# Improving Subduction Zone Hazards Assessments Using the Coastal Stratigraphic Record*

**Tina Dura[1]**

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## Abstract

Earthquake and tsunami records on centennial and millennial temporal scales are necessary to understanding subduction zone hazards and the occurrences of large, but infrequent events. Subduction zone paleoseismology combines the methods of coastal stratigraphy, sedimentology, micropaleontology, geophysical and sediment transport modeling, and sea-level research to produce some of the most detailed long-term histories of coseismic vertical deformation and tsunami inundation along subduction zone coastlines. Microfossil-based (e.g., diatoms, foraminifera) techniques that employ the relation between microfossils and salinity, tidal elevation, and life form to quantify coseismic land-level change across sharp stratigraphic contacts and identify anomalous sand beds deposited by tsunamis are particularly valuable to subduction zone paleoseismic studies. Microfossil-based techniques have been successfully employed in the reconstruction of earthquake and tsunami histories in Chile, the Indian Ocean, Japan, New Zealand, the North Sea, the Pacific Northwest of North America, and the South Pacific. In Alaska and Chile, microfossils have documented both uplift and subsidence at proposed subduction zone segment boundaries, expanding our knowledge of the variability of slip in megathrust ruptures. In tsunami studies in Alaska, Chile, and Japan allochthonous marine and brackish microfossils within anomalous sand deposits signaled previously undocumented high-energy marine incursions into coastal lowlands. At the Cascadia subduction zone, a marsh monitoring experiment emphasized the importance of studying the modern diatom response to changing environmental conditions to refine estimates of past coseismic deformation. Finally, paleoseismic studies have better informed our modeling of teleseismic tsunamis that pose a flooding hazard to near- and far-field coastlines. Forward modeling of teleseismic tsunamis originating along the Aleutian megathrust combined with probabilistic sea-level rise projections for southern California illustrate the increased flooding threat to highly populated areas from far-field tsunamis as sea level rise accelerates over the next 100 years, emphasizing the need for interdisciplinary approaches to future coastal hazards assessments.

## References Cited

Bamber, J., and W. Aspinall, 2013, An Expert Judgement Assessment of Future Sea Level Rise from the Ice Sheets: Nature Climate Change, 4 p. doi:10.1038/nclimate1778

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Mueller, C.S., R.W. Briggs, R.L. Wesson, and M.D. Petersen, 2015, Updating the USGS Seismic Hazard Maps for Alaska: Quaternary Science Reviews, v. 113, p. 39-47. doi.org/10.1016/j.quascirev.2014.10.006

# Improving Subduction Zone Hazards Assessments Using the Coastal Stratigraphic Record

NSF | Sea Level Research | VIRGINIA TECH | SEPM Society for Sedimentary Geology

Tina Dura
VT Geosciences
2019

Presenter's notes: This presentation will give an overview of the application of diatoms to subduction zone earthquake and tsunami studies. Diatoms can be applied to characterize modern earthquakes and tsunamis, and are a big component of paleoseismic studies. As we know, paleoseismic studies are very important to assessing subduction zone hazards because they allow us to extend earthquake and tsunami records beyond the historical period. I'll use case studies from Chile, Alaska, and Cascadia to highlight some of the successes and challenges we've faced applying diatoms to earthquake and tsunami studies.

## Significance of work

Historical and instrumental records are ***temporally restricted***

Short datasets may ***miss largest earthquakes***

Japan 2011 ($M_w$ 9.0) earthquake ***larger than expected***

Geologic datasets on ***millennial*** temporal scales are necessary


Presenter’s notes:

- Why is it important to extend earthquake and tsunami record?

- Temporally restricted historical and instrumental records limit our understanding of long-term subduction zone behavior
- Datasets on centennial and millennial temporal scales are necessary to capture the spatial variability of subduction zone ruptures
- Only then can the largest, but infrequent events be captured (e.g. 2004 Sumatra)
- Paleoseismic studies allow us to extend earthquake and tsunami records over multiple earthquake cycles
- This allows us to address fundamental questions about rupture mode variability and segmentation of subduction zones

# Significance of work

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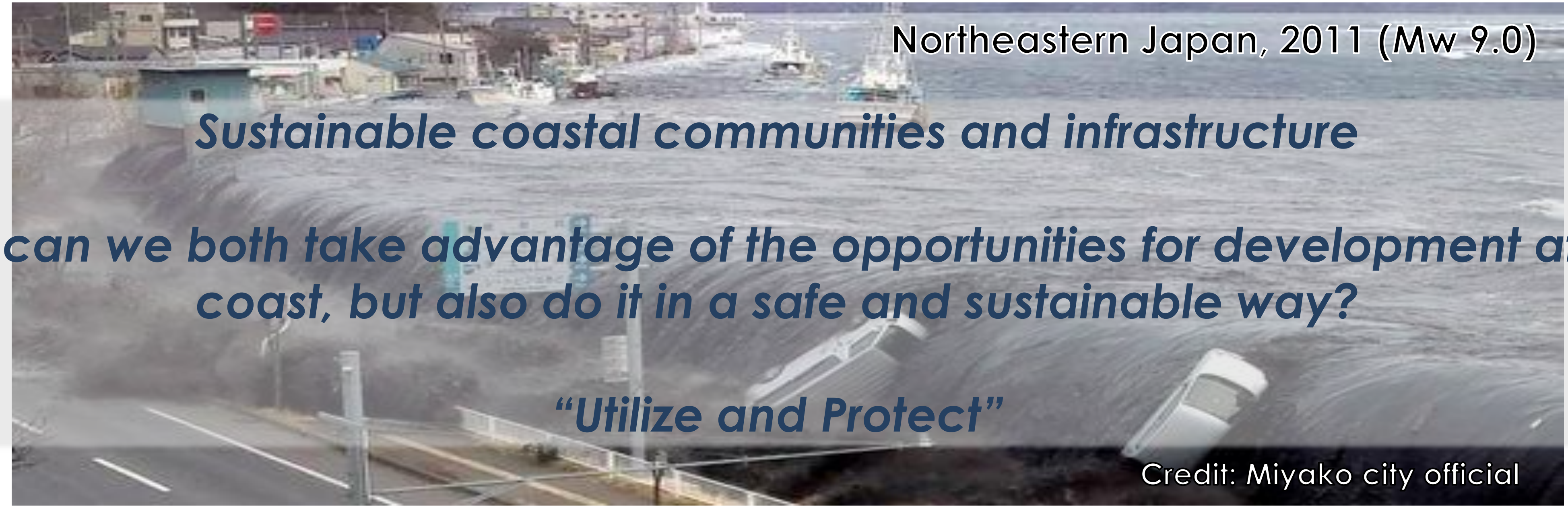
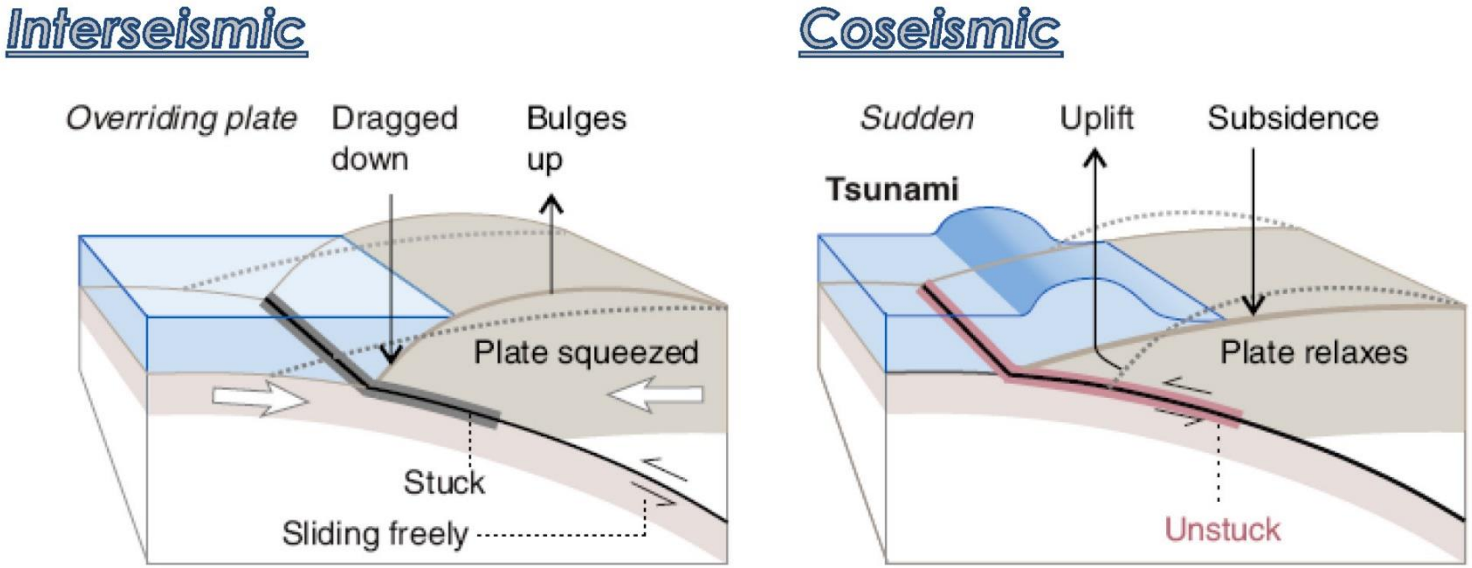



***Sustainable coastal communities and infrastructure***

***How can we both take advantage of the opportunities for development at the coast, but also do it in a safe and sustainable way?***

***“Utilize and Protect”***

# Earthquake deformation cycle



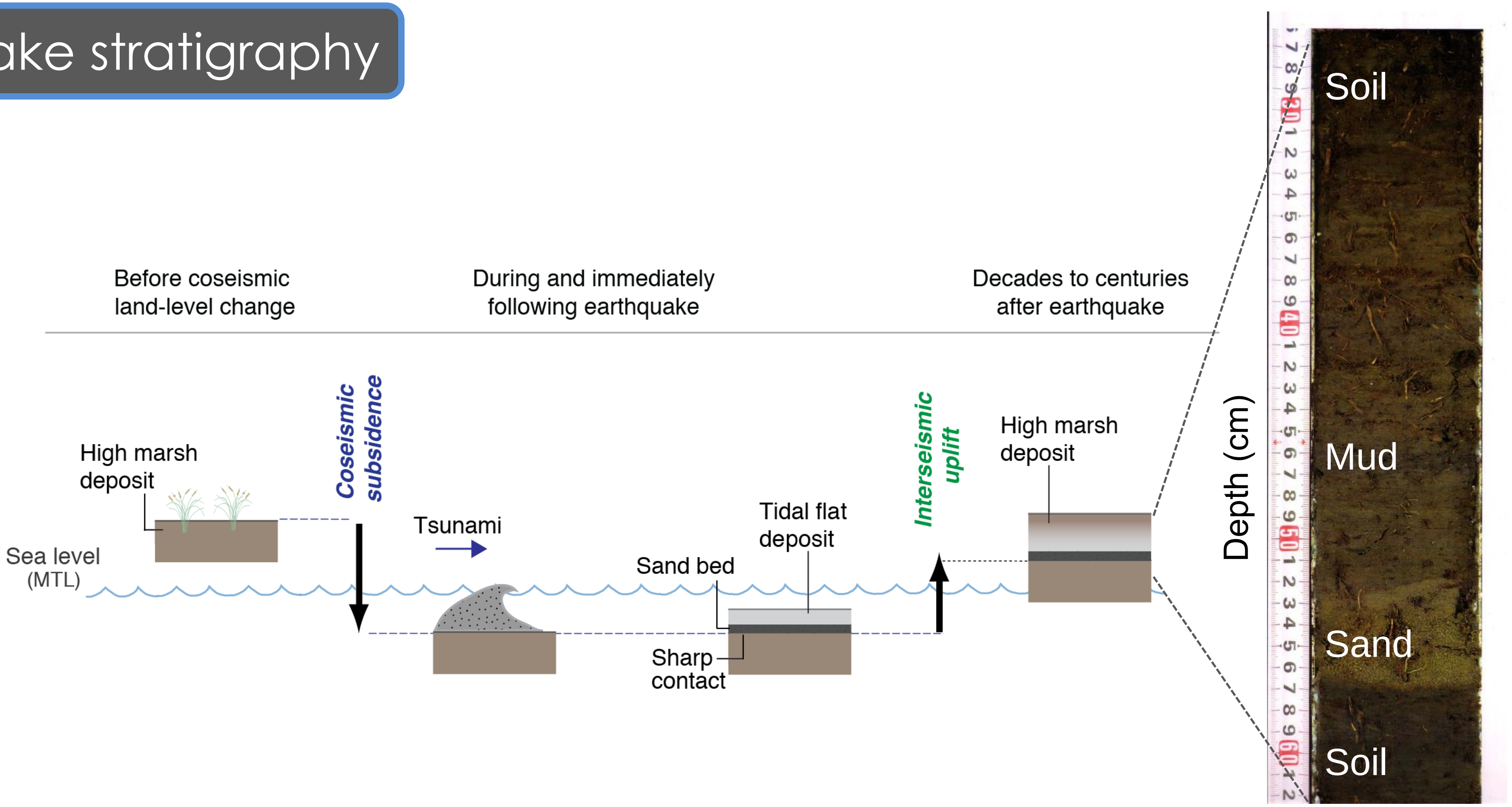

***Interseismic*** period = ***gradual*** deformation

***Coseismic*** period = ***sudden*** deformation

Recorded in the coastal stratigraphy as a ***series of relative sea-level (RSL) changes***

Presenter's notes: Coastal marshes, lagoons, estuaries that are sensitive to RSL changes are the best places to preserve earthquake and tsunami records.

