Paleoseismic data for constraining models of Cascadia earthquake deformation and tsunamigenesis

Carrie Garrison-Laney CRESCENT Paleoseismology Working Group

Sea Grant WASHINGTON

Copalis Ghost Forest in Washington
Photo: Jessie Pearl

Providing essential insight into long-term fault behavior

- Improving estimates of coseismic deformation to better understand the spatial variability of past CSZ earthquakes
- Mapping tsunami deposit distribution and characteristics to constrain earthquake/tsunami models
- Applying the best radiocarbon sampling strategies and using age models to obtain more precise ages and recurrence intervals for past CSZ earthquakes
- Enhancing our ability to forecast coastal impacts and assess long-term risks for communities and infrastructure in Cascadia’s low-lying coastal zones

Humboldt Bay, California
Photo: USGS

Cascadia paleoseismic records

- Coseismic deformation – buried soils (subsidence) or raised platforms (uplift)
- Tsunami deposits
- Turbidites – offshore and lake
- Liquefaction – sand dikes, sills, blows
- Landslide runout, slump blocks

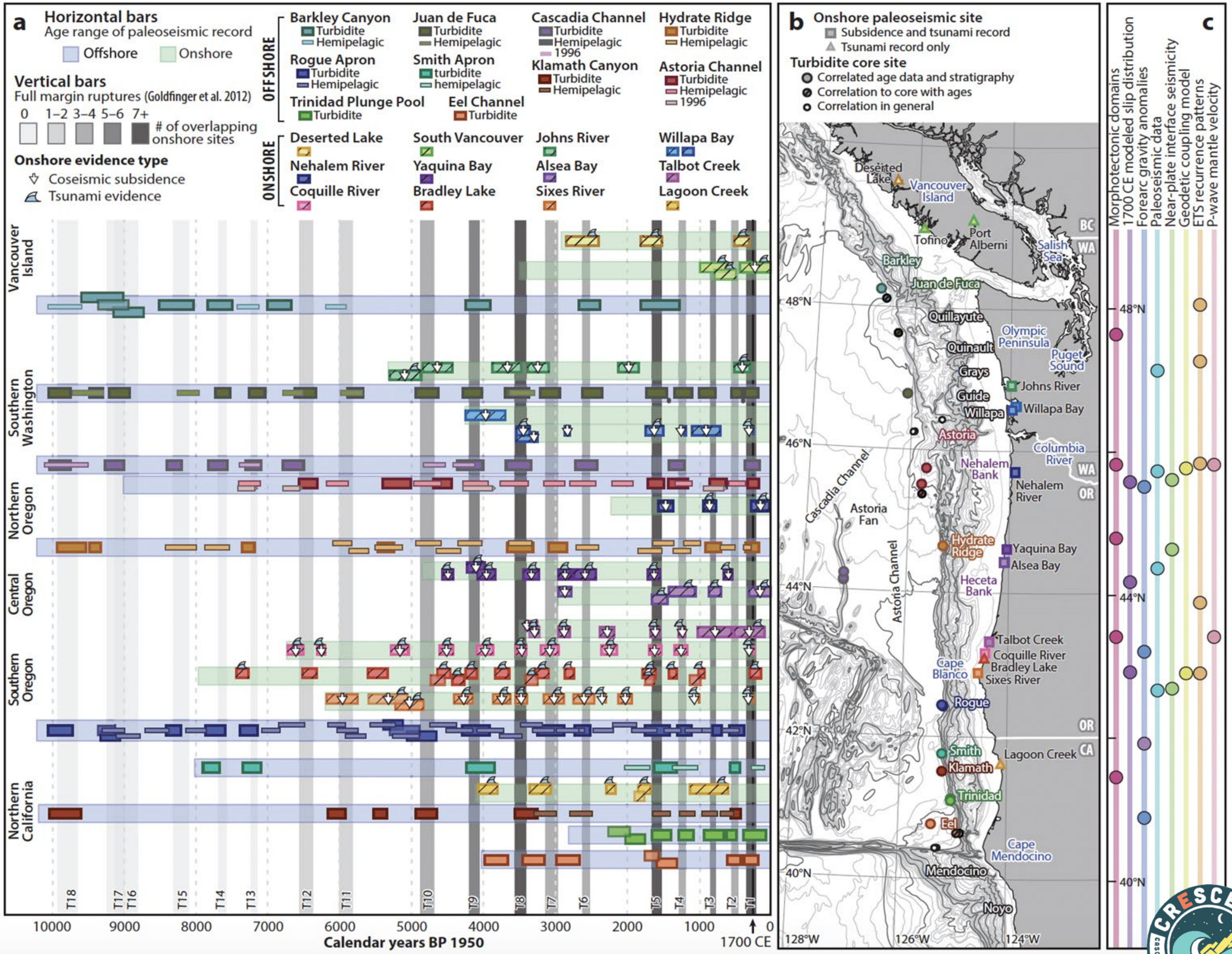

Figure 4 Walton et al., 2021

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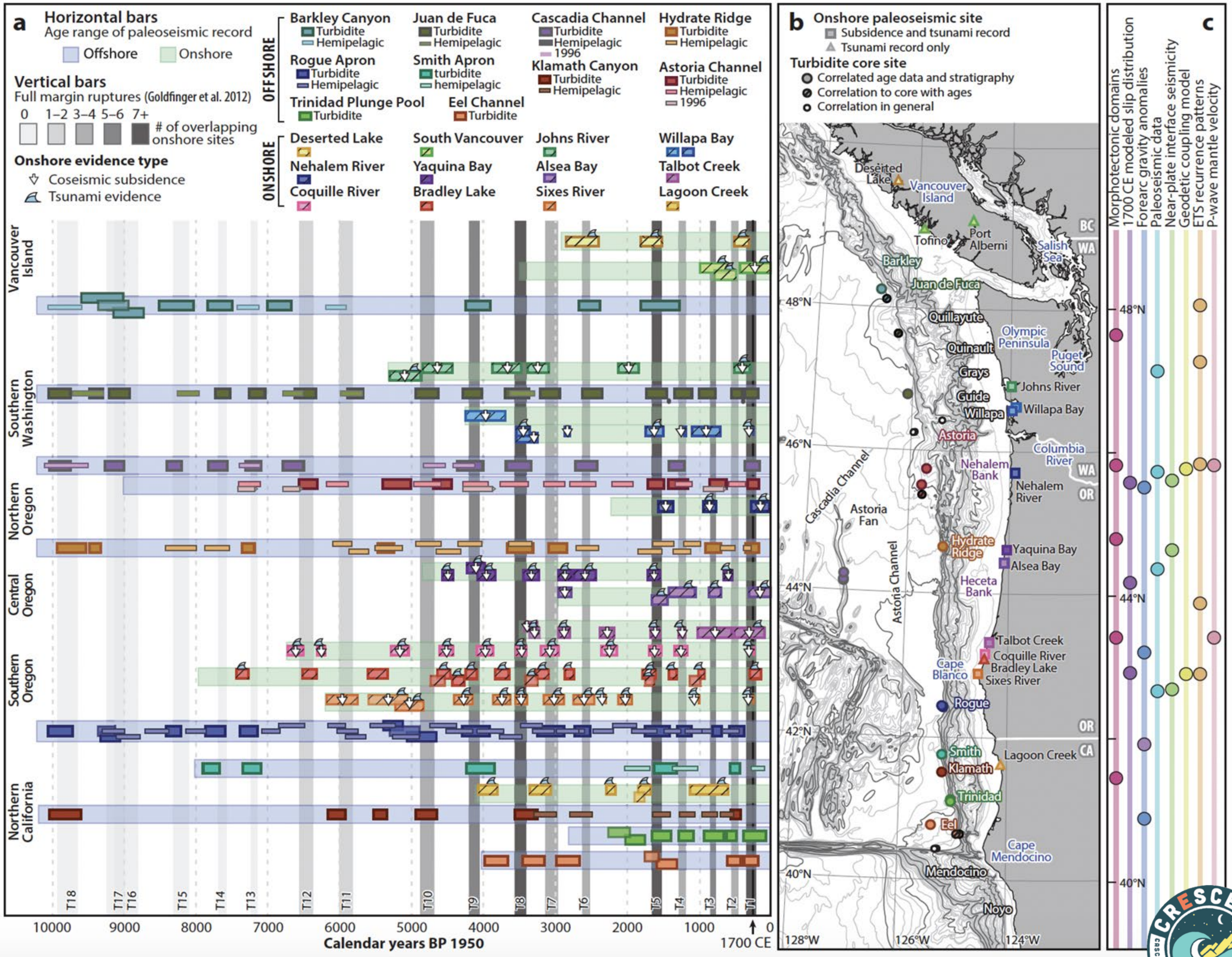
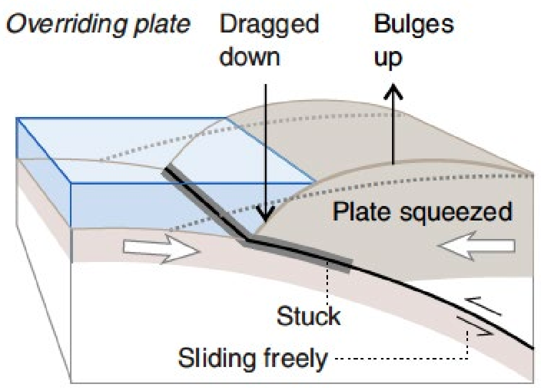
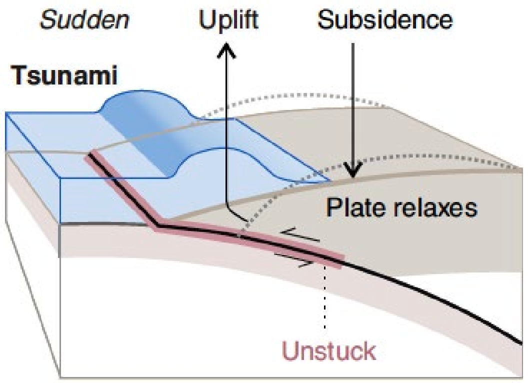


