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The crustal viscosity structure beneath the North Anatolian Fault Zone deduced from post- and inter-seismic deformation

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The evolution of crustal stress during the earthquake cycle is controlled by visco-elastic relaxation in the lower and middle crust. Crustal viscosity, however, is a rather poorly constrained property. This study, based on 3D finite element calculations, describes the response of linear Maxwell visco-elastic models to periodic strike-slip faulting events in the presence of a constant far-field loading process, providing constraints on the actual variation of viscosity in the crust beneath the North Anatolian Fault Zone (NAFZ) from observed post- and inter-seismic surface displacement rates. The ratio of Maxwell relaxation time to earthquake cycle period is the principal controlling-factor of the system, though viscosity variation within the crust implies a wide spectrum of relaxation times in the system. Geodetic observations along the western NAFZ before and after the 1999 Izmit (17 August, Mw = 7.5) and Duzce (12 November, Mw = 7.2) earthquakes show that: (1) 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, and (2) 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. Our numerical experiments find that (1) any model with a uniform viscosity (UNV) beneath an elastic lid is unable to explain these observations, (2) models with a depth-dependent viscosity (DDV) beneath an elastic lid might potentially satisfy the observations, but the wavelength of the strike-perpendicular post-seismic displacement profile does not fit well, and (3) models with laterally varying viscosity, including a localised weak zone (LWZ) 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, and the spatial distribution of the surface velocities constrain the width and thickness of the LWZ. Several physical processes can be considered as possible explanations for why a LWZ should be present 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. Explaining the origin of the weak zone may require a detailed multi-disciplinary study of the tectonic history of the North Anatolian Fault system.

Keywords: Earthquake cycle, Visco-elastic relaxation, Crustal viscosity structure, North Anatolian Fault Zone