Discoveries and opportunities in illuminating Geohazards: The essential role of seafloor and subseafloor sampling and monitoring

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FUTURES Workshop
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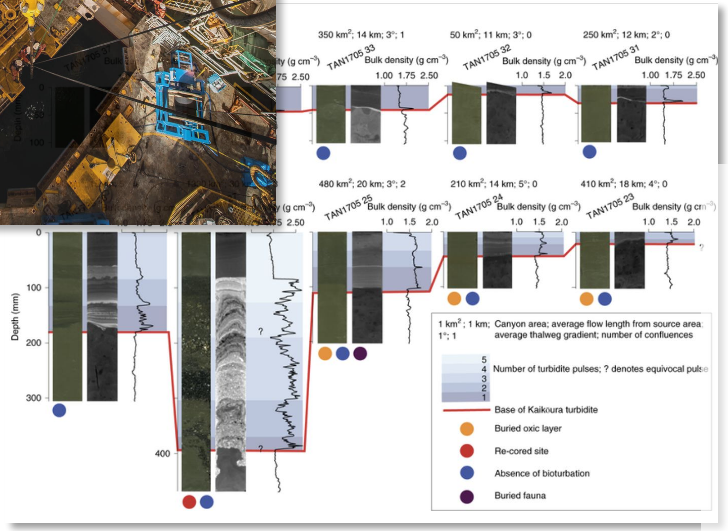
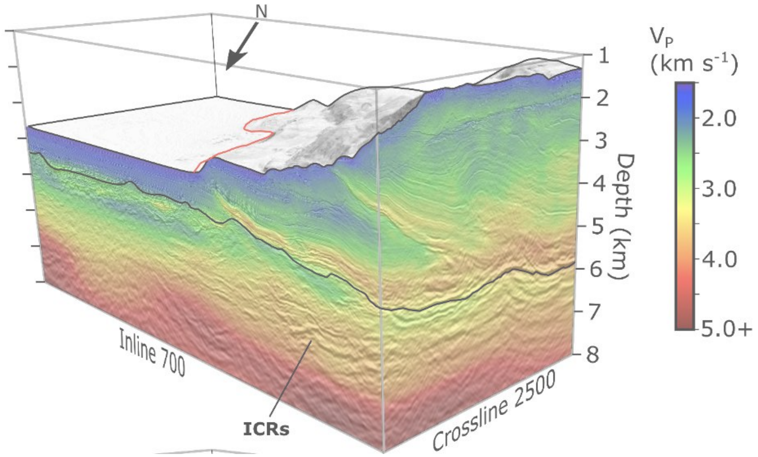
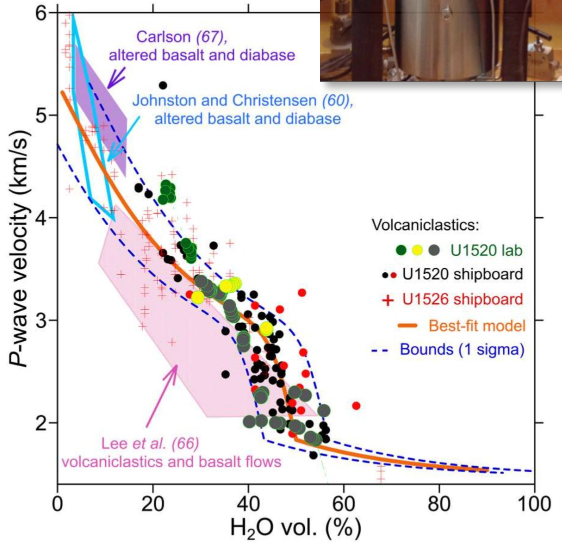




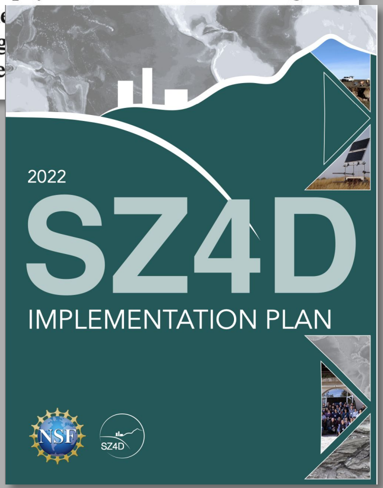


NSF
IODP
INTERNATIONAL OCEAN DISCOVERY PROGRAM

Discoveries and opportunities in illuminating Geohazards: The essential role of seafloor and subseafloor sampling and monitoring

- Feature Prominently in OCE Sea Change Decadal Survey; CORES Report; IODP Science Plan; USGS; etc…
- Diversity of GeoHazards Prioritized: Volcanic, Seismic, Tsunamis, Slope Failures (not just subduction earthquakes!)

- **What are the rates, mechanisms, impacts, and geographic variability of sea level change?**
- **How are the coastal and estuarine ocean and their ecosystems influenced by the global hydrologic cycle, land use, and upwelling from the deep ocean?**
- **How have ocean biogeochemical and physical processes contributed to today's climate and its variability, and how will this system change over the next century?**
- **What is the role of biodiversity in the resilience of marine ecosystems and how will it be affected by natural and anthropogenic changes?**
- **How different will marine food webs be at mid-century? In the next 100 years?**
- **What are the processes that control the formation and evolution of ocean basins?**
- **How can risk be better characterized and the ability to forecast geohazards like mega-earthquakes, tsunamis, undersea landslides, and volcanic eruptions be improved?**
- **What is the geophysical, chemical, and biological character of the**
does it affect g
standing of the



4. What is an earthquake?

Earthquake rupture is complex, and the deformation of the Earth occurs over a spectrum of rates and in a variety of styles, leading Earth scientists to reconsider the very nature of earthquakes and the dynamics that drive them.

5. What drives volcanism?

Volcanic eruptions have major effects on people, the atmosphere, the hydrosphere, and the Earth itself, creating an urgent need for fundamental research on how magma forms, rises, and erupts in different settings around the world and how these systems have operated throughout geologic time.

6. What are the causes and consequences of topographic change?

New technology for measuring topography over geologic to human time scales now makes it possible to address scientific questions linking the deep and surface Earth and urgent societal challenges related to geologic hazards, resources, and climate change.

10. How do biogeochemica

To quantify the role of biology throu
mation and weathering of rocks and n
of carbon, and the composition of the
requires a deeper understanding of bio

11. How do geological proc
biodiversity?

The diversity of life on the Earth is a
of the planet and yet we do not fully know how it came to be. We need to understand how and why diversity has varied over time, environment, and geography, including major events like extinctions.

12. How can Earth science research reduce the risk and toll of geohazards?

A predictive and quantitative understanding of geohazards is essential to reduce risk and impacts and to save lives and infrastructure.