Figure 4 Walton et al., 2021

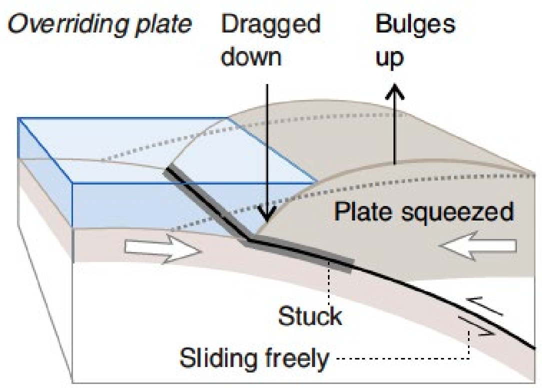
Earthquake and tsunami stratigraphy



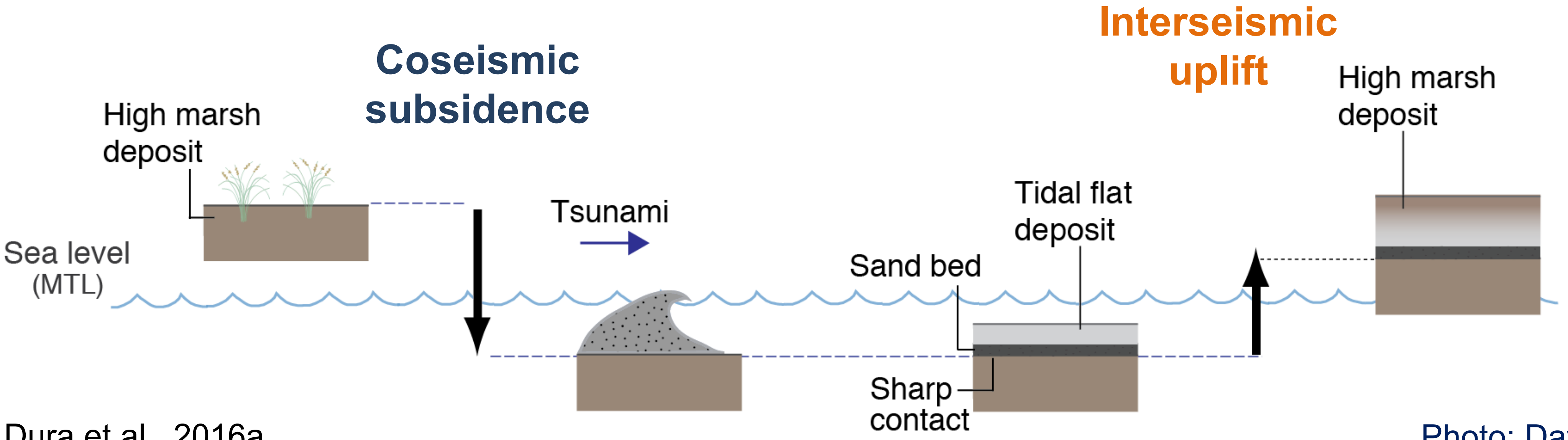
Before coseismic land-level change



During and immediately following earthquake



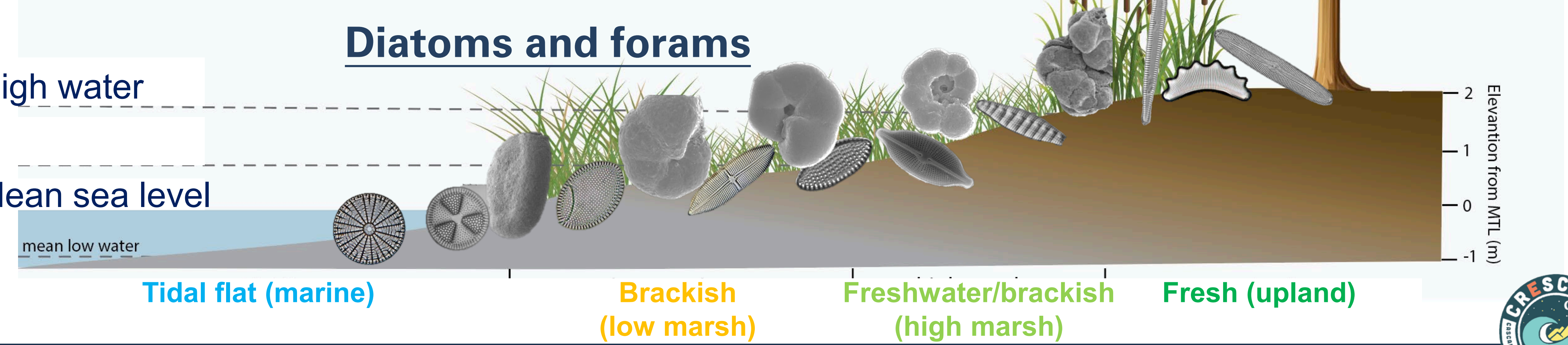
Decades to centuries after earthquake



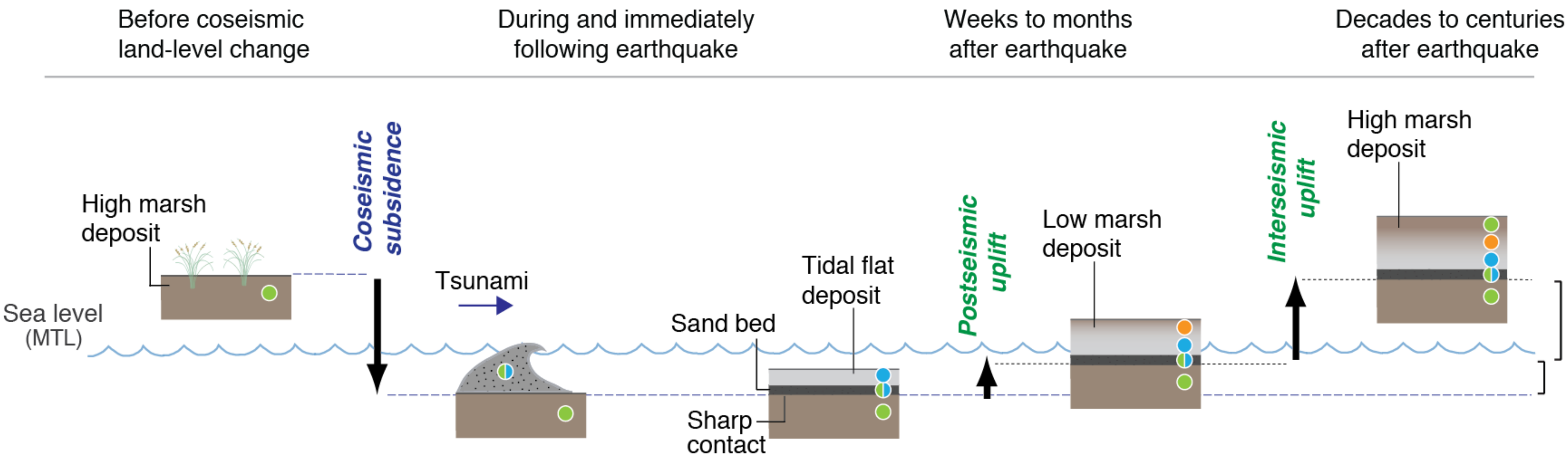
Dura et al., 2016a

Photo: David Bruce

Coseismic subsidence estimates from microfossils (forams, diatoms)



Coseismic subsidence estimates from microfossils



Dura et al., 2016a

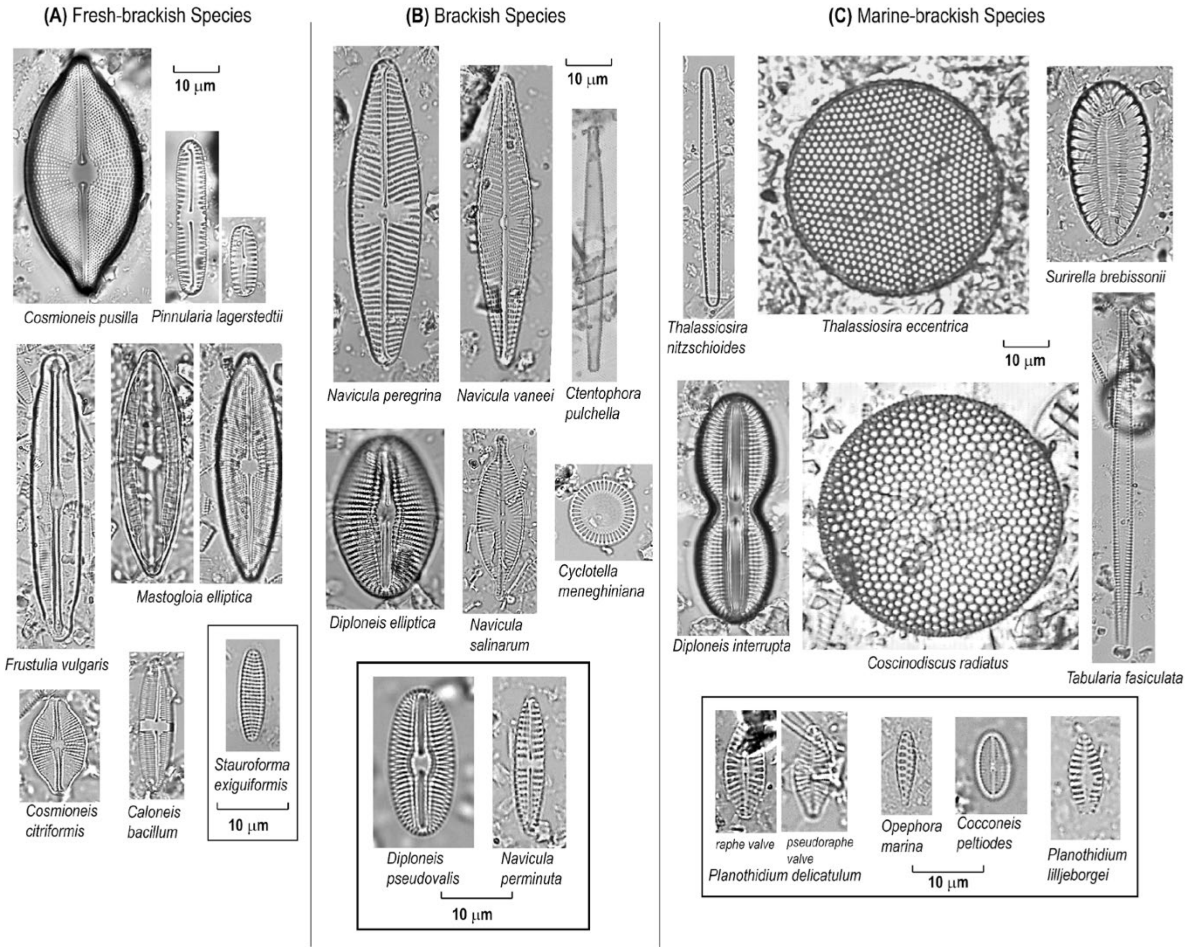
- Freshwater/brackish
- Brackish
- Marine
- Mixed

