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南海トラフ沈み込み帯での応力状態と変形機構
Stress state and deformation mechanism in the Nankai Trough subduction system

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In subduction zones, the updip transition from aseismic to seismic slip behavior with increasing depth is coincident with porosity loss associated with consolidation, lithification, and diagenesis. Porosity decreases from ~80% within incoming sediments to less than 10% in subducted/accreted rocks at burial depths of a few to ~15km, as observed in the ancient accretionary prism outcrops. Stress states are one of the most important factors governing porosity loss, deformation modes, and fault strength, because in subduction systems where tectonic stress is large, sediments are subjected to complicated stress conditions in time and space. In the Nankai Trough, the input sediments on the subducting Philippine plate and shallower sediments in the modern accretionary prism have been recovered during the Integrated Ocean Drilling Program (IODP) Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) expeditions. In this study, we aim to understand the evolution of physical properties (porosity, permeability, and P-wave velocity) and sediment deformation in subduction systems by conducting deformation experiments on both the input sediments and the prism sediments from the Nankai Trough. We conducted ~30 uniaxial and triaxial (both triaxial compression and triaxial extension) deformation experiments on sediments recovered from different depths at different drill sites. Cylindrical samples were deformed by controlling confining pressure, axial stress, and pore pressure, and all pressures, axial displacement, and pore volume change were monitored. Permeability, and ultrasonic velocity were also measured during consolidation and deformation.

We deformed samples of Lower Shikoku Basin (LSB) silty-claystone (initial porosity of 44%) from Site C0011 are loaded under a range of different stress paths including isotropic loading, triaxial compression, and triaxial extension by controlling axial stress (up to 70 MPa), confining pressure (up to 70 MPa), and pore pressure (0.5-28 MPa). We find that the evolution of physical properties (porosity, permeability, and P-wave velocity) is dependent on both effective mean stress and differential stress. Differential stress enhances reduction in porosity and permeability and results in an increase in P-wave velocity. The relationship between defined by our experimental data is fit well by a Cam-Clay model, which describes elasto-plastic behavior of sediments. We also find that the input sediments at the reference sites (Site C0011 and Site C0012) are normally consolidated or slightly overconsolidated, whereas the prism sediments are highly overconsolidated. In particular, mudstones of similar age (Miocene) show a progressive increase in the degree of consolidation with a distance from the deformation front. This suggests tectonic stress (i.e., larger horizontal and differential stress within the accretionary prism) enhance further consolidation and porosity loss, and thus induce brittle faulting deformation rather than cataclasitc flow deformation.

We also apply our observed experimental relationship between P-wave velocity and stress state to estimate in situ stress state and pore pressure within a well-defined low-velocity zone (LVZ) identified in the outer accretionary wedge [Park et al., 2010]. This LVZ is located at ~3 km depth, immediately above the decollement and extends from 15-35 km from the trench. Our lab data constrain the in situ vertical effective stress to be 7-14 MPa, effective maximum horizontal stress of 28-35 MPa, and excess pore pressure of 23-16 MPa. This corresponds to a value of the pore pressure ratio lambda$*$ = 0.53-0.77. This technique to estimate the in-situ stress from the empirical relationship between P-wave velocity and stress states can be further tested in the future drilling to the deeper accretionary complex and the plate boundary faults.

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