Evaluating the central Hikurangi Subduction Margin stress state from geophysical logging

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November 24, 2022

Abstract

Quantifying the orientation and magnitude of tectonic stresses is essential to better understand active crustal deformation and faulting in the Hikurangi Subduction Margin (HSM), North Island, New Zealand. In this study, We estimate the horizontal stress magnitudes (Shmin and SHmax) utilizing leak-off test (LOTs) data, borehole breakout widths measured from borehole image logs, and rock unconfined compressive strengths (UCS) derived from empirical relationships using P-wave velocity wireline logs. Stress field results are used to infer the tectonic regime experienced in the region where three boreholes, Makareao-1, Kauhauroa-5, and Tuhara-1A, are drilled. Relative stress magnitudes in Makareao-1 at 260-900 m TVDss (True vertical depth from sea level) suggest thrust or strike-slip tectonics (SHmax[?] Shmin= Sv). Moving east to Kauhauroa-5, the stress results report a gradual transition from shallow normal/strike-slip tectonics (Sv > Shmin) to thrust or strike-slip tectonics (SHmax> Sv[?] Shmin) at depth. Further east again, at borehole Tuhara-1A, stress results suggest normal/strike-slip tectonics (Sv[?]SHmax> Shmin) from 555-2264 m TVDss. The tectonic regimes in individual boreholes are consistent with fault interpretations of seismic reflection profiles from this region. These three boreholes are located within the hangingwall of active, NE-SW striking thrust faults and from borehole breakout azimuths we find a mean SHmax orientation of 065° ± 17° (NE-SW) for the deeper parts of these boreholes. The SHmax orientation is broadly compatible with maximum contraction directions determined from campaign GPS and sub-parallel to far-field relative Pacific-Australian plate motion. This, combined with our stress magnitude observations in Makareao- 1 and Kauhauroa-5 suggests these NE-SW striking faults predominantly experience strike and/or oblique slip despite appearing in seismic profiles as thrust faults. We suggest that these faults originated as thrust faults during older stages of subduction along this margin, which over time have become reactivated in a more strike-slip manner.

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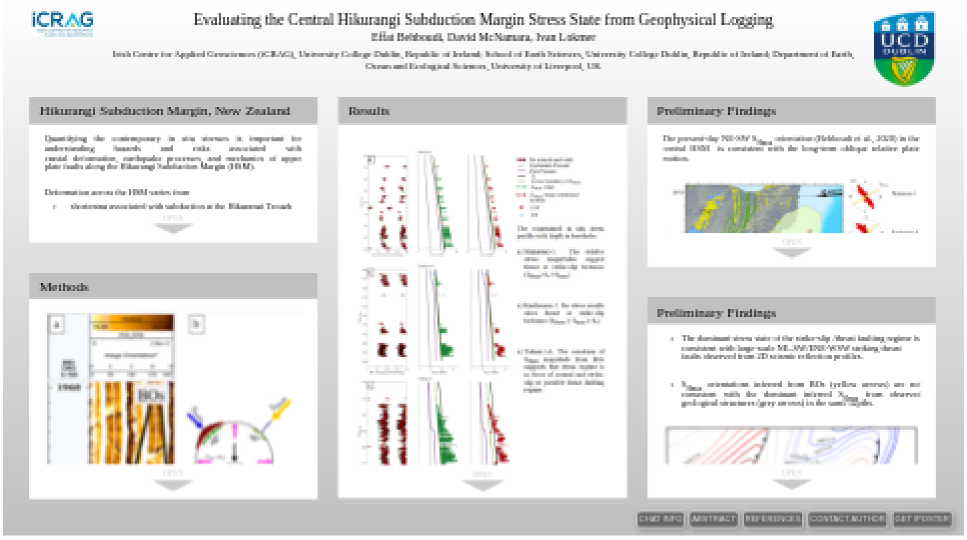

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PRESENTED AT:

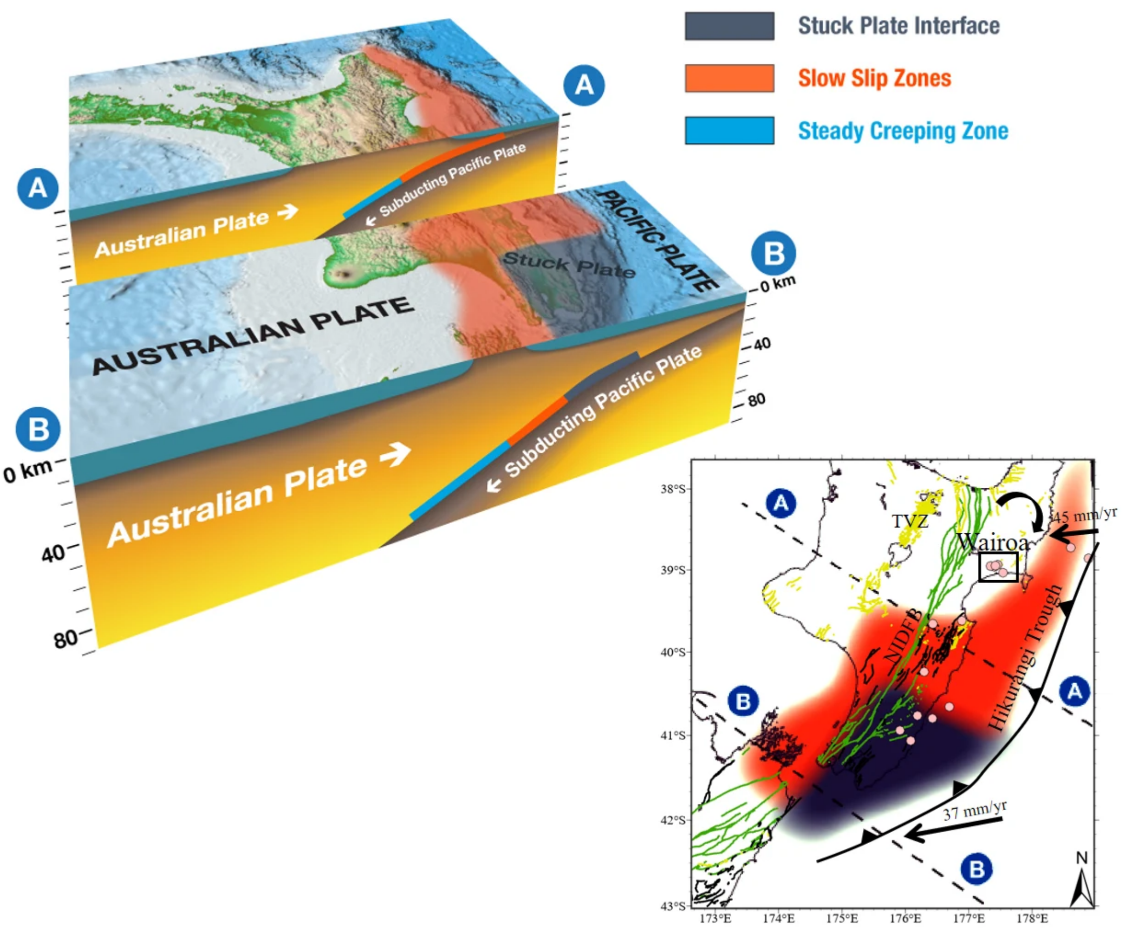
HIKURANGI SUBDUCTION MARGIN, NEW ZEALAND

Quantifying the contemporary in situ stresses is important for understanding hazards and risks associated with crustal deformation, earthquake processes, and mechanics of upper plate faults along the Hikurangi Subduction Margin (HSM).

