Hydrogeological Properties at the Toe of the Nankai Accretionary Prism, using Borehole Geophysical and Petrophysical Data within Hole C0024A, Expedition 358 of IODP–NanTroSEIZE Project.

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Abstract

The Nankai Trough is a locus of slow slips, low frequency, and large-magnitude classical earthquakes. It is assumed that high pore pressure contributes substantially to earthquake dynamics. Hence, a full understanding of the hydraulic regime of the Nankai accretionary prism is needed to understand this diversity of behavior.We contribute to understanding the full hydraulic regime within the Nankai accretionary prism by innovatively integrating the drilling and logging data of the NanTroSEIZE project. We focus on the toe of the Nankai accretionary prism by studying data from hole C0024A drilled during IODP expedition 358. This drilled hole intersected the Nankai décollement at 813 mbsf, about 3 km from the trench. Pore pressure was first estimated using Eaton's method on both drilling and sonic velocity data. Both results show that pore pressure follows hydrostatics until the top of the hemipelagites, with local pore pressure rising up to 38% above hydrostatic especially crossing the décollement. Downhole Annular Pressure was also monitored during drilling, and a careful reanalysis of its variation shows the occurrence and the locus of fluid flow between the formation and the borehole. Primarily, there are two identified fluid flow anomalies intervals: (1) at the shallow depths <100 mbsf with loose coarse sediments, which could be related to erosional unloading, landslide, slope instability. (2) Below the décollement (<813 mbsf) at the two asymmetric damage zones. The damage zones at the footwalls of the major faults are predominantly permeable with significant porosity and permeability values with orders of magnitude between 10-16 to 10-17 m2 as quantitatively estimated using the Hvorslev equation for a fully penetrating well in a confined aquifer. Our results show that the formation fluids are getting significantly over-pressurized only a few hundred meters from the toe of the decollement. The decollement is already impermeable across the fault, and the fluid flow is channelized along the damage zones. The impermeable decollement acts as a hydraulic barrier inhibiting fluid flow upward, keeping high pore pressure at the footwall and increasing the structural weakness of the lithologies. It's therefore probable that high pressure is also expected further down in the locus of tremors and slow slip events.

Hydrogeological properties at the toe of the Nankai accretionary prism, using drilling and petrophysical data from Hole C0024A - IODP NanTroSEIZE Project

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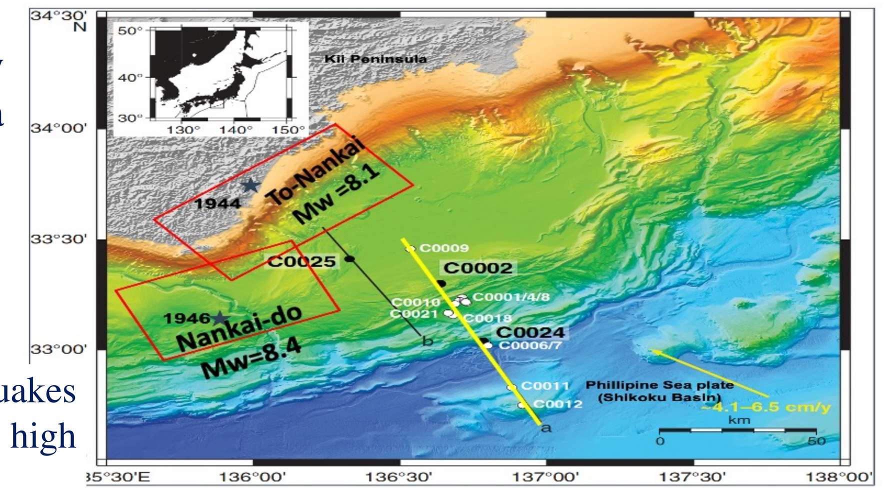
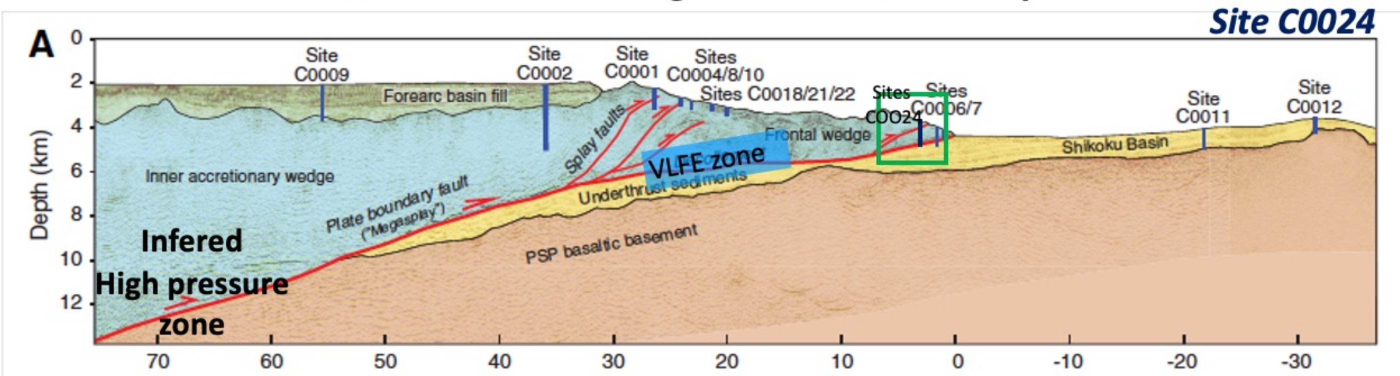
1- Nankai Subduction Zone

