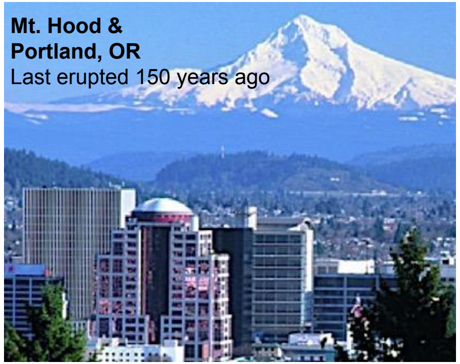
Working Groups defining science goals and designing a program

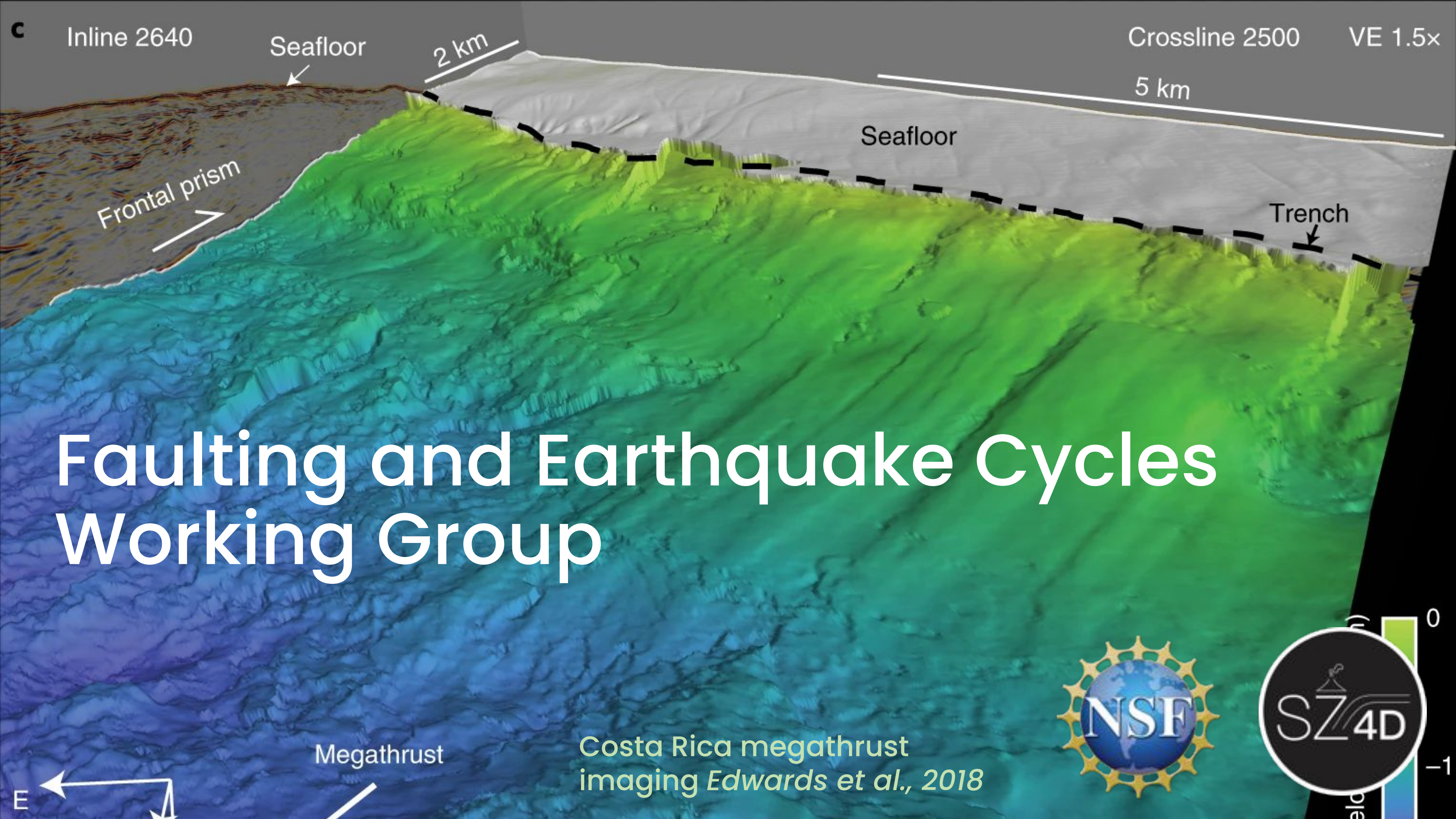


Faulting & Earthquake Cycles Working Group (FEC)

Magmatic Drivers of Eruption Working Group (MDE)

Landscapes & Seascapes Working Group (L&S)

Faulting and Earthquake Cycles Working Group



Costa Rica megathrust imaging *Edwards et al., 2018*

Faulting & Earthquakes Working Group (□2022)

Co-chairs
Emily Brodsky (UC Santa Cruz)
Donna Shillington (Northern Arizona Univ)
Melodie French (Rice University)

