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Deep crustal dynamics driven by local transient transformation weakening

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Mechanisms driving the long-term dynamics of plate interfaces remain poorly-constrained. To date, the rheology of the crust is considered to be controlled by solid-state processes such as crystal plastic deformation (dislocation creep). Yet, most minerals formed at high-pressure conditions are mechanically very strong and can only be deformed plastically at unrealistically high stresses or temperatures. A growing number of studies point to the crucial role of fluid-rock interactions and mineral transformations in the development of crustal shear zones of low viscosity. Rock weakening is interpreted as being induced by dissolution-precipitation creep (DPC) at grains boundaries in chemical disequilibrium. Here, we tackle the eclogite rheology conundrum by performing the first deformation experiments at 850°C, 2.1 GPa and a shear strain rate of 10^{-6} s^{-1} using a new generation of Griggs-type apparatus. Experiments were conducted on a two-phase aggregate representative of the lower crust (plagioclase and pyroxene with 0.2% added water).

Mechanical data indicate that the samples are first very strong with a peak differential stress between 1.0 and 1.4 GPa. Then, a significant weakening is observed with a stress decrease of 0.5 GPa. The high-strain samples are characterized by a strain gradient and a reaction gradient, both increasing toward the center of the shear zone. The nucleation of new phases leads to a drastic grain size reduction and phase mixing. At peak stress, the reaction products are restricted to grain boundaries where they form corona structures, while in the high-strain samples, they occur throughout the sample replacing most of the starting material. The primary plagioclase and clinopyroxene grains show incipient dynamic recrystallization, whereas reaction products never do. The nano-porosity reported in the samples attests to the presence of free-fluid phase along the reactive grain boundaries, despite the high-pressure conditions. This nano-porosity requires grain boundary sliding (GBS) processes to form, as indicated by the spatially associated quadrupole junctions.

Our results show that strain at eclogite-facies conditions is preferentially localized by GBS-accommodated DPC in reactive zones. Therefore, deformation along deep plate interfaces should be initiated and governed by transient and local transformation weakening, allowing long-term deformation at far lower stresses than dislocation creep.