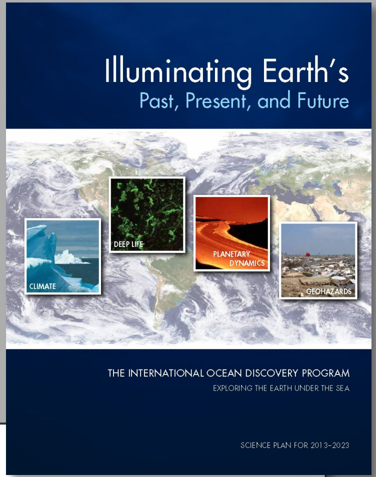
5. Earth in Motion

Processes and Hazards on Human Time Scales

CHALLENGES

12. What mechanisms control the occurrence of destructive earthquakes, landslides, and tsunami?

Many fundamental Earth system processes, including those underlying major

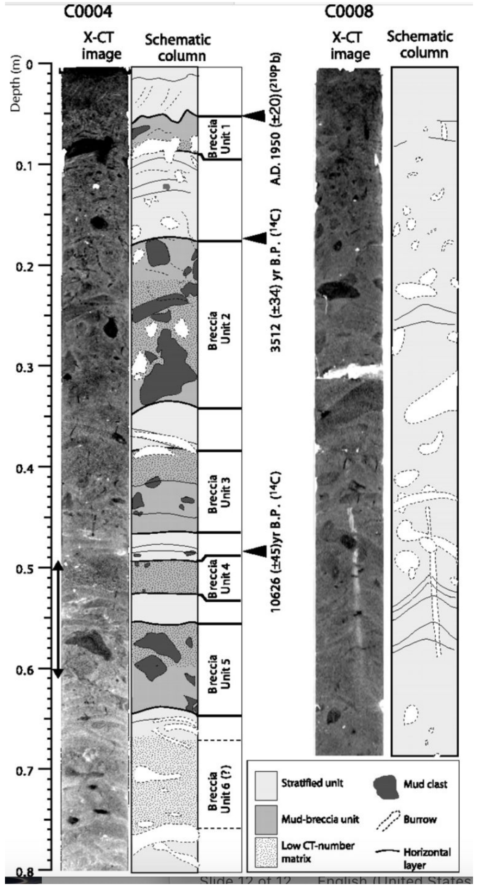


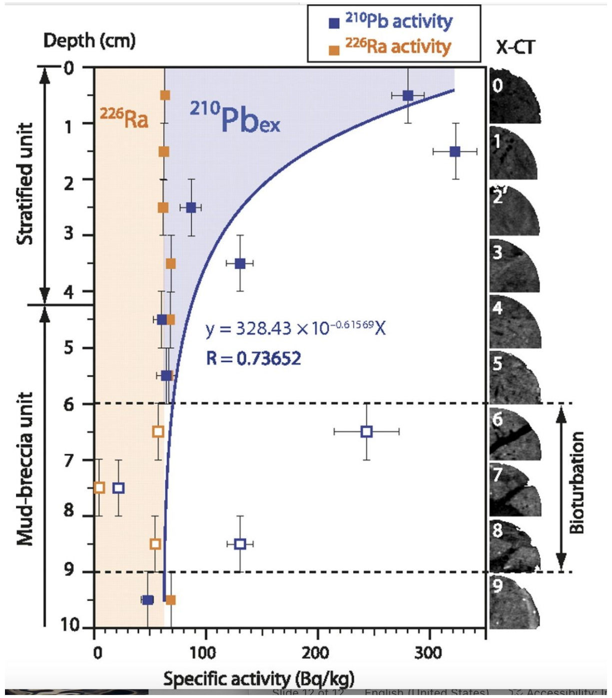
Recent Advances & New Opportunities

- *Legacy Cores*: Emerging Questions; Novel Techniques; Integration with Regional Geophysics
- *Shallow subsurface and surface sampling*: Paleoseismology, Slope failures and faulting/tectonics, Processes & Mechanisms of Geohazards
- *Monitoring*: Hydrogeologic signals applied to geohazards; Geodesy; Seafloor and Shallow Subsurface observatories

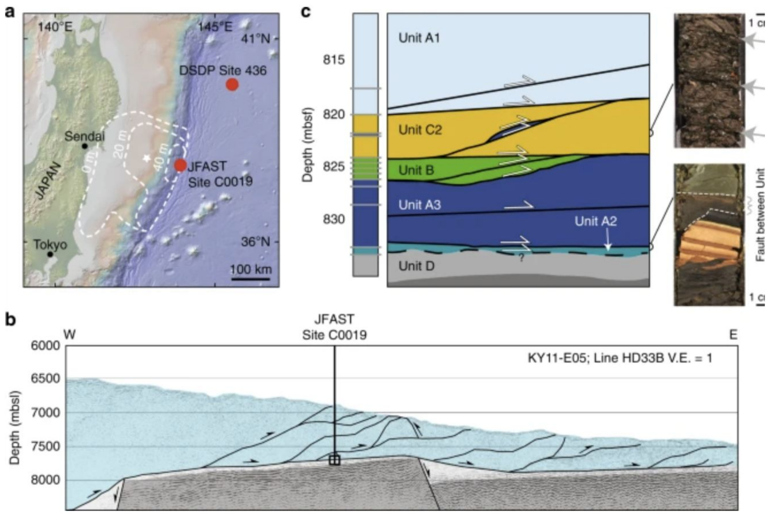
1. Legacy Cores: Novel Approaches to Extract New Insights

- *Interrogation of cores using emerging analytical tools: constraints on earthquake rupture processes, sizes, and timing!*
- *Merged with insights from very shallow core, illumination of the geological fingerprint and involvement of specific faults in historical (1940s) rupture.*

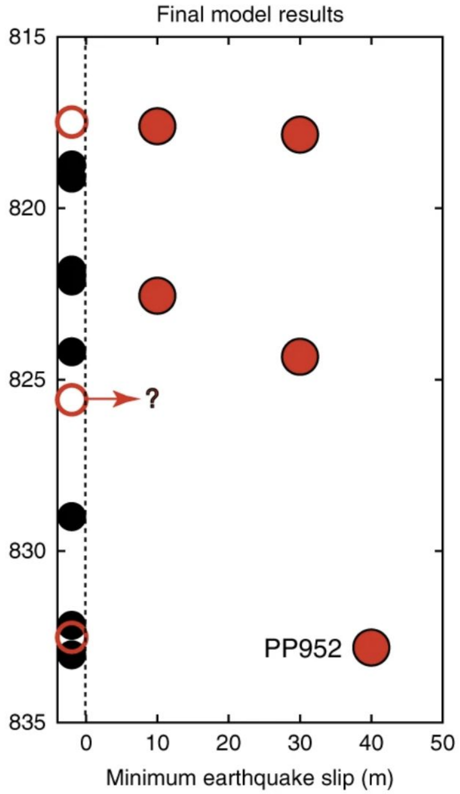




Sakaguchi et al., 2011



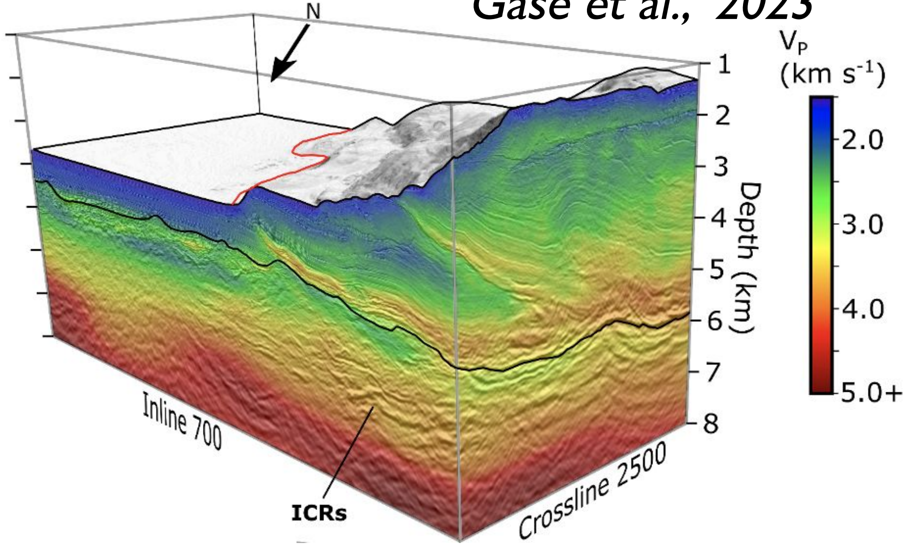
Rabinowitz et al., 2020

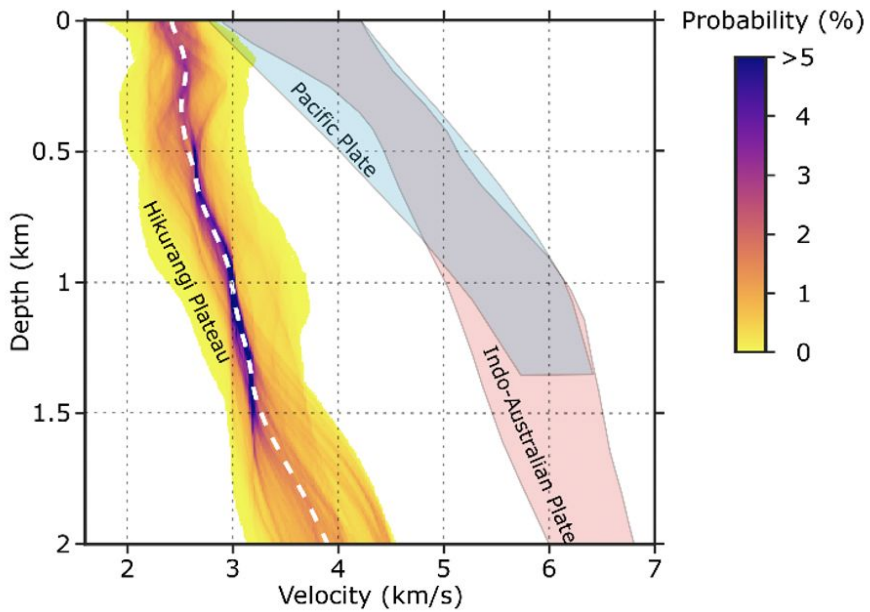


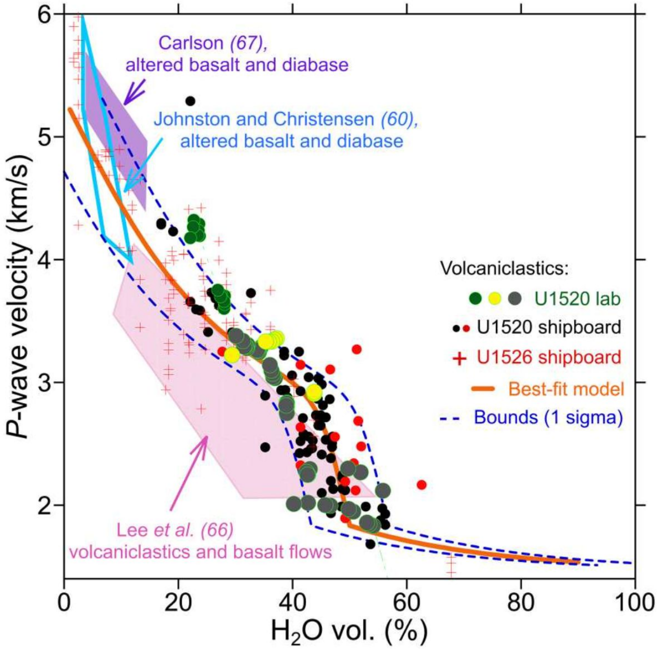
1. Legacy Cores: Fluid influx to the shallow megathrust

