Detailed imaging of fault-zone material properties at seismogenic depths is a difficult seismological problem owing to the short length scales of the structural features. Seismic energy trapped within a low-velocity damage zone has been utilized to image the fault core at shallow depths, but these phases appear to lack sensitivity to structure in the depth range where earthquakes nucleate. Major faults that juxtapose rocks of significantly different elastic properties generate a related phase termed a fault-zone head wave that spends the majority of its path refracting along the fault. We utilize data from a dense temporary PASSCAL array of seismometers in the Bear Valley region of the San Andreas Fault to demonstrate that head waves have sensitivity to fault-zone structure throughout the seismogenic zone. Measured differential arrival times between the head waves and direct P arrivals and waveform modeling of these phases provide high resolution information on the velocity contrast across the fault. The obtained values document along-strike, fault-normal, and downdip variations in the strength of the velocity contrast, ranging from 20 to 50% depending on the regions being averaged by the ray paths. The complexity of the fault-zone waveforms increases dramatically in a region of the fault that has two active strands producing two separate bands of seismicity. Synthetic waveform calculations indicate that geological observations of the thickness and rock-type (granite) of the layer between the two strands are valid also for the subsurface structure of the fault. The results show that joint analysis of fault zone head waves and direct P arrivals can resolve important small scale elements of the fault zone structure at seismogenic depths. Detailed characterization of material contrasts across faults and their relation to earthquake ruptures is necessary for evaluating theoretical predictions of the effects that these structures have on rupture propagation.

Figure 1. Map of the Bear Valley section of the San Andreas Fault (black line) and the seismometer locations (black triangles) of the 1994 PASSCAL deployment by Thurber, Rocker, et al. The portion of the fault southeast of station SUM has two strands mapped at the surface with a sliver of granite (light blue) inbetween them. Our analysis of the fault zone head waves indicates that this granite sliver extends throughout the seismogenic zone (middle panel with black dots for earthquake locations). The right panel shows the headwaves recorded at station SUM, aligned on the direct P arrival (0 time). The headwave (HW) moves out with distance. The reverberations between the HW and the direct wave result from the presence of the intermediate velocity granite sliver (blue region in map).