- Nankai subduction is formed by the subduction of the phillipine sea plate under the Eurasian plate.
- Locus of high seismic hazard with M8+ earthquake with identified SSE and VLFE
- Tectonic deformations and earthquakes cycles are substantially influenced by high pore pressure and fluid flows.



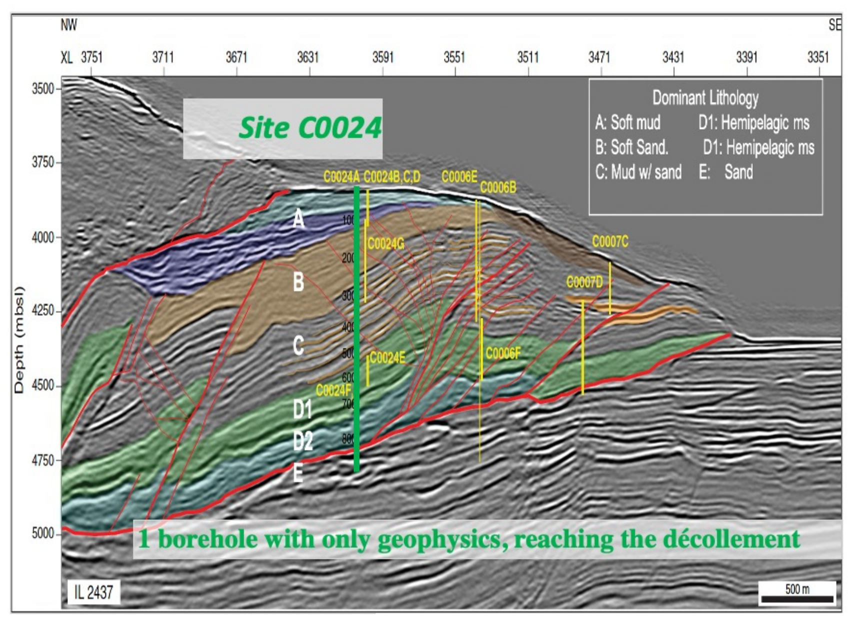
=> **NanTroSEIZE: Nankai Trough Seismic Zone Experiment**