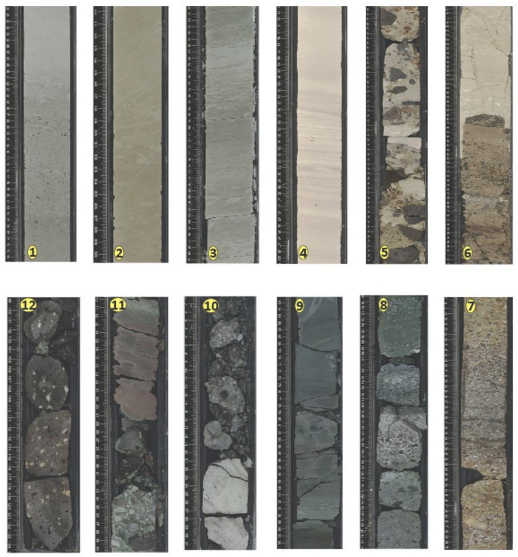
- *Subduction of >2 km-thick clay-rich, heavily altered volcanic breccia/sand/mud.*
- *Manifests as regionally extensive low-velocity "blanket" on the Hikurangi Plateau.*
- *Vp from samples/lab provides constraint on <u>total</u> H_2O content (interstitial plus bound).*

Gase et al., 2023



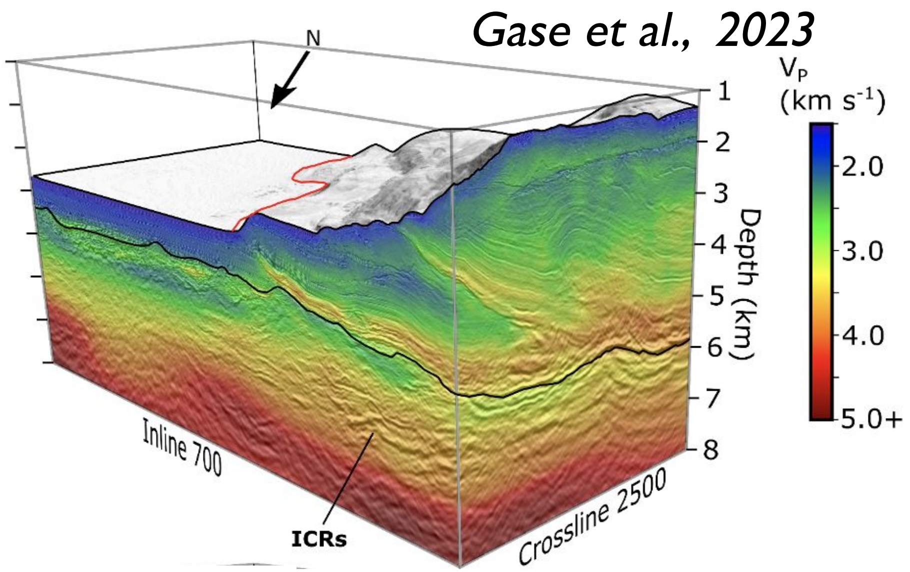


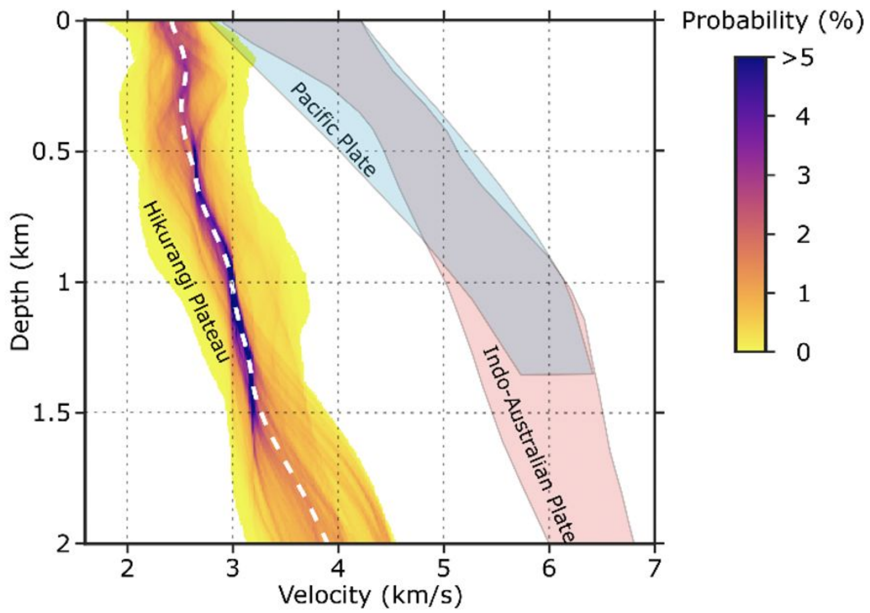


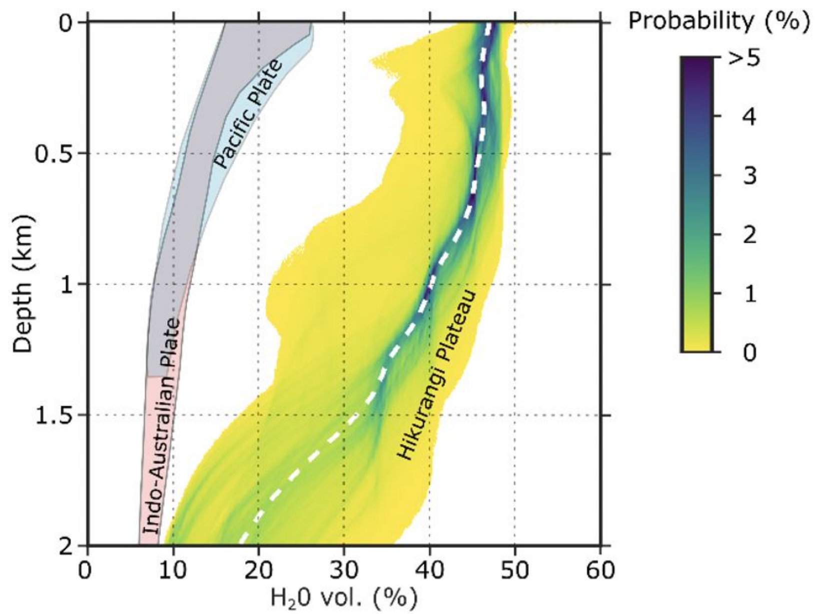


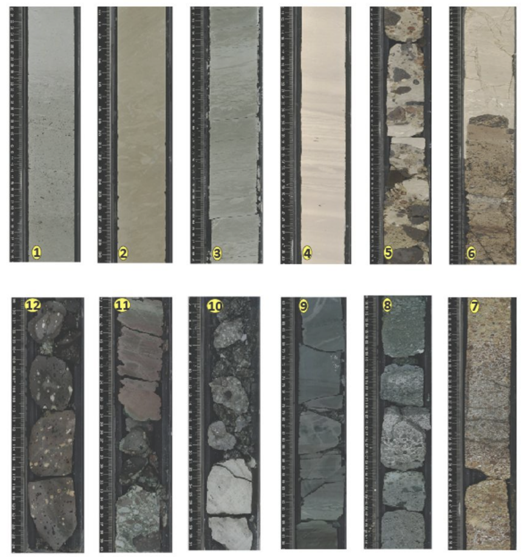
1. Legacy Cores: Fluid influx to the shallow megathrust

- *Delivery of fluid to the fault zone as one key control on slip behavior and hazard.*
- *Provides means to assess fluid budget, pressure/stress in situ <u>state</u>.*