Deformation across the HSM varies from

- shortening associated with subduction at the Hikurangi Trough
- clockwise rotation of the East Coast,
- strike-slip faulting along the North Island Dextral Fault Belt (NIDFB),
- back-arc extension in the Taupo Volcanic Zone (TVZ).

https://www.geonet.org.nz/about/earthquake/sse



Central and Northern HSM:

mostly creeping with shallow (< 2-15 km), short (weeks) slow slip earthquakes (SSEs)

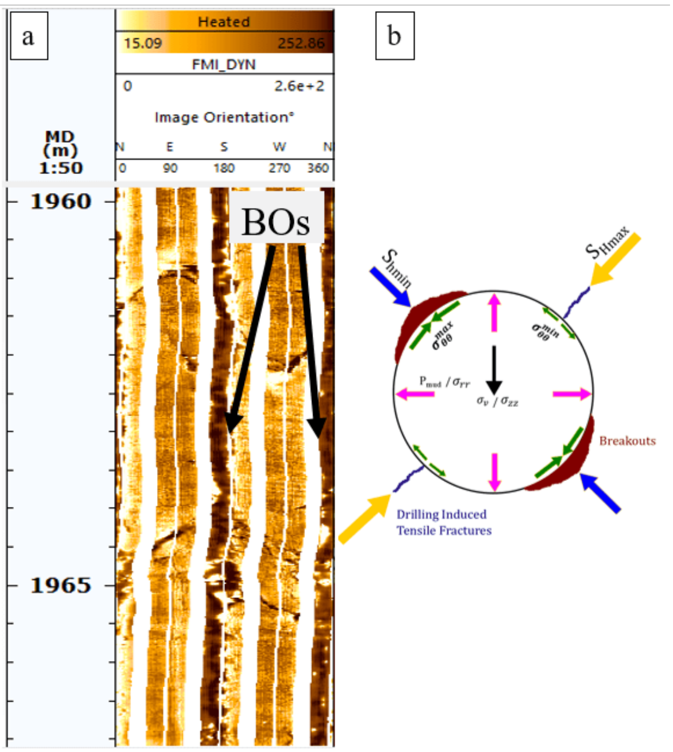
Sothern HSM:

deeply locked with deep (>30 km), long-term (~1 year) SSEs (Wallace, 2020)

METHODS

Borehole breakouts (BOs) are well-known indicators to determine in situ S_{hmin} and S_{Hmax} orientations and to constrain S_{Hmax} magnitudes.

BOs develop perpendicular to the contemporary S_{Hmax} orientation and the S_{Hmax} magnitude can be estimated where BO widths (W_{bo}) measurements are available and rock strength (UCS) is known or can be estimated (Zoback, 2007):



a) Resistivity image log showing examples of borehole breakouts centred at orientations of ~180/360°. b) Schematic representation BOs developed on the borehole wall relative to principal stress orientations (Behboudi et al., 2020).

$$S_{Hmax} = ((UCS + P_p + APRS + \sigma^{\Delta T}) - S_{hmin}(1 + 2cos2\theta_b))/(1 - 2cos2\theta_b)$$

