The complexity of the NE Ecuador subduction megathrust system revealed by joint 3D inversion of refraction and inter-plate reflection travel-times

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Great subduction earthquakes occur along the seismogenic zone of the megathrust, a fault segment that is mechanically coupled so that seismic rupture can propagate. Numerous factors, including the rheology and structure of the plates, shear stress distribution, fluids pressure, or thermal structure, size and width of the coupled zone, have been proposed to play a role to determine and dynamic behavior of the rupture. These factors are conditioned, in turn, by the properties of the rocks undergoing deformation during seismic rupture and by the fault geometry and roughness. While the information on the 3D velocity field and on inter-plate geometry can potentially be extracted from travel-times of active seismic data, the experiments that are appropriate to define these parameters are scarce. Additionally, most 3D travel-time tomography codes use only first arrivals to define the velocity field, so that they do not provide information on the megathrust geometry. Here we combine for the first time ever wide-angle seismic data with a joint refraction and reflection travel-time tomography code [tomo3d, Meléndez et al., 2015], to retrieve a 3D velocity model of margin and the geometry of the inter-plate boundary with unprecedented detail. In particular, we use data acquired in the French project "Esmeraldas" offshore NE Ecuador/SE Colombia in 2005. Our model, which builds on a previous one obtained by first arrival tomography [Garcia-Cano et al., 2014], goes from the surface to 18-20 km depth, covering a substantial part of the seismogenic zone. This region, where the Nazca plate plunges beneath South America, has produced remarkable examples of variable earthquake rupture behavior. The entire ~500 km-long segment ruptured during the great tsunamigenic earthquake of 1906 (Mw = 8.8), and it was ruptured again by three smaller events, directly adjacent to one another, in 1942 (Mw = 7.8), 1958 (Mw = 7.7) and 1979 (Mw = 8.2) [Kanamori and McNally, 1982]. According to our results, the inter-plate boundary where these earthquakes took place is of variable dip and rough, spotted by 2-3 km-high and 10-15 km-wide features that resemble subducting seamounts. The velocity of the overriding plate just above the inter-plate boundary is strongly heterogeneous, showing velocity-derived rock rigidity variations of up to 30-40% both along- and across-strike. The presence of inter-plate relief and velocity changes is confirmed by parameter uncertainty analysis and data sensitivity tests. Interestingly, the sharpest velocity contrasts appear to follow the limits between crustal blocks of different origin and composition that, according to previous work, could correspond to crustal-scale faults acting as barriers during earthquake propagation [Collot et al., 2004]. The combined effect of a rough inter-plate boundary and heterogeneous elastic properties on earthquake rupture remains to be tested by dynamic rupture models.

Collot, J.-Y., et al. (2004), JGR., 109, doi:10.1029/2004JB003060

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Kanamori, H., K. C. McNally (1982), BSSA, 72(4), 1241–1253

Meléndez et al. (2015), GJI, 203, 158–174, doi:10.1093/gji/ggv292