The damaged Sambagawa metamorphic rocks, which formed during the exhumation through the brittle-ductile transition zone

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Beaumont et al. (2004, JGR) have numerically shown that the midcrustal metamorphic rocks are never exhumed to the surface of the Earth, if the brittle and ductile strengths in the upper crust are comparable with those experimentally determined. In particular, only for the case that the brittle strength is less than one-third of the experimental one, thrust extrusion of the midcrust into the upper crust will occur. In this context, it is very important to investigate how metamorphic rocks deform and what kinds of softening mechanisms operate at the brittle-ductile transition zone.

We have recently demonstrated that pervasive D2 normal faulting occurred in the Sambagawa metamorphic rocks of central Shikoku at the conditions of brittle-ductile transition during exhumation (El-Fakharani and Takeshita, in review). Interestingly, in regions where normal faults pervasively develop, in particular, in the Niihama area, shear bands pervasively develop, along which phengite and chlorite newly grow. Similarly, in quartz schist, shear bands densely develop, and further, the existing quartz c-axis fabrics become weakened, and in some samples obliterated to become random. These facts indicate that dissolution-precipitation creep enhanced by microcracking greatly progressed. Furthermore, a large amount of strain fringes of chlorite with higher aspect ratios than 10 develop in the mafic schist.

Recently, Vidal et al. (2006, JMG) have concluded that chlorite grew at the two stages, high-temperature stage (T=450-600 oC) and low-temperature stage (200-350 oC) based on mineral equilibrium in the pelitic schist with densely developed shear bands from the boundary between the garnet and albite-biotite zones along the Asemi river. It should be noted that the amount of grown chlorite is larger at the second stage than at the first stage. I have recently discovered that in the oligoclase-biotite zone of the Niihama area chlorite characterized by a fairly low Mg/Fe ratios ranging between 0.66-0.95 (5 samples) grows along shear bands. These low Mg/Fe values in chlorite can be correlated with those in the garnet zone after Higashino (1990, JGSJ), indicating that the shear bands formed at a low temperature. Furthermore, in the albite-biotite zone of the Tachikawa area, where normal faults develop, a mafic schist with a very high volume fraction of chlorite greater than 50 % occur. In this rocks, although matrix amphibole and epidote are almost replaced by chlorite, amphibole with the compositions closer to those of barroisite and epidote are overgrown by albite porphyroblasts as inclusions. Actinolite also occurs in the matrix. Chlorite is a hydrated mineral with water of ca. 13 wt%. Hence, it is inferred a large amount of water was added to this rock during the chloritization, which was probably brought through the normal faults.

In summary, when metamorphic rocks are exhumed into the upper crustal level above the depth of brittle-ductile transition, not only pervasive faulting, but also dissolution-precipitation creep assisted by micro-faulting prevail. Further, a great amount of water migrates along faults and added to the metamorphic rocks at this depth range. These conditions for faulting and amount of water can be monitored with the knowledge of metamorphic petrology, which can lead to the new view of the brittle-ductile transition region. While it is inferred that faulting and dissolution-precipitation creep in these regions could occur at a low stress, based on the model by Beaumont et al. (2004), the detailed mechanisms for softening must be investigated in the future.