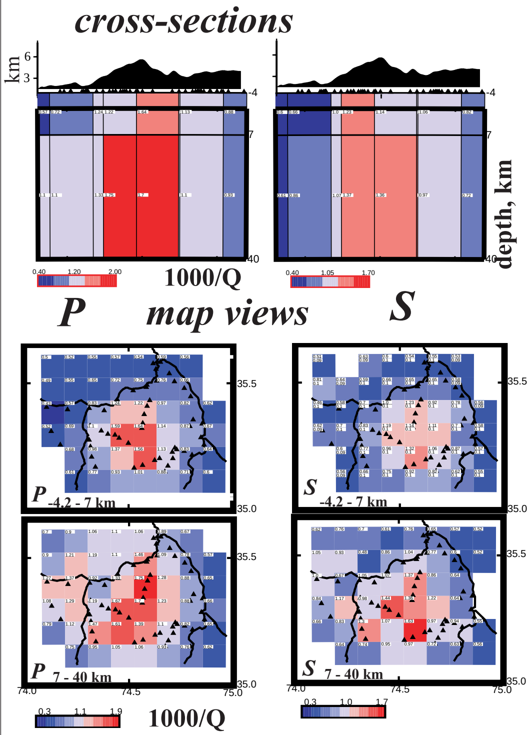
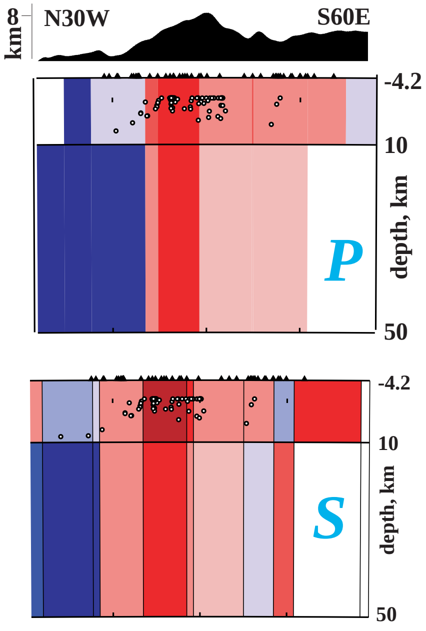


Figure 20d. Severe attenuation variations are seen between paths that traverse the Nanga Parbat and those that do not. Records for an event from Hindu Kush. Attenuation values, *t**, were determined from individual spectra of body waves at frequencies where signal to noise ratios are high (>5), typically between 2 and 16 Hz. Each spectrum is fit to a three-parameter model of the form $H(f) = I(f)S(f)\exp(-\pi f t^*)$, where $H(f)$ is the observed amplitude spectrum, $I(f)$ is the instrument response to ground displacement, t^* is the frequency-independent attenuation operator, and $S(f)$ is a source model parameterized by seismic moment and corner frequency. The $S(f)$ term implicitly includes geometric spreading and other frequency-independent effects. A least squares inversion fits the log-amplitude spectra of *P* and *S* waves to $H(f)$ to determine t^* and two source parameters. The t* estimates are inverted for Q^{-1} using the relation $t^* = \int_{path} Q^{-1}(r)\,[dr/V(r)]$, where the integral represents the ray paths of a seismic arrival and $V(r)$ is the velocity for each ray paths, determined from arrival time inversion. The main features of the inversion results include: (1) high attenuation beneath the Nanga Parbat massif compared to the surrounding regions; (2) high attenuation extends throughout the entire crust; (3) attenuation increases with depth; (4) high attenuation corresponds to the core of the massif and to high topography; (5) $Q^{-1}(s)$ is marginally similar to $Q^{-1}(p)$; and (6) path-averaged Q values for paths within the massif are more than 3 times smaller than those that stay outside the massif. (Sarker and Meltzer, in review).