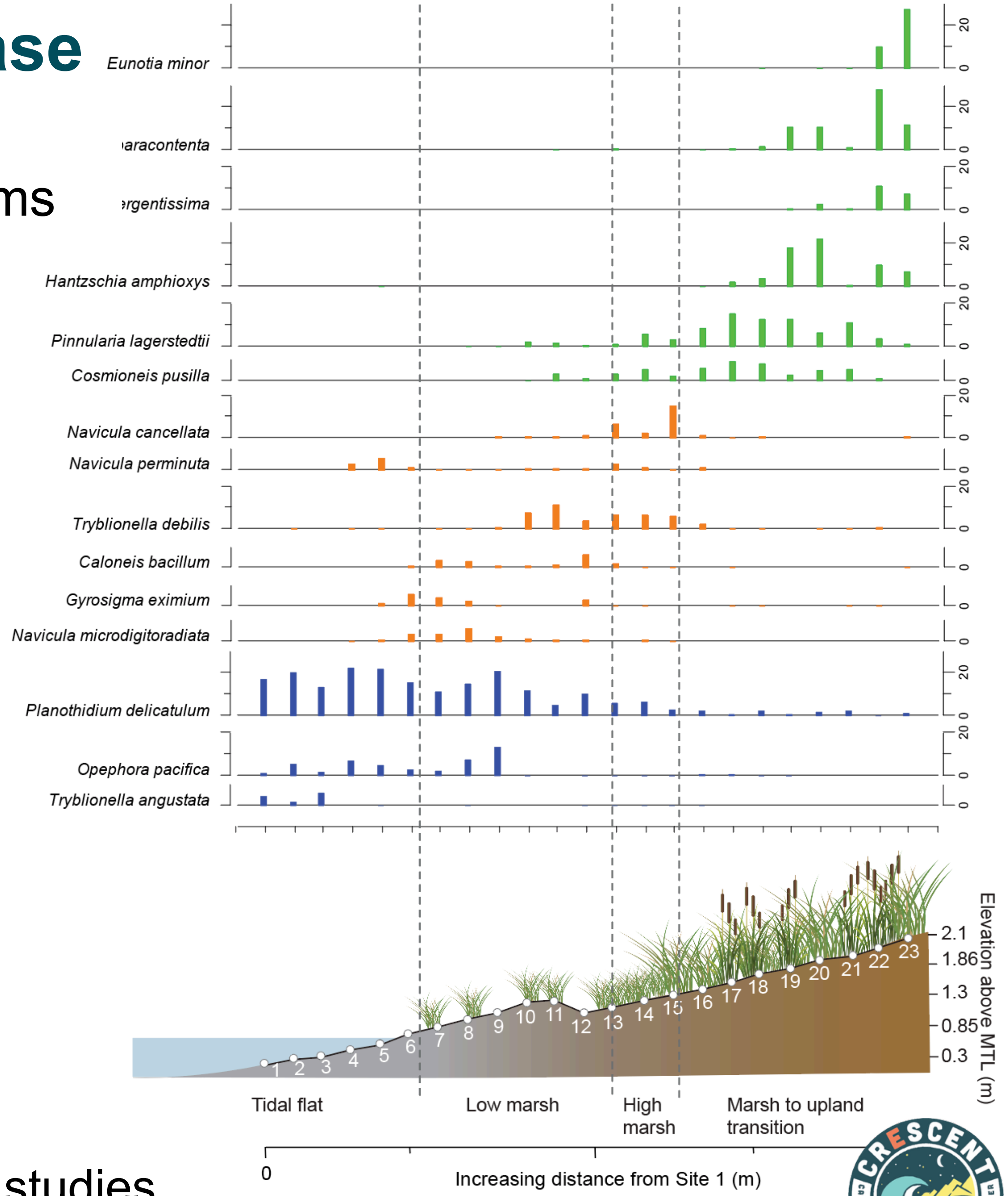
Microfossils can provide quantitative estimates of coseismic subsidence and can constrain rates of interseismic uplift

Photo: David Bruce

Paleoseismic data – new diatom database

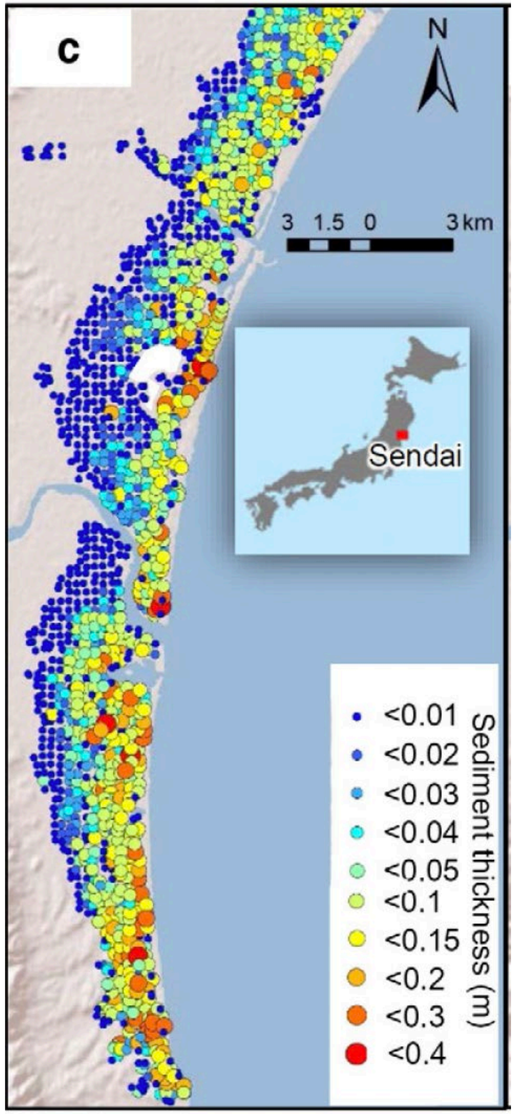
CPAL produced a database with ***standardized taxonomy***, and photographs of modern coastal diatoms



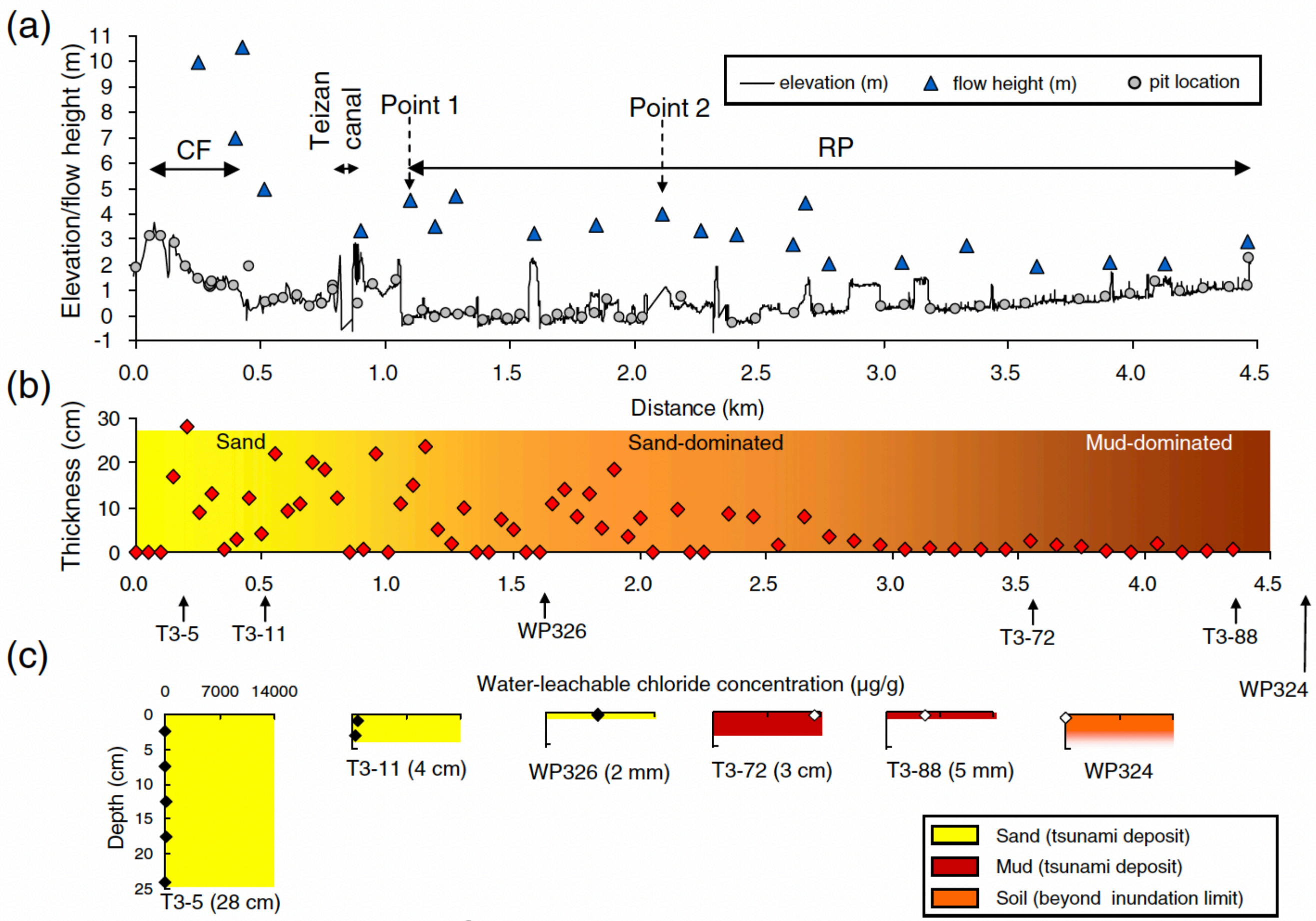


- Increases accessibility
- Encourages more quantitative coastal land-level change studies