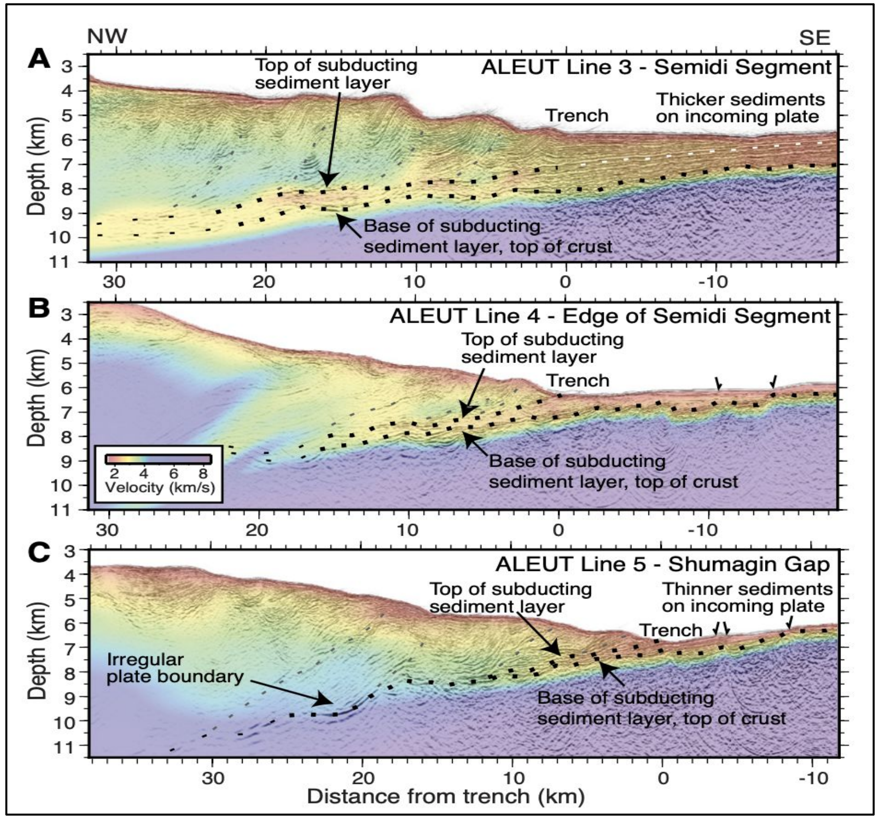


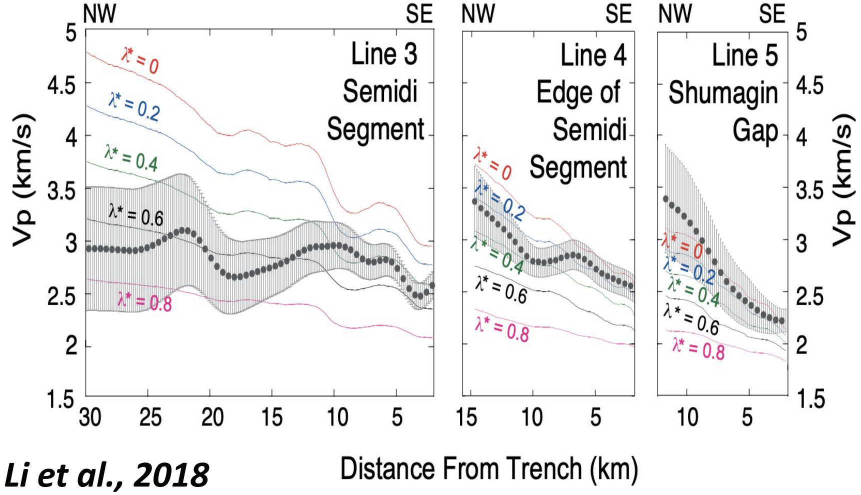




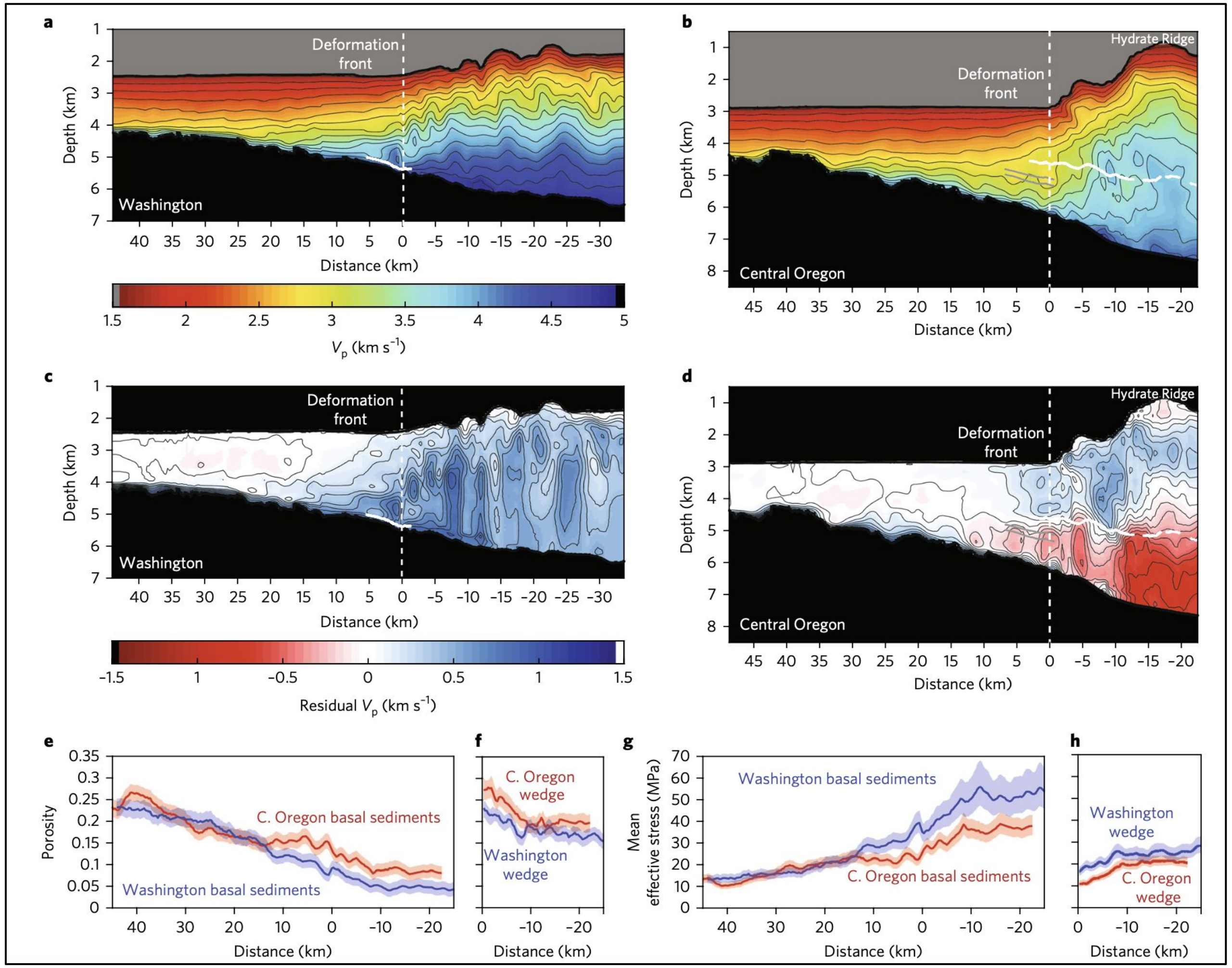


Application to Aleutians & Cascadia: Limited - but important! - insights even without new drilling