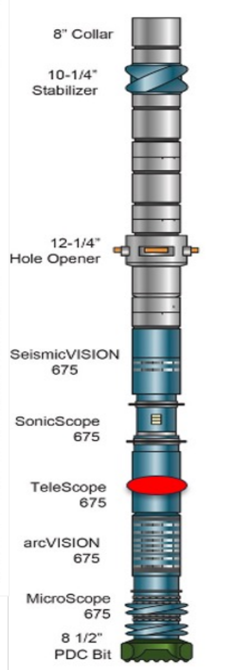


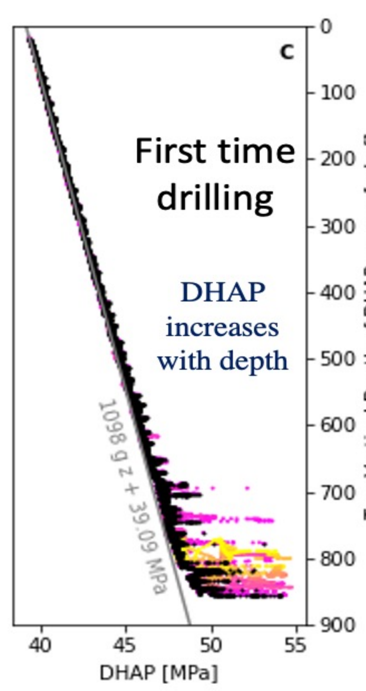
Modified from Exp 358 Proceedings

2- Objective

To provide continuous quantitative hydraulic information of the Toe of the Nankai accretionary prism at metric scale using a new technique by quantitatively interpreting Mud Pressure (DHAP) data.

