Rheology in the brittle-ductile transition zone of upper crust: pervasive brittle deformation and dissolution-precipitation creep

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Profile of differential stresses versus depth, which was constructed at 1980's, shows that the depth of brittle-ductile transition (B-D transition hereafter) in the upper crust determines the lower limit of depth of hypocenters for the case of quartz-controlled upper crustal rheology. However, problems such as that the calculated differential stresses are too high, using the experimentally determined values (e.g. 480 MPa at the depth of 13 km, assuming thrusting and a pore-fluid pressure equal to the hydrostatic pressure), and whether or not the sudden changes in deformation mechanisms and differential stresses is valid, have been little investigated. Recently, they have been argued that deep-seated metamorphic rocks can be exhumed along faults only for the case of very-low frictional stresses, and that friction coefficient of fault-rock forming minerals (e.g. clay minerals) is in fact low, and elevated pore-fluid pressure lowers the brittle strength of rocks (Faulkner et al., 2006, Nature).

To investigate these problems, observations of exhumed and fossil B-D transition zones are important. The Sambagawa metamorphic rocks are suitable for this purpose, because these rocks are exhumed to the surface of the Earth passing through the B-D transition zone. Recently, we have found that intensive normal faulting occurred in the Sambagawa metamorphic rocks at D2 phase under the condition of brittle-ductile transition. Through these studies, important facts have become apparent for the rheology of brittle-ductile transition zone. One 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. In quartz schist, anastomosing conjugate shear bands develop, where their width increases with increasing deformation, and recrystallized quartz grains are only preserved as lenses. These occurrences are very similar to those reported from a shear zone in Spain, which also forms at the conditions of B-D transition (Schrank et al., 2008). They infer that the widening of these shear zones does not indicate strain hardening, but occurs during strain softening.

Another important finding is that dissolution-precipitation creep greatly progresses under the conditions of B-D transition. In the left-over lenses consisting of recrystallized quartz formed at D1 phase mentioned above, a strong quartz c-axis fabric (type I crossed girdles) develops, but in some quartz schist samples, quartz c-axis fabric fabrics are random, where quartz grains are not only characterized by irregular shape, but also fairly straight grain boundaries. These shape fabrics are in contrast with those in quartz schist showing a strong quartz c-axis fabric. Accordingly, these peculiar shape fabrics perhaps form by dissolution-precipitation processes, which results in the formation of random quartz c-axis fabrics. Furthermore, in mafic schist strain fringes with higher aspect ratios than 10 in some cases densely develop, indicating dominant dissolution-precipitation creep.

In summary, anastomosing shear bands develop in the B-D transition zone, indicating that deformation does not only occur along discrete fault zones, but rather distributed in the damage zones, where dissolution-precipitation creep also occurs at low-differential stress conditions.