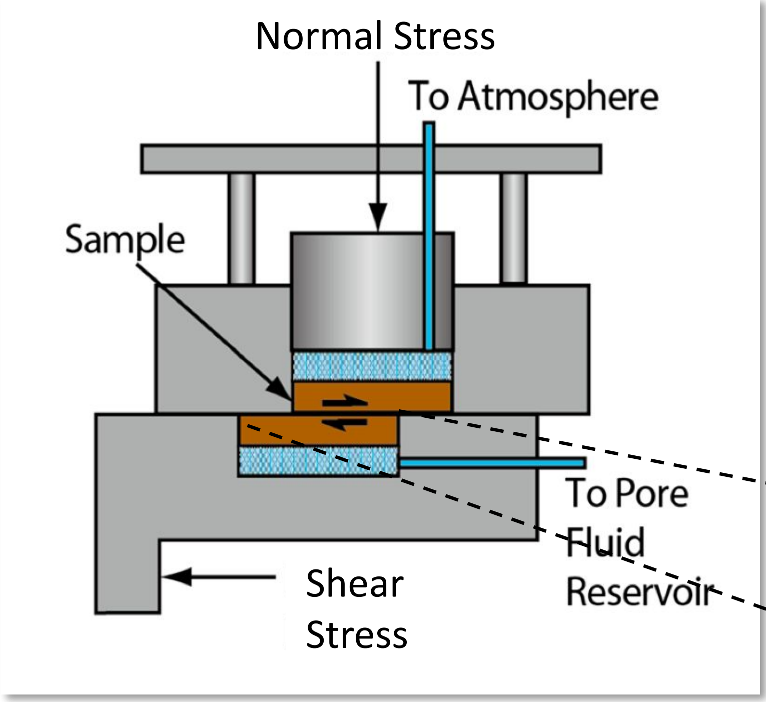
Li et al., 2018

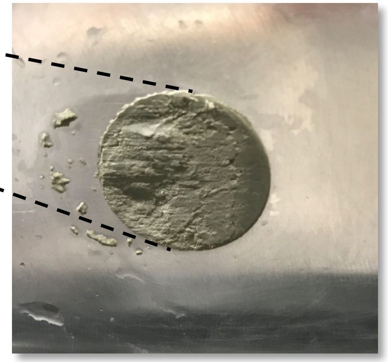


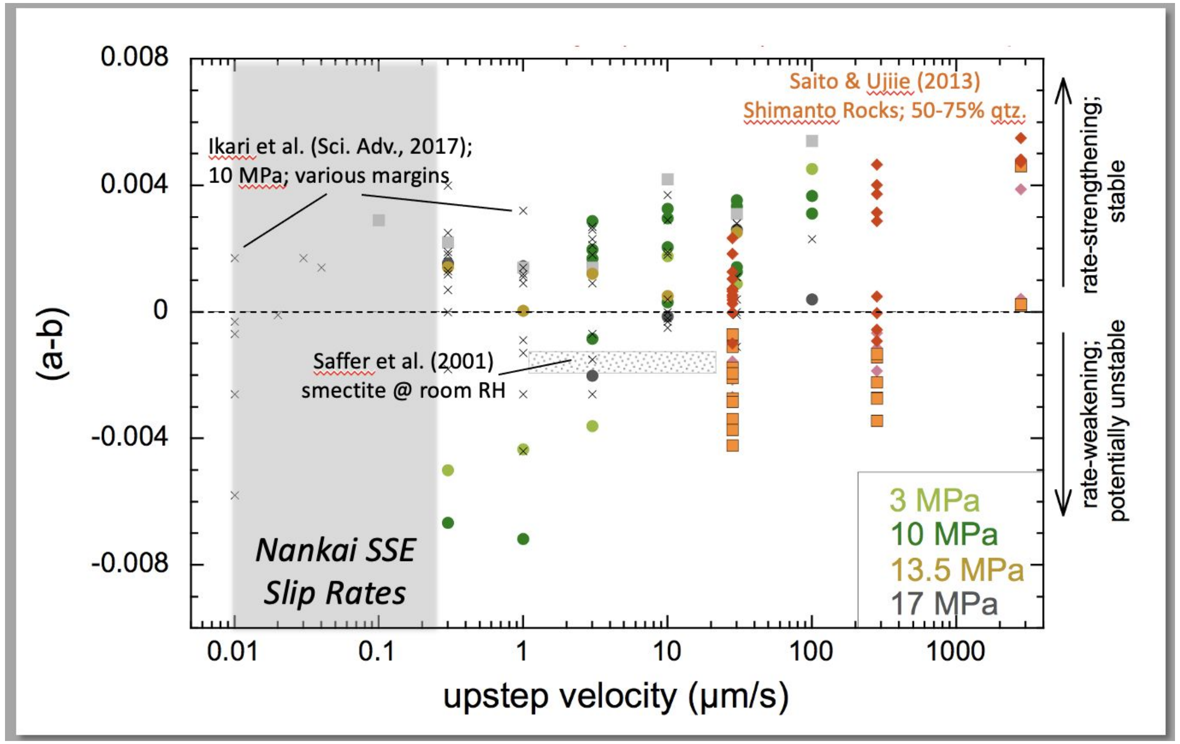
Han et al., 2017

1. Legacy Cores: Lab Measurements Constrain Mechanisms & Properties

- *Frictional, consolidation, hydrological, and elastic properties of core samples – legacy core and natural exposures are widely sought-after and used (Faulting, Flank Collapse, Slope Failure settings).*
- *Example of Rate-State-Friction (below) – providing a mechanism to explain geodetic and seismological observations at Nankai.*



