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The crustal viscosity structure beneath the North Anatolian Fault Zone

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Visco-elastic relaxation of stress in the lower and middle crust plays an important role in the evolution of crustal stress during the earthquake cycle. Crustal viscosity, however, is a strongly variable and rather poorly constrained property of the crust. In this study, using 3D finite element calculations, we describe the response of linear Maxwell visco-elastic models to periodic strike-slip faulting events in the presence of a constant far-field loading process. By comparing predicted post-seismic and inter-seismic surface displacement rates with observations from the North Anatolian Fault, we aim to provide constraints on the actual variation of viscosity in the crust beneath that fault zone. The principal determinant of the system is the ratio of Maxwell relaxation time to earthquake cycle period, but viscosity variation within the crust implies that there is a wide spectrum of relaxation times present in the system. Geodetic observations along the western North Anatolian Fault Zone before and after the 1999 İzmit (17 August, Mw = 7.5) and Düzce (12 November, Mw = 7.2) earthquakes show that: (1) after an earthquake, surface displacement rates near the fault are greater, by a factor of 4 or so, than the estimated long-term displacement rates, and (2) before an earthquake, the surface displacement rate gradient within a zone about 40 km wide is greater by a factor of about 2 than the gradient further afield. Based on our numerical experiments, we find that (1) no model based on a uniform viscosity model (beneath an elastic lid) can explain these observations, (2) models based on a viscosity profile that decays exponentially with depth (beneath an elastic lid) come close to satisfying the observations, but the wavelength of the strike-perpendicular post-seismic displacement profile does not fit well, and (3) introducing a lateral variation of viscosity by means of a weak zone beneath the faulted elastic lid can best explain the observations, if the weakened and non-weakened domains have viscosities for which Maxwell relaxation times are significantly shorter and longer than the earthquake cycle period, respectively. In this type of model the spatial distribution of the surface velocities constrains the width and thickness of the weak zone. Several physical processes can be invoked to explain why a weak zone should be found beneath a major fault like the North Anatolian, including: (1) non-Newtonian viscosity, (2) thermal dissipation, (3) grain-size reduction, and (4) pore fluid partial pressures. Future work on this topic should aim to determine a self-consistent explanation for the properties of the weak zone, based on the known history of the North Anatolian Fault system.