Homologous temperature of olivine links deformation experiments and rheology of the upper mantle

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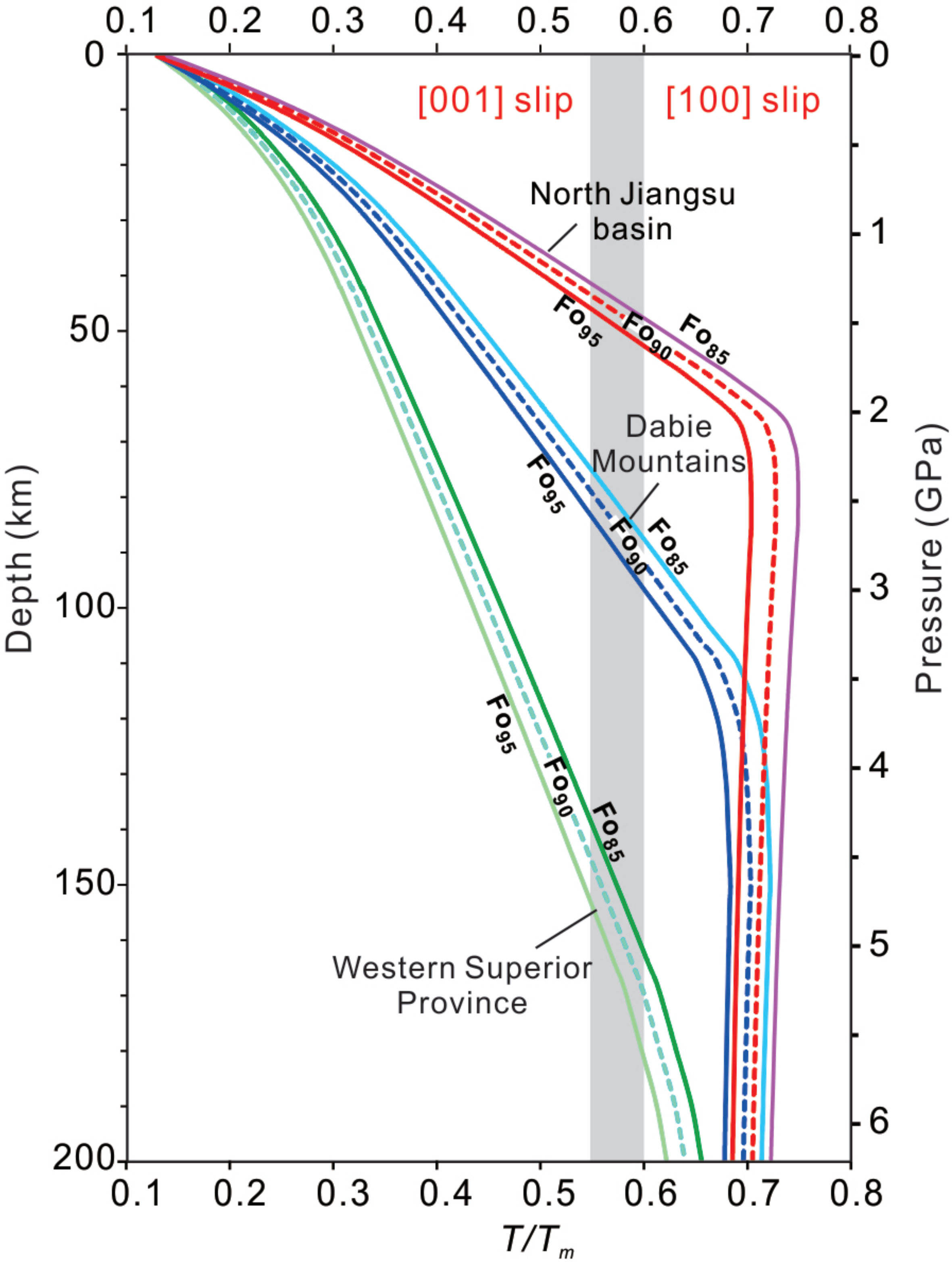

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
[001] slip
[100] slip
North Jiangsu basin
Dabie Mountains
Western Superior Province
Fo95
Fo90
Fo85
Depth (km)
0 50 100 150 200
Pressure (GPa)
0 1 2 3 4 5 6
T/Tm

Variations of the homologues temperature of olivine with depth beneath typical continental units. Fo number indicates the mole concentration of forsterite in olivine. Credit: ©Science China Press

The homologous temperature of a crystalline material is defined as the ratio between temperature and the melting (solidus) temperature (Tm) in Kelvin. Because Tm of a crystalline material is controlled by the bonding force between atoms, T/Tm has been widely used to compare the creep strength of crystalline materials. As the most abundant mineral in the upper mantle, olivine is the solid solution of forsterite (Mg2SiO4) and fayalite (Fe2SiO4). Recent deformation experiments have revealed the influence of water, temperature, pressure, stress and partial melting on fabric development of olivine. However, how to extrapolate laboratory results to mantle deformation is still under debate.

In a recent review in *Science China Earth Sciences*, Qin Wang from Nanjing University established the phase diagram of dry olivine up to 6.4 GPa using previous melting experiments and generalized means. She found that the change of T/Tm of olivine with depth allows comparison with the strength of the upper mantle under different thermal states and olivine compositions. The transition from semi-brittle to ductile deformation in the upper mantle occurs at a depth where T/Tm of olivine equals to 0.5 (Figure 1).

In addition, T/Tm is used to analyze fabric transitions of olivine. The results indicate that the effect of water on olivine fabrics is closely related with pressure. Below 6.4 GPa (less than 200 km) and under the strain rate and low stress in the upper mantle, the [100](010) slip system (A-type fabric) becomes dominant when T/Tm > 0.55-0.60. When T/Tm

This study provides new information on tracing mantle flow from seismic anisotropy. Seismic anisotropy of the upper mantle is controlled by the A-type fabric of olivine in most regions, where the fastest P-wave velocity and the polarization direction of the faster S-wave velocity are parallel to the mantle flow direction. However, olivine in subduction zones may develop the B- or C-type fabric, making the fastest P-wave velocity and the polarization direction of the faster S-wave velocity normal to the mantle flow direction. Seismic anisotropy of the upper mantle beneath cratons can be simulated using a four-layer model with different fabrics.

It is noteworthy that when pressure is higher than 6.4 GPa, the melting behavior of iron-rich olivine and the incorporation mechanism of hydrogen in olivine are different from those at low pressure. The lack of melting experiments on hydrogen-bearing olivine at high pressure hampers our estimation of its homologous temperature. Such knowledge will improve our understanding of the role of water in mantle rheology and planetary evolution.

More information: Qin Wang, Homologous temperature of olivine: Implications for creep of the upper mantle and fabric transitions in olivine, *Science China Earth Sciences* (2016). DOI: 10.1007/s11430-016-5310-z

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