Working Group Members:
Noel Bartlow (Univ. Kansas)
Susan Beck (Univ. Arizona)
Magali Billen (UC Davis)
Roland Bürgmann (UC Berkeley)
William Frank (MIT)
Alice Gabriel (Munich/UCSD)
Thorne Lay (UC Santa Cruz)
Jeff McGuire (USGS)
Samer Naif (GaTech)
Andrew Newman (GaTech)
Christine Regalla (Northern Arizona Univ)
Summer Ohlendorf (NOAA)
Demian Saffer (UTIG)
Harold Tobin (Univ Washington)
Daniel Viete (John Hopkins)
Doug Wiens (Washington Univ)
Rob Witter (USGS)

Faulting & Earthquakes Working Group (2022–)

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Demian Saffer (UT Austin)

Working Group Members:
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Scott Bennett (USGS)
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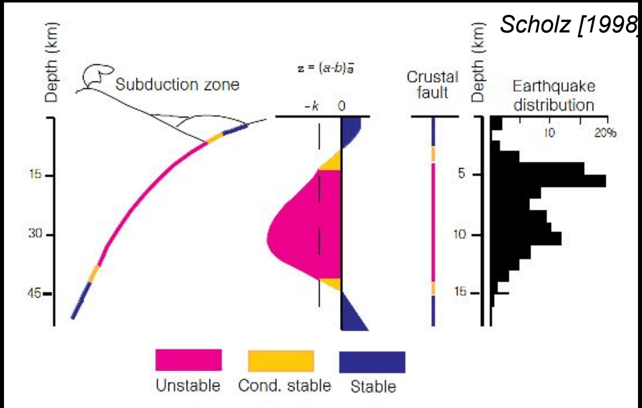
Wenyuan Fan (Scripps/UCSD)
Shuoshuo Han (UT Austin/UTIG)
Yihe Huang (Univ. Michigan)
Hiroko Kitajima (Texas A&M)
Jeff McGuire (USGS)
Samer Naif (GaTech)
Emily Roland (Western Wa. Univ.)
Sergio Ruiz (Univ. Chile)
Heather Savage (UC Santa Cruz)
Ignacio Sepùlveda (SDSU)
Tianhaozhe Sun (Geol. Survey Canada)
Laura Wallace (GNS/UTIG)
Shawn Wei (Mich. State Univ.)

Simplified Representations

A seismogenic zone that exhibits rate-weakening, unstable (stick-slip) behavior and is interseismically locked.

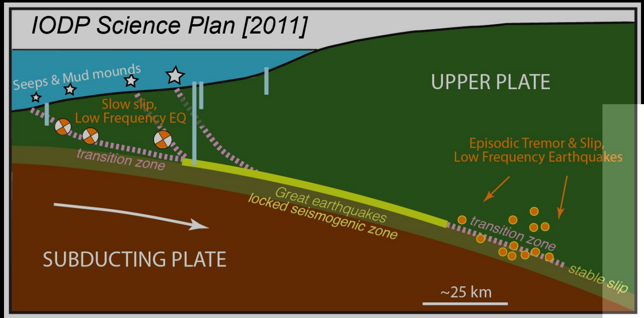
Bounded by upper and lower transitions to zones of stable sliding.

Governed by “simple” RSF friction and effective stress (pore pressure).

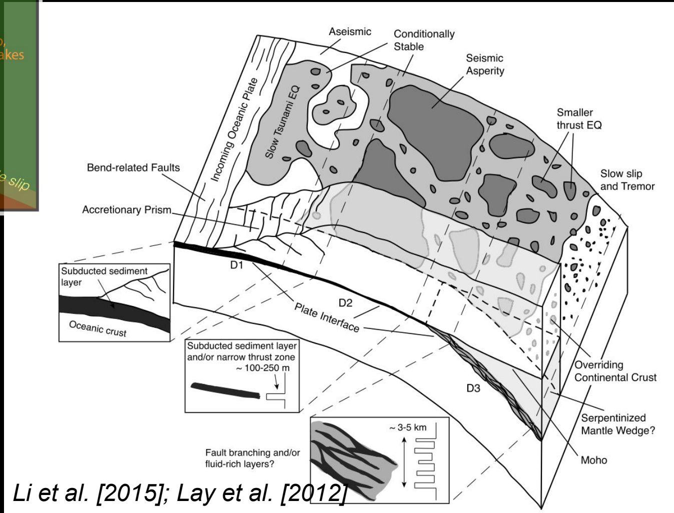


Scholz [1998]

These are very nice…but…

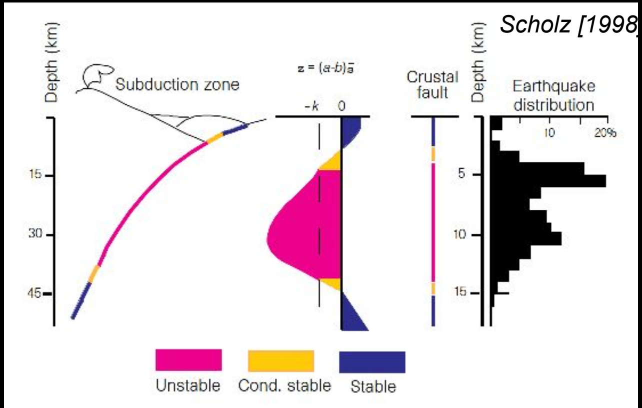


IODP Science Plan [2011]