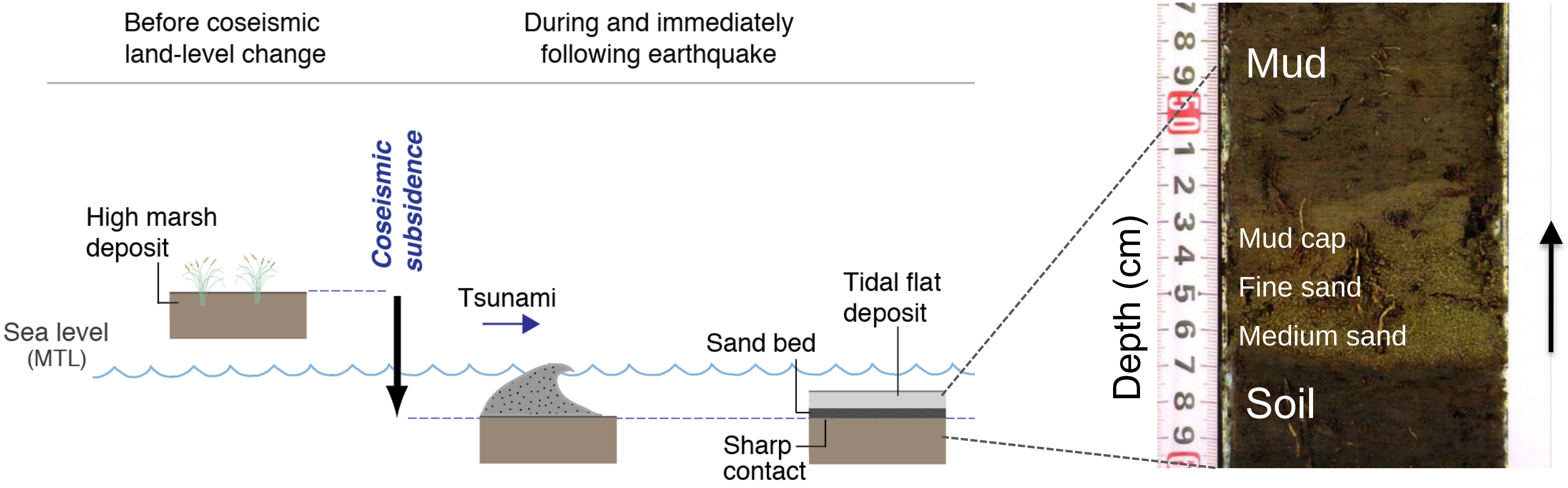
# Earthquake stratigraphy

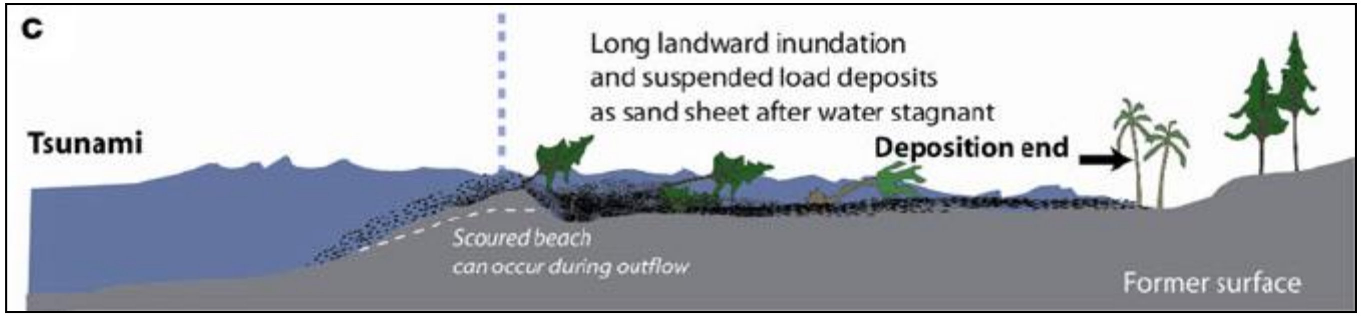



Need ***accommodation space:*** low-energy depositional environments

***Sharp contacts*** (1-3 mm), ***juxtaposition of environments, laterally continuous, correlated between regional sites***, sometimes with ***tsunami deposits***

# Tsunami stratigraphy




***Inverse and forward models***

Tsunami deposit characteristics: ***anomalous marine sediment, landward thinning and fining, upward fining, rip-up clasts, sharp or eroded lower contact, coincident with land-level change***

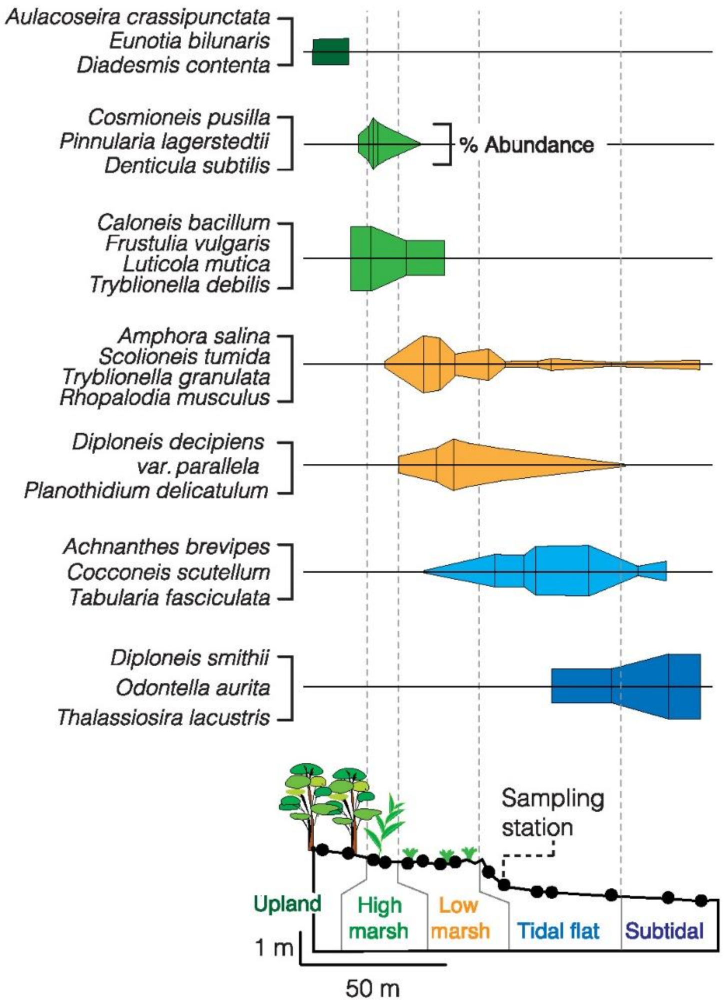
## Diatom-based studies

Photosynthetic, unicellular algae that inhabit ***freshwater, brackish and marine*** environments

Valuable in reconstructing paleoenvironmental changes due to their ***preferences to a number of environmental factors***

***Salinity and substrate*** for EQ and tsunami studies

Independent test of stratigraphic interpretations




Presenter's notes:

Photosynthetic, unicellular algae that inhabit ***freshwater, brackish and marine*** environments.
Valuable in reconstructing paleoenvironmental changes due to their ***preferences to a number of environmental factors.***
Preferences for ***salinity and life form are particularly valuable*** for earthquake and tsunami studies.

# Diatom-based studies

Photosynthetic, unicellular algae that inhabit ***freshwater, brackish and marine*** environments

Valuable in reconstructing paleoenvironmental changes due to their ***preferences to a number of environmental factors***

***Salinity and substrate*** for EQ and tsunami studies

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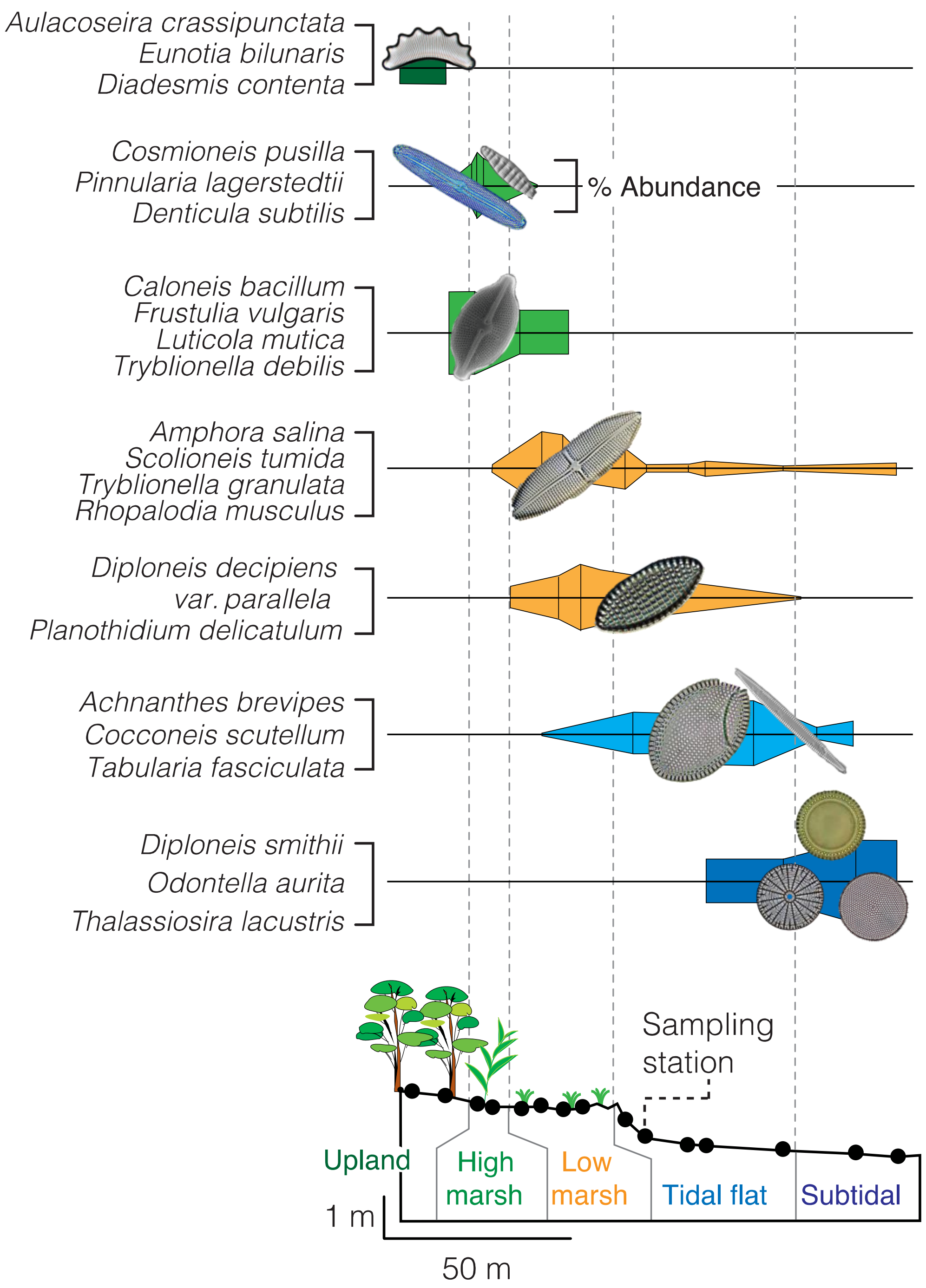
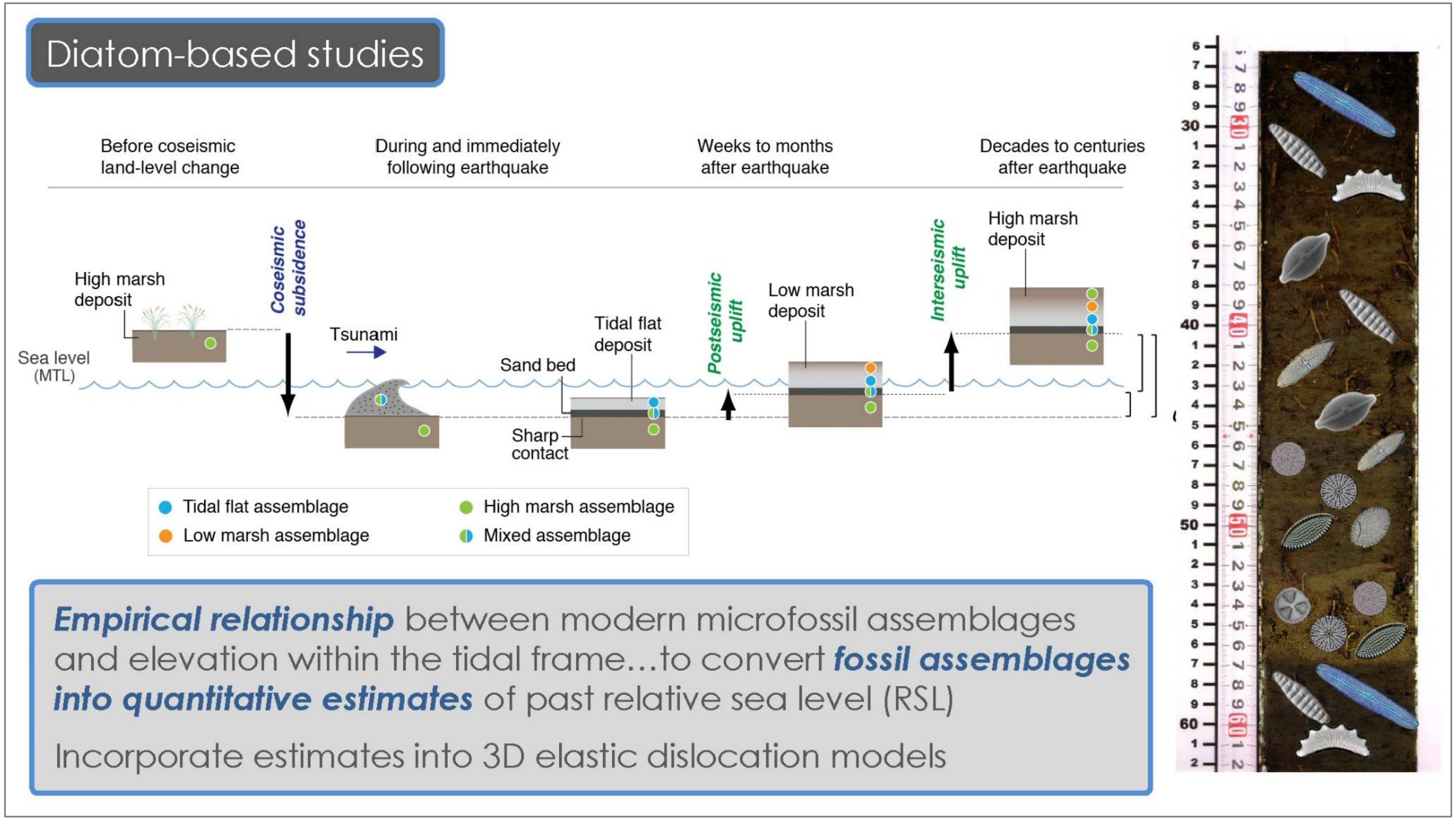
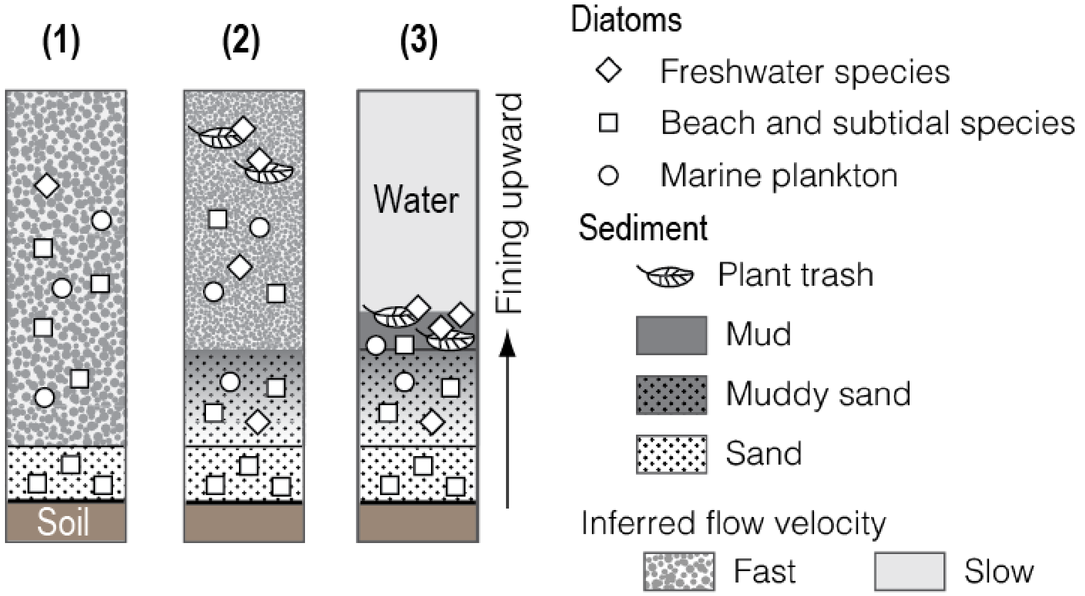


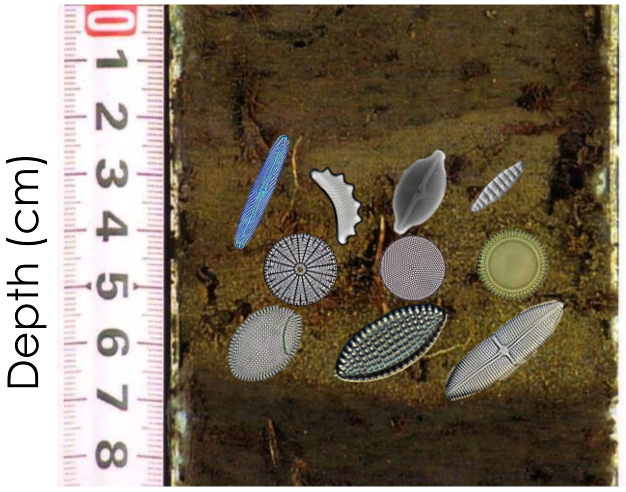



Presenter's notes: Diatom diagram is a cycle.

