Excess fluid pressure development beneath the décollement at the Nankai subduction zone

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Pore fluid pressure in subduction zones is very important for understanding earthquake generation processes. However, quantitative constraints on the pore pressure are quite limited. Here we report two estimates of the pore pressure developed within the underthrust sediments in the Nankai Trough off Cape Muroto, Japan, using the shipboard data obtained at Site C0023 during IODP Expedition 370 (T-Limit) (Heuer et al., 2017).

First estimates are based on the depth trend of porosity data in the lower Shikoku Basin (LSB) facies, in which the décollement zone has propagated. Porosities in the LSB facies generally decrease with depth, but turn to increase by 5-7% below the décollement zone at ~760 mbsf. Deeper than ~830 mbsf, porosities resume a general compaction trend. The characteristic downward porosity trend across the dé collement is consistent with those reported from Sites 808 and 1174, ~4 km SW of Site C0023 (Shipboard Scientific Party, 1991, 2001). Screaton et al. (2002) compared a reference site (Site 1173) porosity versus depth curve to data from Sites 808 and 1174 within the protothrust zone and concluded that the downward increase in porosity beneath the décollement is reflected by an excess pore pressure (overpressure ration λ of ~0.42). By applying the same method, we estimated the highest excess pore pressure of ~4.2 MPa (λ = ~0.45) at ~1020 mbsf within the underthrust sediments.

Another estimate is based on the analysis of upwelling drilling-mud flow from the borehole. After installation of a casing at 850 mbsf for the protection of the fragile décollement zone and having drilled down to nearly the bottom of the LSB facies at ~1100 mbsf, the drilling pipes were pulled out from the borehole. At this time, the continuous mud flow from the head of the casing pipe was confirmed by an underwater TV. The evidence directly indicates the development of overpressure somewhere in the depth interval between 850 and 1100 mbsf. The pore pressure which is necessary to flow the drilling mud through the casing pipe out of the hole can be calculated by solving an energy balance Bernoulli equation. Parameters such as density and viscosity of the drilling mud for the calculation were known. The flow rate that was estimated from mud particle movement shown in the TV video. The calculation yields that pore pressure reaches more than lithostatic pressure by 1~3 MPa ($\lambda > 1$).

The pore pressure estimate from the depth porosity trend could yield a minimum value of excess pore pressure because porosity change is only partially reversible (Screaton et al., 2002), while the estimate from the upwelling mud-flow could reflect the current pore pressure state. Our analysis indicates a significant development of excess pore pressure (nearly lithostatic) beneath the décollement zone, most likely at the depth of ~1020 mbsf where the highest overpressure was estimated from the downhole porosity trend and also an anomaly in relative hydrocarbon gas concentrations was observed (Heuer et al., 2017). Friction experiments by Sawai et al. (2016) show that a transition from stable to unstable slip behavior appears with increasing pore fluid pressure that is a prerequisite for the generation of slow earthquakes. Thus, slow earthquakes that occurred off Cape Muroto (Ito and Obara, 2005) can be attributed with the observed significant overpressure beneath the décollement.

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