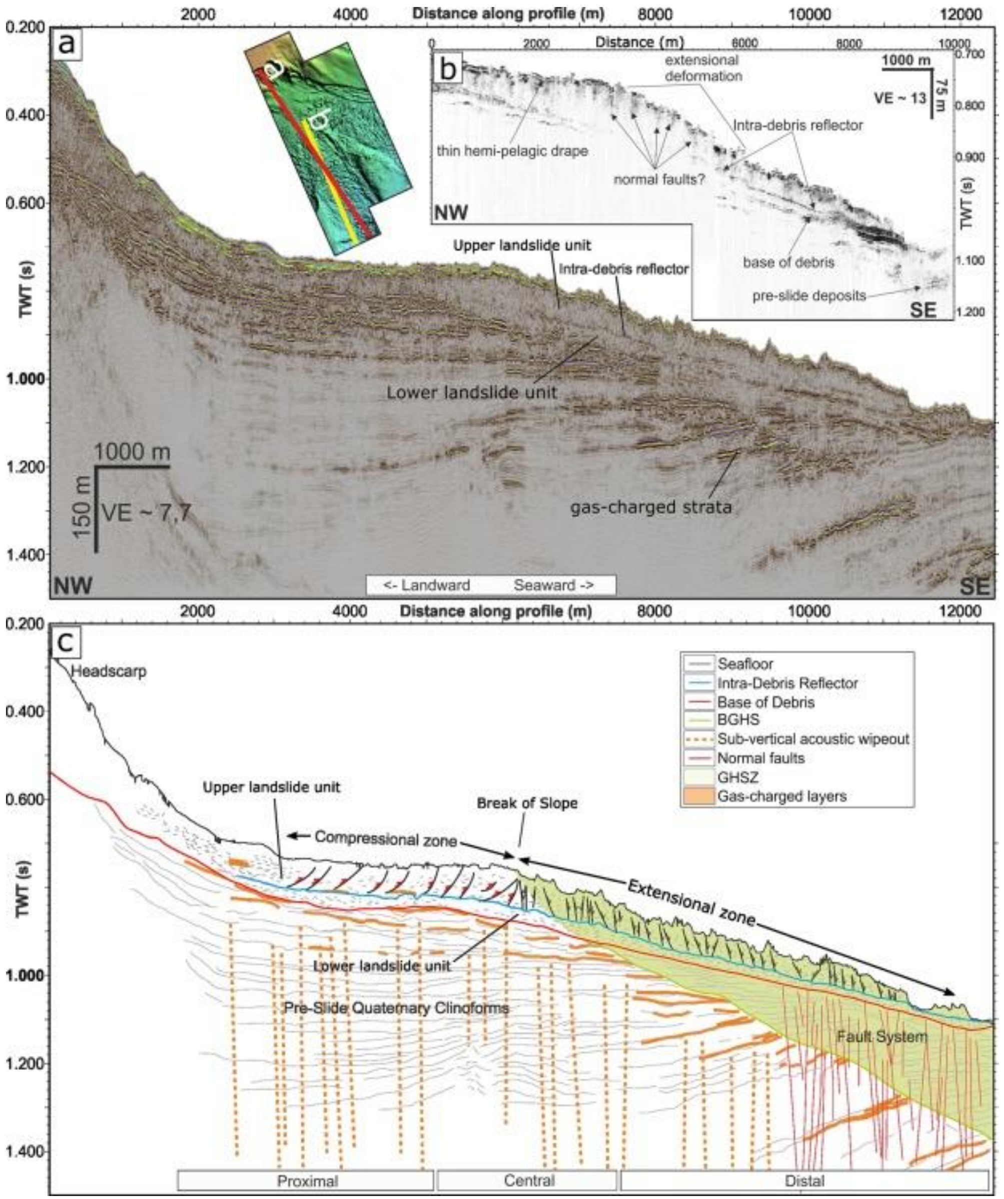




Saffer et al., 2017

2. Shallow subsurface and surface sampling: Slope failure dynamics

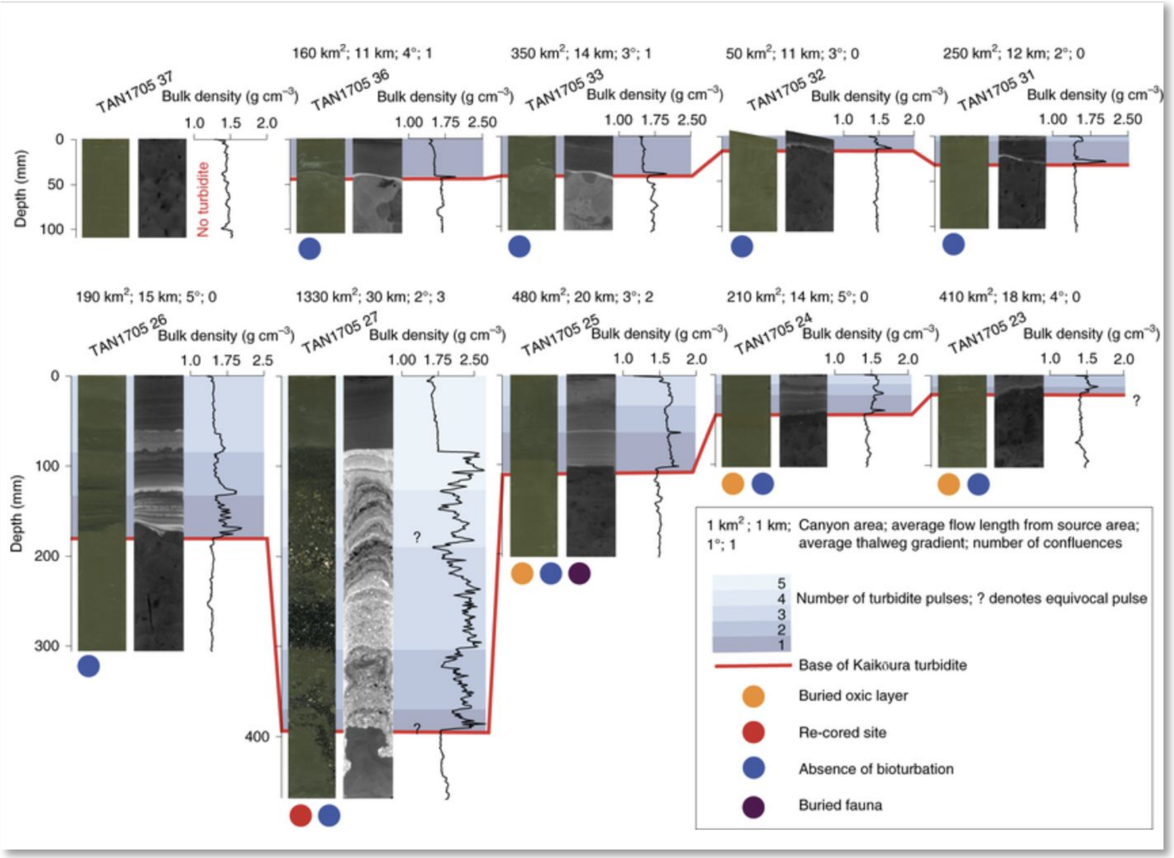
- *Integration of high-resolution seismic/imaging, seafloor seep observations, and shallow subsurface sampling.*
- *Analysis of core samples in the context of rheology (slide plane behavior), potential overpressure and stress state, and methane hydrate dynamics.*
- *Enabled development of mechanistic model for slope failure motion – thresholds for slip and factors controlling nature of failure.*

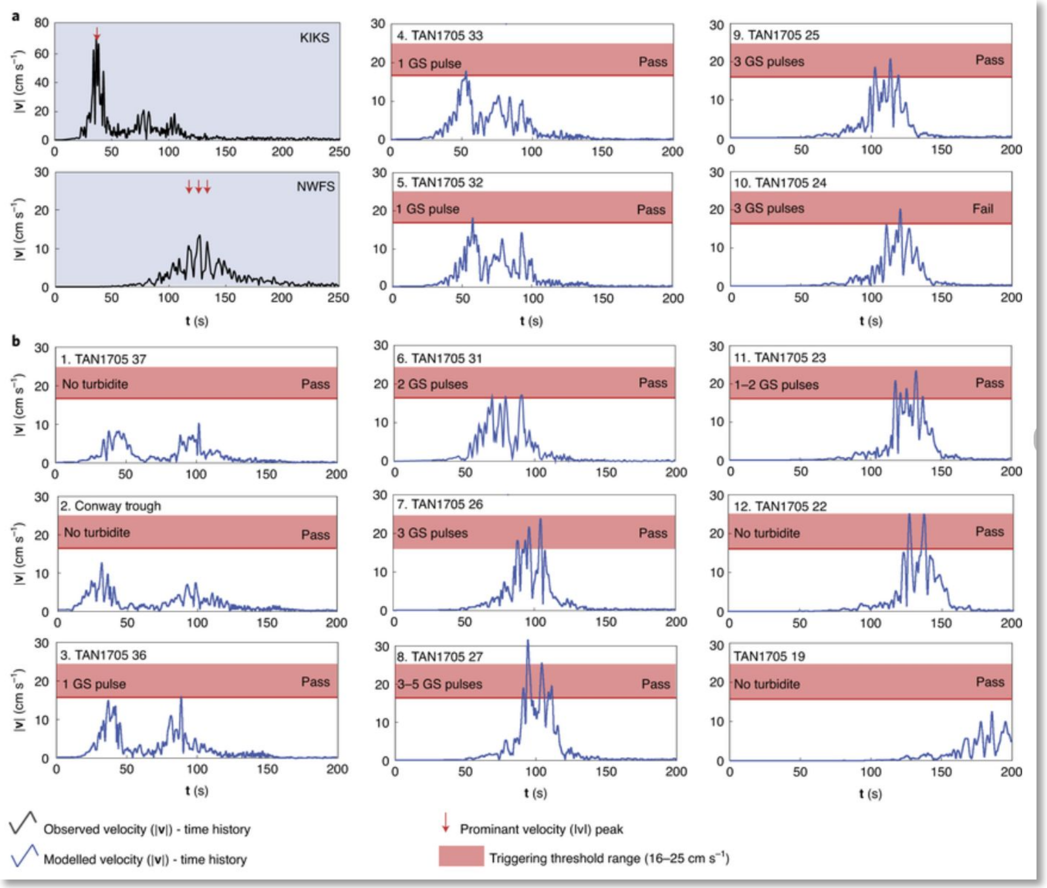


Gross et al., 2018; See also Carey et al., 2019

2. Shallow subsurface and surface sampling: Paleoseismology

- *Calibration of the turbidite paleoseismic record – Kaikoura example.*
- *Detailed correlation of deposit architecture with EQ ground motions: potential for extraction of new information for past events in unprecedented detail.*