Observations from the 2011 Tohoku tsunami in Sendai



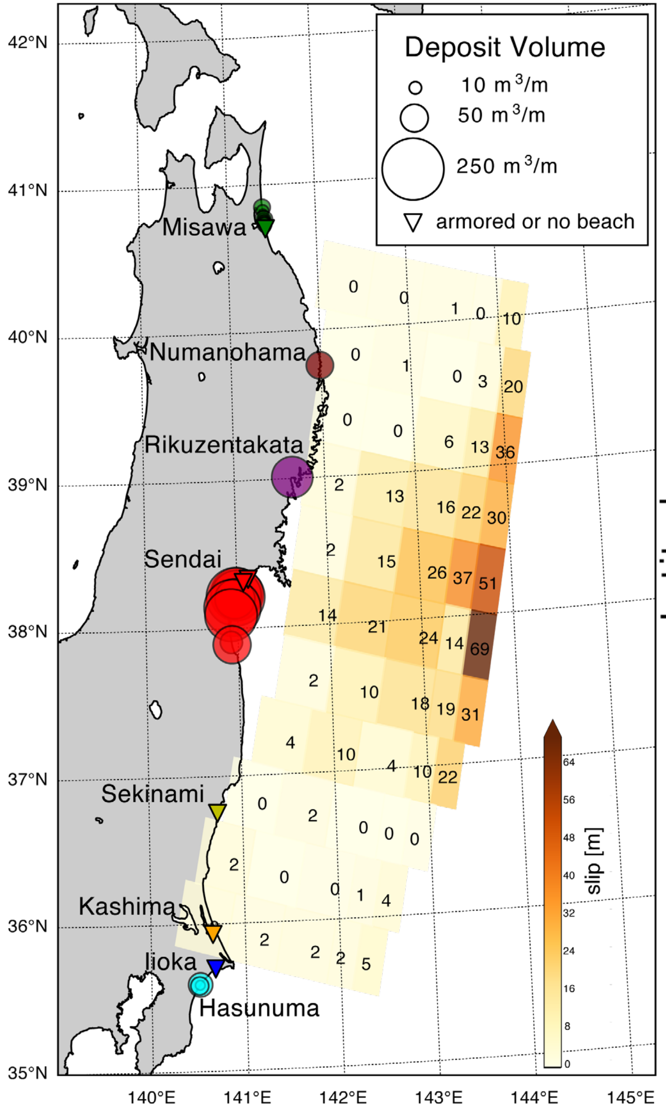
Goto et al., 2014



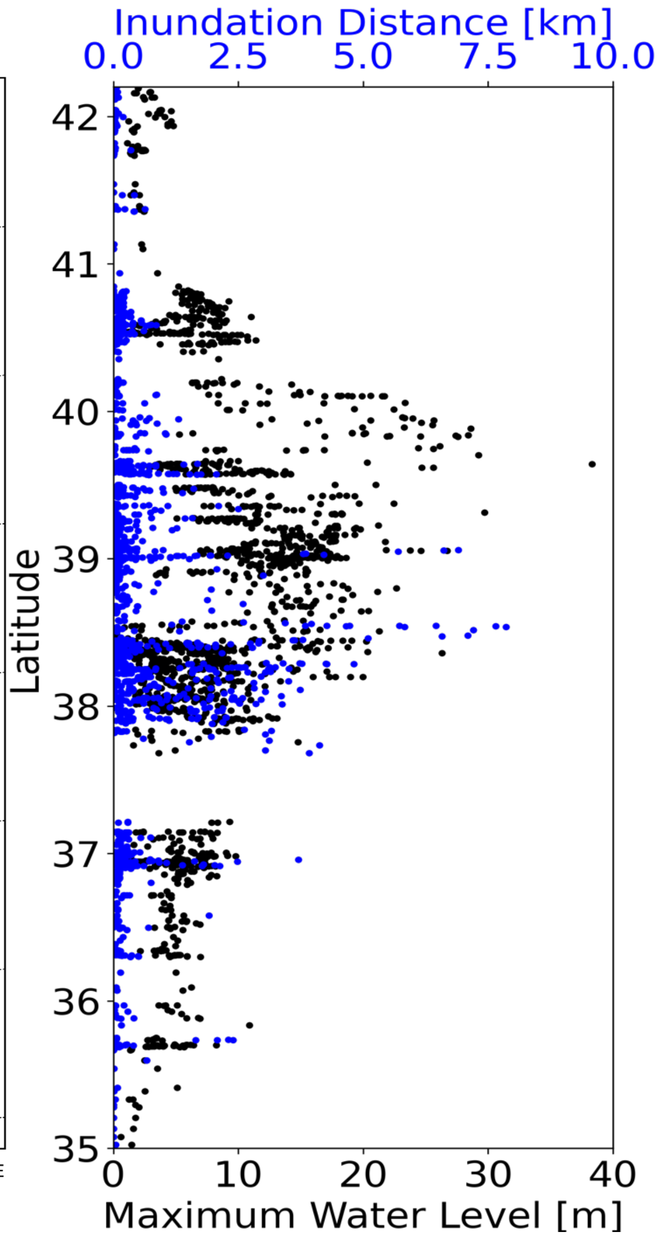
Goto et al., 2011

- The tsunami inundated up to 4.5 km inland
- Tsunami deposit sand extended as far inland as 2.8 km
- Tsunami deposit mud extended to the inundation limit

Observations from the 2011 Tohoku tsunami in NE Japan



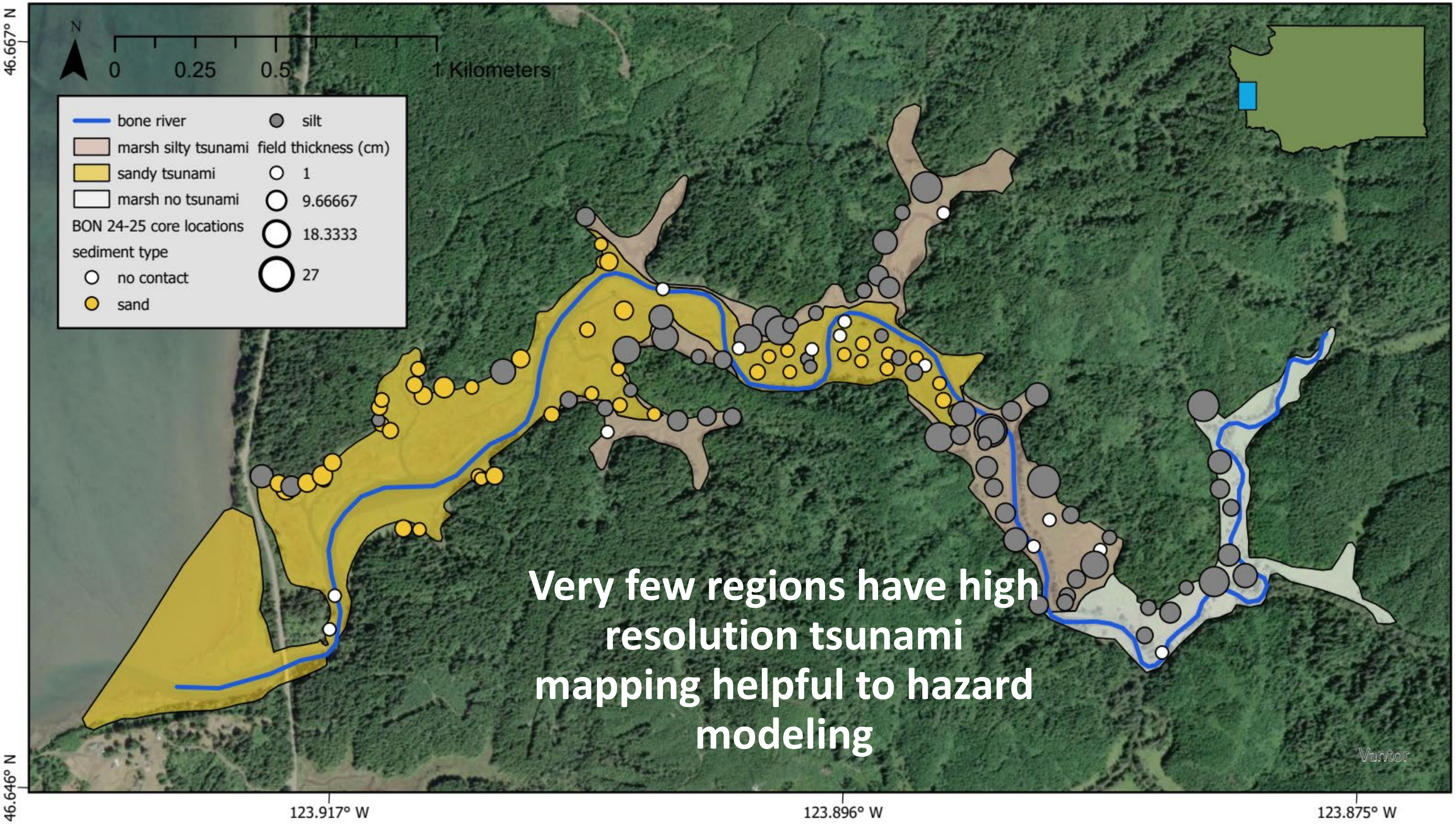
Gelfenbaum et al. 2026, in prep



Areas of highest offshore slip correspond with sites where inundation distance and water levels were the largest, resulting in the largest observed tsunami deposit volumes.

