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Constraints on Crustal Viscosity from Geodetic Observations

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Laboratory measurements of the ductile deformation of crustal rocks demonstrate a range of crystal deformation mechanisms that may be represented by a viscous deformation law, albeit one in which the effective viscosity may vary by orders of magnitude, depending on temperature, stress, grain size, water content and other factors. In such measurements these factors can be separately controlled and effective viscosities can be estimated more or less accurately, though the measured deformation occurs on much shorter time scales and length scales than are typical of geological deformation. To obtain bulk measures of the in situ crustal viscosity law for actual geological processes, estimated stress differences are balanced against measured surface displacement or strain rates: at the continental scale, surface displacement and strain rates can be effectively measured using GPS, and stress differences can be estimated from the distribution of gravitational potential energy; this method has provided constraints on a depth-averaged effective viscosity for the lithosphere as a whole in regions that are actively deforming. Another technique measures the post-seismic displacements that are interpreted to occur in the aftermath of a large crustal earthquake. Stress-differences here are basically constrained by the co-seismic deformation and the elastic rigidity (obtained from seismic velocity) and the strain rates are again provided by GPS. In this technique the strain is a strong function of position relative to the fault, so in general the interpretation of this type of data depends on a complex calculation in which various simplifying assumptions must be made. The spatial variation of displacement history on the surface in this case contains information about the spatial variation of viscosity within the crust. Recent post-seismic studies have shown the potential for obtaining measurements of both depth variation and lateral variation of viscosity in the crust beneath major strike-slip fault zones. Difficulties with this method remain however: the separation of strain fields caused by viscoelastic relaxation of the overall stress field and that caused by post-seismic slip on the fault can create ambiguity in the interpretation. More fundamentally, the stress field associated with the co-seismic deformation is added to a background tectonic stress field that must be constrained independently, and ultimately is determined by the large-scale variation of gravitational potential energy and plate boundary stresses. Viscosity estimates obtained from these methods, however, are broadly consistent with those determined from laboratory deformation experiments.