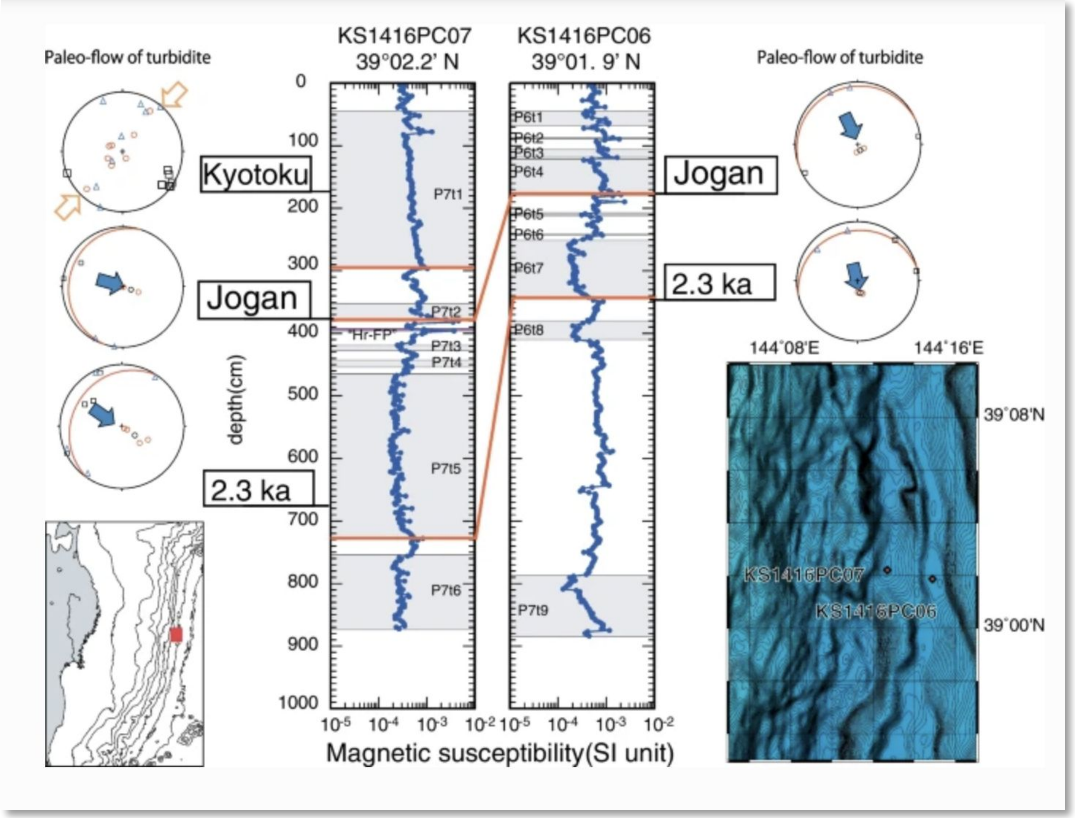




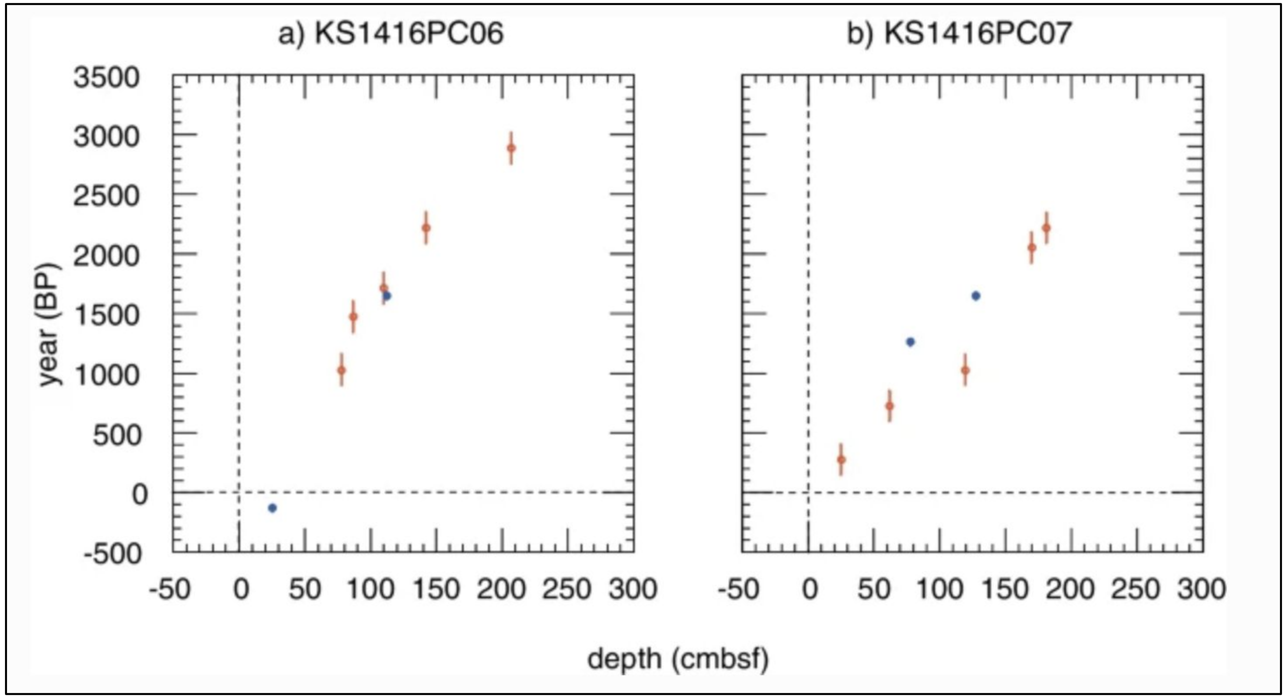
Howarth et al., 2021

2. Shallow subsurface and surface sampling: Paleoseismology

- *Ultradeep piston coring along the trench axis.*
- *Calibration with – and extension of – historical record of major events.*

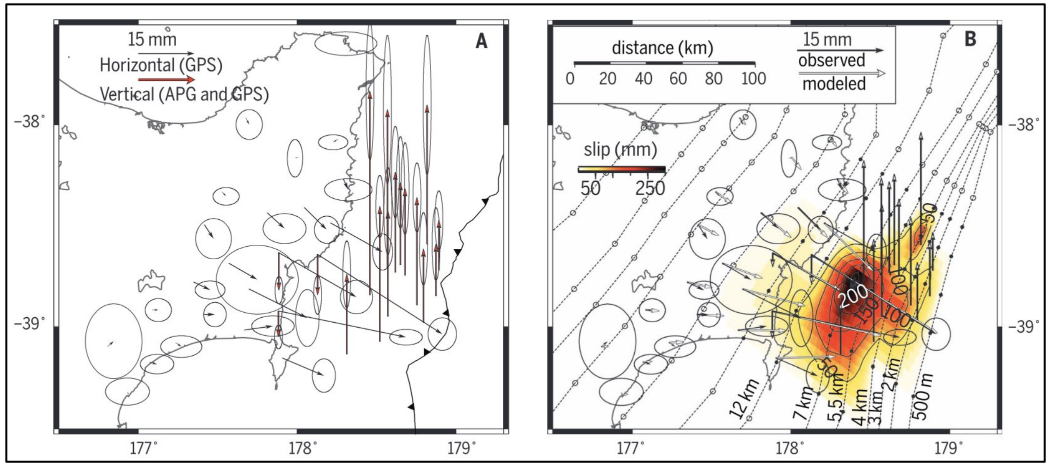


Kanamatsiu et al., 2023

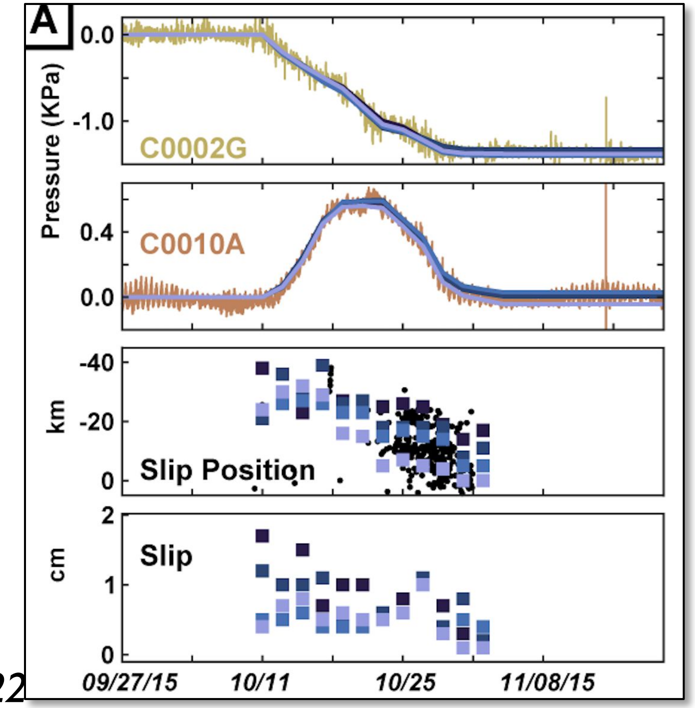


3. Monitoring of Geohazards: Timeseries of Active Processes… "*Geodesy*" at the Seafloor and Below

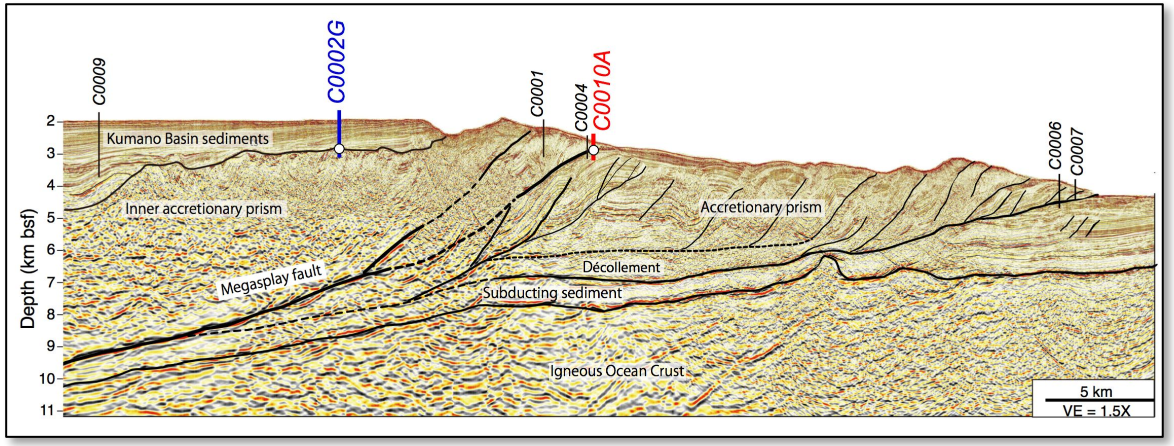
- *Seafloor geodesy (GNSS-A, APG) documents fault slip processes to the trench.*
- *Borehole observatories offer ~order of magnitude increased resolution, document small near-trench SSE.*
- *Insight into EQ & tsunami hazard.*



