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The Earthquake Loading Cycle and the Deep Structure of the North Anatolian Fault

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Deformation of the Earth's upper crust is localised onto narrow fault zones, which may slip suddenly and catastrophically in earthquakes. Strain in the upper mantle is more broadly distributed and is typically thought to occur by continuous ductile creep. The transition in the lower crust from broad shear zone to a narrow structure in the upper crust is poorly understood but the properties of the lower crust are an important control on the behaviour of the system during the earthquake loading cycle. The properties of lower crustal rocks, and their spatial variation, cannot be measured directly; instead inferences are typically made from seismic observations, exhumed geological analogues, and modelling of surface deformation data. Existing seismic experiments have poor resolution in the lower crust; and current geodetic models do not reproduce observations of rapid post-seismic and focussed inter-seismic strain.

Here we present the preliminary findings of FaultLab, an interdisciplinary experiment using seismic imaging, geodesy, numerical modelling, and geology to investigate how the earthquake loading cycle of the North Anatolian Fault Zone is controlled by its deep crustal structure. We present results from an 18 month deployment of a 73 station network encompassing the northern and southern branches of the NAFZ in the Sakarya region. The dense array (nominal station station spacing of 7 km) crosses the 1999 Izmit earthquake rupture and is designed to provide high resolution images of the mid-lower crust. Teleseismic scattering tomography and receiver function analysis suggest that the two branches of the fault remain as relatively narrow structures to at least 20 km, and that the faults separate very different terranes. This portion of the North Anatolian Fault has the best geodetic record for any strike-slip fault, with deformation well recorded both before and after the 1999 earthquakes. Prior to the earthquake, strain was focused in a $\sim$50 km region around the fault. Following the earthquake, a rapid post-seismic transient was observed, which slowly decayed over the subsequent decade. Viscoelastic modelling requires materials with at least two relaxation time constants to explain these observations – a strong material to allow focused interseismic strain, and a weak material to give rapid postseismic deformation. Geological analogues of the mid-lower crust beneath the North Anatolian Fault are consistent with the idea that strain is focused in relatively narrow shear zones. We present a shear-zone model for the earthquake deformation cycle that is consistent with these interdisciplinary observations, and discuss the implications for other fault zones.