Constraints on paleo-stress magnitude in Hikurangi Margin, New Zealand, at Site U1518, Expedition 375

*Yoshitaka Hashimoto[1], Ryo Nishimori[1], Annika Greve[2], Julia Morgan[3]

1. Kochi University, 2. Utrecht University,, 3. Rice University

Understanding stress and strain in subduction zones is essential to understand earthquake-slip behaviours. After the 2011 Tohoku earthquake, a horizontal compressional stress changed to a horizontal extensional stress at a regional scale (e.g., Asano et al., 2011). Paleo-stress analyses using micro-fault inversion has been used to demonstrate temporal changes in stress in on-land accretionary complexes such as the Shimanto Belt (Japan) and near the Chelung-pu fault in Taiwan (Hashimoto et al., 2014; Hashimoto et al., 2015). In the latter study the paleo-stress magnitude was also constrained using stress polygons. The results found an increase in magnitude of the horizontal compressional stress. The change in stress could be caused by a decrease in shear stress on the plate boundary, which contributes to the horizontal compressional stress.

Site U1518 of International Ocean Discovery Program (IODP) Expedition 375 is located at the toe of the Hikurangi subduction margin (North Island, New Zealand). In cores from this site, normal faults, fractures and a small number of thrust faults coexist. This is indicative of stress changes in the past. We conducted paleo-stress analysis to examine the stress changes in the shallow portion of Hikurangi margin, New Zealand.

We conducted paleo-stress analysis on normal faults, and open and filled fractures. The deformation structures are distributed mainly below around 300 m where two fractured fault zones were identified (Fagereng et al., 2019). Although the cross-cutting relationship is not clear based on the limited core-observations, the distributions of the structures overlap. Paleomagnetic declinations were used to reorient the faults into a geographic reference frame. Because open and filled fractures show no visible displacement, paleo-stress analysis was conducted using the dike method. Many normal faults have no striations, therefore, we used them as sense data only, using a micro-fault inversion method. Both methods were modified to subdivide the stress history into multiple stages using computed statistics.

The estimated orientation of σ_1 is NW-SE or WNW-ESE and σ_3 is vertical for open and filled fractures, which indicates thrust-type stress. The stress ratio, $(\sigma_1 - \sigma_2) / (\sigma_1 - \sigma_3)$, is about0.5. The σ_1 direction is consistent with a NE-SW lineation of K_{max} in the upper strand of the fault zone as was determined using the Anisotropy of Magnetic Susceptibility (AMS) method (Greve et al., in revision). For the normal faults, σ_1 is vertical and the stress ratio is 0.5. Because the normal faults have only sense without a defined slip direction, the orientations for σ_2 and σ_3 are not well constrained.

Both thrust- and normal-fault stress states were observed in the cores at U1518 for the brittle faults or fractures, which suggests that both compressional and extensional critical states were achieved during the evolution of this system. Using stress polygons with the stress orientations and the stress ratio (Hashimoto et al., 2015), the stress magnitudes were constrained for each stress state, allowing us to estimate variations in pore pressure ratio. The differential stresses for horizontal compression and horizontal extension are about 2-4 MPa and about 1 MPa, respectively. The range for maximum shear stress is about 1-3 MPa. Additionally, applying dynamic Coulomb wedge theory (Wang and Hu, 2006) to the high angle slope at the toe of Hikurangi margin, the basal effective friction coefficient and shear stress around 300 m depth for each state can be calculated. Accordingly, the shear stress difference between the compressional and extensional critical state was about 1-2 MPa. The shear stress change determined from both methods (stress polygons and dynamic critical taper model) are mostly consistent. The stress drop is larger than expected for slow earthquakes but probably consistent with a large tsunami earthquake near the trench.

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