- Low-energy depositional environments with a strong environmental gradient are most likely to archive evidence of coseismic RSL changes.
- RSL changes are recorded by changes in lithology.
- Sharp (1-3 mm) contacts, laterally continuous, sometimes with tsunami deposits.
- Coastal stratigraphic records at Cascadia contain records > 6000 years.

# Diatom-based studies




Diatoms in tsunami deposits:

***Anomalous marine diatoms-*** provenance

***Low concentration-*** provenance

***High fragmentation-*** energy

***Normal grading-*** transport

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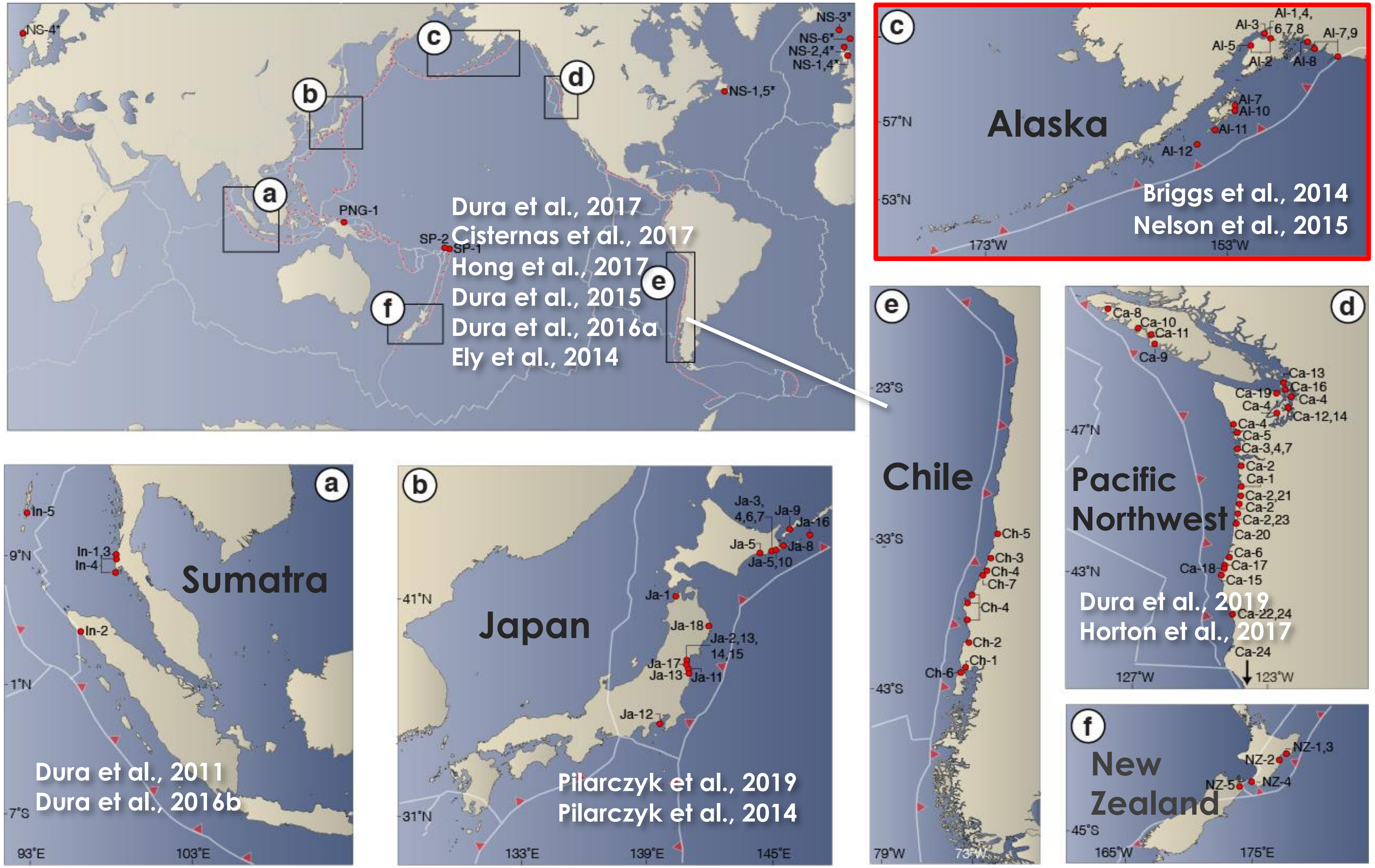
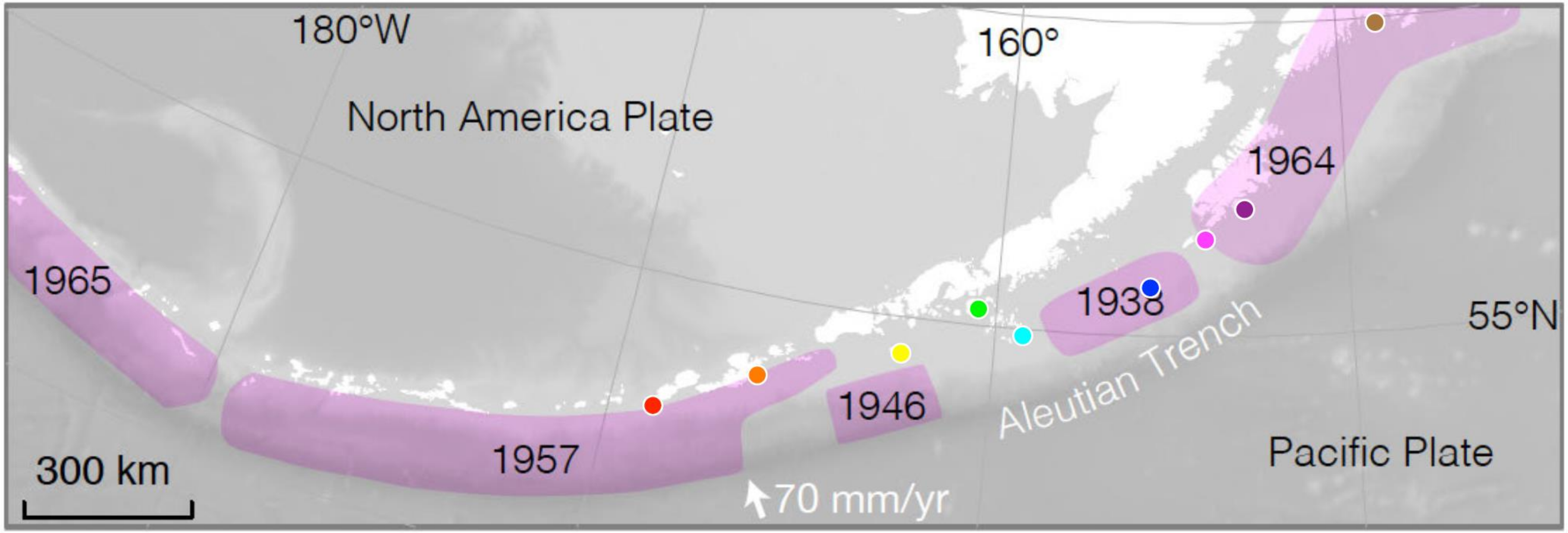
# The application of diatoms to reconstruct the history of subduction zone earthquakes and tsunamis

Tina Dura [a,b,*], Eileen Hemphill-Haley [c], Yuki Sawai [d], Benjamin P. Horton [a,b,e]



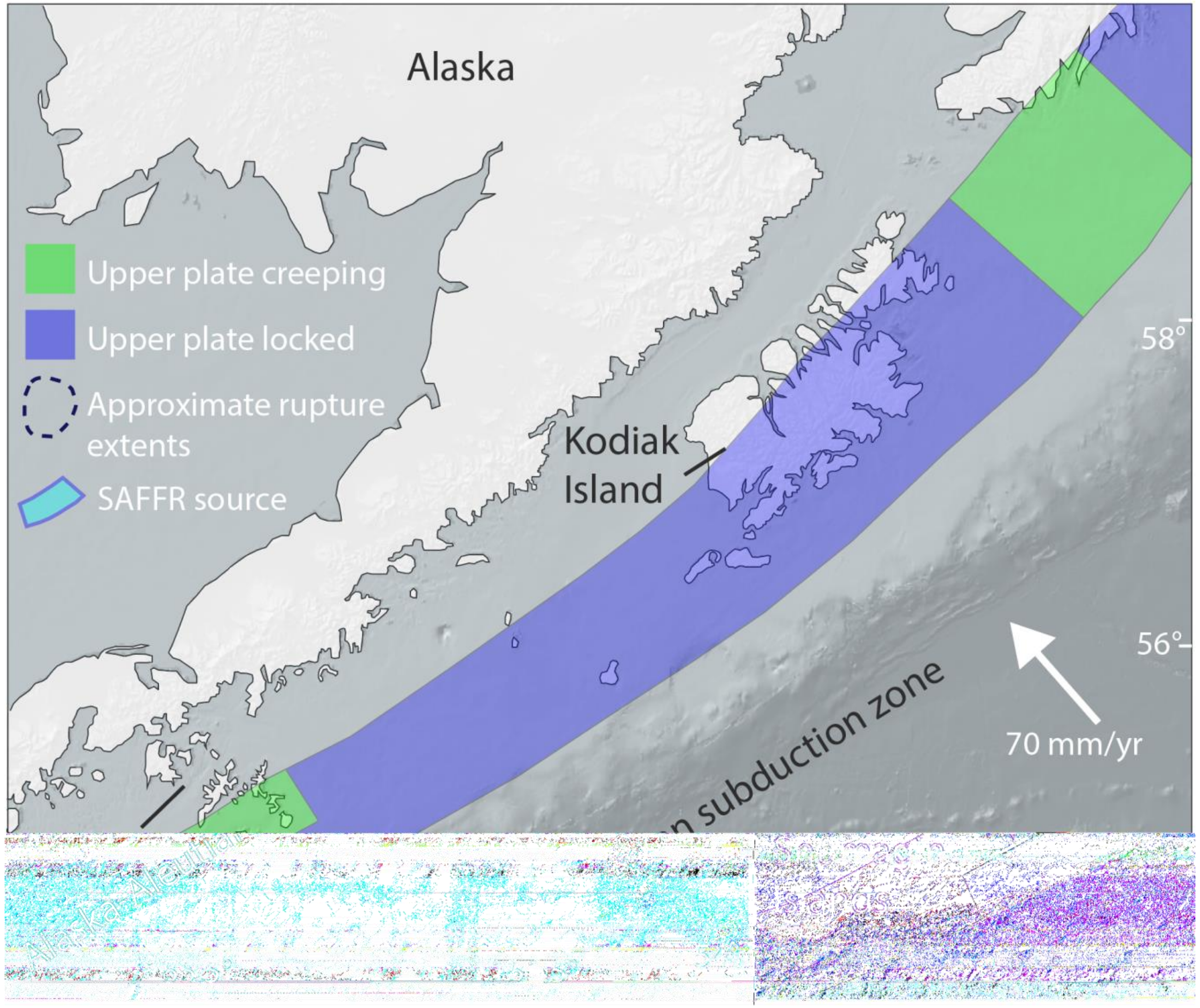
# Alaska-Aleutian subduction zone




## Nine investigations from 2010–2016

- Umnak Island
- Sedanka Island
- Sanak Island
- Unga Island
- Simeonof Island
- Chirikof Island
- Sitkinak Island
- Sitkalidak Island
- Kenai Fjords

# Alaska-Aleutian subduction zone




Active subduction zone

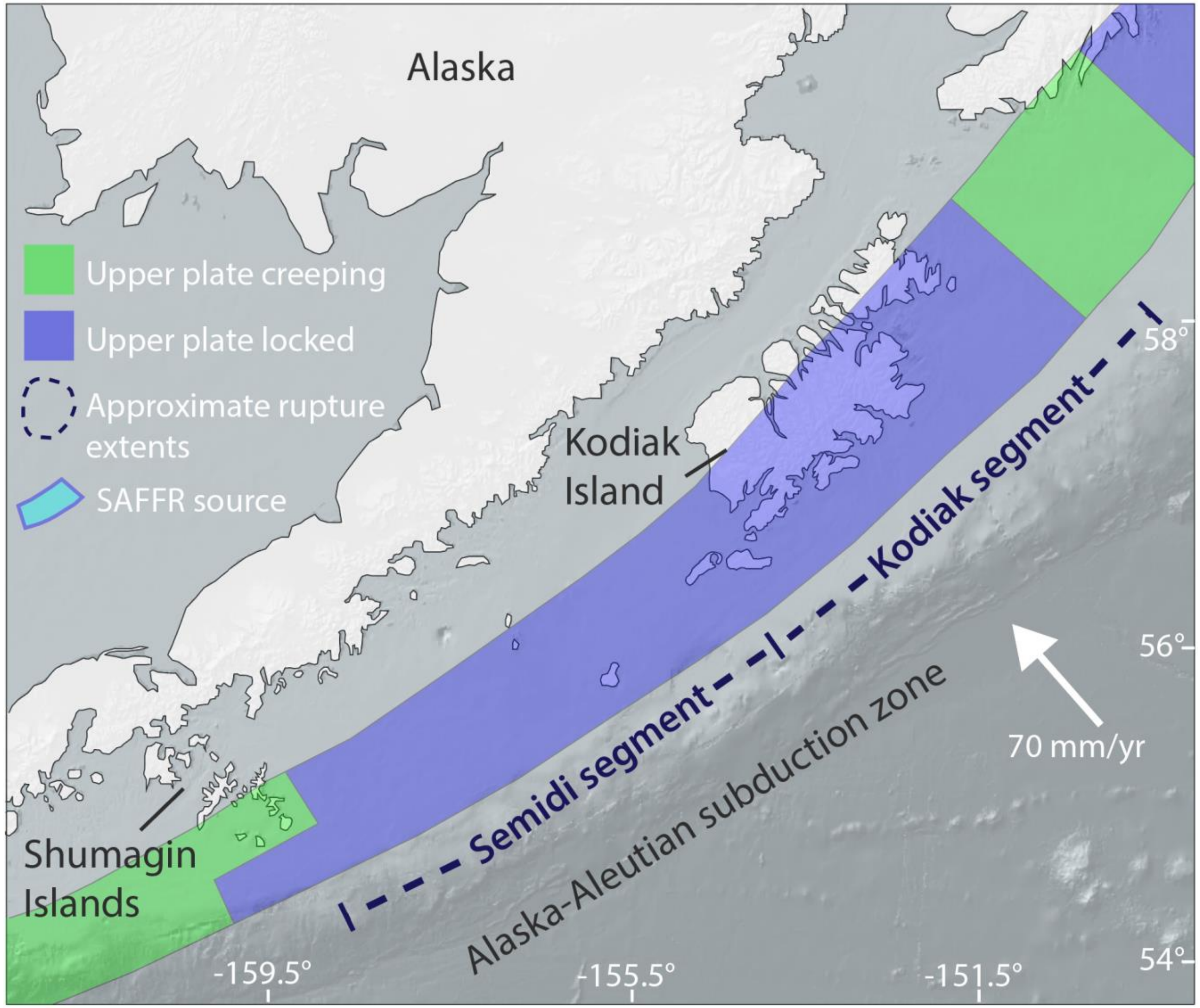
One "great" EQ ***(>M8)*** every ~13 years