Data from Mori et al., 2011

Constraining tsunami inundation limits at the Bone River, WA



Anderberg, MS thesis, UNCW 2026

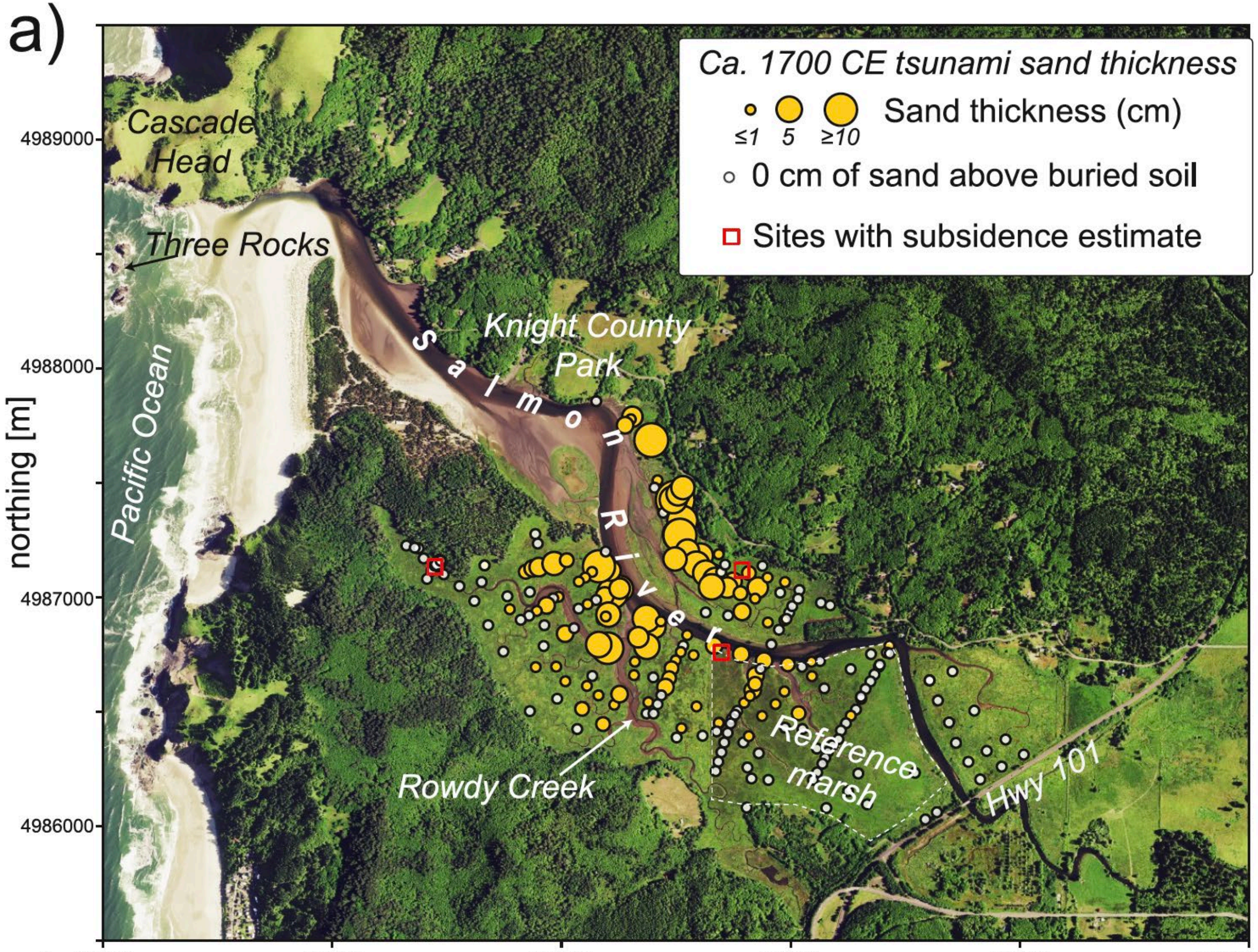
Tsunami observations were extended an additional 0.8km from 3.5km to 4.3km

Constraining earthquake source models with tsunami deposit limits at the Salmon River estuary, OR

La Selle et al. (2024) used numerical tsunami sediment transport models (Delft3D-FLOW) to infer the minimum amount of slip and coseismic subsidence required to match the 1700 CE tsunami deposit.

Earthquake models tested:

- Gao et al. (2018) sources
- DOGAMI Witter et al. (2011)



La Selle et al., 2024, Testing Megathrust Rupture Models Using Tsunami Deposits, JGR Earth Surface

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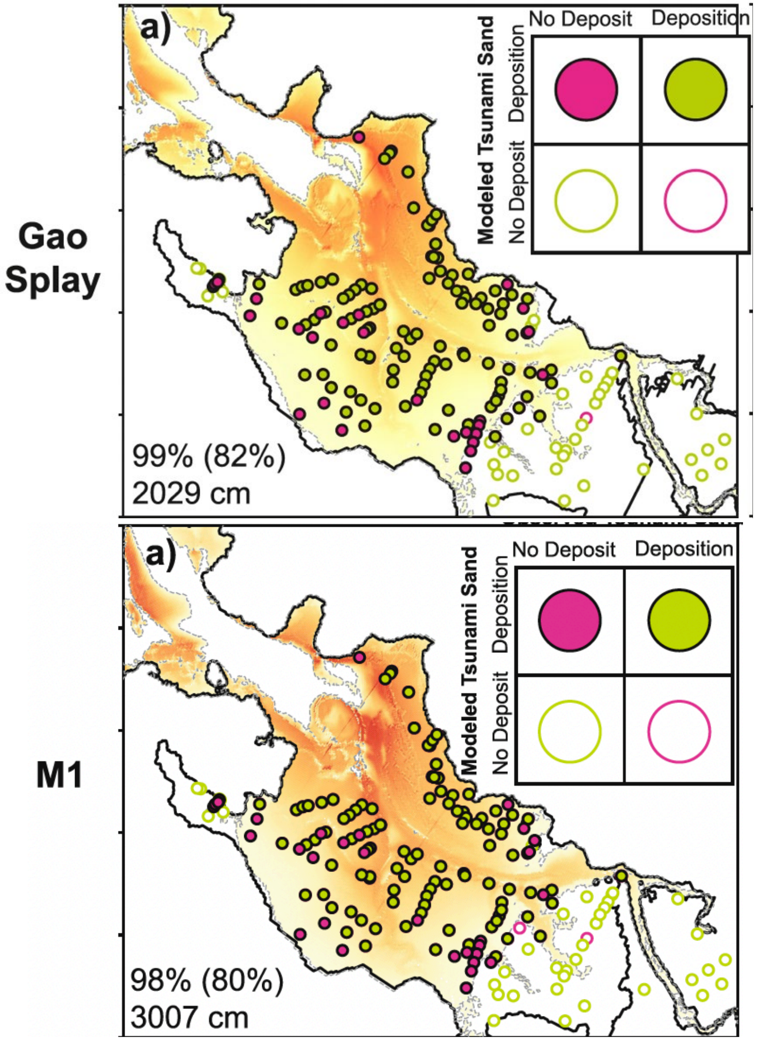
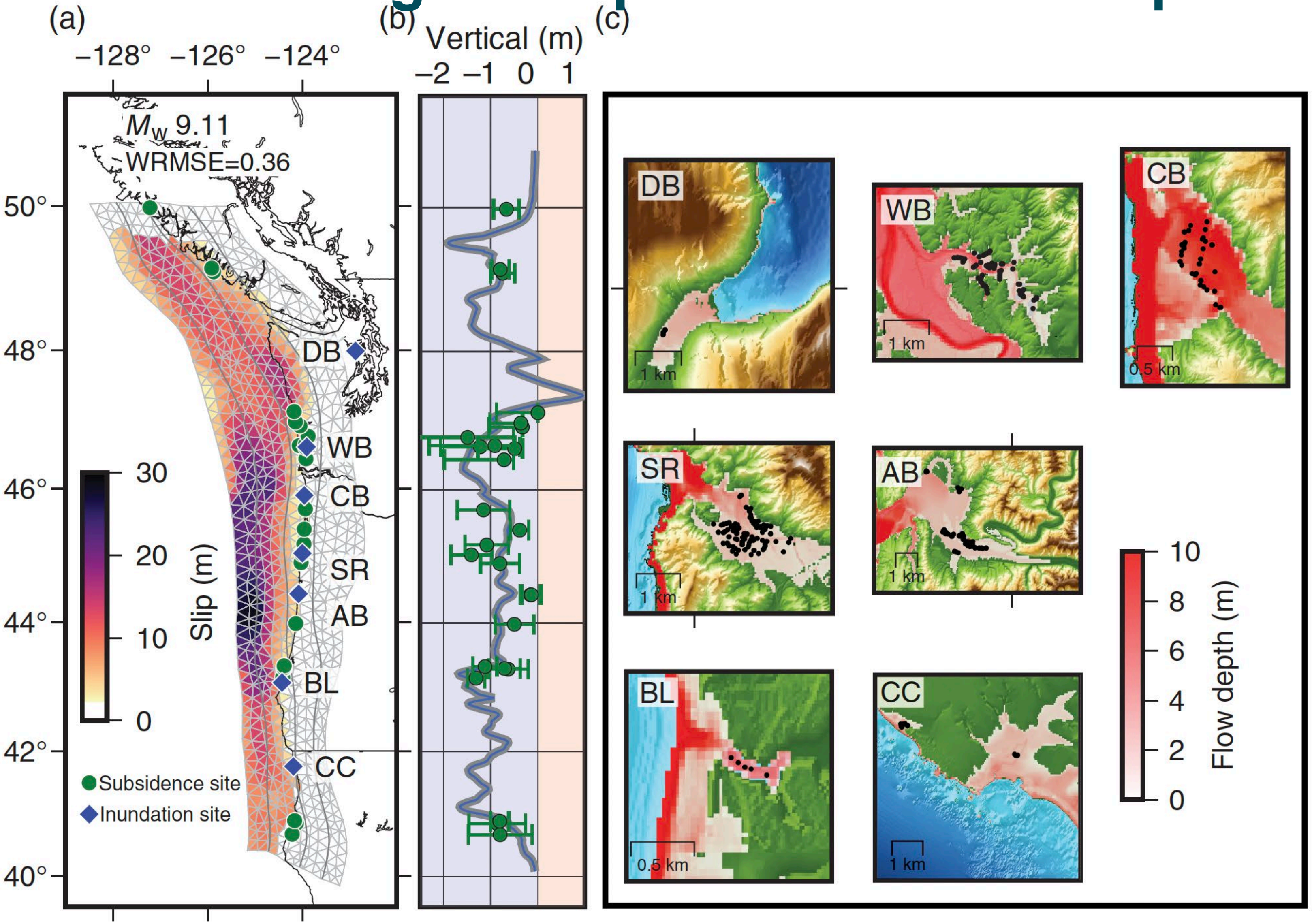


The tsunami sediment transport models that best matched the deposition extent of the ca. 1700 CE deposits:

- Splay fault sources with as little as 0.8 m of subsidence or 12 m of peak slip at low tide and at MHHW
- Without a splay fault, sources with at least 18–27 m of peak slip on the megathrust and 0.9–1.4 m of subsidence were required (low tide)

