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Paleostress estimate for the inland hypocentral regions at subgreenschist conditions and strain-softening mechanisms

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In mobile belts such as the Japanese Islands and California district, inland earthquakes occur most frequently at the depth range of 10-15 km. Since the geothermal gradient in these areas range between 20-30 oC/km, the temperature conditions at the hypocentral regions could vary between 200-450 oC. This temperature conditions around 300 oC correspond to subgreenschist facies, where dislocation creep in quartz, which is a major constituent mineral of the upper part of crust, commences at natural conditions. A peak differential stress in the upper crust can be calculated to be 2 kb using experimental flow laws of quartz, assuming a natural strain rate of 10**-15/s. This value of differential stress is significantly higher than those estimated from the stress drop during earthquakes, and those (less than 200 bars) for the San Andreas Fault. In this research, we estimate how much stress the upper crust can support from microstructures in natural quartz, which deformed at subgreenschist conditions. Furthermore, we discuss what mechanisms operate as strain softening mechanisms in fault rocks.

In this research, deformed quartz from two localities was analyzed. One is from the Sambagawa-North Chichibu belt, central Shikoku, and the other from a protomylonite, which occurs along the Hidaka Main Thrust, Hokkaido. In both the deformed quartz, subbasal deformation lamellae, kink bands and healed microcracks pervasively develop. There are two types of kink bands. While type I is conjugate, and very narrow (the width, 1.5-10 microns), and only formed in grains, the (0001) plane of which is oriented parallel to the maximum principal stress axis, type II is monoclinal and wide (the width, 10-80 microns), and formed in grains, the (0001) plane of which is inclined to it. Dislocation densities in the deformed quartz vary between 1-2*10**9/cm**2. Interestingly, very fine recrystallized grains (the average diameter, 1.3 microns) occur only in type I kink bands. The protomylonite originated from biotite gneiss, but plagioclase and biotite were altered to muscovite and chlorite, respectively during the mylonitization. The width of type I and II kink bands ranges 5-10 and 50-100 microns, respectively, in the quartz. Its dislocation densities vary between 0.6-3*10**9/cm**2. Similarly, very fine recrystallized grains (the average diameter, 1.0 micron) occur only in type I kink bands.

The dislocation densities and recrystallized grain size are almost the same between the analyzed two samples, and the differential stresses of 2 and 5 kb were inferred for the respective microstructures, which are comparable with those calculated for the brittle-ductile condition with the experimental flow law. Note that the formation of type I kink bands suggests that even in those grains unfavorably oriented for (0001) slip, the intracrystalline slip occurred, and the higher differential stress of 5 kb probably indicates that for strain hardening. The next question is why in the hypocentral region of high stresses, large differential stresses do not operate as for the San Andreas Fault. In fact, at subgreenschist conditions, a significant degree of alternation aided by fluid occurred, resulting in the formation of fine-grained rocks, consisting of a large amount of mica and clay minerals. In the fine-grained rocks, the deformation mechanism changes from dislocation to grain-boundary diffusion creep (dissolution-precipitation creep at low temperatures). Since grain-boundary diffusion creep is a Newtonian creep, and its differential stress is proportional to (grain size)**3, it becomes 1/1000 as the grain size 1/10 at constant strain rate. Accordingly, it could be inferred that in rocks constituting the hypocentral regions, strain softening progressed with increasing strain (time) due to alternation after the attainment of a peak stress, and the deformation becomes accelerated at relatively low stresses, leading to the generation of earthquakes.