One ***M7-8*** EQ per year

Six ***M6-M7*** EQ per year

Subduction zone highly coupled between eastern Kodiak Island and the Shumagin Islands

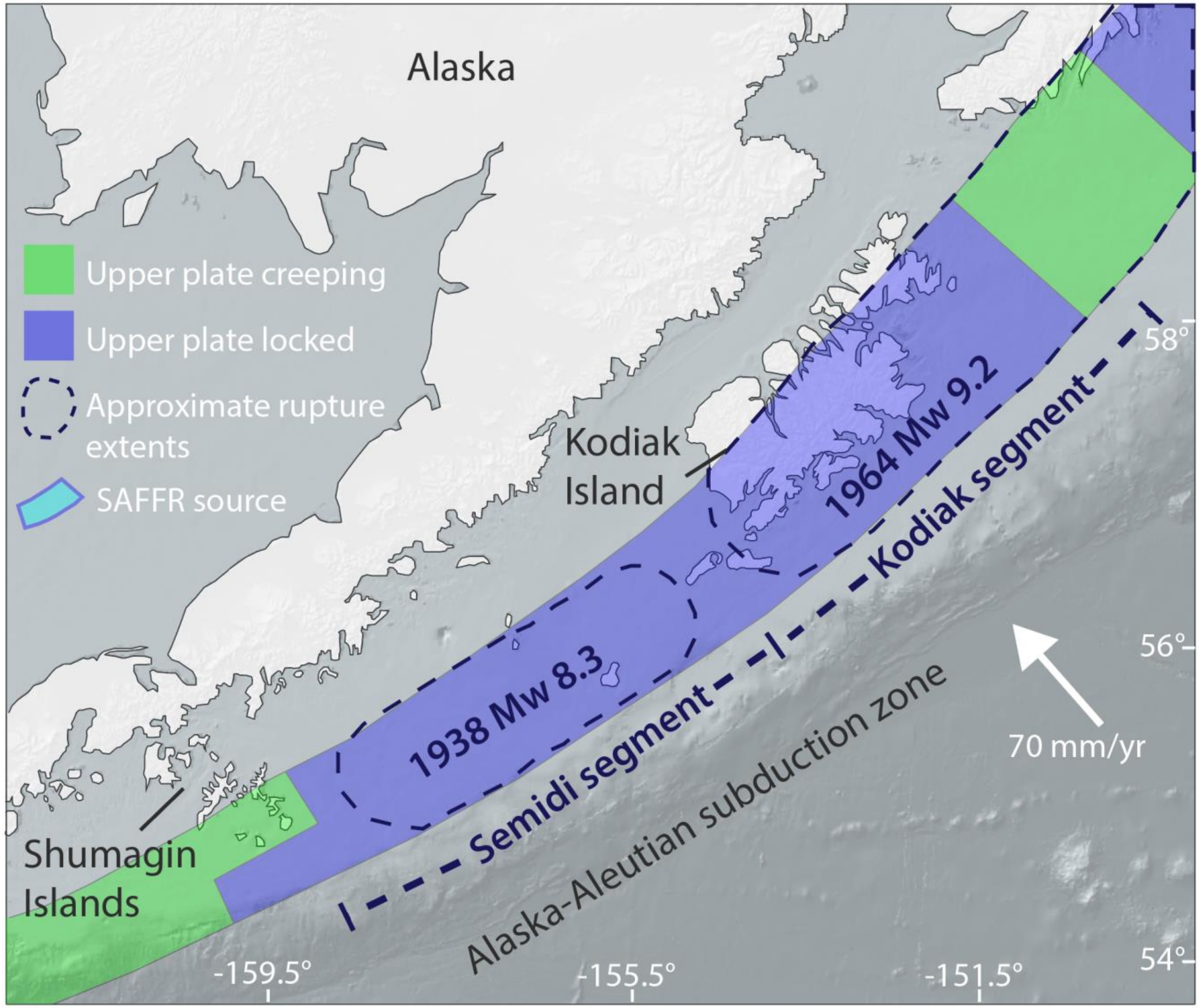
# Alaska-Aleutian subduction zone




Of particular concern: ***Semidi segment***

Orientation ***directs tsunamis to CA coast***

# Alaska-Aleutian subduction zone




Of particular concern: ***Semidi segment***

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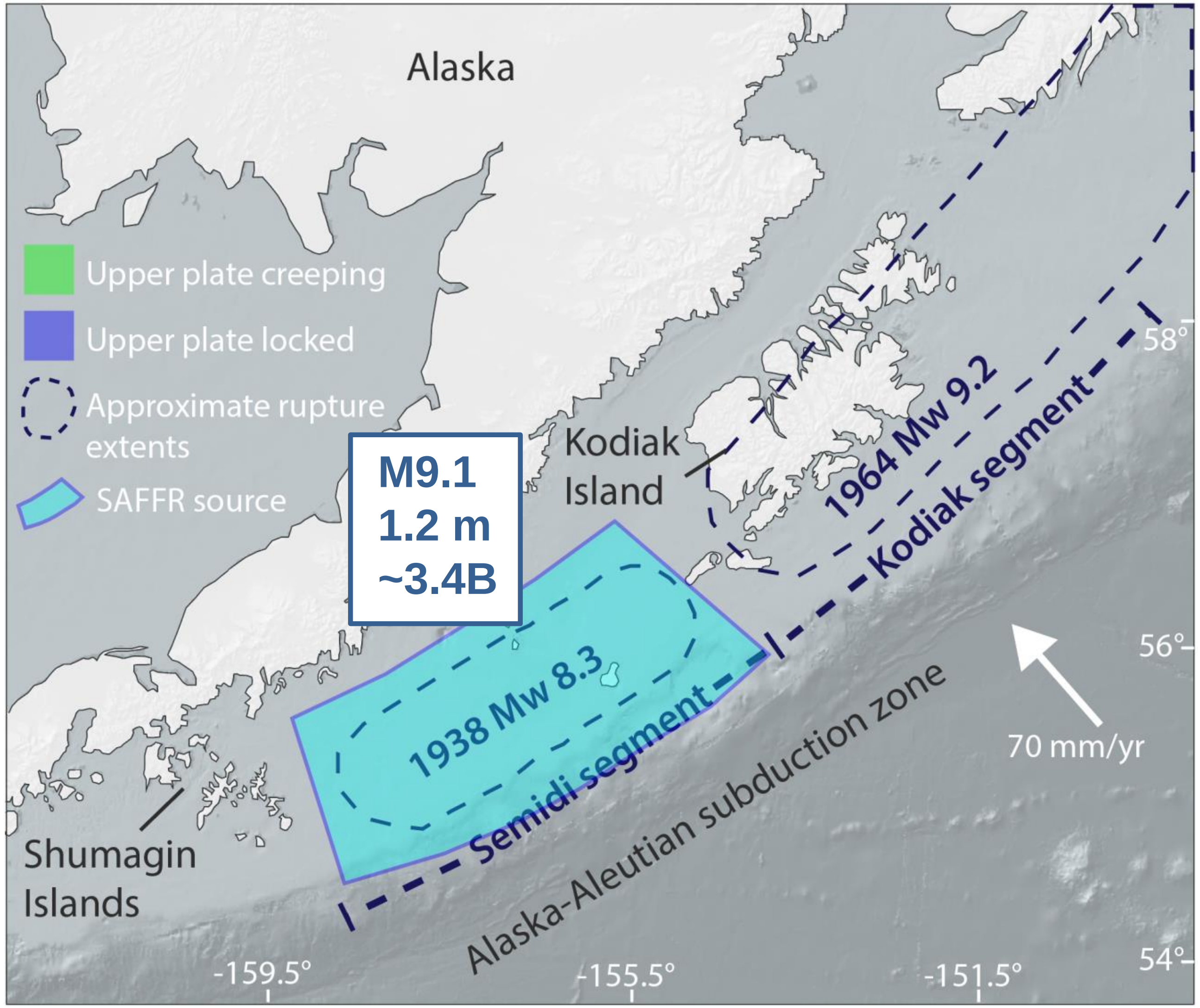
1964 was to the east on the ***Kodiak segment***

# Alaska-Aleutian subduction zone

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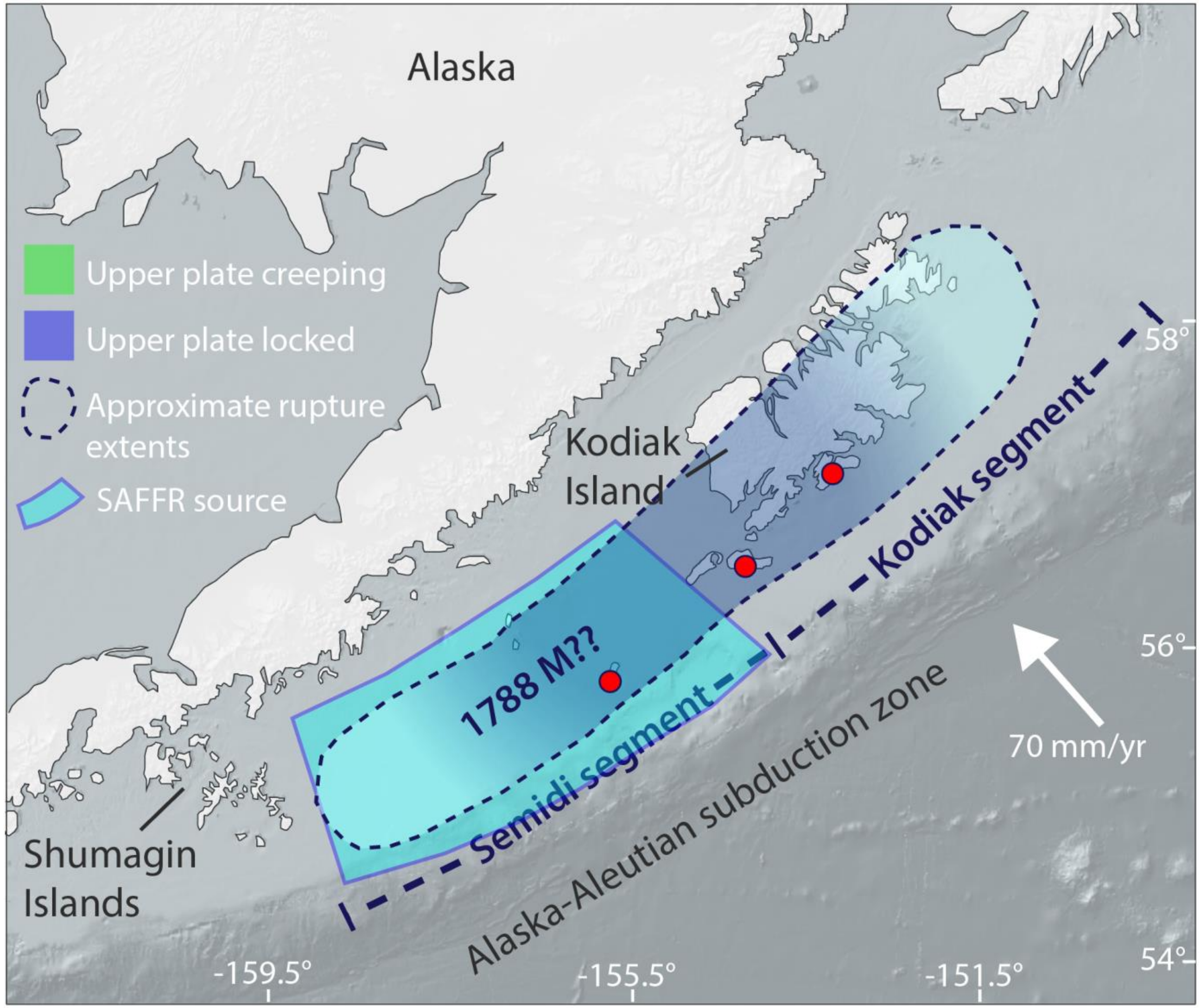
***SAFFR*** scenario (USGS)

# Alaska-Aleutian subduction zone




Of particular concern: ***Semidi segment***

Orientation ***directs tsunamis to CA coast***

Last EQ was in ***1938 (Mw8.3)***-did not reset

1964 was to the east on the ***Kodiak segment***

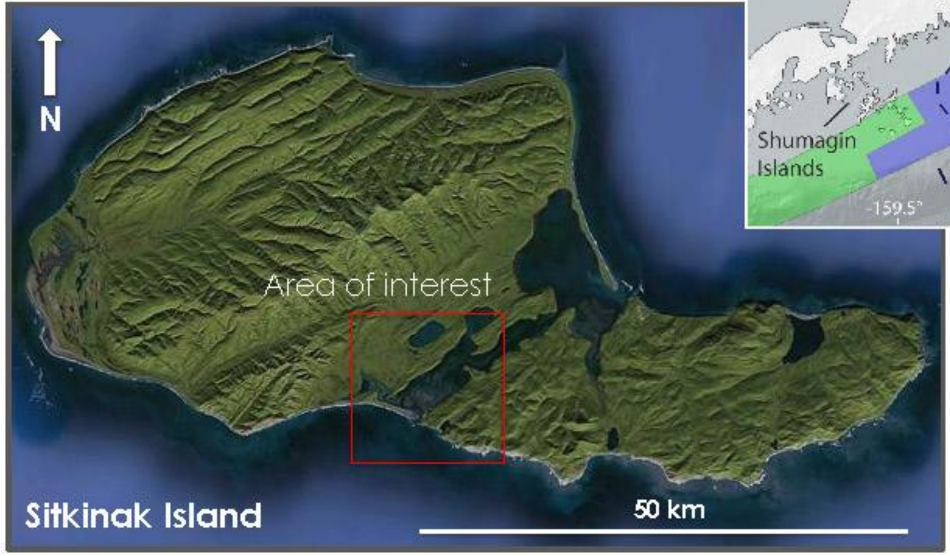
***SAFFR*** scenario (USGS)