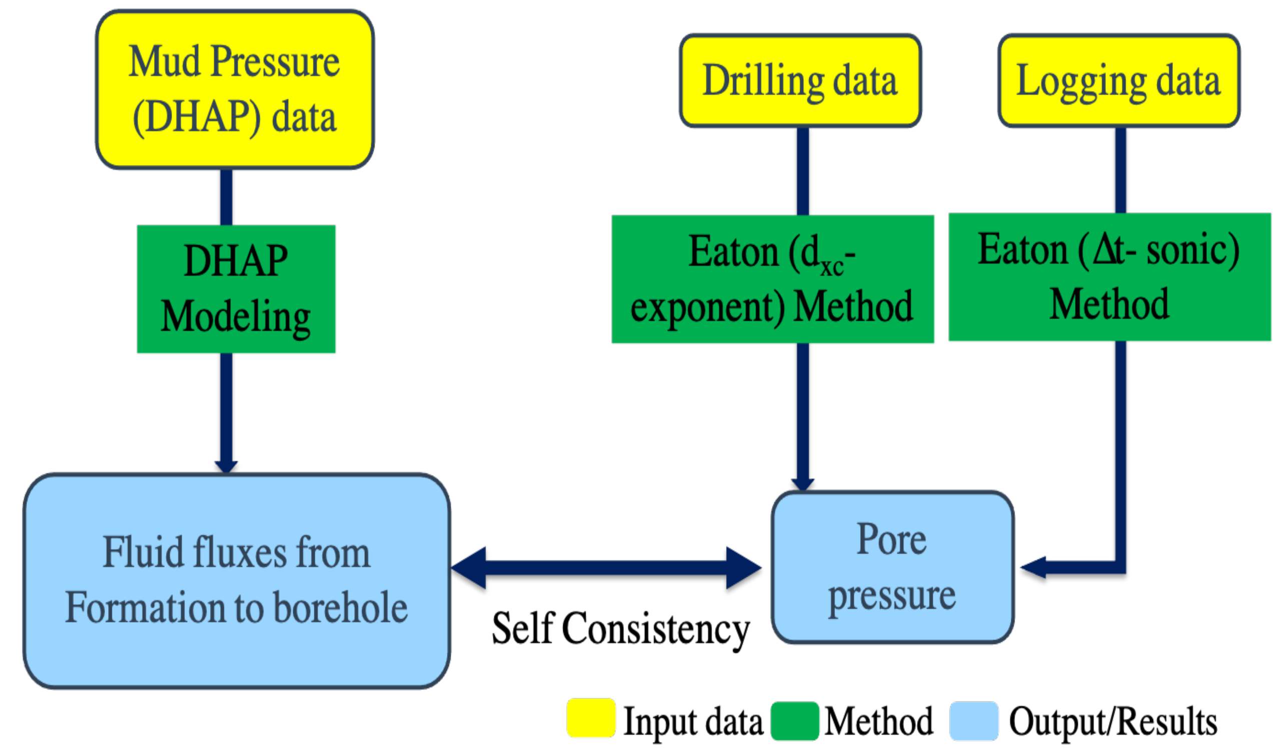






Modified from H. Tobin et al 2020

3 - Methodology

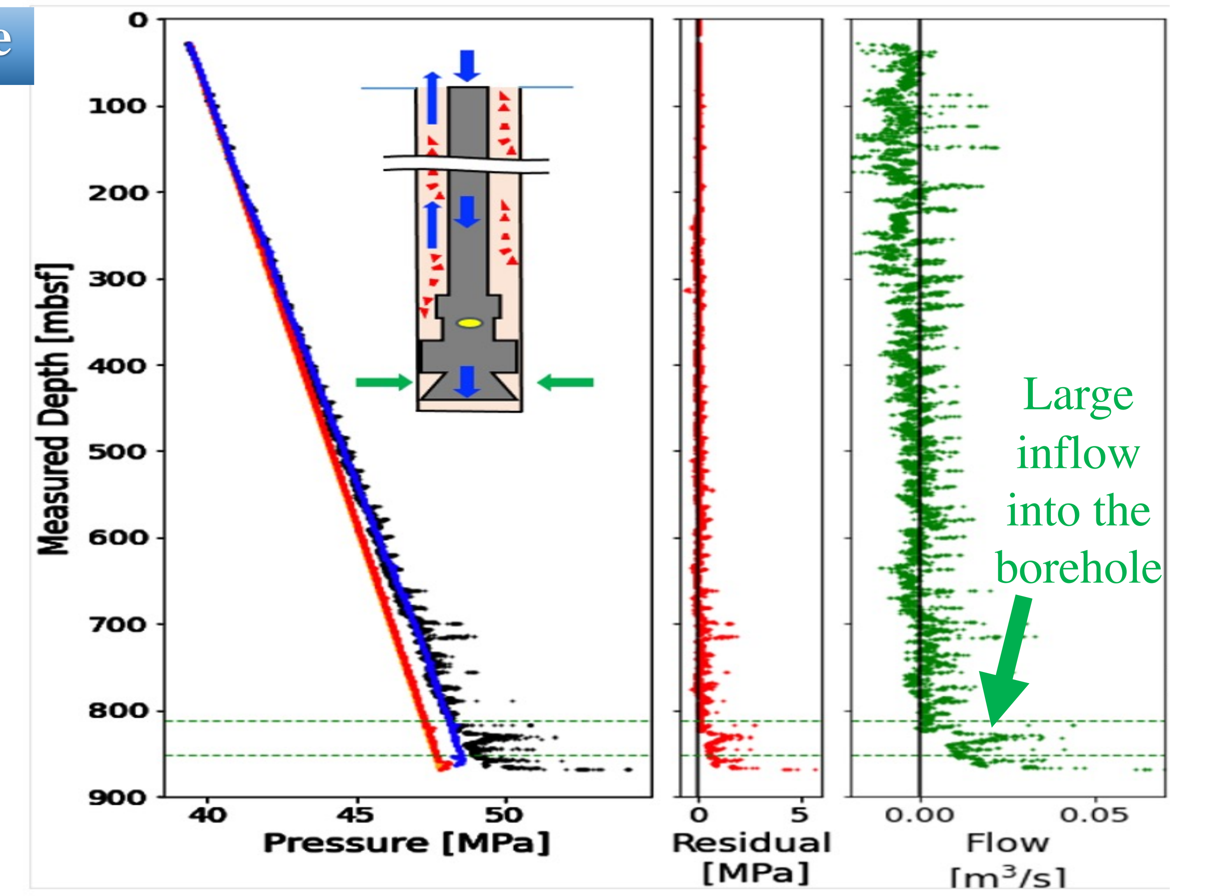


4 – Results : Inflow from modeling of Mud Pressure

Hydraulic Model of Mud Pressure

Hydrostatic clean mud density
+ Weight of cuttings
+ Hydraulic (dynamic) losses due to mud circulation along the borehole
= Mud Pressure (DHAP) Model

Mud pressure anomaly not explained by the hydraulic model
⇨
large inflow into the borehole when crossing the décollement



