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Creep of phyllosilicates at the onset of plate tectonics

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Plate tectonics occur only after the onset of subduction at the Earth's surface. Subduction initiates if a material with low yield strength is present in the otherwise stiff cold lithosphere at the thermal boundary layer with hydrosphere. Models suggest that plate tectonics initiates when the strength of lithosphere is lower than 20-200 MPa, below the frictional strength of lithospheric rocks (>700 MPa).

Previous deformation experiments on serpentine minerals for pressure up to 4 GPa suggested plastic behavior and flow strength of antigorite an order of magnitude lower than dry lithospheric rocks. However, extrapolations from laboratory strain rates (10^{-4}-10^{-6} s^{-1}) to tectonic strain rate (as low as 10^{-15} s^{-1}) have large uncertainties because they are based on empirical rheological laws and the structural differences in serpentine variety may influence the deformation mechanisms and rheological behavior.

We carried out high-pressure deformation experiments with *in-situ* stress and strain measurements on polycrystalline Elba Island lizardite - the low temperature variety of serpentine - using a Deformation-DIA apparatus coupled with monochromatic synchrotron light source (APS), at the GeoSoilEnviroCARS, Argonne National Laboratory. Fourteen deformation cycles were performed on four specimens at pressures (P) and temperatures (T) ranging from 1 to 8 GPa and 150 to 400°C, with strain rates ($\dot{\varepsilon}$) between 10^{-4} and 10^{-6} s^{-1}. Thin sections were extracted parallel to the compression direction using Focused Ion Beam. TEM observations of recovered samples show plastic deformation features and no evidence of brittle failure.

Lizardite has a large rheological anisotropy, comparable to that observed in the micas.The alignment of the basal (001) planes normal to the compression axis leads to high stresses corresponding to the elastic response of crystals whose orientation precludes glide on (001). Crystals where basal planes are oblique to the compression, allowing glide on (001) show yield stress in the range 50-200 MPa with no systematic dependence with strain rate, grain size, pressure or temperature within experimental uncertainties. First-principles calculations confirmed easy gliding on lizardite basal plane and show that the flow stress of phyllosilicate is in the range of the critical value of 20-200 MPa down to depths of about 200 km. Thus, foliated serpentine or chlorite-bearing rocks are sufficiently weak to account for plate tectonics initiation, and aseismic sliding on the plate interface below the seismogenic zone. Serpentinisation easing the deformation of the early crust and shallow mantle reinforces the idea of a close link between the occurrence of plate tectonics and water at the surface of the Earth.