High Resolution Imaging of Fault Zone Structures with Seismic Fault Zone Waves

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Large fault zone (FZ) structures with damaged rocks and material discontinuity interfaces can generate several indicative wave propagation signals. High crack density may produce prominent scattering and non-linear effects. A preferred crack orientation can lead to shear wave splitting. A lithology contrast can produce FZ head waves that propagate along the material interface with the velocity and motion polarity of the faster medium. A coherent low velocity layer may generate FZ trapped waves. These signals can be used to obtain high resolution imaging of the subsurface structure of fault zones, and to track possible temporal evolution of FZ material properties. Several results have emerged from recent systematic analyses of such signals. The trapped waves are generated typically by ~100-m-wide layers that extend only to ~3–4 km depth and are characterized by 30%–50% velocity reduction and strong attenuation (Ben-Zion et al., 2003; Lewis et al., 2007). The trapping structures appear to be surrounded by broader anisotropic and scattering zones limited primarily to the shallow crust (Fig. 1). Results associated with anisotropy and scattering around the North Anatolian fault using repeating earthquake clusters do not show precursory temporal evolution (Peng and Ben-Zion, 2004, 2005, 2006). The anisotropy results show small co-seismic changes, while the scattering results show larger co-seismic changes and post-seismic logarithmic recovery. The temporal changes probably reflect damage evolution in the top few hundred meters of the crust. Systematic analyses of head waves along several sections of the San Andreas fault reveal material interfaces that extend to the bottom of the seismogenic zone (Ben-Zion and Malin, 1991; McGuire and Ben-Zion, 2005). Joint arrival time inversions of direct and FZ head waves and waveform modeling imply (Fig. 2) velocity contrasts of 20% or more in the top 3 km and lower contrasts of 5%–15% in the deeper section (Ben-Zion et al., 1992; Lewis et al., 2007). In several places, analyses of trapped and head waves indicate that the shallow damaged layers are asymmetric across the fault (Lewis et al., 2005, 2007). The observed damage asymmetry may reflect preferred propagation direction of earthquake ruptures (Ben-Zion and Shi, 2005).

Figure 1. (a) Hypocentral distribution of ~18,000 earthquakes recorded by the PASSCAL seismic experiment along the Karadere-Düzce branch of the north Anatolian fault. (b) An example of FZ waveforms recorded by stations on (VO) and off (FP) the fault. (c) An example of rotated horizontal seismograms showing split shear waves. (d) A summary plot of average splitting parameters (bars) in our study area. The bars are oriented parallel to the average fast direction and scaled by the average delay time. (e) Median delay times for the early S-coda waves plotted against the earthquake occurrence times for the vertical-component seismograms generated by 36 repeating clusters and recorded at station VO. (f) A schematic summary of the fault zone model around the study area. Panels (a)-(b) are from Ben-Zion et al. (2003). Panels (c)-(d) are from Peng and Ben-Zion (2004, 2005). Panel (e) is from Peng and Ben-Zion (2006).
Part 3: Fault Zone Structure, Composition, and Physical Properties


References


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