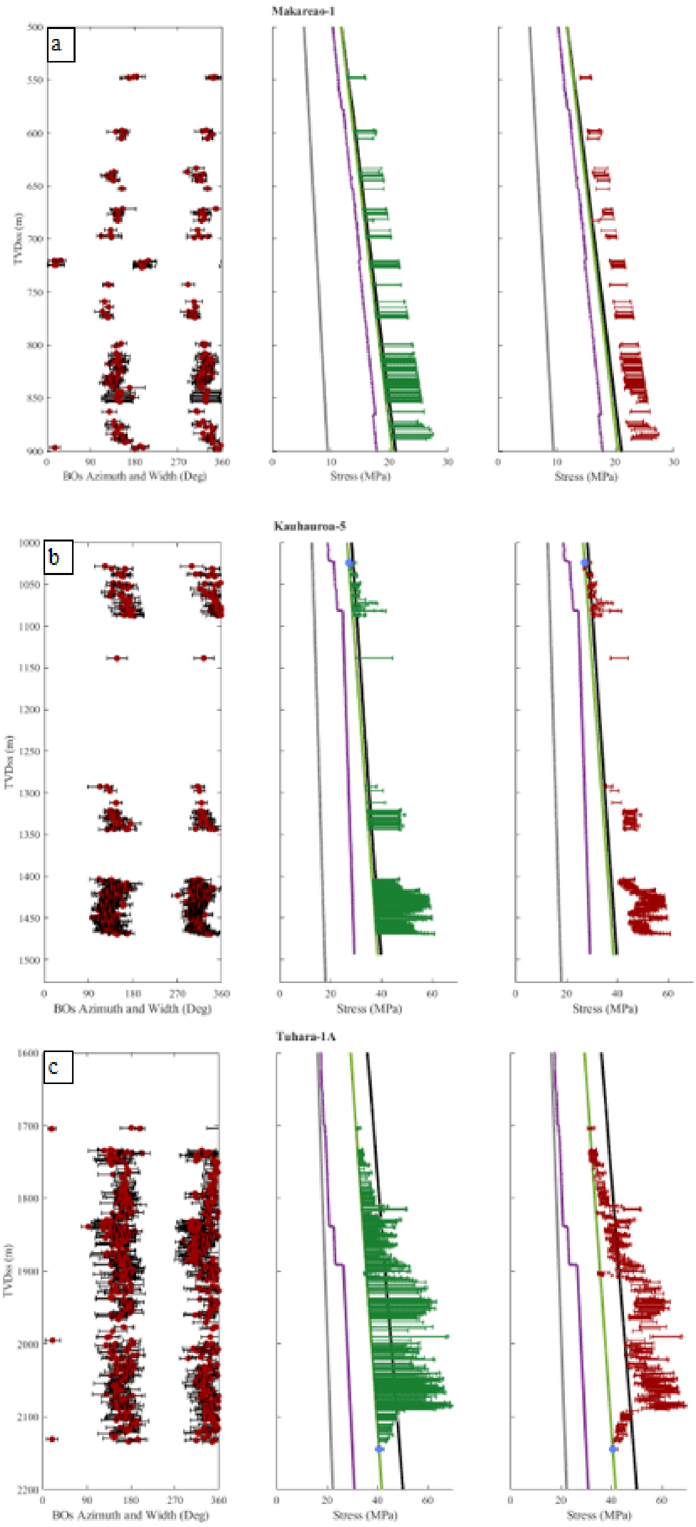
$$2\theta_b = \pi - W_{bo}$$

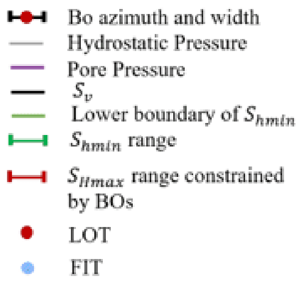
UCS is determined indirectly from empirical equations that relate rock strength with P-wave slowness.

P_p is calculated from mud weight and, in some boreholes, from Repeat Formation Tests (RFT).

S_{hmin} is determined by extrapolating points from leak-off Tests (LOT) and Formation Integrity Tests (FIT).

