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3-D seismic tomography study of the Sumatra subduction zone near Simeulue island

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The megathrust along the Sumatra subduction zone is shown to be segmented by recent seismic and geological studies. The rupture zone of the 2004 M9.3 earthquake appears to terminate in northwest of Simeulue, which is also the northwestern edge of the rupture zone of the 2005 Nias earthquake. A band of minimal uplift during both earthquakes is identified around here, known as the ‘Simeulue saddle’. Possibly, this band is a weak zone in the incoming plate and serves as a barrier to the ruptures along the megathrust. To investigate the nature of this boundary, wide-angle data were collected around Simeulue island using ocean bottom seismometers (OBS) and a tuned air-gun array with a total capacity of 5420 cu. in.. In total, 50 OBS were deployed in an area of 203 km long and 192 km wide, and 10462 air-gun shots were fired along 1550 km of profiles. About 150,000 P-wave first refracted arrivals were picked from the OBS data and were inverted for a velocity model of minimum structure required by the travel-times. The top of the oceanic crust and the oceanic Moho were then constrained by normal-incidence and wide-angle reflected arrivals, and jointly inverted with the velocities. The aftershocks of the 2005 Nias earthquake were recorded in a separate OBS array deployed here between 2005 and 2006. These events were also used to image the plate interface beneath Simeulue at a depth of $\sim$15-20 km. The final model we obtained is a 3-D velocity model around and beneath Simeulue up to a depth of 45 km with the plate interface and the oceanic Moho. The preferred model shows a structural discontinuity in the incoming oceanic plate, with a roughly NNW-SSE trend, subducting beneath the northwestern tip of Simeulue island. Moreover, the dip angle of the megathrust appears to be steeper to the northwest of the discontinuity than to the southeast, while on the continental margin, there are some patches of anomalously high velocity ($\sim$ 7 km/s) in the backstop block. The features of the discontinuity can be linked to a fossil fracture zone which is related to the Wharton spreading center initiated in Late Cretaceous. These fracture zones are elongated in a NNE-SSW trend, consistent with the trend observed for the discontinuity due to the oblique subduction. The contrasting dip angle over the discontinuity may correlate with different age of the two flanks of the fracture zone, and the steeper angle appears to be associated with an older segment of the oceanic plate to the northwest. Tectonic reconstruction shows that the oldest oceanic crust associated with Wharton fossil ridge is Late Cretaceous, and the oceanic crust at the trench offshore Simeulue is $\sim$ 50 Ma, suggesting $\sim$20-40 Ma of the oceanic plate containing the fracture zone has been subducted. The change in elevation over the fracture zone may have developed into a warp or even a tear in the subducting plate, which is represented by the structure of the discontinuity in our model. We interpret the velocity anomalies shown in the backstop as ophiolites formed by oceanic volcanism in the Meso-Tethys and accreted over the continental margin of Sundaland in an earlier phase of subduction. As the 2004 earthquake coincidently occurred to the northwestern edge of these velocity anomalies, it may indicate that a changing property of the overriding block might also have influence on the dip angle of the subduction.