Li et al. [2015]; Lay et al. [2012]

Simplified Representations



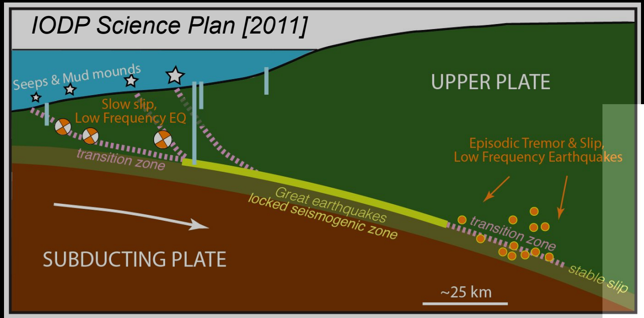
A seismogenic zone that exhibits rate-weakening, unstable (stick-slip) behavior and is interseismically locked.

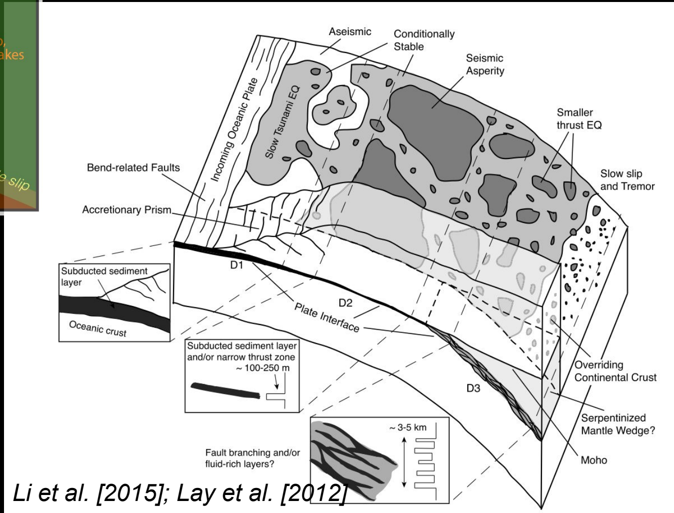
Bounded by upper and lower transitions to zones of stable sliding.

Governed by "simple" RSF friction and effective stress (pore pressure).

Observations indicate much richer and more complex behaviors!

- Constitutive behavior of fault and environs.
- Constraints & interpretation of pore pressure, stress.
- Heterogeneity & roughness, upscaling of these.
- Role of significant variability in elastic properties +/- anelastic deformation in strain energy accumulation and slip stability.





When and where do large, damaging earthquakes happen?

Question 1:
How do subduction zone fault systems interact in space and time? How do these fault systems and associated deformation regulate subduction zone evolution and structure?

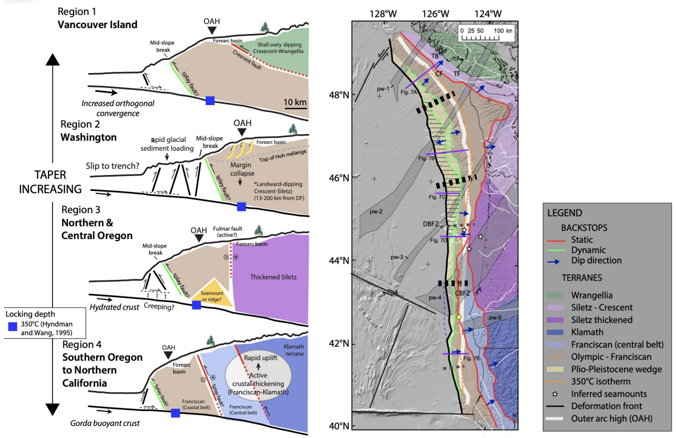
Question 2:
What controls the speed and mode of slip in space and time?

Question 3:
Does distinctive precursory slip or distinctive foreshocks exist before earthquakes? What causes either foreshocks or precursory slip?

Question 4:
Under what physical conditions and by what processes will rapid slip during an earthquake displace the seafloor and increase the likelihood of generating a significant tsunami?