RESULTS





The constrained in situ stress profile with depth in boreholes

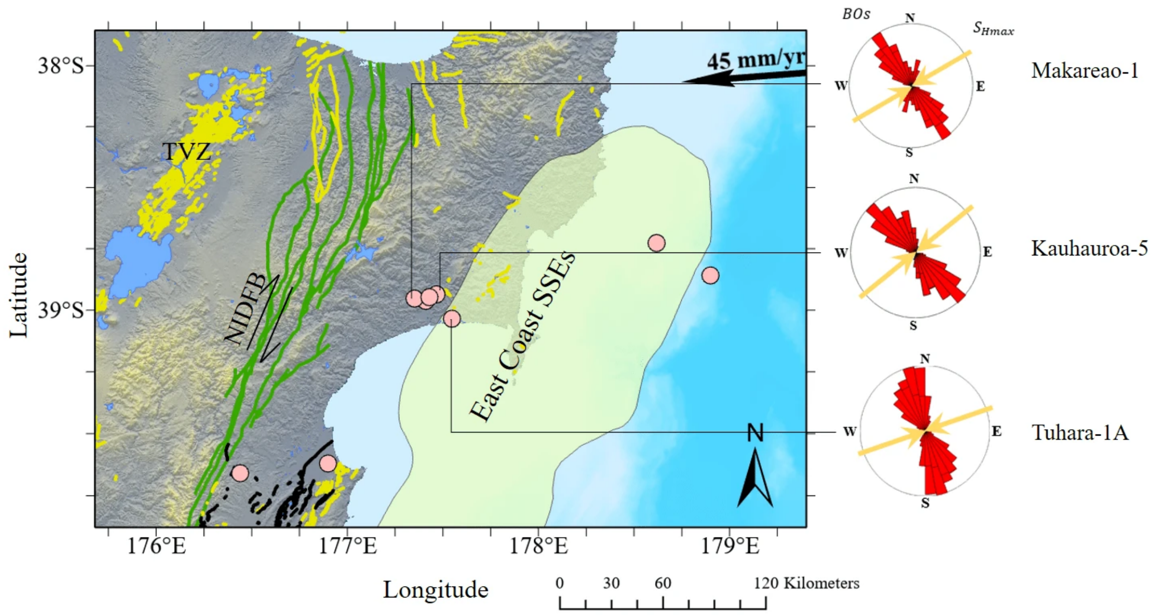
a) Makareao-1. The relative stress magnitudes suggest thrust or strike-slip tectonics ($S_{Hmax}>S_v \approx S_{hmin}$).

a) Kauhauroa-5. the stress results show thrust or strike-slip tectonics ($S_{Hmax} \geq S_{hmin} \geq S_v$).

a) Tuhara-1A. The constrain of S_{Hmax} magnitude from BOs suggests that stress regime is in favor of normal and strike-slip or possible thrust faulting regime.

PRELIMINARY FINDINGS

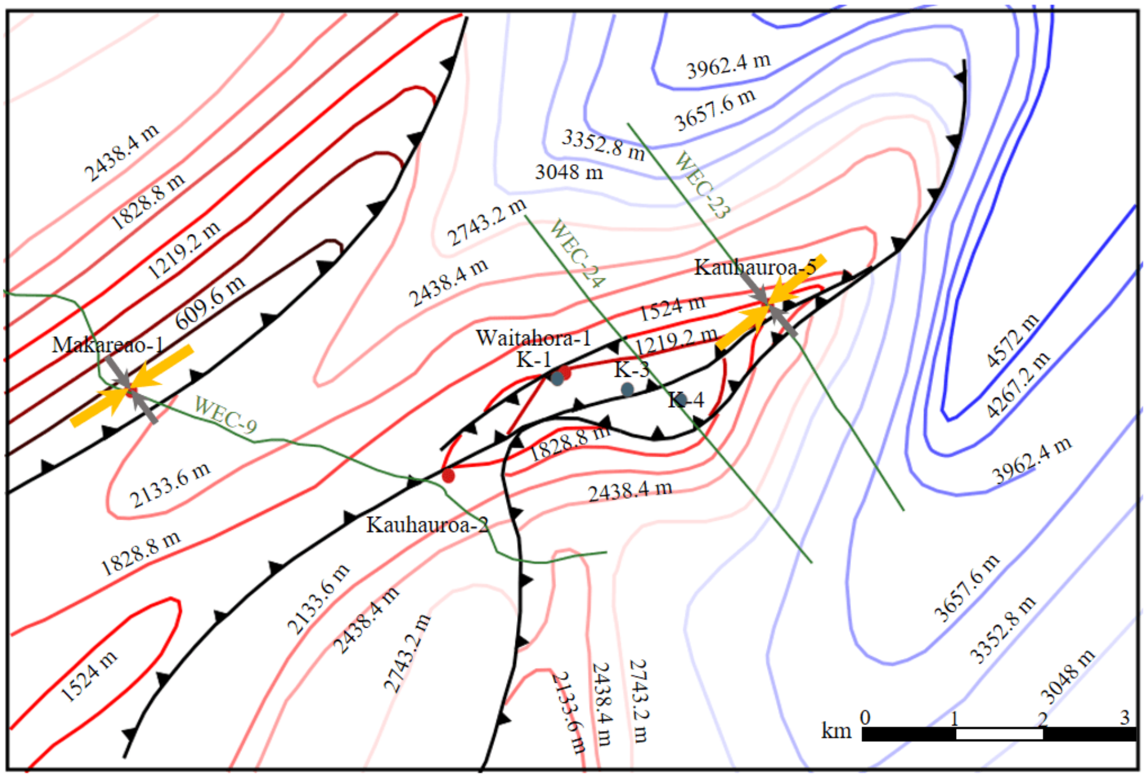
The present-day NE-SW S_{Hmax} orientation (Behboudi et al., 2020) in the central HSM is consistent with the long-term oblique relative plate motion.



