In situ stress state within the inner accretionary prism in the Nankai Trough: Inferences from drilling observations during IODP Expedition 348

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In November 2013- January 2014, Integrated Ocean Drilling Program (IODP) Expedition 348 drilled into the inner accretionary prism of the Nankai subduction zone offshore SW Japan, to investigate the physical properties, structure and state of stress deep within the hanging wall of a seismogenic subduction plate boundary. Drilling deepened Site C0002 to a depth of >3000 m below the seafloor (mbsf) at holes C0002N/P, and included coring over a limited interval from 2163-2218.5 mbsf, and a suite of logging while drilling (LWD) measurements to collect continuous annular pressure while drilling, gamma ray, azimuthal resistivity, and sonic velocity data over the entire depth of the holes. The hole was drilled in a riser mode, with controlled mud pressure and continuous monitoring of mud gases that, together with observations of mud losses, annular pressures, and/or hole conditions, provide indirect constraints on in situ pore pressure and stress state. Operations also included a leak-off test (LOT) at 1954.5 mbsf, and a stepped-rate injection test at 2920 mbsf that provide measurements of the minimum principal stress (S_3). Observations of mud losses during drilling and a previous LOT at 874 mbsf conducted during IODP Expedition 338 both provide an additional indication of S_3 at a shallower depth. Finally, several pack-offs occurred near the base of the borehole (3002 mbsf), but without indications of mud loss, suggesting that the accompanying spikes in annular pressure remained lower than the minimum tangential stresses at the borehole's circumference. Because the tangential stresses around a wellbore are a function of the differential stress in the horizontal plane, these data provide an independent constraint on the maximum horizontal stress (SHmax) magnitude.

As an ensemble, these observations - for the first time - constrain stress state and pore pressure in the deep interior of an accretionary wedge. The LOTs show that the minimum principal stress as less than the vertical stress defined by the overburden (Shmin = S_3), and define a nearly linear gradient in Shmin from the seafloor to the base of the hole. Several observations of mud loss, and the lack of observed gas shows even during pipe connections, indicate that formation pore pressure is not significantly (<~10 MPa) greater than hydrostatic. Our estimate of SHmax is close in magnitude to the vertical stress, and defines either a normal or strike-slip faulting regime. At 3002 mbsf we estimate that the effective stresses are as follows: Sv' = 33 MPa; SHmax' = 25-36 MPa; and Shmin' = 18.5-21 MPa. A key implication of our analysis is that, at least to ~3 km depth in the hanging wall of the subduction thrust, differential stresses are low, on the order of 10 MPa or less. On this basis, we posit that: (1) the inner wedge is not critically stressed in horizontal compression, consistent with its flat surface slope and the development of a large forearc basin above; (2) basal traction along the megathrust must be low, in order to permit concurrent sliding along décollement and low differential stresses deep within the upper plate; and (3) although differential stresses may remain low all the way to the plate boundary at ~5.4 km bsf, the maximum horizontal stress SHmax must transition to become greater than the vertical stress below the base of the borehole in order to drive thrust motion along the décollement.