5 – Results : Pore Pressure from Eaton's Model

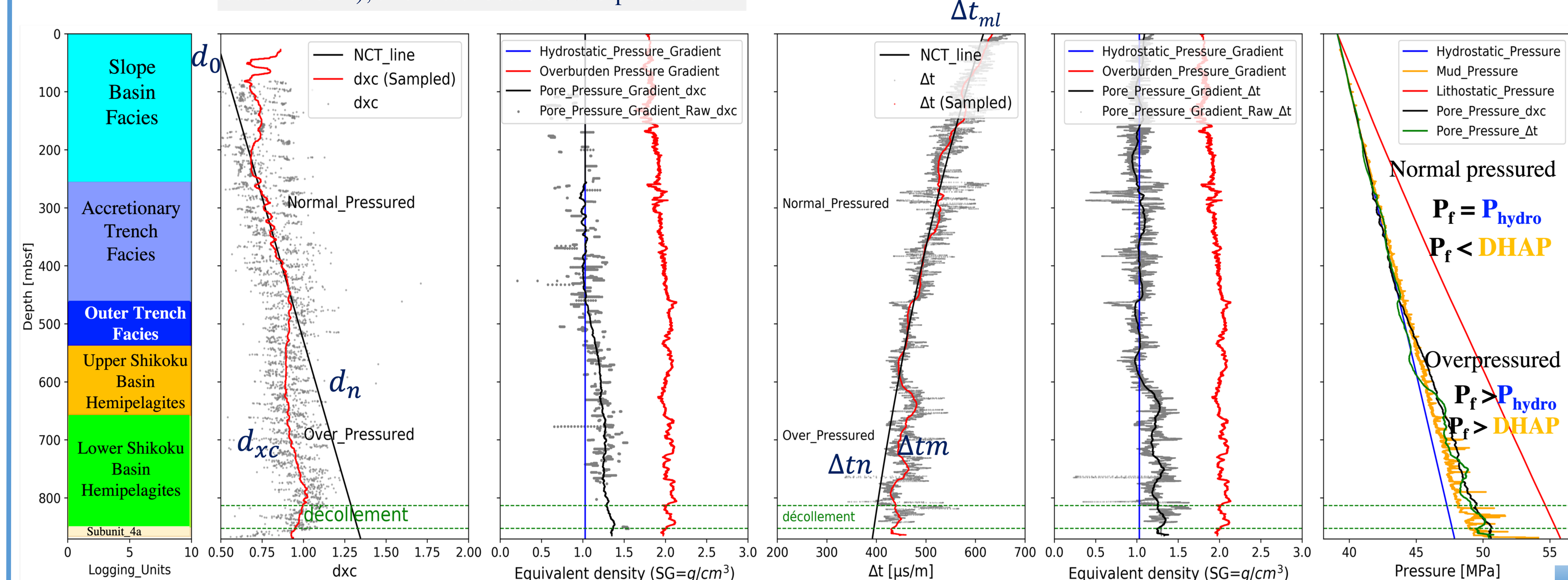
D_{xc} – exponent method

Proxy for "un-drillability", if lithology is the same, but *d*-exponent coefficient decreases (rocks get easier to drill), this is attributed to overpressure.

Δt –sonic method

Seismic slowness follows an exponential decay with depth. Same lithology but seismic slowness increases, this is attributed to overpressure.

Pore pressure



Hemipelagites in the Hanging wall are getting overpressurised.

There is further step in pore pressure when crossing each strand of the décollement into the footwall

