the metamorphic rocks (midcrust) into the upper crust will never occur, unless the brittle strength is less than one-third of the experimental one. Accordingly, the peak value of differential stresses at the brittle-ductile transition could be greatly reduced , compared to that inferred from the experiments.

In order to argue these problems, we have made two important discoveries through the researches on exhumation tectonics in the Sambagawa metamorphic rocks. One is that the brittle strength itself could be much lower than those expected from the law of Byerlee. We have recently discovered that the Sambagawa metamorphic rocks of central Shikoku experienced a pervasive D2 normal faulting during exhumation (Takeshita and Yagi, 2004, GS London, Special Pub.; El-Fakharani and Takeshita in review). These are low-angle normal faults (i.e. the angle of shear ranges between 90 to 120 degrees), the formation mechanisms and strength of which have not been still resolved (e.g. Zheng et al., 2004, JSG). Furthermore, the coefficient of friction along fault plane strongly depends on pore-fluid pressure, kinds of rocks, degree of smoothness of fault surface, etc. In particular, in case of fault breccias consisting of clay minerals such as serpentine, which often occurs in the Sambagawa belt, the coefficient of friction could be greatly reduced. Similarly, we have found that chlorite and phengite grow like a lace along shear bands, which could also reduce the coefficient of friction.

Another point is the importance of dissolution-precipitation creep (or solution mass transfer, SMT) at the brittle-ductile transition zone. Although in the stress-depth profile, only the brittle strength is delineated at the upper most crust, SMT occurs under low stresses at this depth range. Gratier et al. (1999, JSG) and Gratier and Gueydan (2007, Tectonic Faults, MIT press) conclude that the rate of SMT creep is greatly enhanced in rocks with high crack densities, because it is strongly dependent on diffusion distance. Therefore, damaged rocks by intense fracturing no longer support the brittle strength. In fact, in quartz schists from the Sambagawa metamorphic rocks, we have found those, which experienced a great amount of SMT creep at the conditions of brittle-ductile transition (ca. 300 degrees) during the D2 stage of exhumation. In these rocks, a type I crossed girdle quartz c-axis fabric is weakened or completely obliterated to become random due to SMT creep. The dominance of SMT creep is also evidenced by no wavy extinction and straight grain boundaries indicative of normal grain growth in recrystallized grains from rocks with a random quartz c-axis fabric, while wavy extinction and cuspate or lobate grain boundaries indicative of dislocation creep occur in those from rocks with a strong quartz c-axis fabric.

In summary, although the problems of deformation mechanisms and differential stresses at the brittle-ductile transition zone have been argued for a long time, these have not been resolved yet. These problems are a first class topic in rheology, which is broadly related with tectonics in the continental crust, in particular, tectonics of inland earthquakes.