Figure 20e. A 3-D joint inversion for hypocenter location, Vp, and Vs shows that the seismic velocity structure beneath the Nanga Parbat massif is anomalously low, up to 10%, over lateral distances of 10-20 km (16) (Figure 4). Both P and S wave low velocity anomalies are observed within the core of the massif and extend to depth through the entire crust. In the shallow crust (<7 km depth) Vp ranges from 5.5-5.8 km/s and Vs from 3.2-3.5 km/s within the core of the massif compared to velocities of Vp=5.9-6.2 km/s and Vs=3.5-3.7 km/s in adjacent regions. Analyzing arrivals at stations deployed in glacial valleys as small linear arrays yields similar velocity values. At mid-crustal depths (7-20 km) Vp ranges from 5.6-5.75 km/s and Vs from 3.4 to 3.5 km/s within the massif compared to velocities of 6.3-6.5 km/s and Vs= 3.6-3.8 km/s in the surrounding area. At lower crustal depths (20-40 km), Vp at the core of the massif ranges between 5.6 and 6.0 compared to 6.4 to 6.6 km/s, while Vs within the massif ranges between 3.4 and 3.7 compared to Vs=3.7-3.9 km/s in the surrounding area. Low velocities imply hot rocks at depth in this region as the composition of the massif is homogeneous with respect to seismic wavelengths. Inversions yield slightly low Vp/Vs ratios at several areas within the massif which may reflect the presence of super-critical fluids in small regions of limited extent.The uppermost mantle velocity, constrained from teleseismic P arrivals, is also about 10% slower within the core of the massif (Vp=7.5 km/s) compared to the surrounding mantle velocity (Vp=8.2 km/s). The depth to the Moho, as determined from best fit 1-D velocity model inversions and preliminary receiver function analysis, is 40 km. (Sarker and Meltzer, in review).



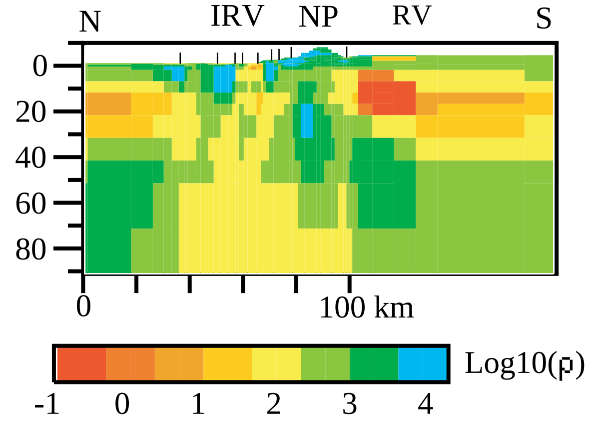


Figure 20f. MT results based on 2-D modeling. Station locations marked at surface by vertical bars. Model is well resolved for features below 10 km depth. Crust below Nanga Parbat is anomalously resitive indicating there are no connected pore fluids - the crust is dry (Park and Mackie, 1999).

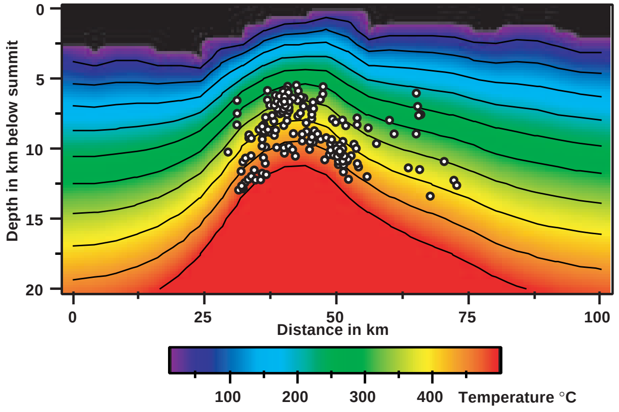


Figure 20g. Hypocenters plottted on results from numerical model examining the evolution of the conductive geotherm during rapid advection of crustal rocks (uplift rate 4mm/yr). Focal mechanisms, travel time and waveform anomalies, low Vp and Vs, and low Vp/Vs ratios are consistent with the model in which rapid and dramatic exhumation leads to pervasive reworking of continental crust. As Indian gneisses are transported from depth toward the surface advection of isotherms results in low P and S wave velocities throughout the crust and elevates the position of the brittle-ductile transition causing it to bow, convex upward beneath the massif.