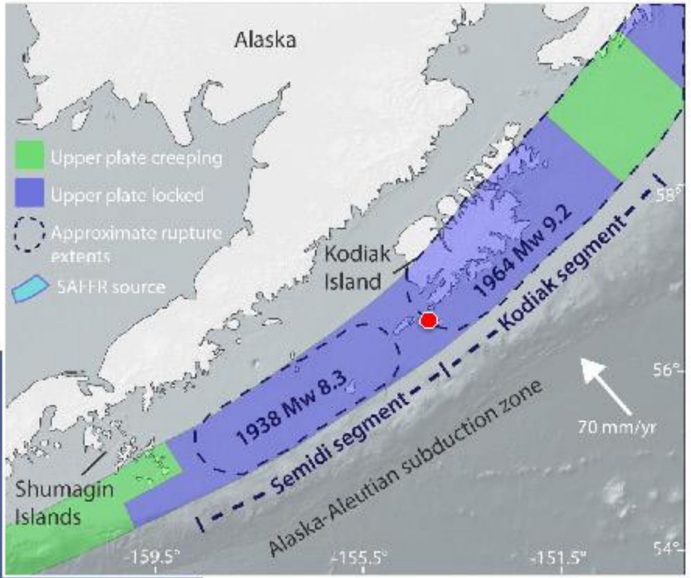
Need to consider ***multi-segment EQ's? RSL rise?***

# Sitkinak Island, Alaska

In the ***perfect location*** to catch tsunamis and land-level change

***Imagery shows low-energy depositional environments***



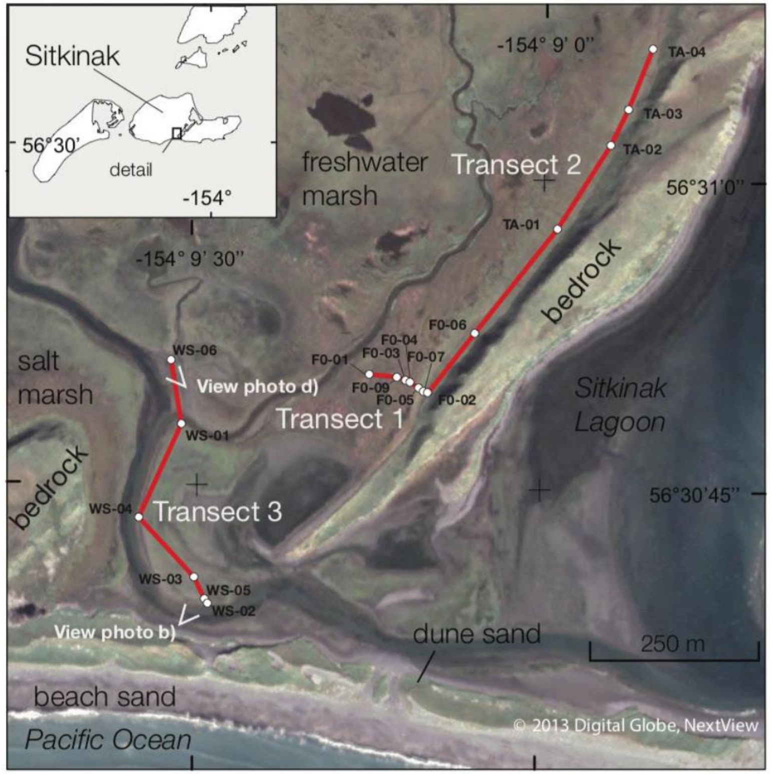




Presenter's notes:

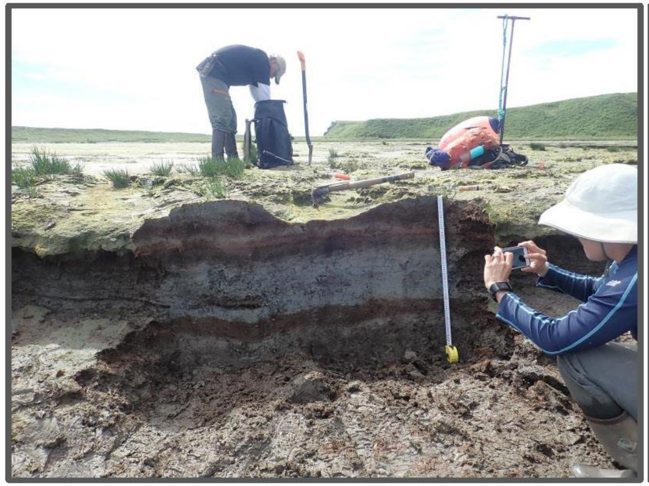
Assemble team.
Determine an area that we can learn a lot from.
Get there somehow.
Choose a site for coring etc.

Core.
Describe core.
Correlate and Survey.
Sample key sections.
Send samples home and process.
Everyone does their part to put the story together.

# Sitkinak Island: stratigraphic investigation

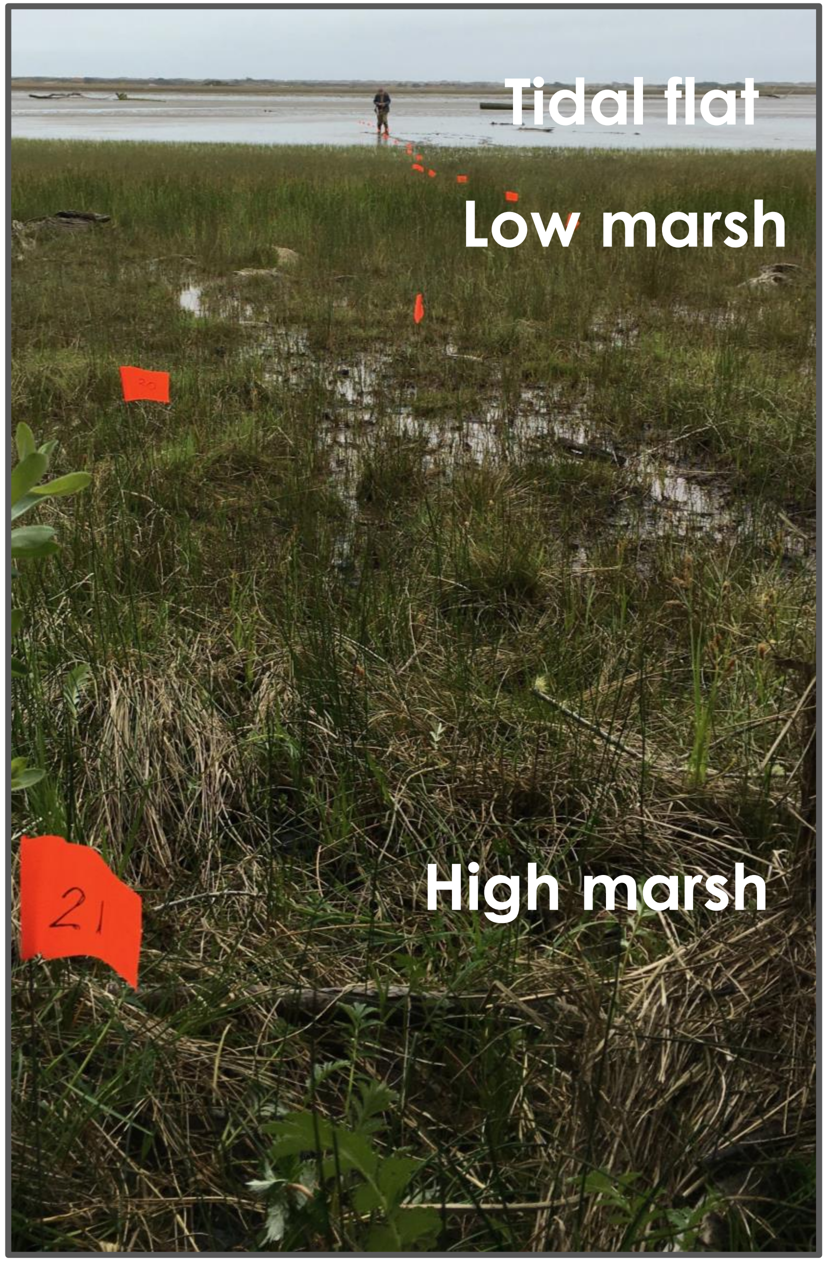


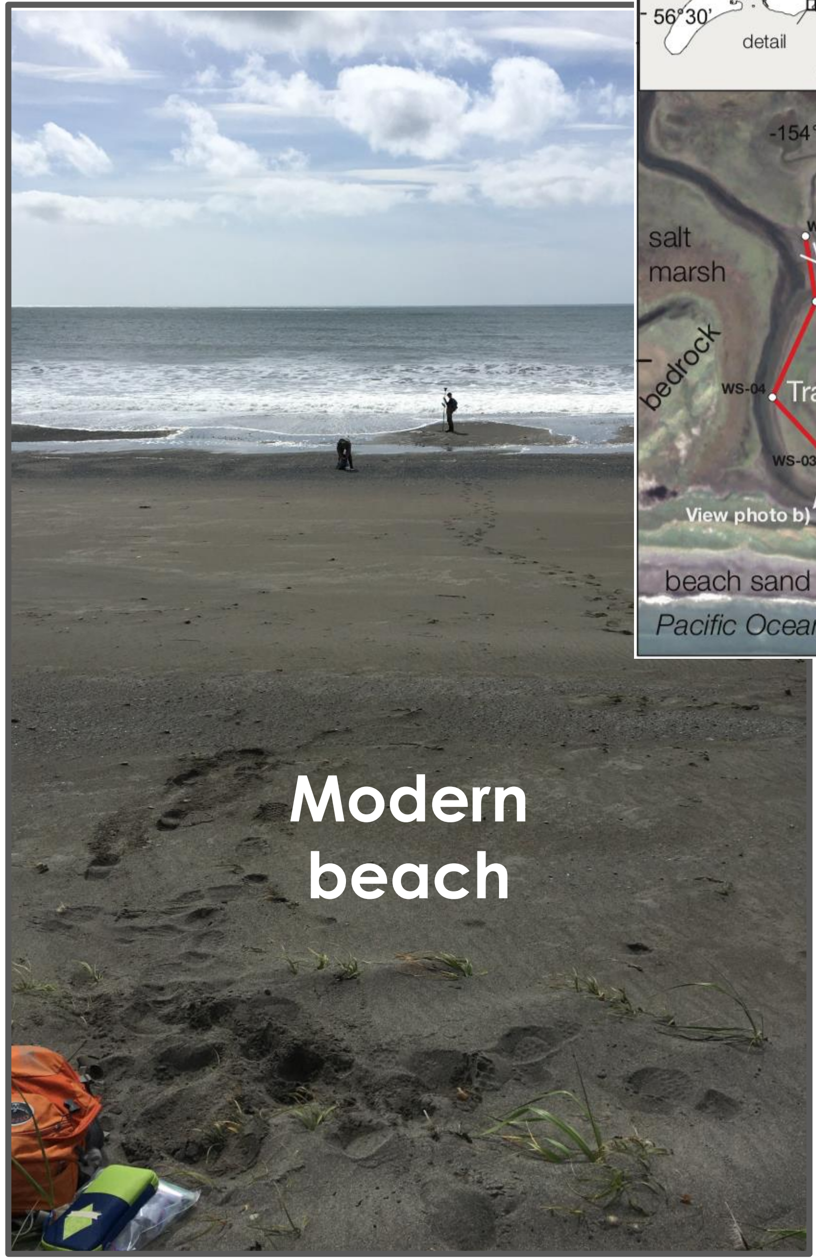


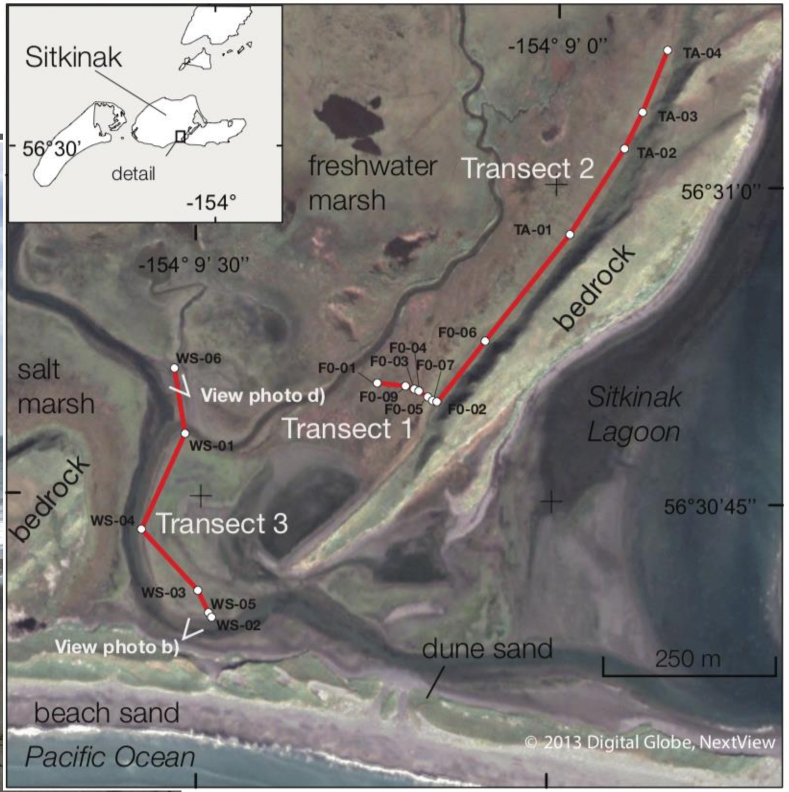


Presenter's notes: Position cores, cut banks, and pits over coast-parallel and coast-perpendicular transects (hundreds of meters)

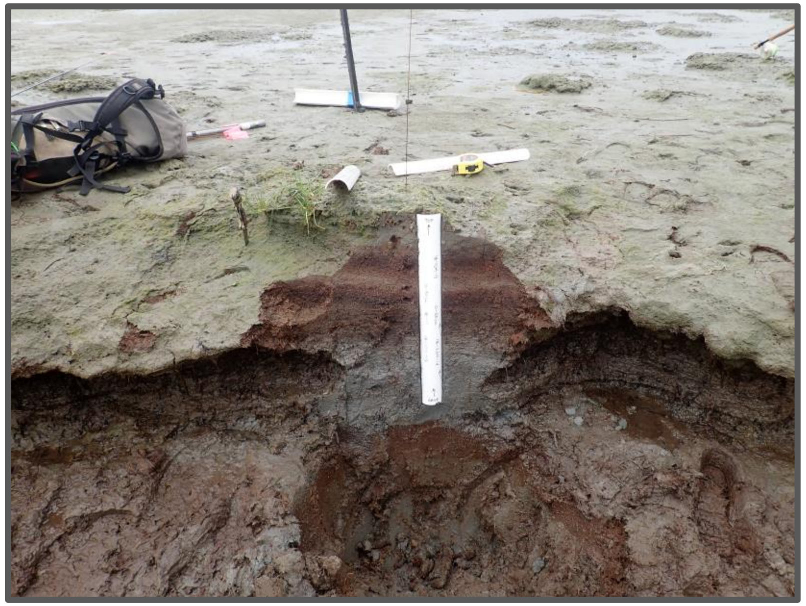
# Sitkinak Island: characterizing modern environments



