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The realities of deformation, metamorphism and fluid migration in 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 friction coefficient incorporating pore-fluid pressure is less than 0.1, 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, 2008, Journal of Asian Earth Sciences). 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. Recently, Vidal et al. (2006, JMG) have reported that a large amount of chlorite grew along shear bands at the temperature conditions of 200-350 oC based on mineral equilibrium in the pelitic schist from the albite-biotite zone along the Asemi river, which perhaps occurred at D2 based on the temperature conditions. 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 fringe of chlorite with higher aspect ratios than 10 develops in the mafic schist. These facts suggest that normal faulting is pervasive accompanied by a thick damage zone, and not limited to the portions along the faults (i.e. distributed brittle deformation). We have also 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. The Fe-rich chlorite grows because the chlorite forms replacing Fe-rich biotite and garnet during retrograde metamorphism (Miyashiro and Shido, 1985).

Furthermore, they have been found that in areas, where normal faults develop, mafic schist in which matrix amphibole and epidote are almost totally replaced by chlorite occurs, and that along fractured zones of D2 faults a large amount of chlorite and carbonates precipitates. Hence, it is inferred that a large amount of fluid migrates along D2 normal faults, because chlorite contains 10-13 wt.% crystal-bound water. Also, accompanied by the fluid migration along D2 normal faults, metasomatism with the loss of Ca and Si and the gain of Mg and Fe occurs.

In summary, it has been found from the studies on exhumation of the Sambagawa metamorphic rocks into the upper crustal level that not only pervasive faulting (distributed brittle deformation) accompanied by dissolution-prrecipitation creep, but also a large amount fluid migration leading to a large-scale metasomatism occur at the brittle-ductile transition zone. In the future, the realities of deformation, metamorphism and fluid migration at the brittle-ductile transition zone must be further clarified. In addition, softening mechanisms in these regions must be investigated.