Structural Evidence for a Cause of the Tokai Slow Slip Event

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We carried out an active source seismic experiment along the 485 km long onshore - offshore profile crossing central Japan. Investigating the co-seismic / nter-seismic slip phenomena in the Tokai segment is one of the key purposes of this experiment. In addition to the active source seismic studies, we newly compiled passive source (earthquake) seismic tomography results for central Japan (Kamiya and Kobayashi, 2004). The obtained seismic velocity / reflectivity images, from the active source seismic experiment, are characterized by repeated crustal thickening down to 45 km depth. This structure is interpreted as cyclic ridge subduction. In the offshore part of the profile, we recognize subducting ridges at 300 km (referred to as the north ridge) and 350 km (referred to as the south ridge) from the northern end of the profile with maximum thicknesses of 20 km and 12 km, respectively. Comparing the location and size of the north ridge and the back slip rate (Sagiya, 1999) indicates that the north ridge is situated precisely in the area where the strong coupling is predicted.

The subducted crust beneath the Japanese island is imaged as a highly reflective interface from 25 to 45 km depth. A slightly upward doming structure (2 km high) at the top of the subducted crust can also be recognized at 190 - 230 km from the northern end of the profile. This might be attributed to an even deeper ridge system. A striking result found by comparing the results of the wide-angle study and the seismic tomography, is that a landward dipping high Poisson's ratio (more than 0.34) zone is located exactly at the highly reflective subducted crust. We also note that, from the compilation of the seismic tomography results, the landward dipping high Poisson's ratio zone (100 km wide in subduction direction and 10 km thick) only exists in the Tokai district where the subducted ridge system is inferred.

We propose, on the basis of a laboratory experiment (Christensen 1985), that a high pore pressure zone is the cause of the highly reflective / high Poisson's ratio subducted crust. A possible mechanism for generating a high pore pressure zone in subducting oceanic crust is the dehydration of hydrous minerals in the oceanic crust. The precise seismic reflectivity image along part of the profile shows several fractures cutting into the subducted ridge, which are interpreted to have formed during the subduction and collision of the ridge system. These fractures may function as conduits that transport water into the subducted crust, and consequently, significant amounts of hydrous minerals are expected within the subducted ridges.

The structures discussed above can well explain the inter-seismic silent slips observed in the coastal region of the Tokai segment. A synoptic model for depth variations of the critical stiffness of a fault, kc, for a typical subduction zone interface has been proposed by Scholz (1998). Note that the width of the conditionally stable region is quite narrow in this model. In contrast, the expected variation of kc across central Japan, based on our imaged structure, suggests a significantly wider region of conditionally stable slip. This is because the pore pressure may approach the normal stress in a high pore pressure zone, and the critical stiffness of the plate interface would dramatically decrease as a result, maintaining a conditionally stable region over the high pore pressure zone.

We conclude from our structural results that the Tokai silent slip was caused by the high pore pressure region in the deeper portion of the locked zone. This high pore pressure region is the result of dehydration of the subducted ridge, and significantly extends the conditionally stable region. Episodic silent slip would make the recurrence interval in the Tokai segment more complex, because episodic silent slip in the deeper part would affect an increase in shear stress in the strongly coupled region.