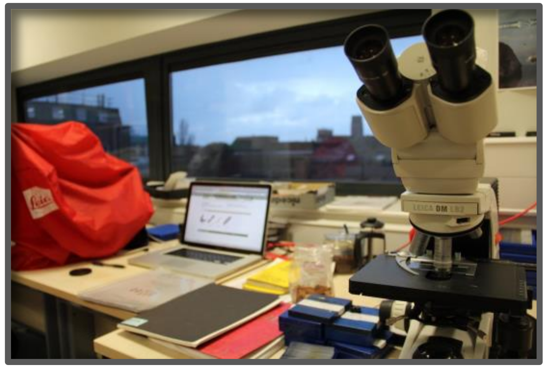



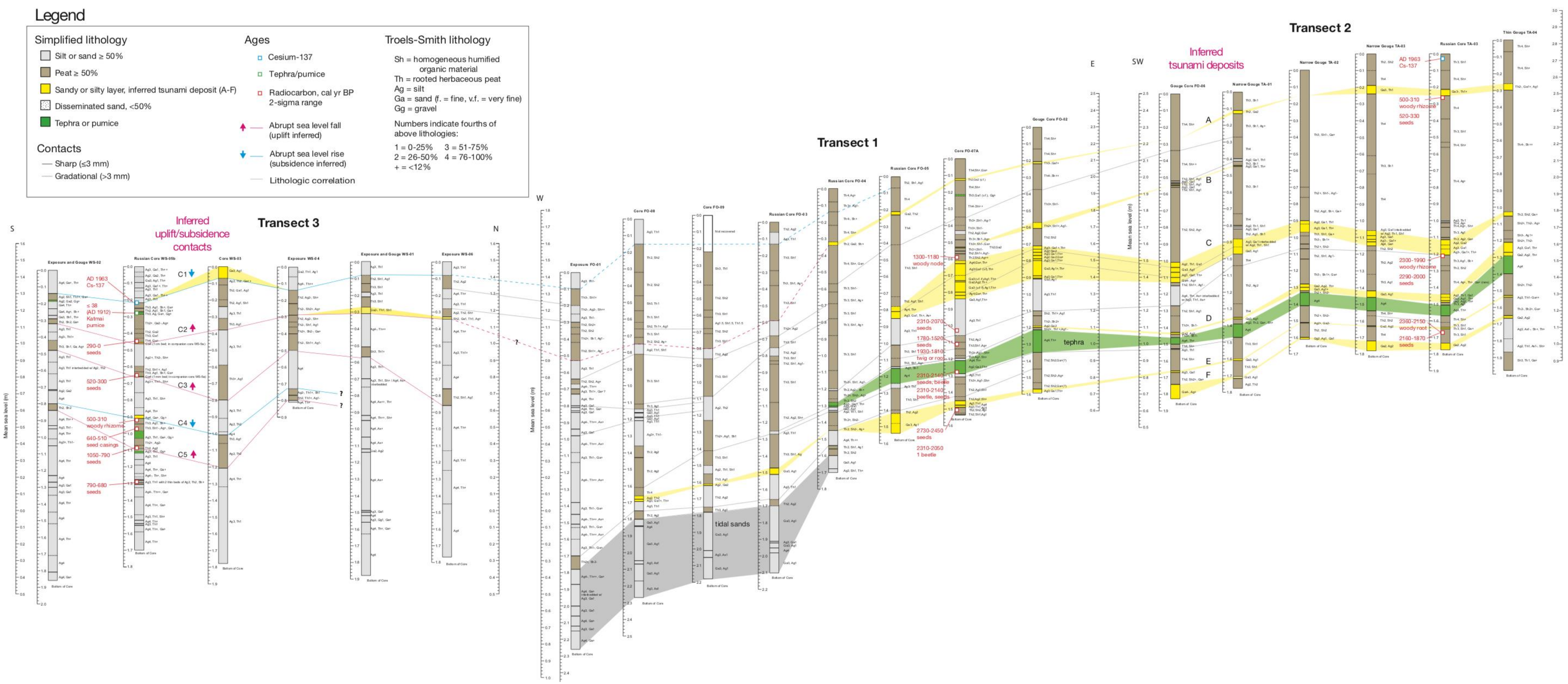
# Sitkinak Island: sampling and analysis





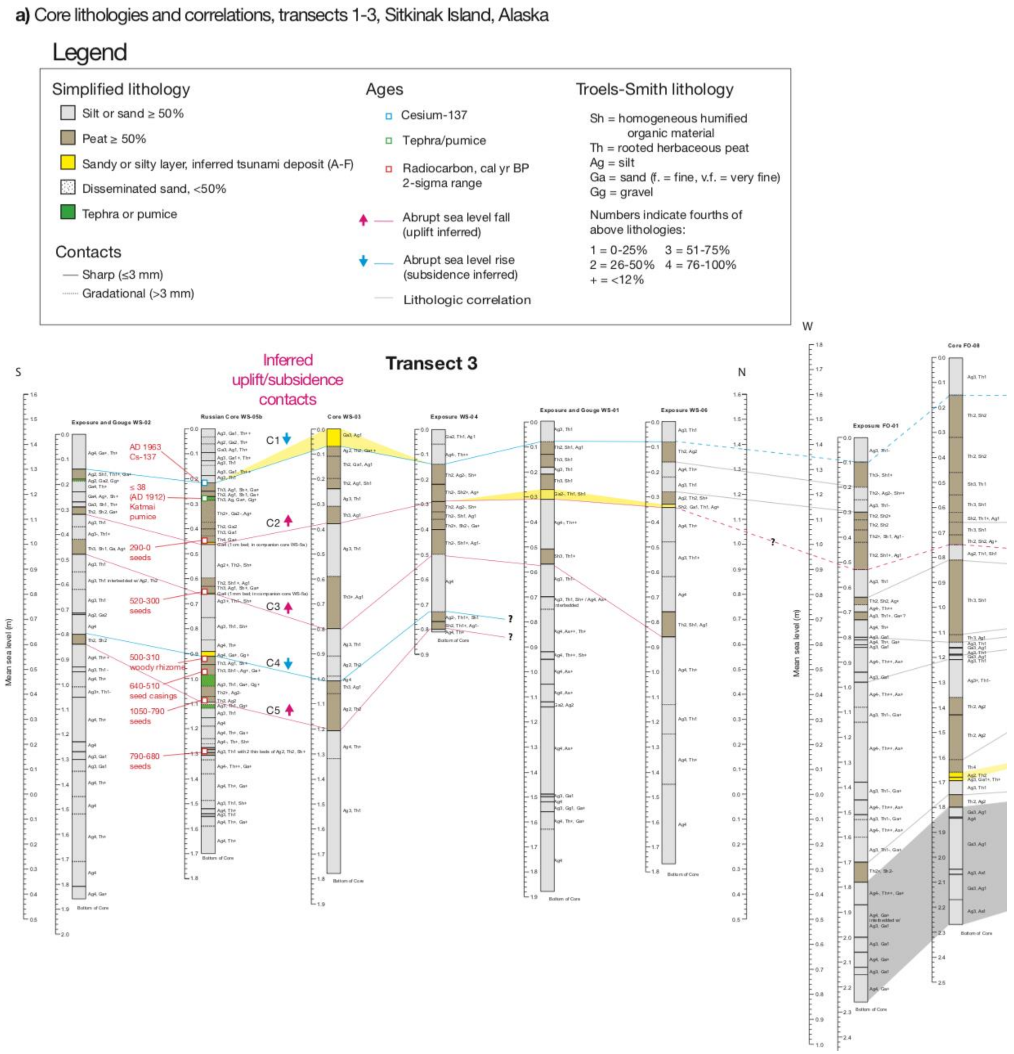



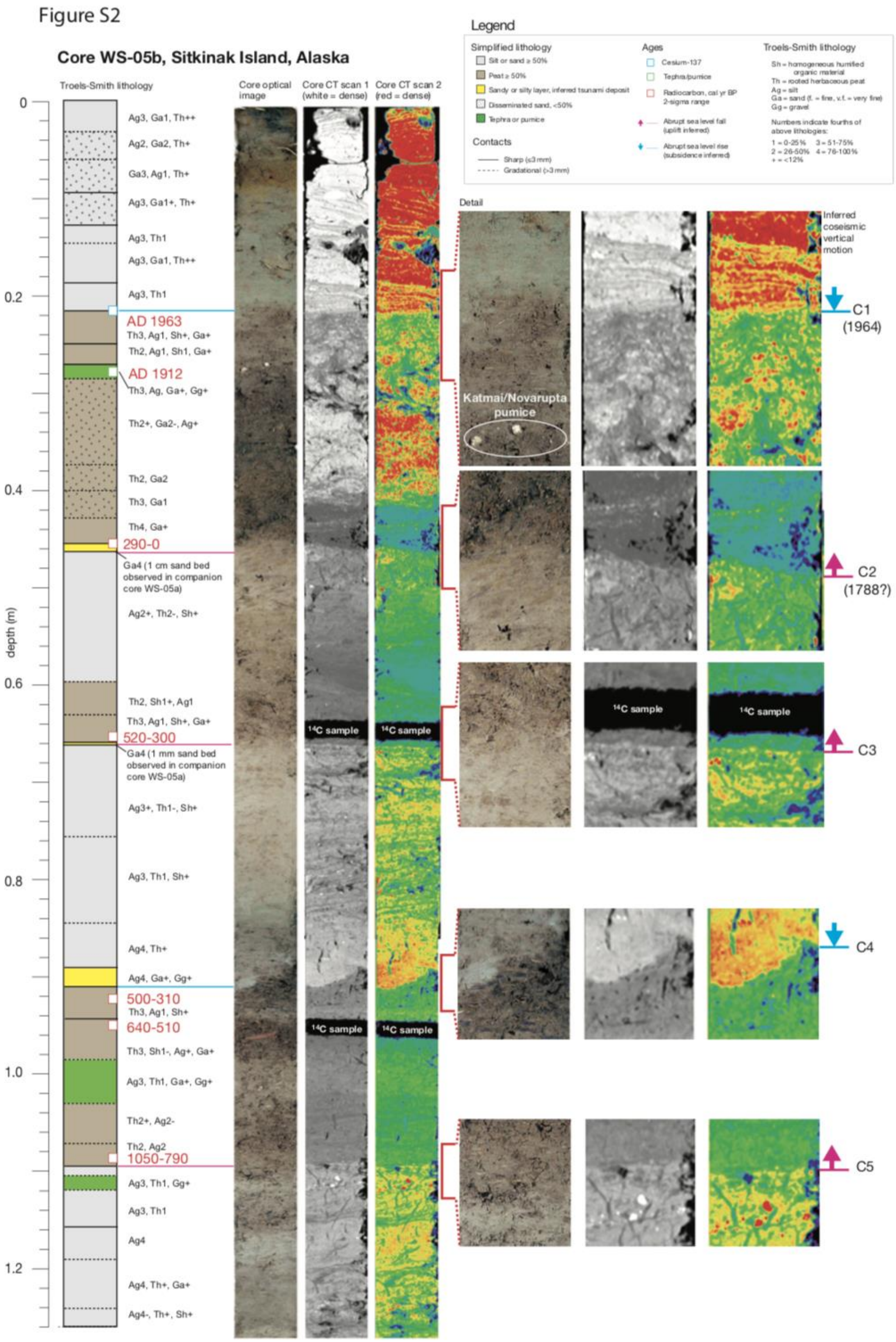
# Sitkinak Island: results

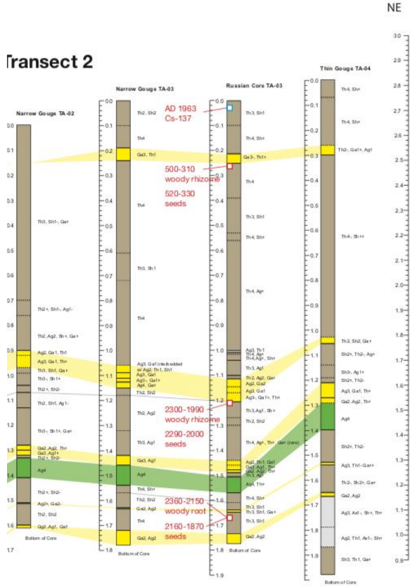


a) Core lithologies and correlations, transects 1-3, Sitkinak Island, Alaska

# Sitkinak Island: results



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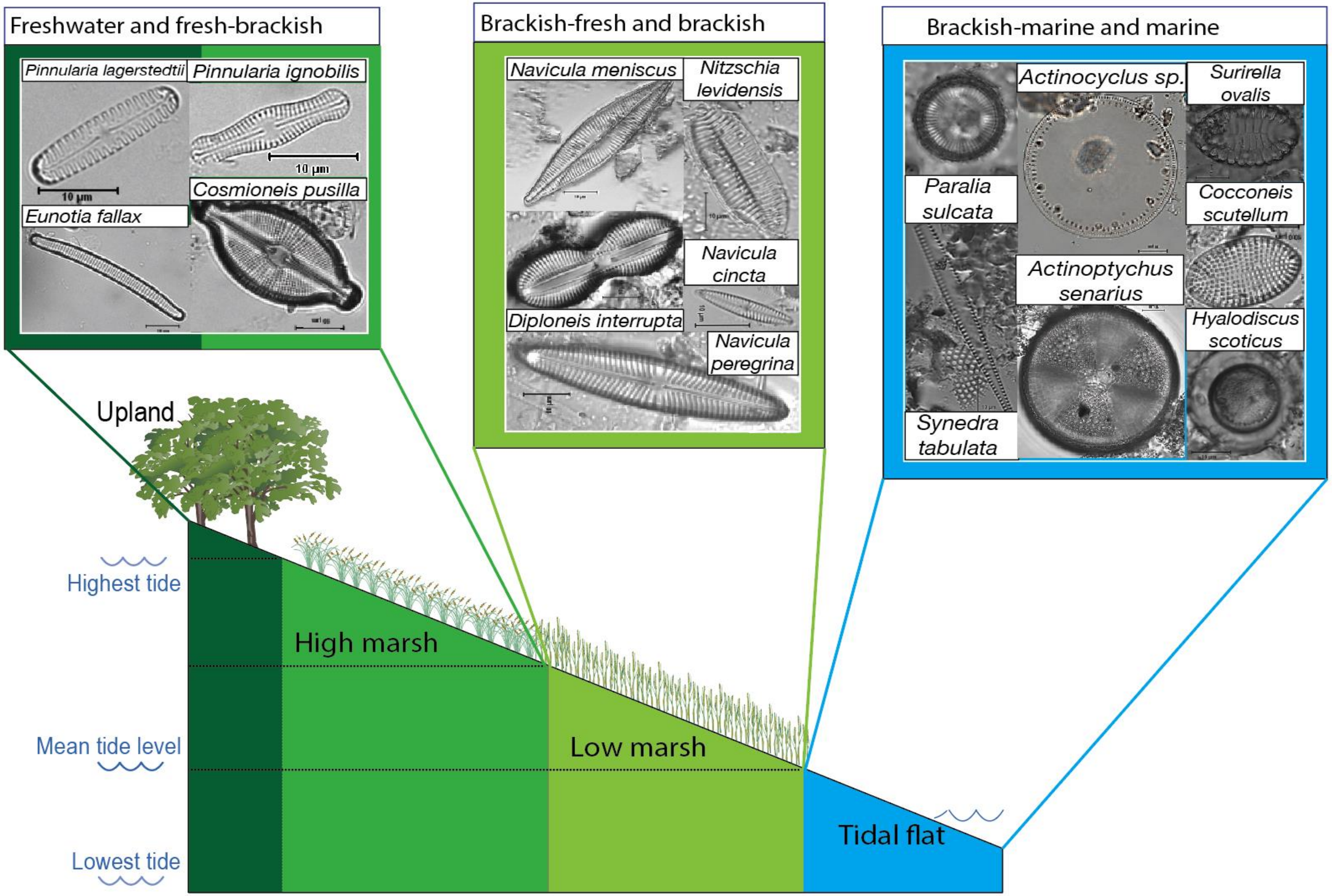