$$P^* = P_f - P_{hyd}$$

$$\lambda^* = \frac{P_f - P_{hyd}}{\sigma_v - P_{hyd}}$$

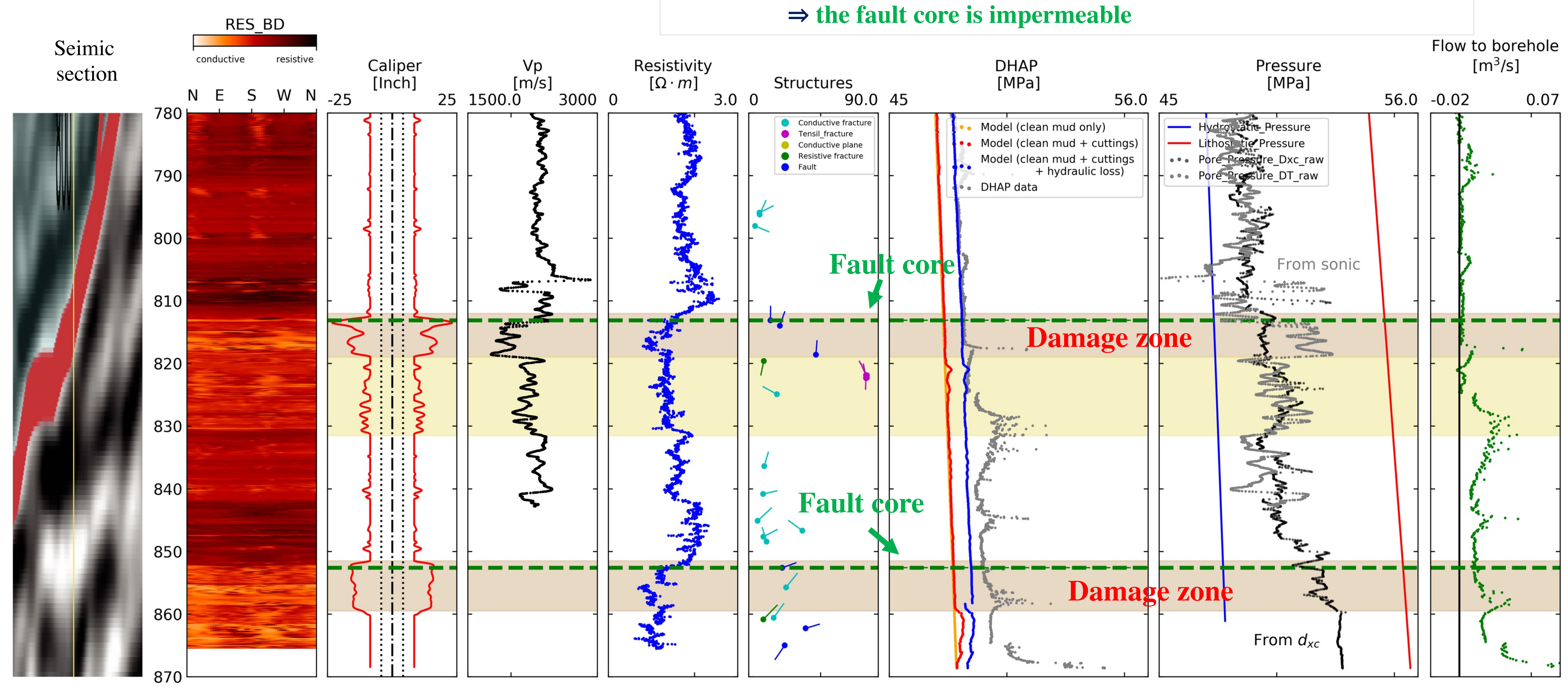
Hemipelagites
$P^* \approx 0.04 – 2.7$ MPa
$\lambda^* \approx 0.27 – 0.34$

Below the décollement
$P^* = 2.99$MPa
$\lambda^* = 38\%$ of the overburden stress

6- Discussion

Hydraulic structure of the décollement

- Décollement: 2 strands at 813 & 852 mbsf.
- Step in pore pressure when crossing the fault core
  ⇒ no hydraulic connection between the hanging wall and the footwall
  ⇒ the fault core is impermeable

