Comparison of in-situ rock strength of the input materials and prism sediments at the Hikurangi Margin

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Introduction

The northern Hikurangi Margin, located offshore New Zealand, experiences slow slip events (SSEs) every 18-24 months at relatively shallow depths. The International Ocean Discovery Program (IODP) Expeditions 372/375 drilled multiples sites along this margin (Figures 1 and 2) (Saffer et al., 2019). I analyzed the drilling data to investigate the in-situ rock strength in that region, particularly at Sites U1518 and U1520.

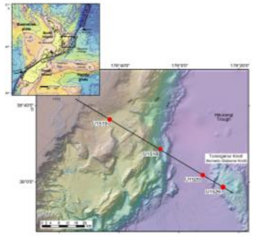


Figure 1. Map of Hikurangi Margin and drilling transect. (Modified from Wallace et al., 2019).

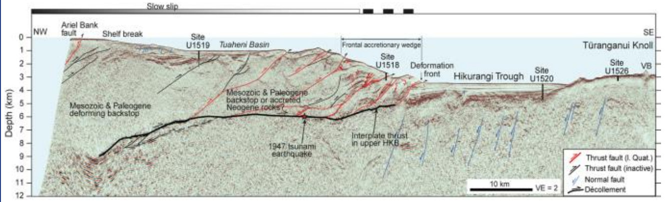
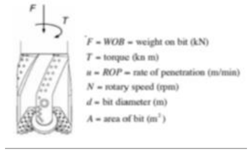


Figure 2. A cross-section of the Hikurangi Margin with drilling locations (Saffer et al., 2019).

Methods

The data is analyzed through drilling performance analysis. The drilling performance curve was developed to maximize efficiency while drilling (Bingham, 1964). Drilling data was collected continuously every 1 second, including:

- Bit depth
- Weight on bit (F)
- Torque on bit (T)
- Rotation speed (N)



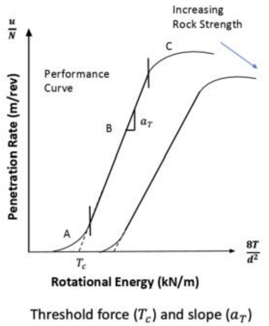


Figure 3. Schematic diagram of drilling performance curve demonstrating the relationship between the ratio of penetration rate (u) to the rotation speed and the ratio of T to the square of bit diameter (d) (Gallegos, 2019). Tc is the threshold force and a is the slope of the performance curve. The curve has three distinct zones, A, B, and C. Zone B is the efficient drilling zone of the curve.

The hardness of the rock affects the energy needed to drill. The drilling performance curve characterizes the relationship between the penetration rate to the rotational energy of the drill bit. An increase in the slope of the performance curve indicates a decrease in rock strength, whereas a decrease in slope indicates that the rock strength increases.

Data Analysis

Each site used the same data analysis process (Figure 4):

1. Extract the data to only include depths where the drill bit advanced based on nonzero WOB values.
2. Calculate time-based moving average. A 10 second window for U1518 and 100 second window for U1520.
3. Extract data with increasing depths.
4. Calculate the rate of penetration (ROP) over 1 m interval.
5. For each 10 m coring interval, plot performance curves based on TOB and determine the slope of the curve.

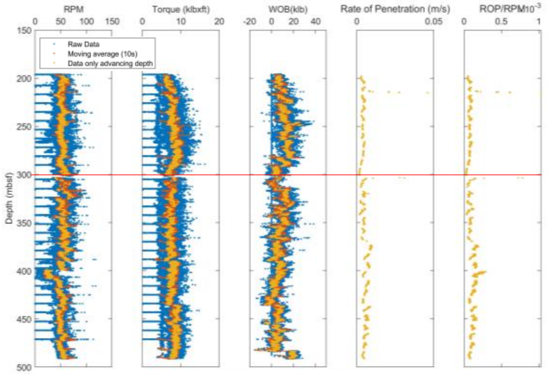


Figure 4. A depth-based plot showing the drilling parameters for Site U1518.

Results

Site U1518 is located near the deformation front and drills through the Pāpaku Fault around 300 meters below sea floor (mbsf). Site U1520 is located on the Pacific plate and recovers “input” materials to the subduction zone. The shallower zone of Site U1520 is composed of the same hemipelagic facies as Site U1518.

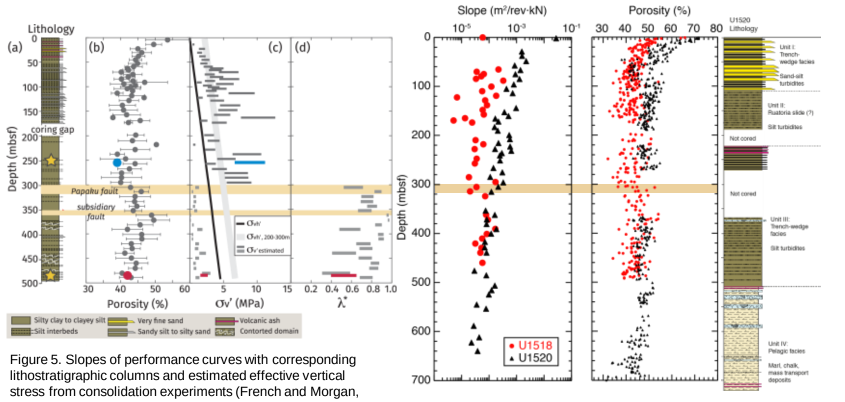


Figure 5. Slopes of performance curves with corresponding lithostratigraphic columns and estimated effective vertical stress from consolidation experiments (French and Morgan, 2020). Highlighted region shows the fault zone.

The results from the analysis are shown above (Figure 5). Key findings include:

- The slope of the hanging wall of the Pāpaku fault at Site U1518 is lower than that observed Site U1520 at the same depth
- The hanging wall porosity is generally lower at Site U1518
- Both slope and porosity of the footwall at Site U1518 are similar to those at Site U1520 at corresponding depths.

These findings suggest that the sediments of the hanging wall of the Pāpaku fault are highly overconsolidated and strengthened likely due to the tectonic loading (French and Morgan, 2020).

Summary

The performance analysis of drilling parameters of Sites U1518 and U1520 indicates that the prism sediments above the Pāpaku fault have greater strength compared to the incoming sediments at Site U1520 and sediments below the Pāpaku fault. This difference in strength signifies the difference in loading and tectonic histories of both sites, where the prism sediments have undergone more compaction through tectonic loading. Drilling performance analysis provides a relative strength measure, so I am conducting deformation experiments to calibrate and quantify the rock strength.

Acknowledgments

This research used samples and/or data provided by the International Ocean Discovery Program (IODP). I appreciate Dr. Hiroko Kitajima for her supervision on this research.

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