PRELIMINARY FINDINGS

- The dominant stress state of the strike-slip /thrust faulting regime is consistent with large-scale NE–SW/ENE-WSW striking thrust faults observed from 2D seismic reflection profiles.

- S_{Hmax} orientations inferred from BOs (yellow arrows) are not consistent with the dominant inferred S_{Hmax} from observed geological structures (grey arrows) in the same depths.



Tectonic setting in Wairoa region at the central HSM.

The S_{Hmax} orientation may have changed over time due to:

1) long-term tectonic deformation resulting from clockwise rotation of the Hikurangi forearc,

2) stress release following great earthquakes or frequent earthquakes.

ABSTRACT

Quantifying the orientation and magnitude of tectonic stresses is essential to better understand active crustal deformation and faulting in the Hikurangi Subduction Margin (HSM), North Island, New Zealand. In this study, We estimate the horizontal stress magnitudes (S_{hmin} and S_{Hmax}) utilizing leak-off test (LOTs) data, borehole breakout widths measured from borehole image logs, and rock unconfined compressive strengths (UCS) derived from empirical relationships using P-wave velocity wireline logs. Stress field results are used to infer the tectonic regime experienced in the region where three boreholes, Makareao-1, Kauhauroa-5, and Tuhara-1A, are drilled. Relative stress magnitudes in Makareao-1 at 260-900 m TVDss (True vertical depth from sea level) suggest thrust or strike-slip tectonics ($S_{Hmax} \geq S_{hmin}$=Sv). Moving east to Kauhauroa-5, the stress results report a gradual transition from shallow normal/strike-slip tectonics (Sv > S_{hmin}) to thrust or strike-slip tectonics (S_{Hmax}> Sv ≥S_{hmin}) at depth. Further east again, at borehole Tuhara-1A, stress results suggest normal/strike-slip tectonics (Sv≥S_{Hmax}> S_{hmin}) from 555-2264 m TVDss. The tectonic regimes in individual boreholes are consistent with fault interpretations of seismic reflection profiles from this region. These three boreholes are located within the hangingwall of active, NE-SW striking thrust faults and from borehole breakout azimuths we find a mean S_{Hmax} orientation of 065° ± 17° (NE-SW) for the deeper parts of these boreholes. The S_{Hmax} orientation is broadly compatible with maximum contraction directions determined from campaign GPS and sub-parallel to far-field relative Pacific-Australian plate motion. This, combined with our stress magnitude observations in Makareao-1 and Kauhauroa-5 suggests these NE-SW striking faults predominantly experience strike and/or oblique slip despite appearing in seismic profiles as thrust faults. We suggest that these faults originated as thrust faults during older stages of subduction along this margin, which over time have become reactivated in a more strike-slip manner.

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