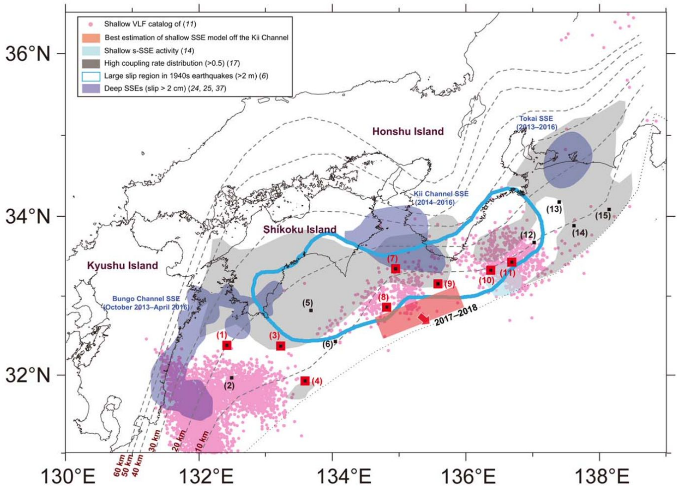
SZ4D Faulting and Earthquake Cycles Science Questions

1. How do subduction zone fault systems interact in space and time? How do these fault systems and associated deformation regulate subduction zone evolution and structure?



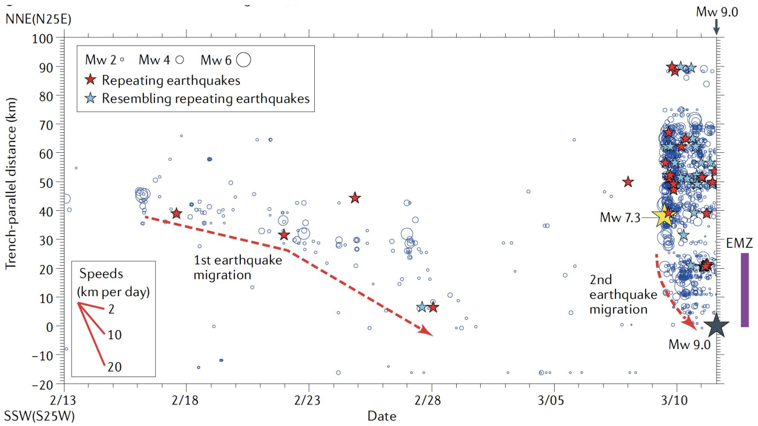
Watt & Brothers, 2021

2. What controls the speed and mode of slip in space and time?



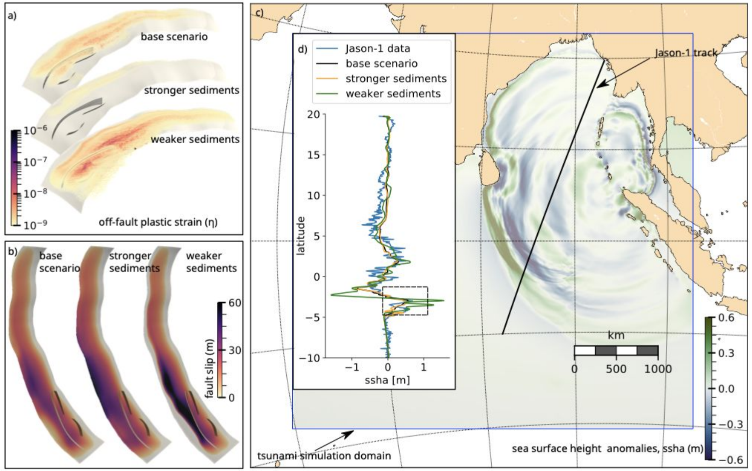
Yokota & Ishikawa, 2020

3. Does distinctive precursory slip or distinctive foreshocks exist before earthquakes? What causes either foreshocks or precursory slip?



Kato and Ben-Zion, 2020

4. Under what physical conditions and by what processes will rapid slip during an earthquake displace the seafloor and increase the likelihood of generating a significant tsunami?



Ulrich et al., 2020

Developing a strategy to address these science questions

What?

What kinds of observations and field data, and at what scales and durations? What kinds of experimental data and models?

- **Traceability matrix**: Method to evaluate relevance of different types of data and methods to addressing each of the science questions. *In progress now.*
- Develop **plans for generic experiments** at different scales. *Planned for summer/fall.*

Where?

What types of subduction zones do we need to study to address these questions?

- Define **subduction zone attributes** required by science questions. *In progress now.*
- Assemble resources to inform decision making on locations. *In progress now.*
  - **Subduction zone inventory**
  - **Onshore analog inventory**

Who?

- Engage US community to solicit input on implementation plan and participation in future SZ4D.
- Develop and strengthen international partnerships

Traceability Matrix: Mapping activities & data needs to driving questions

Observables or required parameters		Geodetic deformation long timescale (>6 months, a few cm or microstrain)	Geodetic deformation short timescale (<6 months, a few mm or nanostrain)	Low (Mc~2) magnitude of completeness	EQ location precision	Broadband seismic waveform data (periods >2 s)	Long duration (decadal) of measurements	Multicycle coverage of slip	Multiple study regions required	Late in seismic cycle
1. What controls the speed and mode of slip in space and time?	Average	2.00	1.92	1.25	1.83	1.50	1.75	1.17	1.92	1.00
2A. Does distinctive precursory slip or distinctive foreshocks exist before earthquakes?	Average	1.92	2.00	1.92	1.92	1.83	1.75	0.83	2.00	1.83
2B. What causes either foreshocks or precursory slip?	Average	1.42	1.58	1.75	1.92	1.33	1.33	0.92	1.92	1.83
3. Under what physical conditions and by what processes will rapid slip during an earthquake displace the seafloor and increase the likelihood of generating a significant tsunami?	Average	1.86	1.50	1.07	1.36	1.55	1.50	1.07	2.00	1.29
4. How do other subduction zone faults (outer rise, forearc, and hazardous slab) and earthquakes interact with the plate boundary? (interact in many ways)	Average	1.86	1.57	1.79	1.86	1.55	1.79	1.14	1.79	1.00