La Selle et al., 2024, Testing Megathrust Rupture Models Using Tsunami Deposits, JGR Earth Surface

Constraining earthquake models with paleotsunami deposit sites

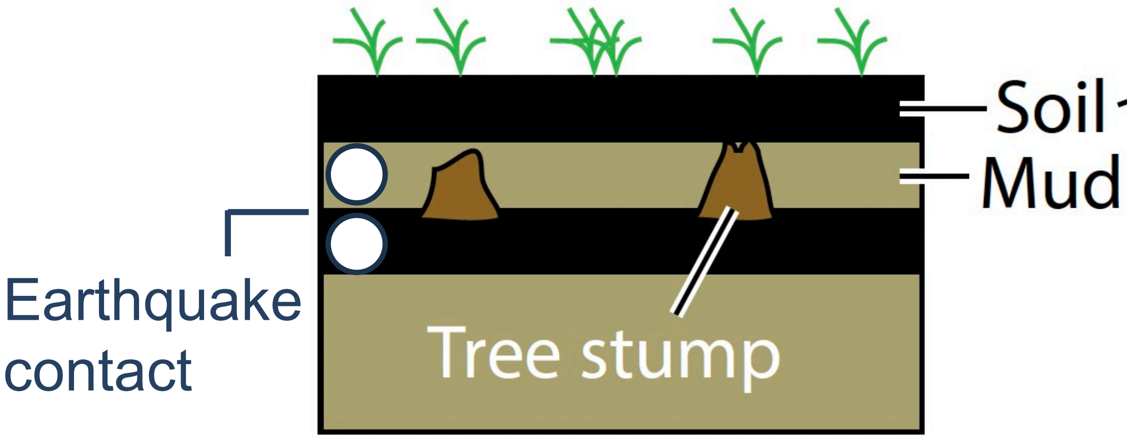


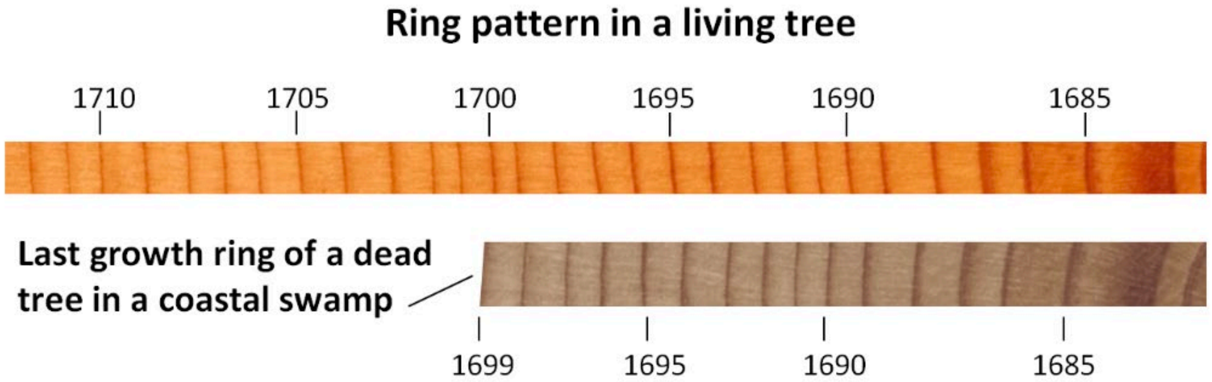
- Results suggest one rupture for 1700.
- Incorporating paleotsunami deposits as constraints for models reduces potential ruptures and sequences by 90%.

Small, D. T., D. Melgar, S. La Selle, and A. Meigs (2025). Combining Multisite Tsunami and Deformation Modeling to Constrain Slip Distributions for the 1700 C.E. Cascadia Earthquake.

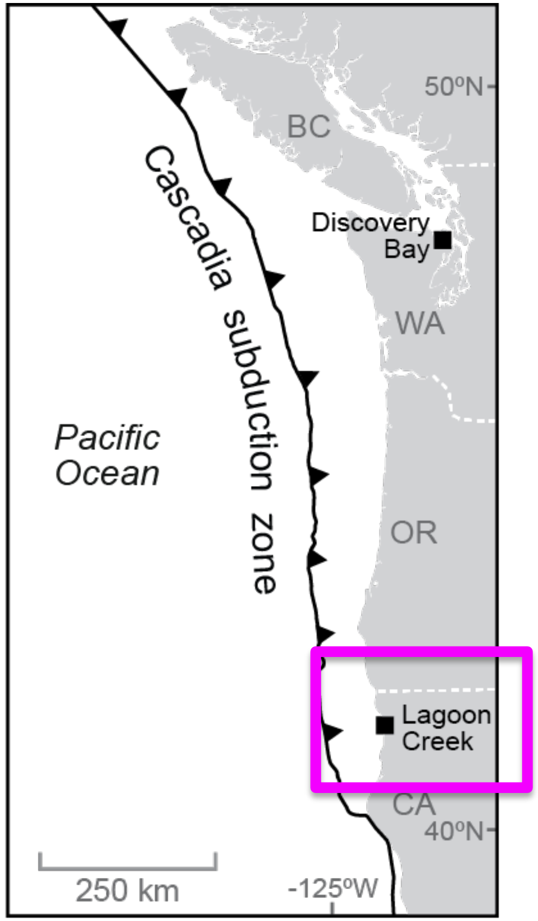
Refining earthquake and tsunami chronologies

- Seeking a consensus of ages across coastal, lacustrine, and marine depositional archives
- Primarily radiocarbon dating
- Bracketing ages on growth-position material produce the best age constraints
- Dendrochronology can provide annual to seasonal precision





Refining chronology and inland extent of tsunami deposits at Lagoon Creek, CA



Tse, (in-prep)

- New ages demonstrate that the deposits are younger than previously measured.
- The deposits show evidence of turbulent and erosive onland flow.
- Multi-proxy data including microfossils (diatoms), CT scans, and XRF data will be used to map the inland extent of tsunami flow beyond the limits of sand deposition.

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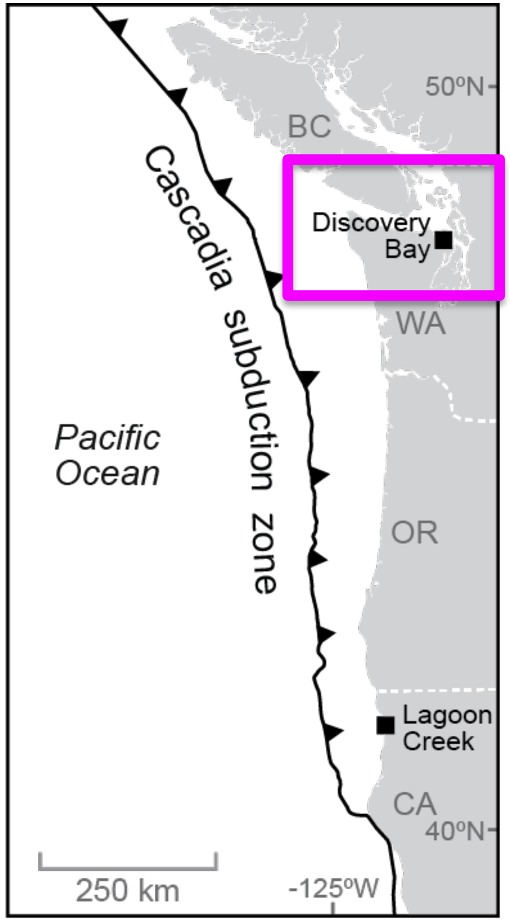
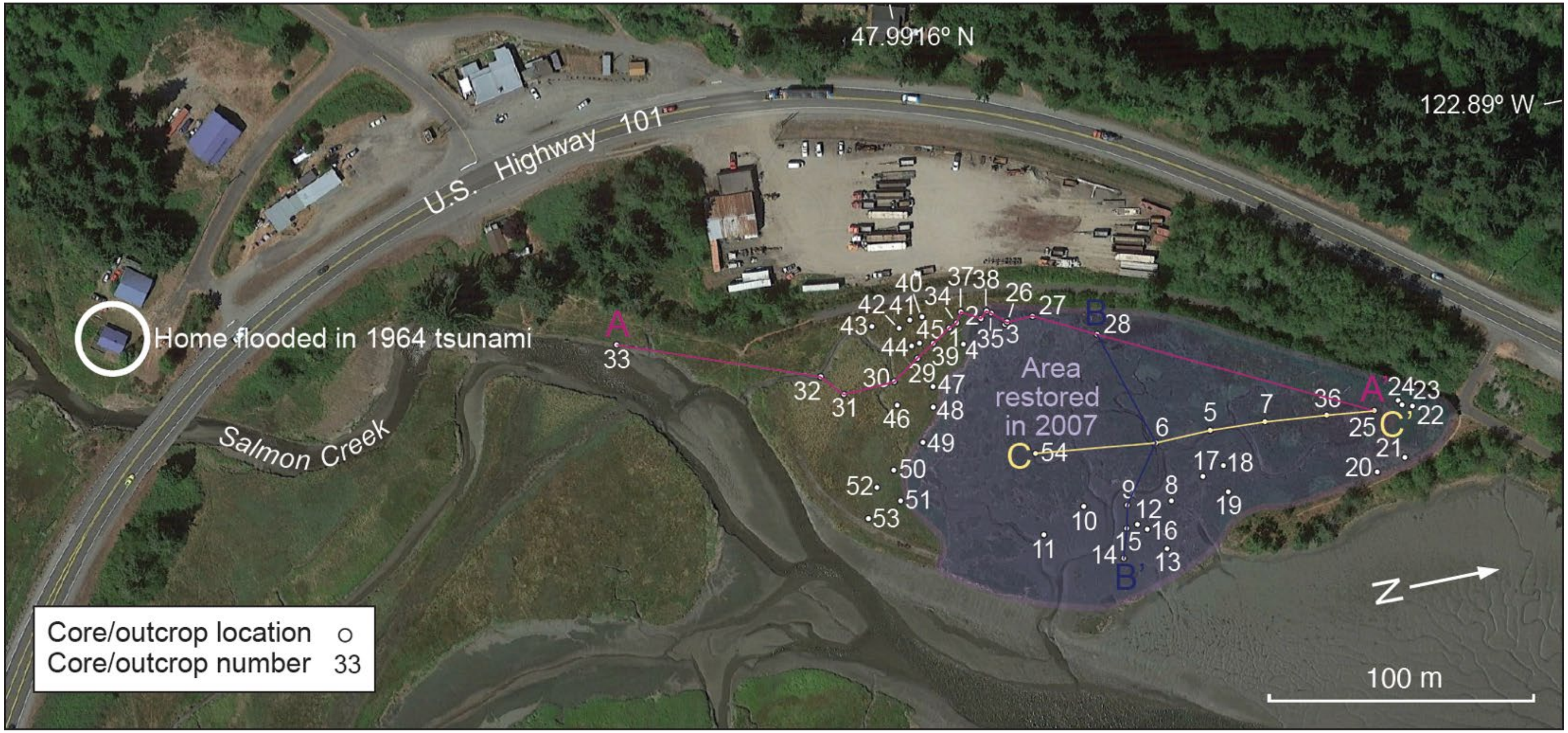
Refining the chronology, extent, and sources of tsunami deposits at Discovery Bay, WA