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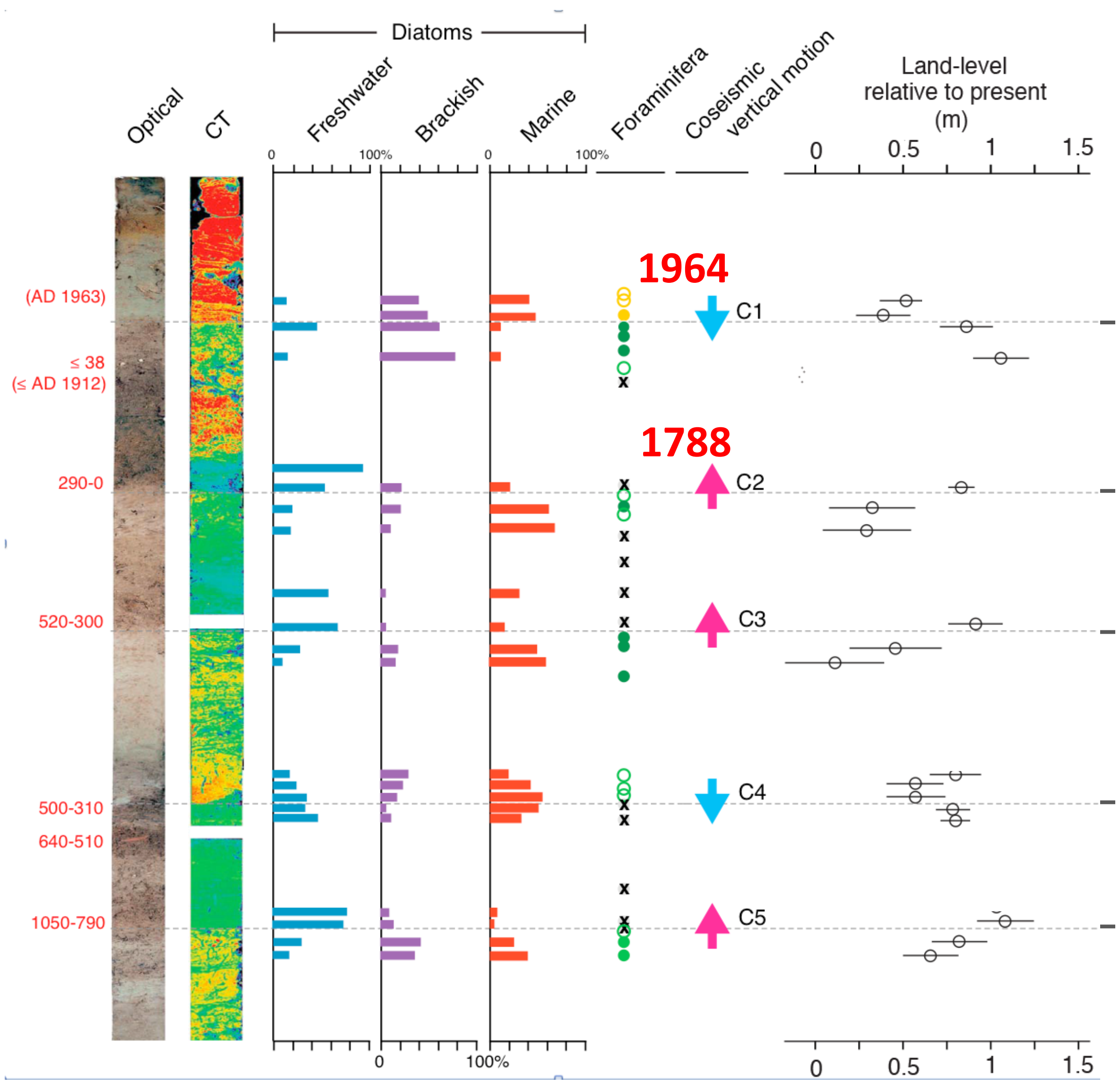
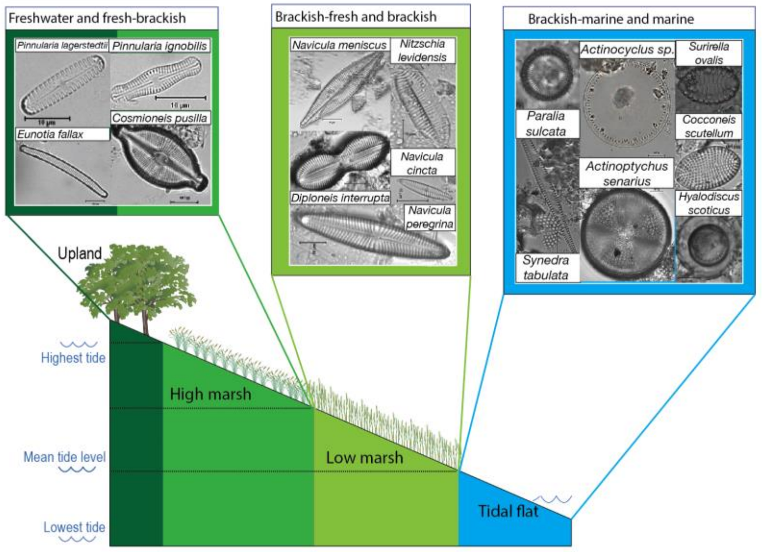
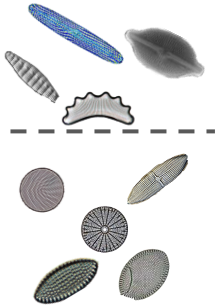



Tidal flat
Low marsh
High marsh
Low marsh
High marsh
Tidal flat
Tidal flat
High marsh
High marsh
Tidal flat



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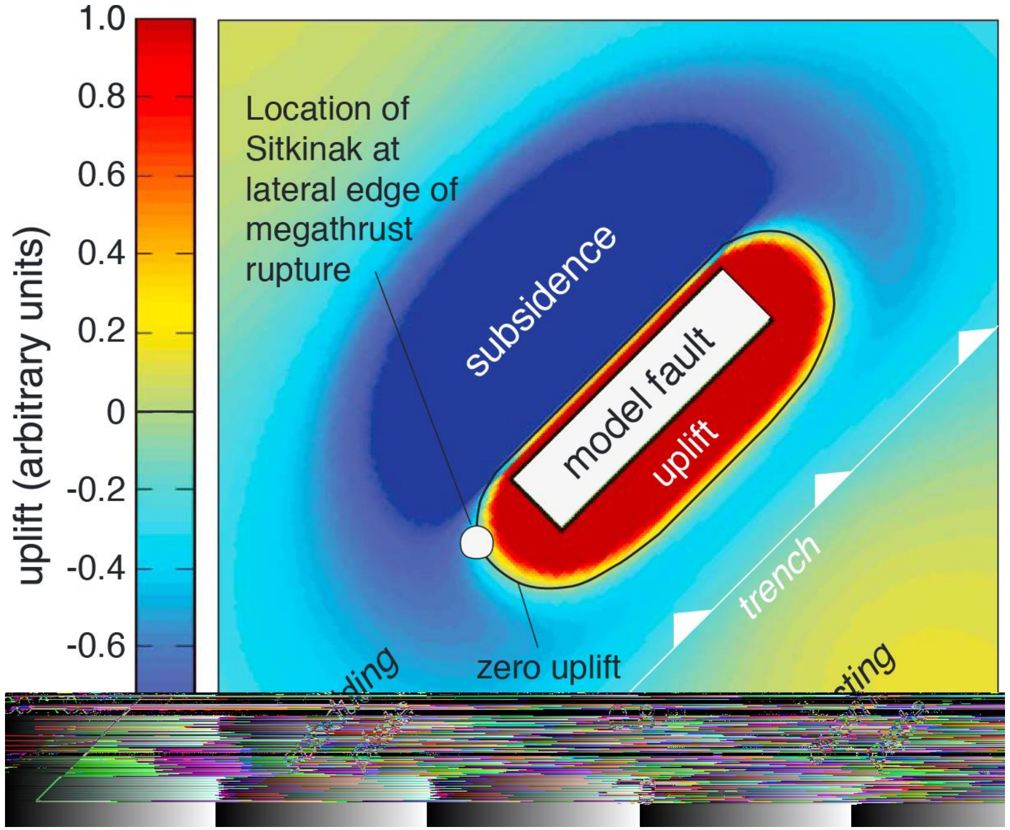
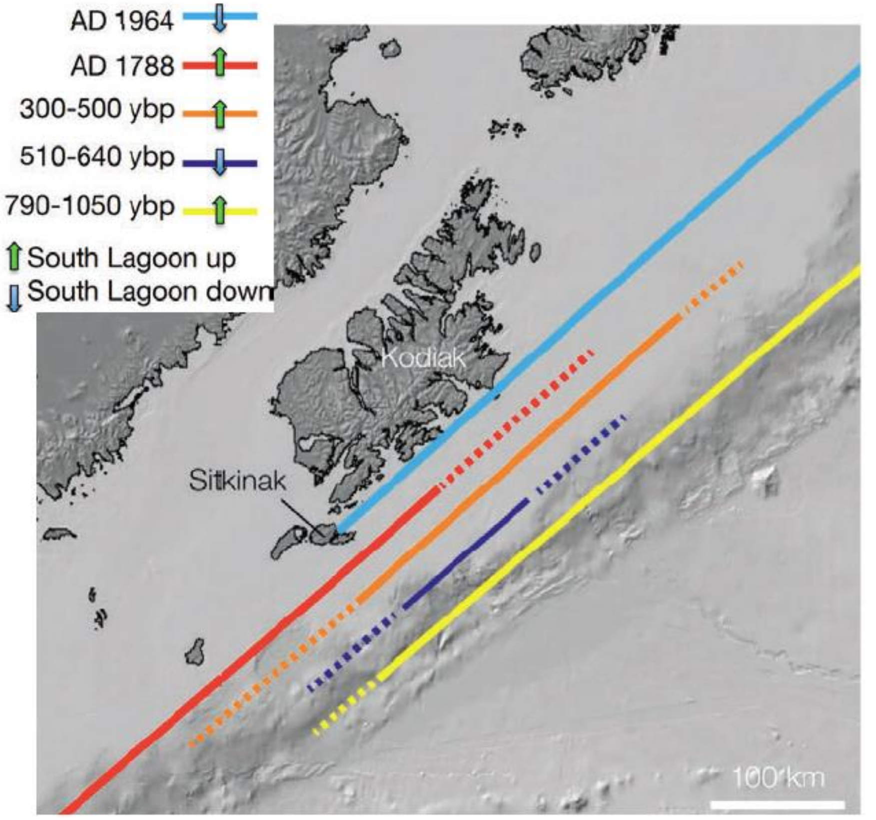



When ruptures ***stop at Sitkinak*** you get ***coseismic subsidence***

When ruptures ***propagate through Sitkinak*** you get ***coseismic uplift***

***This suggests that the segment boundary is not persistent***

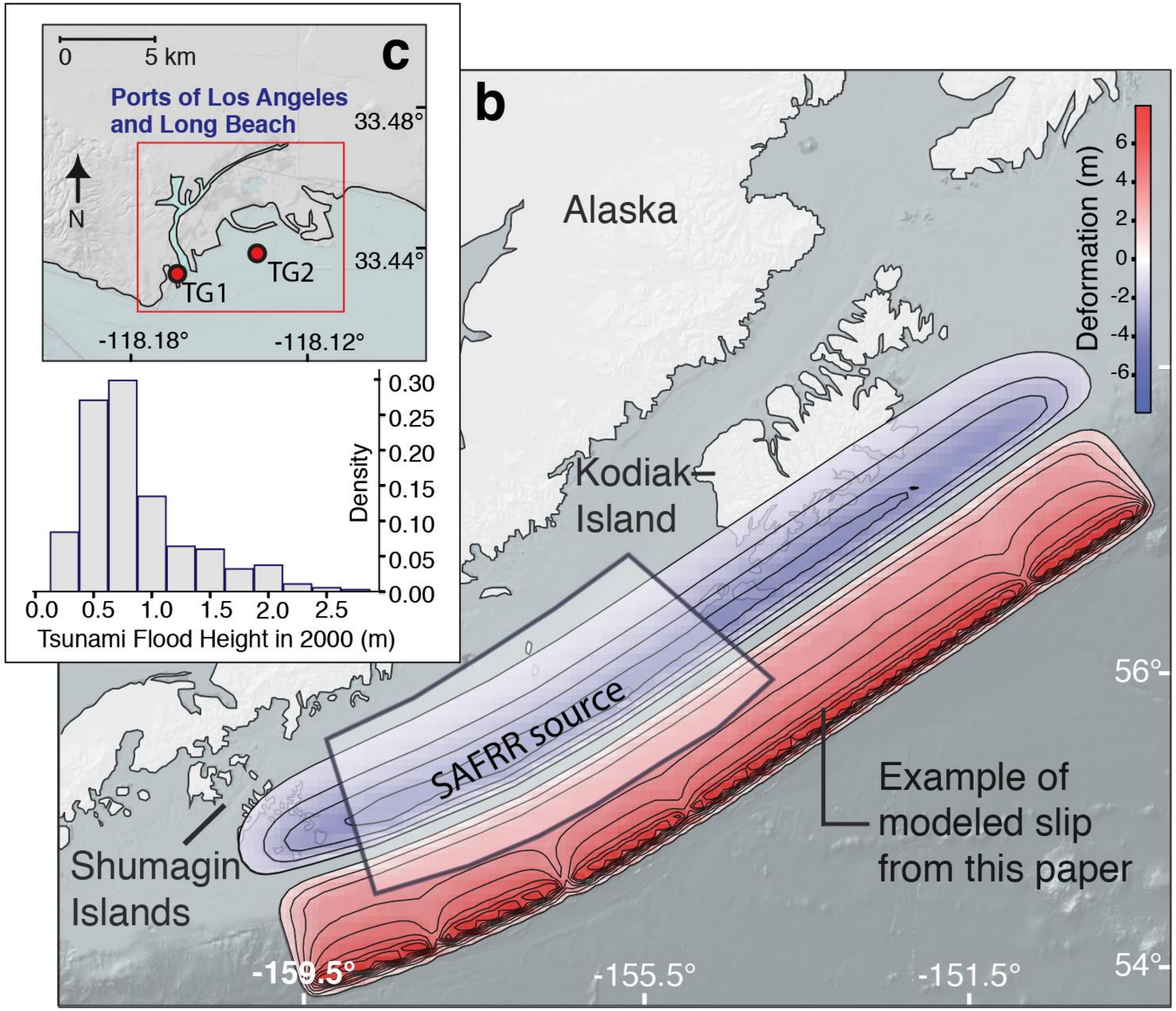
# Multi-segment earthquake far-field tsunami impacts

***Next steps:***

Take results and ***incorporate them into seismic hazard maps***

Use results to ***inform earthquake and tsunami modeling*** to learn more about potential impacts of future events

