Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SCG66-05 Room:201A Time:May 24 10:00-10:15

Stress states and physical properties along the Nankai Trough plate boundary

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Recent seismic reflection and ocean bottom seismometer (OBS) studies reveal broad regions of low seismic velocity along the megathrust plate boundary of the Nankai subduction zone offshore SW Japan. These low velocity zones (LVZs) extend to ~55 km from the trench, corresponding to depths of >~10 km below sea floor. Elevated pore pressure has been invoked as one potential cause of both the LVZs and very low frequency earthquakes (VLFE) in the outer forearc. Here, we estimate the in-situ pore fluid pressure and stress state within these LVZs by combining P-wave velocities (Vp) obtained from seismic reflection and OBS data with well-constrained empirical relations between (1) P-wave velocity and porosity; and (2) porosity and effective mean and differential stresses, defined by triaxial deformation tests on drill core samples of the incoming oceanic sediment. We used cores of Lower Shikoku Basin (LSB) hemipelagic mudstone (322-C0011B-19R-5, initial porosity of 43%), and Middle Shikoku Basin (MSB) tuffaceous sandstone (333-C0011D-51X-2, initial porosity of 46%) that have been recovered from IODP Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) Site C0011 (~20 km seaward from the deformation front). Samples were loaded under a range of different stress paths including isotropic loading, triaxial compression, and triaxial extension. During the tests, all pressures, axial displacement, and pore volume change were continuously monitored; and ultrasonic velocity and permeability were measured at regular intervals.

The relationship between P-wave velocity and porosity for both LSB mudstone and MSB sandstone is independent of stress path, and is well fit by an empirical function derived by Hoffman and Tobin [2004] for LSB sediments sampled by drilling along Muroto transect, located ~150 km southwest of the NanTroSEIZE study area. The MSB sandstone exhibits slightly higher P-wave velocity and higher permeability than LSB mudstone at a given porosity.

Based on our experimental results, and assuming that the sediments in the LVZs are at shear failure defined by a critical state stress condition, we estimate that effective vertical stress in the LVZ ranges from 15 MPa at 13 km landward of the trench, to 41 MPa at a distance of 55 km. The maximum horizontal effective stress ranges from 41-124 MPa over this region. Excess pore fluid pressure ranges from 15-81 MPa, corresponding to modified pore pressure ratios, lambda* of 0.44-0.73. If LVZ is composed dominantly of sandstones, both the effective vertical and horizontal stresses would be lower, and the excess pore pressure would be higher, with pore pressure ratios lambda* = 0.31-0.90. Our results suggest that the sediments have been loaded under poorly drained conditions, and that pore fluids support ?~53-91 % of the overburden stress along the base of the accretionary wedge across the outer forearc. The low effective stress should lead to a mechanically weak plate boundary, and is spatially correlated with well-located low-frequency earthquakes in the outer accretionary wedge. The heterogeneous distribution of inferred pore pressure also suggests that fluid sources and drainage are localized and possibly transient.

Keywords: subduction zone, IODP, NanTroSEIZE, pore pressure, low frequency earthquake