Strength of single crystal of orthopyroxene under lithospheric conditions

Tomohiro Ohuchi[1]; Shun-ichiro Karato[2]

[1] Department of Geology and Geophysics, Yale Univ.; [2] Yale University, Department of Geology and Geophysics

The strength of the lithosphere is an important parameter that controls the tectonic style of a planet. The critical strength for the operation of plate tectonics has been estimated to be less than 150 MPa (e.g., Richards et al., 2001). In most of the previous studies, however, the power-law creep laws and the brittle strength of constituent minerals were used to estimate the strength of the lithosphere that predict exceedingly high strength of the lithosphere which would not allow the operation of plate tectonics (700-800 MPa: Kohlstedt et al., 1995). In this report, we present new results on the strength of orthopyroxene that indicate that orthopyroxene may have much smaller strength than olivine at low temperatures.

Previous studies on deformation of orthopyroxene showed that the strength of orthopyroxene is controlled by the competition of slip (+ recrystallization) and a phase transformation to clinopyroxene (Raleigh et al., 1971; Coe et al., 1973). The latter is less thermally activated and hence the strength of orthopyroxene at low temperatures is mostly controlled by the phase transformation, and is smaller than those determined by slip (+ recrystallization). In fact, in many naturally deformed peridotites at high stresses (low temperatures), evidence of ortho to clino phase transformation is reported. However, the stress magnitude was determined by an external load cell in a solid-medium apparatus and has large uncertainties in the previous studies.

Consequently, we have initiated a series of experimental studies in which we quantify the strength of orthopyroxene single crystals at relatively low temperature conditions. We used a Griggs apparatus at P = 1.0-1.3 GPa and T = 800-1100 degC for a range of strain-rate (1E-5 to 1E-3 in shear strain rate). The strength of two different slip systems [001](010) and [001](100), which have been reported as the major slip systems, were evaluated. In order to reduce the friction, we used CsCl as a confining medium. The strength of a sample was estimated from the load-cell reading as well as the dislocation density of olivine (Karato and Jung, 2003).

Our experimental results showed that the apparent activation energy and the stress exponent of the power-law creep for the slip system [001](010) were obtained to be 141 KJ/mol and 4.2, respectively. The strength of orthopyroxene was about a half of that of olivine which was controlled by Peierls-law creep (Evans and Goetze, 1979) at low temperatures (less than 1000 degC), resulting from the low activation energy of orthopyroxene. The strength on the slip system [001](100) was smaller than that on the system [001](100). The temperature dependency of strength (i.e., the apparent activation energy) on the slip system [001](100) was also smaller than that on the on the system [001](100) at low temperatures (less than 900 degC).

Using the obtained parameters of the power-law creep, the strength of orthopyroxene is estimated to be at least 5 times smaller than that of olivine under the conditions of low temperature (less than 800 degC) and natural strain rates of the lithosphere (e.g., 1E-15). This suggests that the strength of the lithosphere which is controlled by orthopyroxene is much smaller than the strength of the lithosphere estimated by previous studies (e.g., Kohlstedt et al., 1995).