Hydraulic structure of the Tohoku subduction zone (Japan): Drilling provides insights into the 2011 tsunami earthquake

Pei Pei*†[1], Mai Linh Doan[1], and Iodp Expedition 405 Science Party

[1]Institut des Sciences de la Terre – Université Grenoble Alpes – France

Résumé

In 2011, the Tohoku subduction zone endured a Mw 9.0 earthquake and a large tsunami with co-seismic displacement exceeding 40 m at the trench. Such an unexpected tsunami earthquake is believed to have created significant damage across the plate boundary fault zone (PBFZ).
In this study, we characterize the hydraulic structure across the PBFZ of the Tohoku earthquake. To achieve this, we use the rich dataset collected during IODP Expedition 405, during which the PBFZ was directly drilled several times between September and December 2024. We focus in particular on drilling and logging data to estimate the flow entering the borehole. By carefully modelling the mud pressure, we evaluate the hydraulic inflows and outflows to the borehole as drilling advances. The resulting flow profile provides valuable insights into permeable and/or overpressurized intervals.

Based on Logging While Drilling (LWD) data from Hole C0019H, we derive a high-resolution, continuous fluid flow profile along the borehole. Two primary inflow zones are identified: (1) The first incoming fluid flow is located at the base of the plate boundary fault zone (_˜825 mbsf, shown in Figure 1(a)), with a thickness of 2.3 meters. This localized hot inflow generates an overpressure zone with strong temperature anomalies. Furthermore, we examine interstitial water chemistry from the nearby Hole C0019J. As drilling approaches the fault, we observe sharp variations (Figure 1(c)) in Na, K, and Ca^2 concentrations as drilling approaches the fault, which can be attributed to fluid migration along the fault zone. This geochemical anomaly spatially coincides with the inflow zone identified in C0019H, providing strong evidence of active fluid movement along the PBFZ. (2) A second flow zone (Figure 1 (b)) is identified at the base of the basalt layer, with a thickness of approximately 4.5 meters. This flow appears to be supported by fractures also observed in electrical resistivity imaging. Our findings offer direct evidence of localized and active fluid migration along the Tohoku plate boundary fault zone, highlighting its crucial role in fault zone overpressure, weakening mechanisms, and healing after the large earthquakes.

Mots-Clés: Tohoku subduction zone, Hydraulic structure, IODP Expedition 405, Logging, while, drilling (LWD), Drilling mud pressure

*Intervenant

†Auteur correspondant: Pei.Pei@univ-grenoble-alpes.fr