Observables or required parameters		Paleoseismic constraints	Absolute stress (direct or indirect)	3D/4D distribution of strain accumulation	Hydraulic Diffusivity and fluid transport properties	Fluid Pathways	Fluid Production	Temperature Structure	Fine-scale structure of fault zones (<10 m scale)	Large-scale structure of fault zone (>10 m)	Mechanical effect of fluid pressure on rocks	Scaling of friction labs
1. What controls the speed and mode of slip in space and time?	Average	1.08	1.00	1.75	1.25	1.25	1.00	1.08	1.42	1.50	1.50	1.27
2A. Does distinctive precursory slip or distinctive foreshocks exist before earthquakes?	Average	0.58	0.67	1.00	0.50	0.50	0.17	0.17	0.25	0.67	0.42	0.55
2B. What causes either foreshocks or precursory slip?	Average	0.75	1.33	1.75	1.92	1.92	1.33	1.33	1.17	1.83	1.83	1.64
3. Under what physical conditions and by what processes will rapid slip during an earthquake displace the seafloor and increase the likelihood of generating a significant tsunami?	Average	1.43	1.43	1.86	1.14	1.21	1.21	1.29	1.46	1.77	1.42	1.64
4. How do other subduction zone faults (outer rise, forearc, and hazardous slab) and earthquakes interact with the plate boundary? (interact in many ways)	Average	1.50	1.31	1.93	1.21	1.50	1.14	1.21	1.07	1.79	1.21	1.00

Observables or required parameters		Available onshore analogs	Constitutive law	Loading (Plate convergence rate and boundary conditions)	Seafloor roughness	Sediment inputs well constrained (volume, composition, mechanics)	Tectonic history well constrained	In case of an earthquake: Offshore ground motion measurements at >~100 Hz that won't clip at few g acceleration	In case of an earthquake: Onshore ground motion measurements at >~100 Hz that won't clip at few g acceleration	In case of an earthquake: Tsunami measurements (e.g., pressure at ocean bottom, wave height) at 1 Hz sampling, ideally within and outside source region	In case of an earthquake: Bottom pressure measurements that can resolve seismic and ocean acoustic waves in addition to tsunami (sampling >10 Hz, no clipping at few MPa	In case of an earthquake: High-resolution bathymetry survey pre-earthquake over source region
1. What controls the speed and mode of slip in space and time?	Average	1.25	1.55	1.42	1.33	1.42	1.08	1.50	1.50	1.13	1.38	1.56
2A. Does distinctive precursory slip or distinctive foreshocks exist before earthquakes?	Average	0.42	0.82	0.42	0.25	0.25	0.42	1.25	1.25	0.88	1.00	0.44
2B. What causes either foreshocks or precursory slip?	Average	1.17	1.73	1.67	1.00	1.08	0.92	1.13	1.00	0.88	0.88	0.67
3. Under what physical conditions and by what processes will rapid slip during an earthquake displace the seafloor and increase the likelihood of generating a significant tsunami?	Average	1.07	1.77	1.79	1.46	1.77	1.14	1.70	1.10	2.00	2.00	1.91
4. How do other subduction zone faults (outer rise, forearc, and hazardous slab) and earthquakes interact with the plate boundary? (interact in many ways)	Average	1.00	1.23	1.86	1.21	1.14	1.57	1.60	1.70	1.10	1.00	1.55

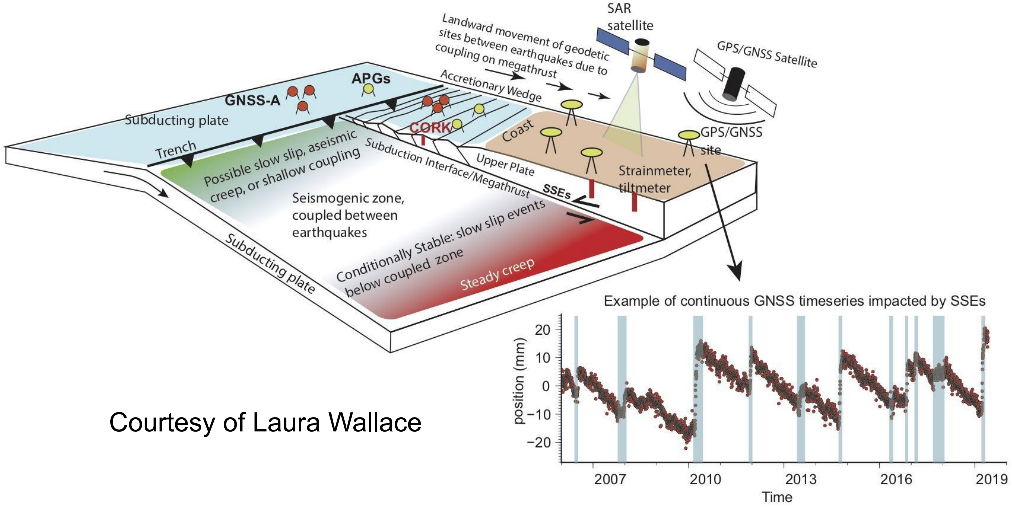
- Means to evaluate and discuss importance of different kinds of data or activities for addressing each question

