Coseismic slip in subduction zones and its relation to crustal structure revealed by gravity anomalies

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The relative landward or seaward distribution of large coseismic slip during great megathrust earthquakes strongly controls shaking and tsunami hazard. We have compiled coseismic slip inversions for 29 of the largest recorded Circum-Pacific megathrust earthquakes to determine how seismic slip is related to the geologic structure of convergent margins (Wells et al. 2003). From Nankai to southern Chile (7500 km of trench length), 69% of the total area of high slip lies beneath the deep-sea slope terrace and its satellite free-air gravity low (DSTL), which comprises only about 40% of the seismogenic zone (defined as the area between the trench and the down-dip limit of slip from the inversions). In a study of the ISC and CMT earthquake catalogs, Song and Simons (2003) found similar results, with about 70% of the seismic moment occurring beneath trench-parallel fore arc gravity lows. Subsequent analysis of the 1995 Antafogasta (Mw 8.1), 1999 Chi Chi (Mw 7.6), 2003 Rat Island, (Mw 7.9), 2003 Tokachi-Oki (Mw 8.3), and 2004 Sumatra (Mw 9.2) earthquakes shows the same pattern, although the 2005 Sumatra earthquake (Mw 8.7) under Nias is a major exception.

The computer-generated maximum gravity gradient marking the landward edge of the deep-sea terrace and its basins is a good approximation to the landward limit of large co-seismic slip and generally coincides with Tichelaar and Ruff's (1993) down-dip limit of thrust faulting. 86% of the centers of high slip in our sample lie on or just seaward of the maximum gravity gradient. In SW Japan, the gradient also coincides with the 350°C isotherm on the plate boundary, and in general, the maximum gravity gradient may indicate where crustal thickness is sufficient to promote higher temperatures and a transition to stable sliding. Possible onshore analogs include the 1999 Chi Chi earthquake and great earthquakes along the Himalayan frontal fault, where the mountain fronts appear to mark the down-dip limit to large coseismic slip.

The seaward limit of our deep-sea terrace low is the outer arc high, a ridge on the outer slope which separates the terrace and its basins from lower strength materials of the outer wedge. This boundary roughly coincides with the seismic front of Byrne et al. (1988) and the locus of major, seaward-vergent splay faults (out of sequence thrusts) that root into the megathrust. Only three of the coseismic slip inversions in our sample put major coseismic slip near the trench (e.g. 1952 Tokachi-Oki). The tendency for the largest coseismic slip to occur deeper on the megathrust is consistent with field observations of deformation in the 1964 Alaska earthquake, where most of the 20 m of slip under Prince William Sound was partitioned up dip onto the Patton Bay fault and onto the Middleton Island splay further offshore. Coseismic slip at the trench was presumably a very small part of the total, and evidence for earlier events suggests that this style of deformation was typical of coseismic behavior. On the other hand, interpretations of seismic profiles of the southern Alaska margin indicate that shortening in the outer accretionary wedge matches the plate convergence rate. One interpretation of this is that much of the outer wedge deformation could be aseismic.