Garrison-Laney et al., (in-prep)

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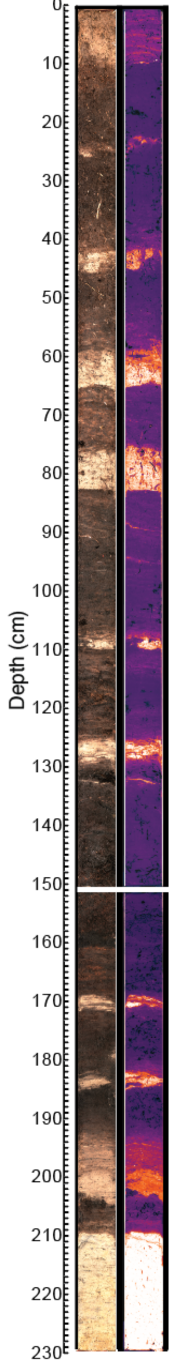

Modeled radiocarbon age	Interpreted source
1: 430-120 cal yr BP (inferred 1700 CE)	Cascadia
2: 620-570	Cascadia*
3: 720-650	Unknown
4: 920-820	Cascadia
5: 1110-1000 (840-950 CE)	Seattle fault?
6: 1370-1280	Cascadia
7: 1660-1540	Cascadia
8: 1830-1620	Darrington-Devils Mtn/Leech R. fault?
9: 2420-2160	Darrington-Devils Mtn/Leech R. fault?
10: 2670-2440	Cascadia
11: 2940-2830	Cascadia

Garrison-Laney et al., (in-prep)

Discovery Bay, WA
Eleven tsunami deposits in ~3,000 years

A mix of Cascadia and other tsunami sources:

- 7 Cascadia*
- 1 Seattle fault?
- 2 Darrington-Devils Mountain/ Leech River fault?
- 1 no known source

*A hypothesized northern Cascadia event ~600 cal yr BP

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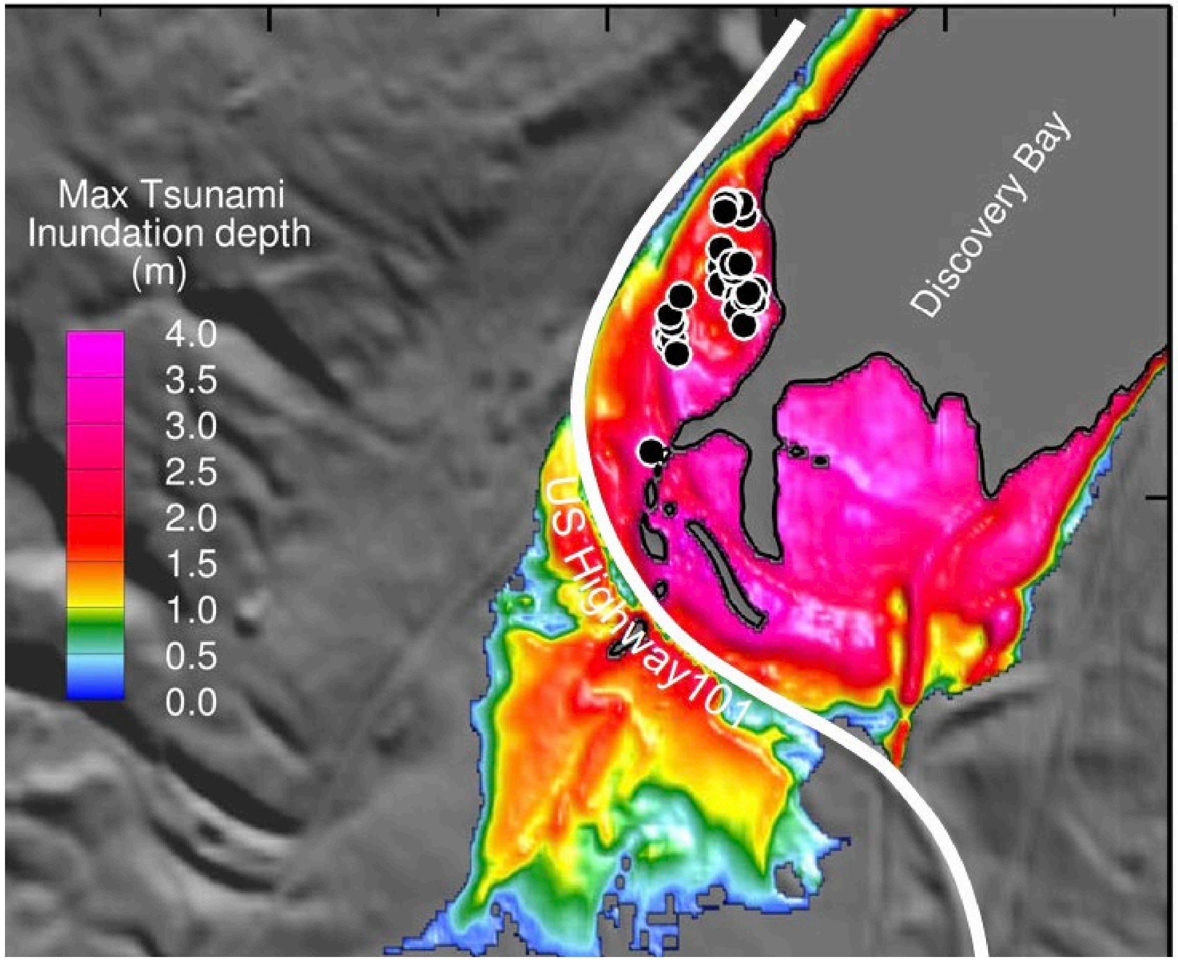
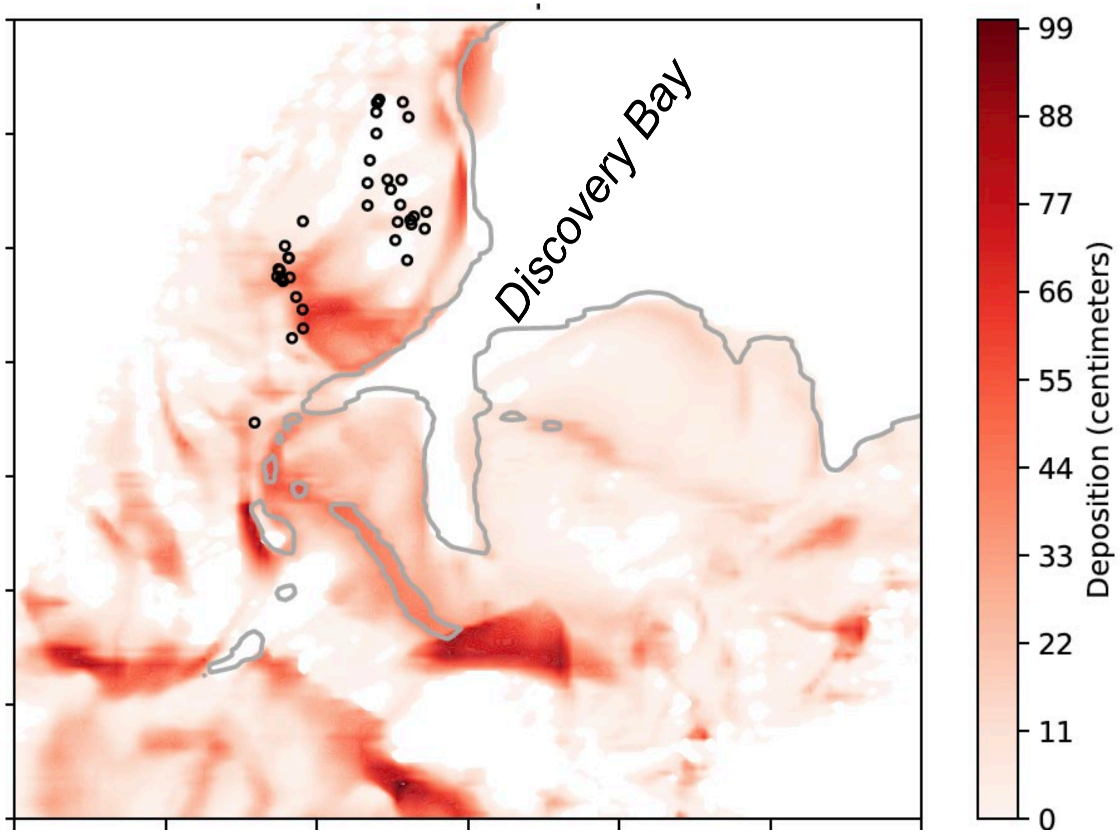
Testing potential tsunami source model flooding and sediment deposition at Discovery Bay