- Some information required for all questions. Others important for some questions, but not all.

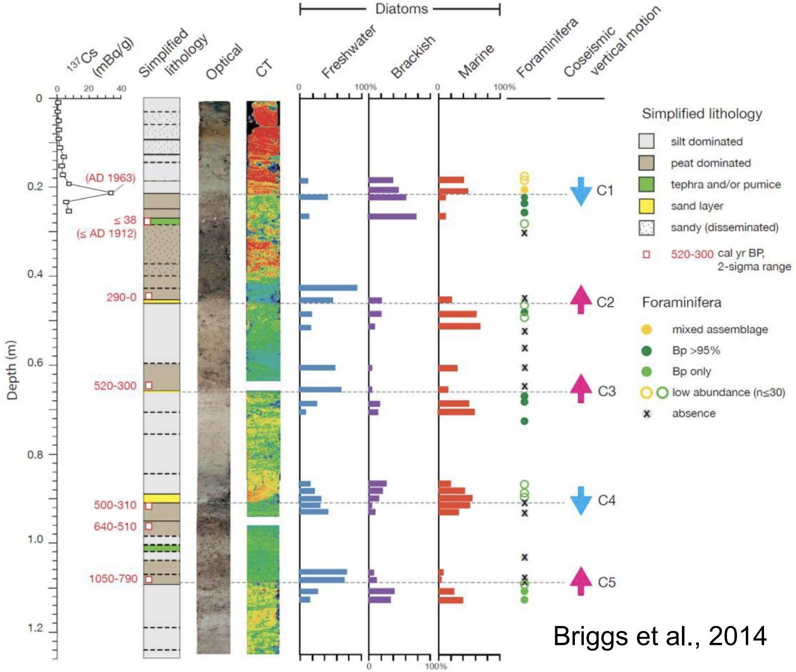
Observations and activities to address science questions

1. New amphibious observations of subduction zone behavior

- Observations of present-day slip behavior over long enough duration, of sufficient density and sensitivity, and over large enough spatial extent
  - *Offshore observations are a particular gap.*
- Paleoseismology/geology required to provide deeper time constraints on long-term behavior



Courtesy of Laura Wallace

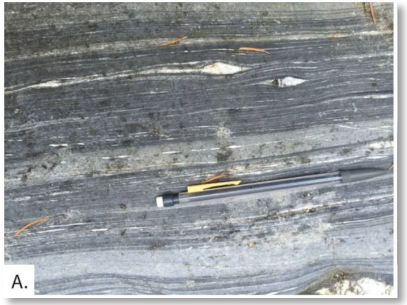


Briggs et al., 2014

Observations and activities to address science questions

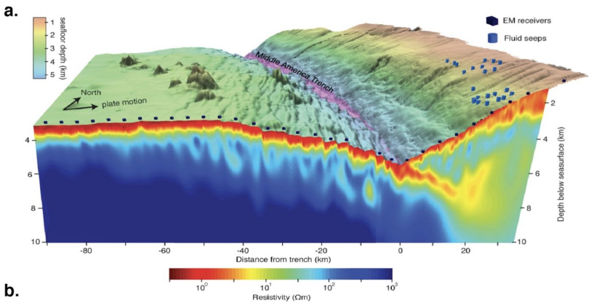
2. Geology, geophysical imaging, experiments, and models needed to understand slip behavior

- Constrain subduction zone structure & physical properties at different scales
- Identify optimal analog sites – **field observations** of faults and wall rock
- **Laboratory experiments** and numerical models to determine constitutive laws and megathrust behavior