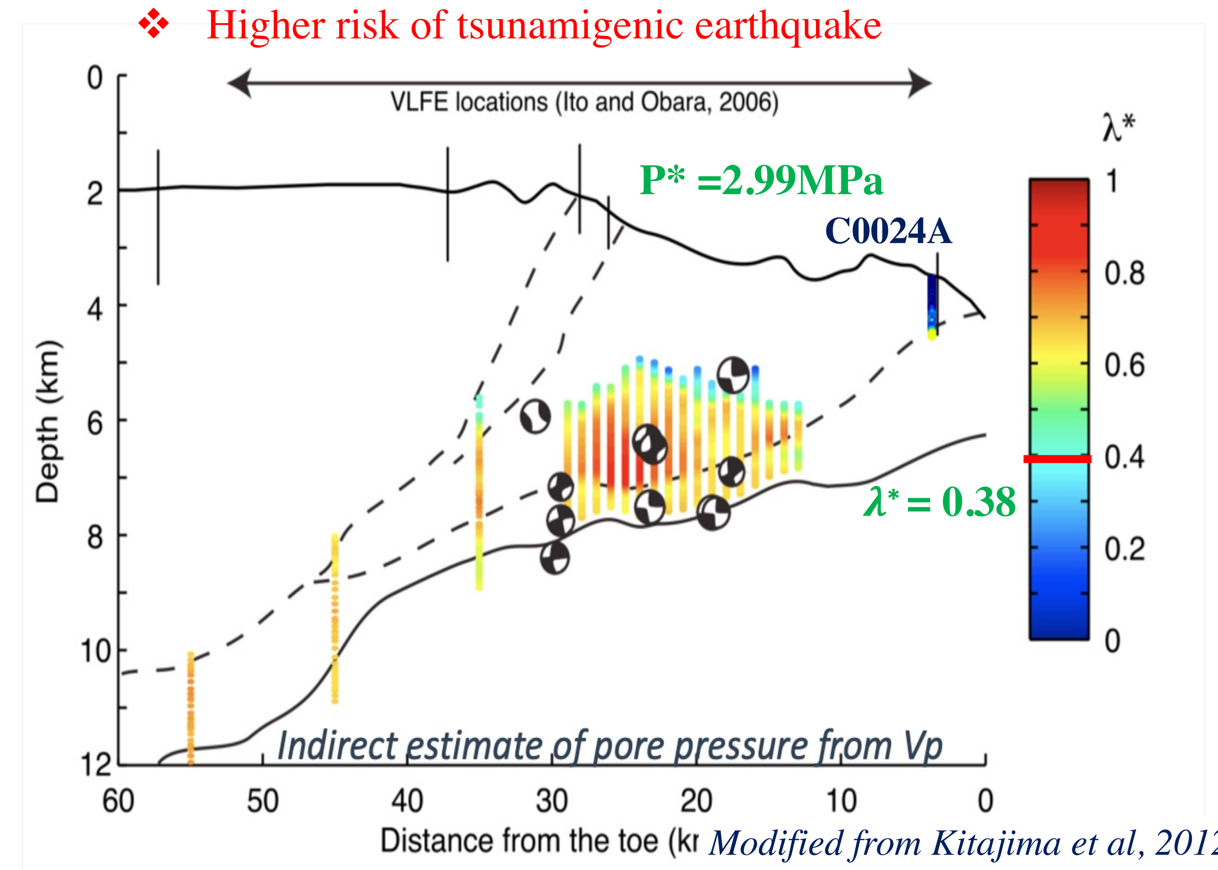


Damage zones: 2 asymmetric damage zones .

- There is a larger caliper (mechanically weak), low P-wave velocity, and low resistivity in the footwall rather than the hanging wall.
- **Also the footwall is the locus of fluid flow from the formation with higher pore pressure.**

Implication on Seismotectonics

- Extension of the high pressure zone to the toe
- Higher risk of tsunamigenic earthquake



Modified from Kitajima et al, 2012

7- Conclusion

- We developed a methodology to characterize the hydraulic state along the C0024A borehole, by processing both drilling and geophysical data, in both time and space.
- Pore pressure increase is pervasive within the accretionary prism and not only at the fault zone.
- The décollement fault zone is associated to an hydraulic anomaly with large fluid flow (>0.04m³/s) and high pore pressure ($P^* = 2.99$MPa and $\lambda^* = 38\%$)
- High pressure happens up to the toe of the accretionary prism, favouring slow slip events and tsunamigenic earthquakes

8- References

- Kitajima, H., & Saffer, D. M. (2012). Elevated pore pressure and anomalously low stress in regions of low frequency earthquakes along the Nankai Trough subduction megathrust. Geophysical Research Letters, 39 (23), 1{5. doi: 10.1029/2012GL053793
- Saffer, D. M., & Tobin, H. J. (2011). Hydrogeology and Mechanics of Subduction Zone Forearcs: Fluid Flow and Pore Pressure. Annual Review of Earth and Planetary Sciences, 39 (1), 157{186. doi: 10.1146/annurev-earth-040610-133408