Wallace et al., 2016

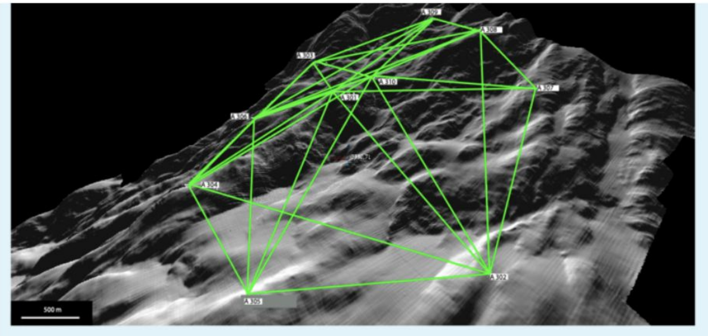


Edgington, Saffer, & Williams, 2022

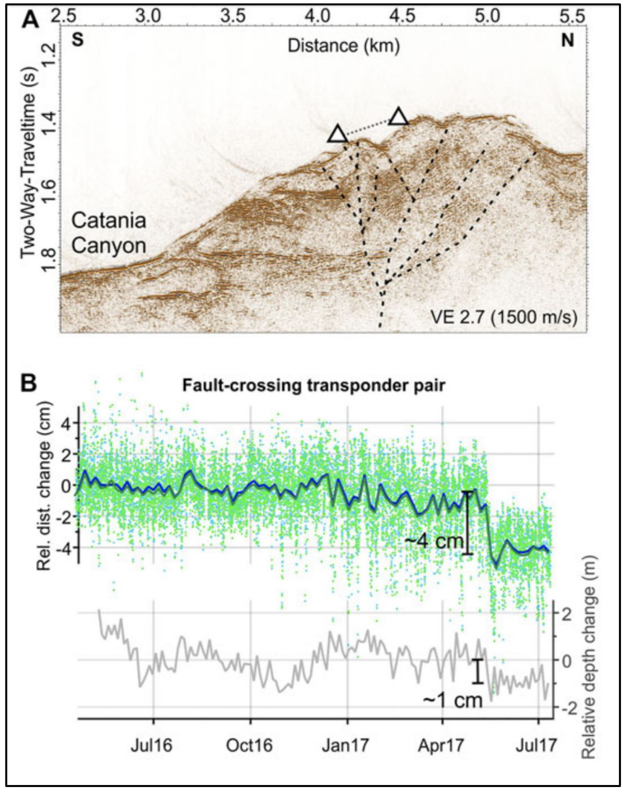


3. Monitoring of Geohazards: Timeseries of Active Processes… "*Geodesy*" at the Seafloor and Below

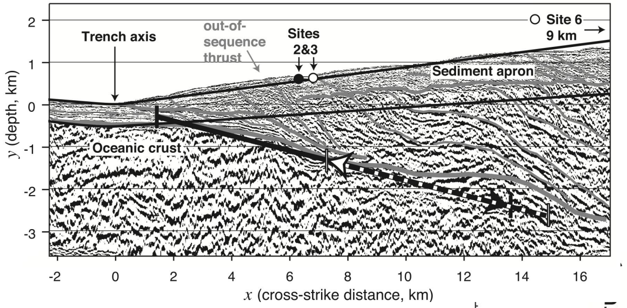
- *Engineering & technology developments for targeted seafloor deformation studies (e.g., direct ranging – Etna flank collapse example).*
- *Seafloor flowmeters as indirect geodetic tools – coupled with modelling yield insight into deformation processes*



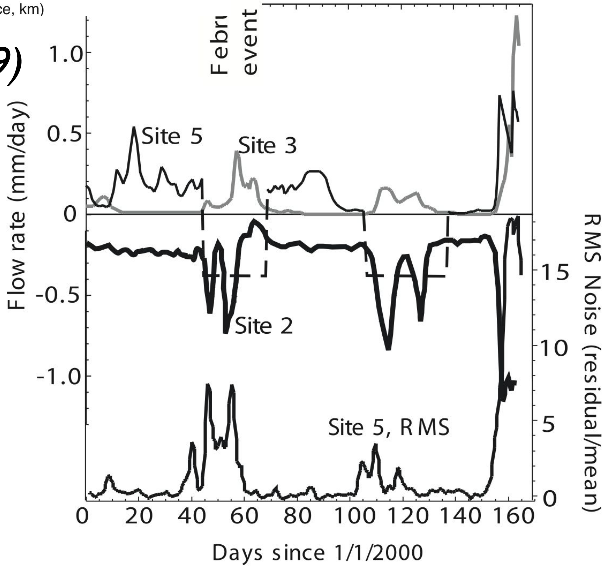
GEOSAT (GeoMAR)



Urlaub et al. (2021)
Etna flank collapse



LaBonte et al.(2009)
Costa Rica Slip



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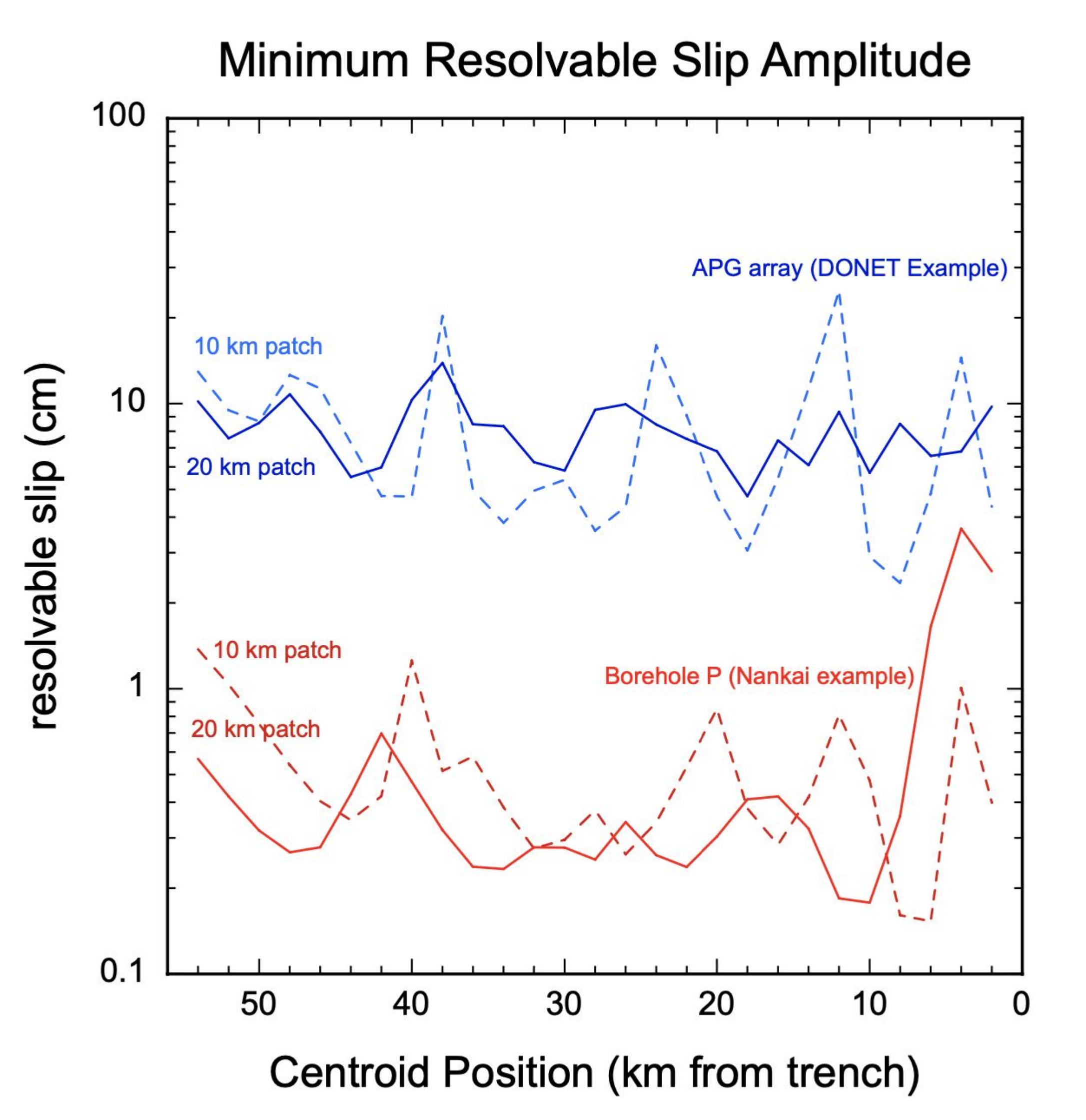
- *Legacy Holes:* Retrofits; Campaign-style Measurements; New Instrumentation

Detection limits and Sensitivity of Borehole Pressure as a Geodetic Instrument



Borehole sensors – lower noise, volumetric strain sensitivity detection of *mm-scale slip offshore (!!!!)*

Highly complementary (even for small n) to seafloor geodetic arrays.