Consider ***compounding hazards***

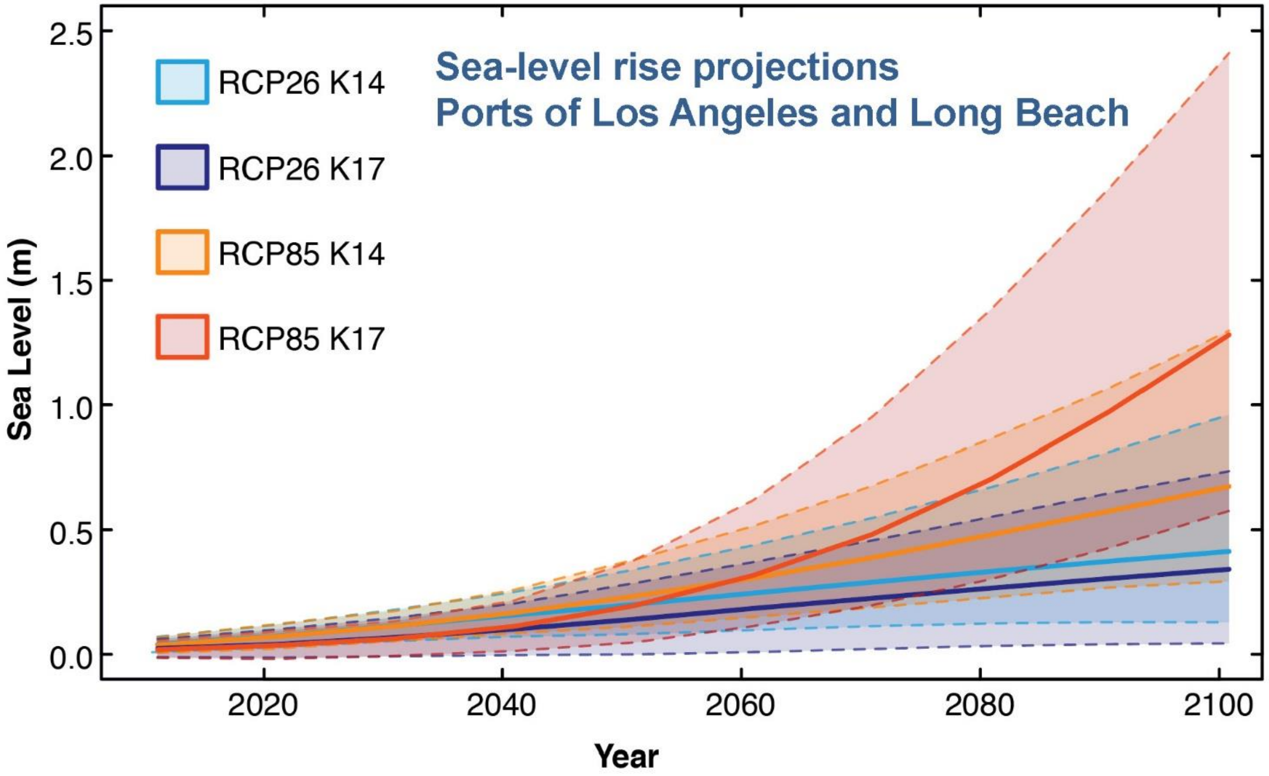


## Compounding impacts of tsunamis and relative sea-level rise

RCP2.6 K14 and K17
**2050: ~0.25 m**
**2100: ~0.5 m**
**Worst case: ~1.5 m**

RCP8.5 K14 and K17
**2050: ~0.25 m**
**2100: ~1.0 m**
**Worst case: ~2.5 m**

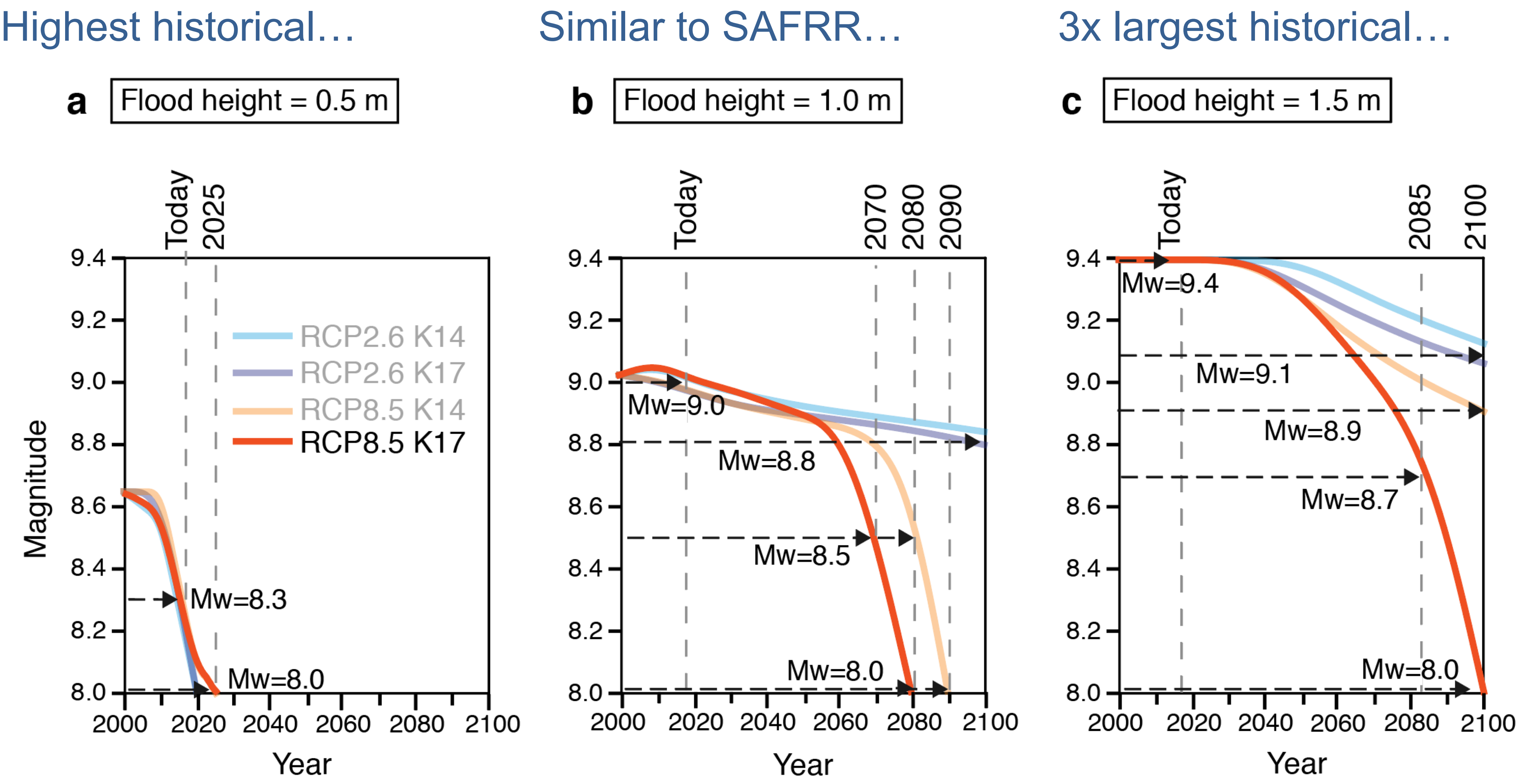
***Need to add this to tsunami inundation heights to get the full picture of possible future flood heights***




Presenter's notes:

***K14 projections*** based on estimates of thermal expansion/ocean dynamics, glacier melt, ice sheet of Bamber and Aspinall (2013), land water storage, non-climatic local sea-level change, and gravitational, elastic, and rotational effects on local sea-level change from geophysical modeling.
***K17 projections*** include an enhanced contribution from the Antarctic Ice Sheet (AIS).

# Compounding impacts of tsunamis and relative sea-level rise




EQ magnitude that has a ***50/50 chance of exceeding a certain flood height***, as a function of time

# Collaborators


Sea-level projections


Earthquake modeling



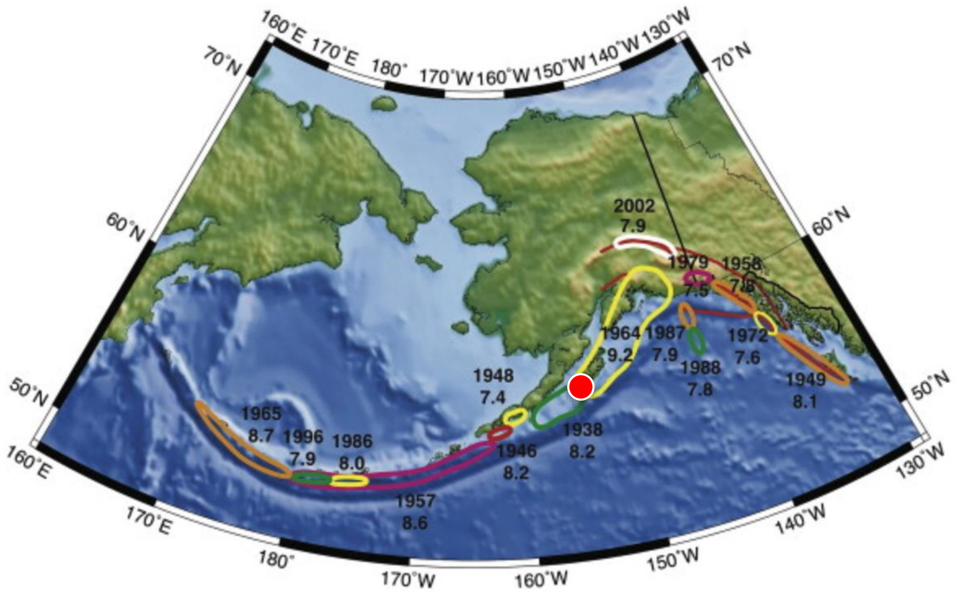
Tsunami modeling

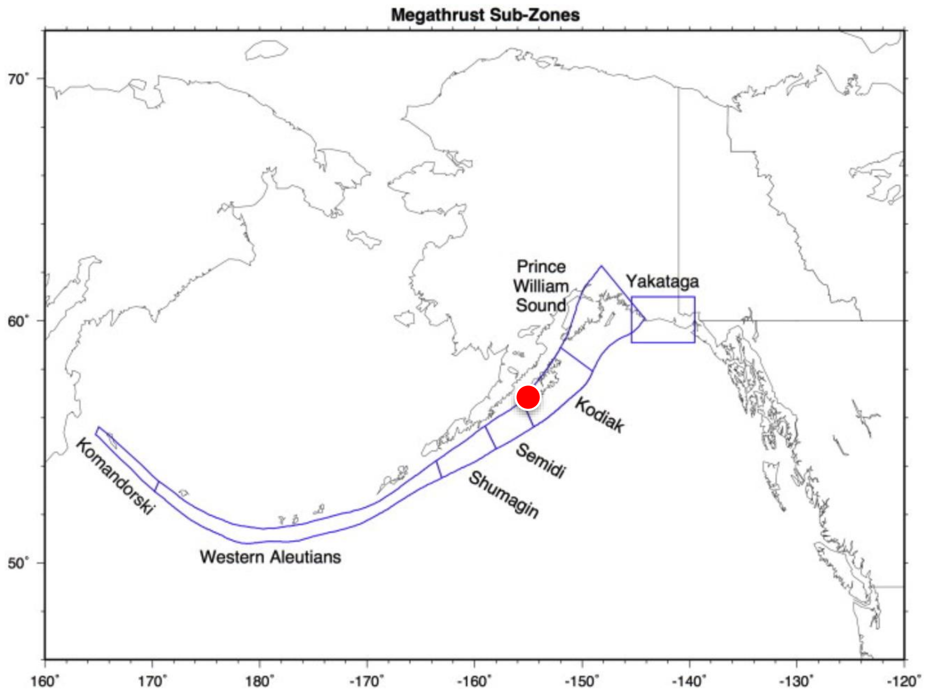

Sea level reconstructions

# Destination: Sitkinak Island

*Goals*:

1. ***Reconstruct land-level change and tsunami inundation***
2. ***Characterize slip during past ruptures***
3. ***Evaluate the persistence of a proposed segment boundary***
4. ***Update hazards maps if needed***




Mueller et al., 2015

# Sitkinak Island: research summary

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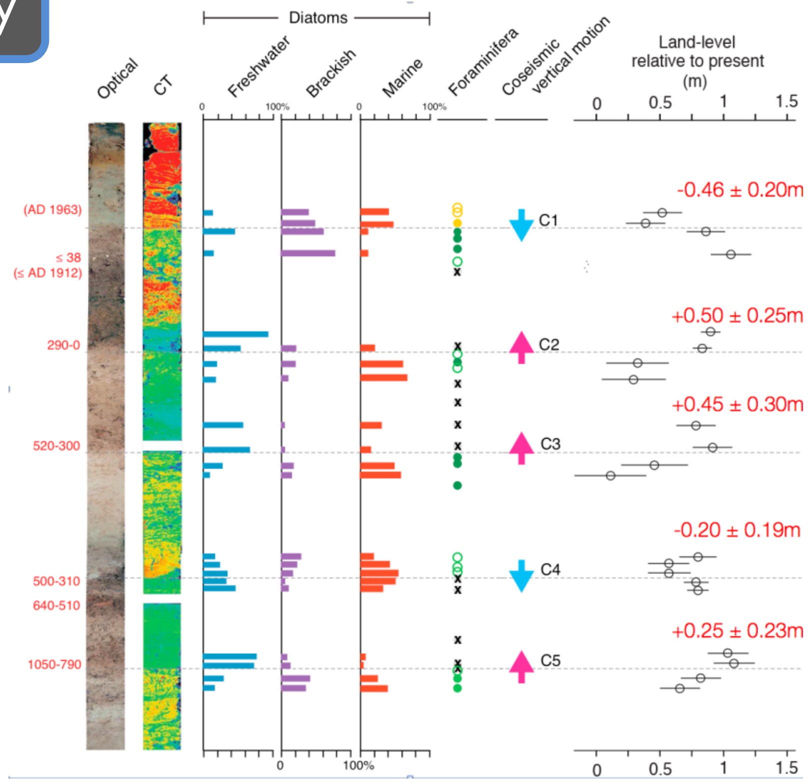
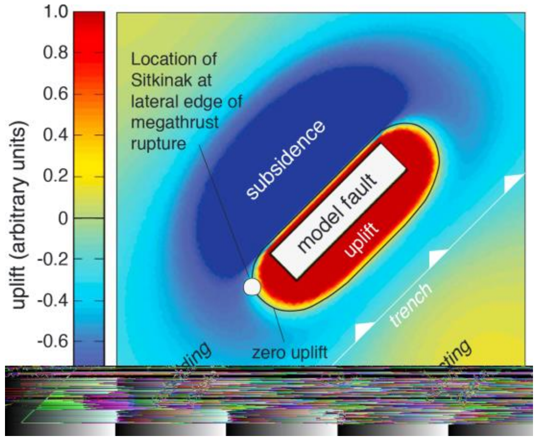
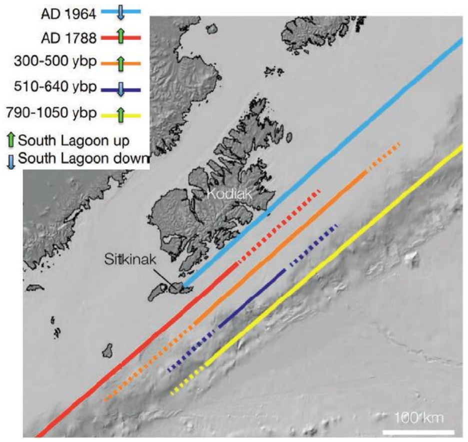
1. ***Reconstruct land-level change and tsunami inundation*** ✔
2. ***Characterize slip during past ruptures*** ✔
3. ***Evaluate the persistence of a proposed segment boundary*** ✔
4. ***Update hazards maps if needed*** ✔



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