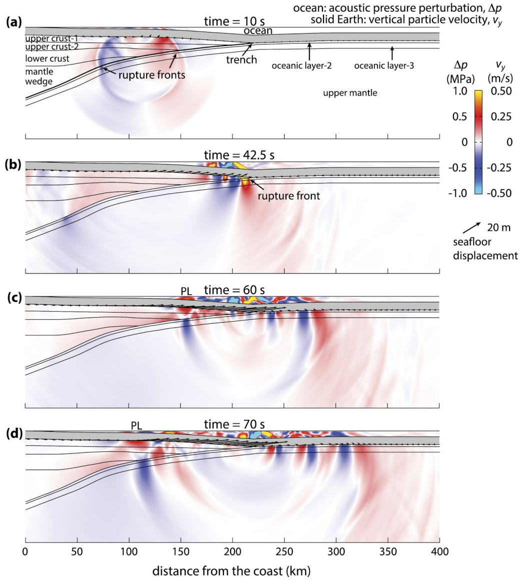


Kirkpatrick et al., 2021

credit: H. Rabinowitz



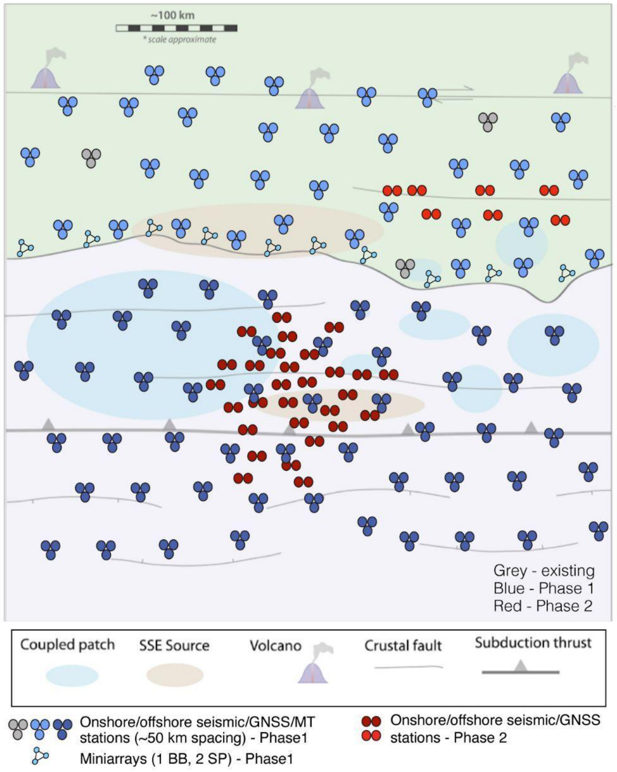
Naif et al., 2016



Kozdon & Dunham, 2014

Notional Observational Plan

MegaArray



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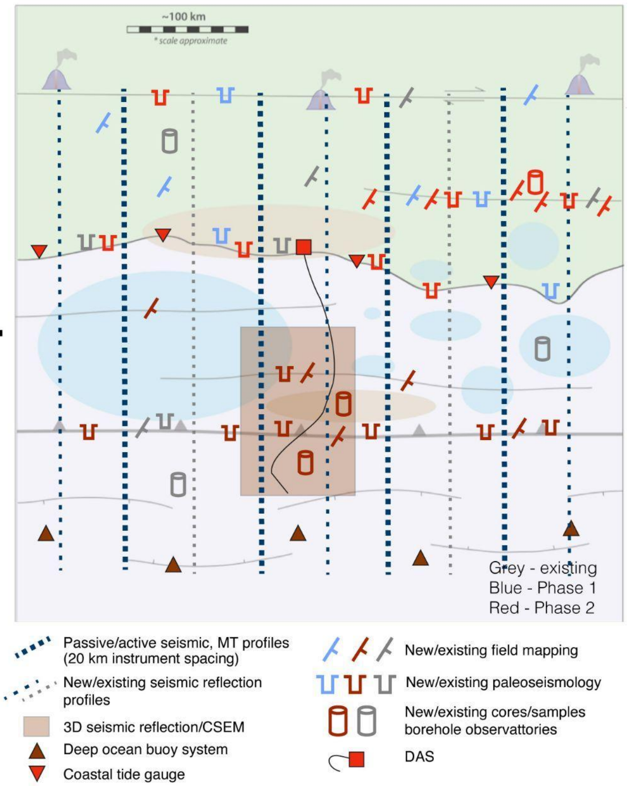
Geological & Geophysical Studies



Phase 2a: Backbone imaging and characterization of subduction zone behavior and structure, *leveraging advantage of existing data*

Phase 2b: Detailed characterization of areas of interest (e.g., those with variations in coupling/behavior, important fault systems) informed by Phase 0 and 1 activities

***both phases interleaved with modeling and experimental efforts*

Geological and Experimental Notional Experiment

Phase 1 Observations

Phase 2 Observations

Phase 0: Synthesis of existing geology, paleoseismology, and relevant rock properties data at subset of analog sites, technology development

