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Transient versus long-term strength of the "dry" lower continental crust (Musgrave Ranges, Central Australia)

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One-dimensional yield strength envelope or "Christmas tree" models for the strength of the continental lithosphere assume homogeneous deformation at constant strain-rate and generally predict that felsic lower crust should be viscous and relatively weak. Over the longer term, distributed flow of this supposedly weak lower crust should tend to flatten any irregularities in the Moho. However, these model predictions are in direct contradiction to observations from the well-exposed lower-crustal Fregon Subdomain in the Musgrave Ranges, Central Australia. This unit underwent dehydrating granulite facies metamorphism during the ca. 1200 Ma Musgravian Orogeny. During the subsequent Petermann Orogeny (ca. 550 Ma), these effectively "dry" rocks were very heterogeneously deformed under sub-eclogitic, lower-crustal conditions (ca. 650°C, 1.2 GPa). Shear zones localized over a wide range of thickness and length scales, from mm to km. Widespread and repeated fracturing and pseudotachylyte generation also occurred during the same deformation event, providing weak and approximately planar precursors on which viscous shear zones subsequently localized. On the lithospheric scale, the present day Moho still preserves an offset on the order of 20 km that was caused by the Petermann Orogeny.

Brittle fracturing of dry rocks and related pseudotachylyte formation at pressures of ca. 1.2 GPa imply high differential stresses on the order of 1 GPa, if the Mohr-Coulomb yield criterion is still approximately correct at such high confining pressure. High stresses, at least transiently, are also implied by the observed local fracturing of granulite-facies garnets in the vicinity of pseudotachylytes. However, the stress associated with slower crystal-plastic flow appears to be much less, on the order of 10's of MPa, as indicated by the dynamically recrystallized grain size of quartz. Several other observations also indicate that the long-term viscous strength could not have been maintained at GPa levels: (1) viscous reactivation of fractures that are highly misoriented, with planes at a large angle to the shortening direction; (2) the lack of any discernible pressure difference between doleritic dykes oriented at varying angles to the shortening direction (i.e. no tectonic overpressure or underpressure effects); and (3) the lack of evident long-term shear heating on major shear zones. The implication is that the high differential stress must have occurred as transient pulses, causing repeated seismic fracturing of lower crustal rocks that on the longer term were deforming by crystal-plastic viscous creep at much lower differential stress.