Earthquake source: Darrington Devils Mountain/Leech River faults



Garrison-Laney et al., 2025 USGS Subduction Zone workshop

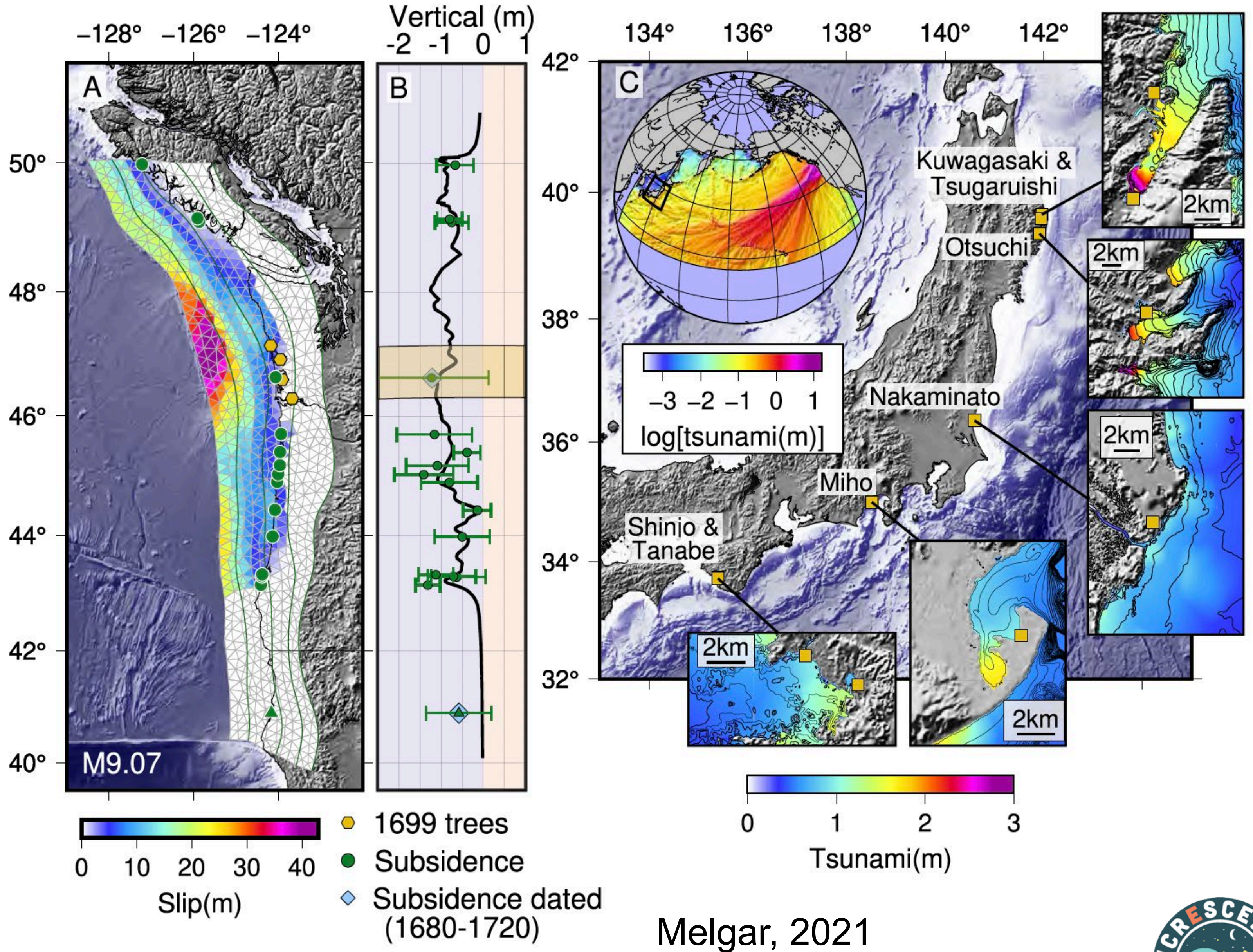


Fernández et al., in preparation

Testing slip models against paleoseismic evidence of subsidence and tsunami inundation

Was the 1700 CE earthquake a single earthquake or a series of closely-spaced quakes?

Earthquake rupture and tsunami propagation models demonstrated that a > M8.7 of 40% of the CSZ satisfies the historical tsunami observations in Japan, and several additional < M8 earthquakes that could satisfy subsidence.



Melgar, 2021

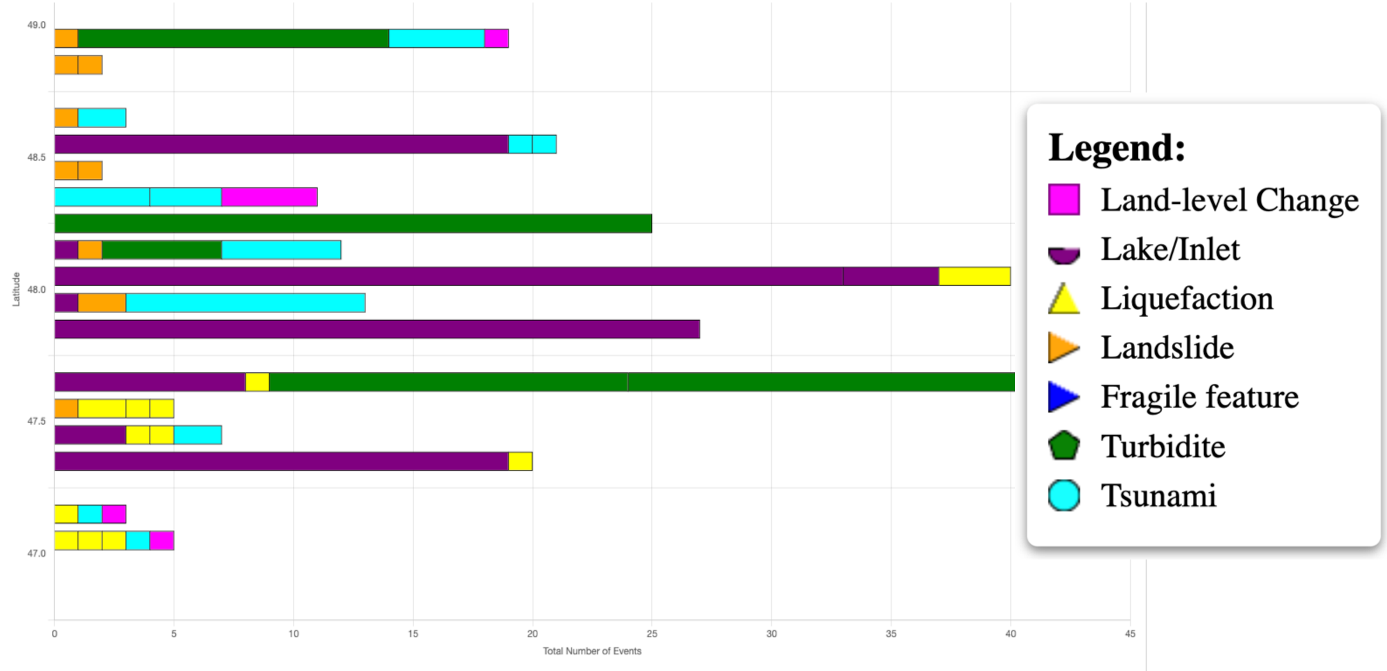
Community Product

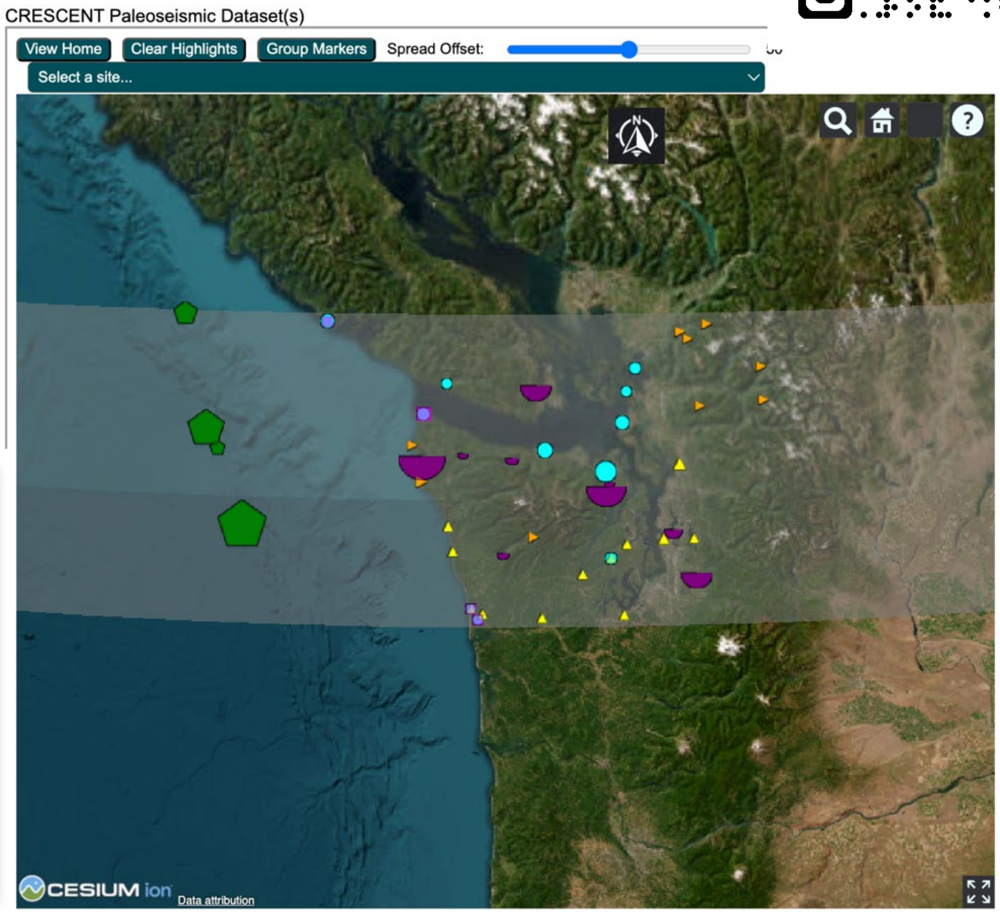
CPAL Viewer

CPAL Viewer

The CRESCENT Cascadia Paleoseismology (CPAL) Viewer is a web-based platform for mapping, cataloging, and visualizing paleoseismic datasets associated with past earthquake evidence along the Cascadia Subduction Zone. The viewer allows users to filter by paleoseismic evidence type, location, quality of age control, and certainty of source mechanism. The CPAL Viewer is an open source tool. Code is available on the CRESCENT GitHub. The underlying dataset is from the *Compiled onshore and offshore paleoseismic data along the Cascadia Subduction zone: U.S. Geological Survey data release*, https://doi.org/10.5066/P13OJQYW.

CPAL database viewer doi: https://doi.org/10.5281/zenodo.15866114





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Niawiakum River, Washington
Photo: USGS

Questions?

Cape Blanco, Oregon
Photo: Tina Dura