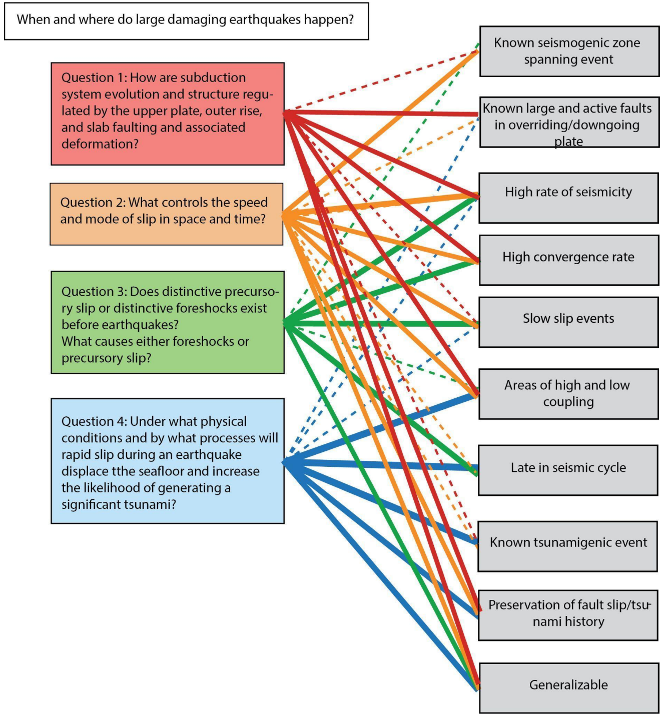
Phase 1: Identification of onshore analogs, reconnaissance work and sampling, backbone characterization of geology/paleoseismology of modern system and of analog systems, experiments on existing samples

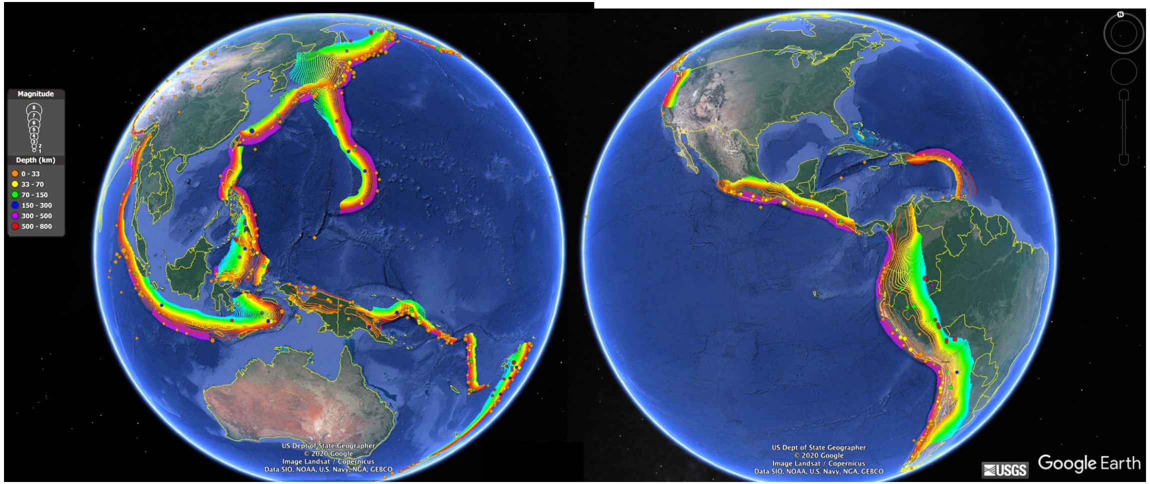
Phase 2: Detailed onshore/offshore characterization of areas of interest in modern system and of relevant onshore analogs, targeted sampling and experiments

***interleaved with modeling and geophysical efforts*

The process of developing a draft science plan

- What do we need to do? Traceability Matrices, Notional Experiments
- **Where do we need to do it? Key Requirements & Subduction zone inventories**





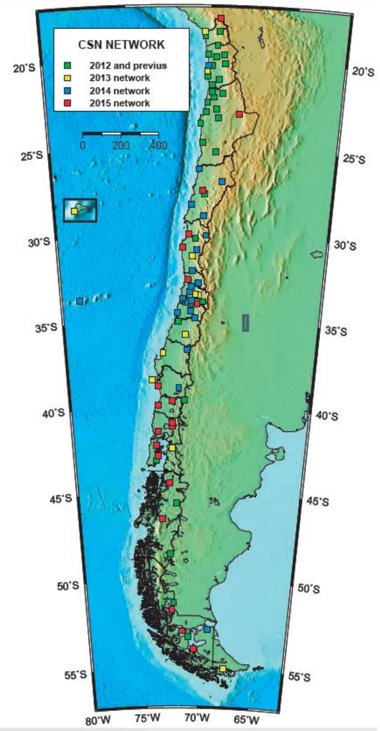
Locations for study

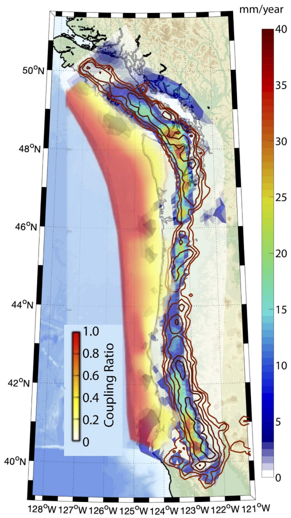
Recommend:

- Complementary domestic and international sites
- International coordination of complementary networks

Regions of Special Interest:

- Chile
- Cascadia
- Alaska





Bartlow (2020)

Liu et al. (2020)