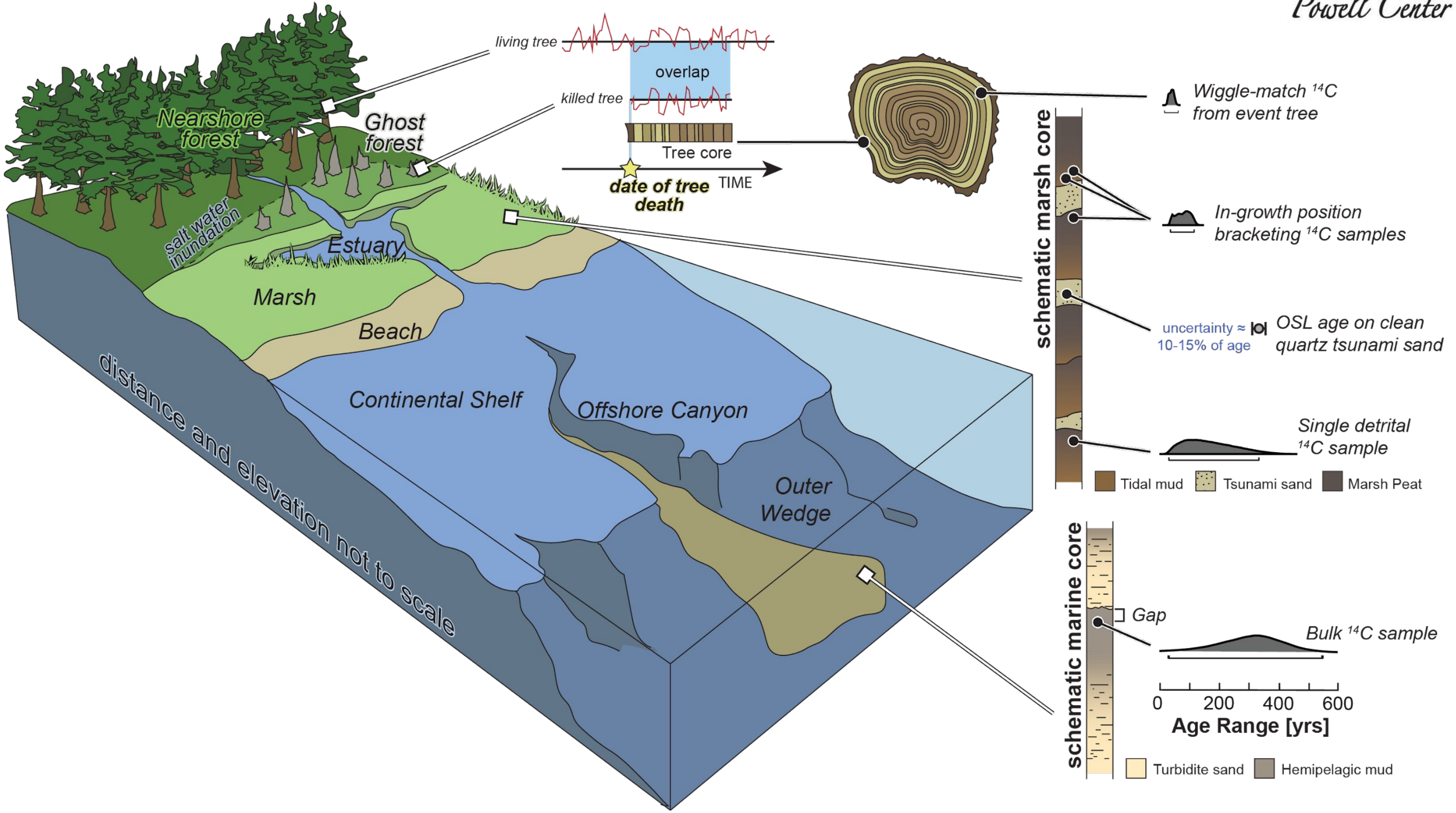
Megathrust paleoseismology:

using past events to estimate future hazard

USGS
science for a changing world

Powell Center

Lydia Staisch, Janet Watt, Rob Witter, Jon Perkins, Danny Brothers, Tina Dura, Chris Goldfinger, Alex Grant, Andrea Hawkes, Jenna Hill, Harvey Kelsey, Brian Sherrod, Simon Engelhart, Randy Enkin, Joan Gomberg, Tark Hamilton, Isabel Hong, Bruce Jaffe, Carrie Garrison-Laney, SeanPaul La Selle, Andrew Meigs, Diego Melgar, Nora Nieminski, Jason Padgett, Jason R. Patton, Jessie Pearl,



HAZARD UNCERTAINTY

Epistemic uncertainty

Uncertainties that stem from limited knowledge

A family of hazard curves at a site (grey lines)

Aleatoric variability

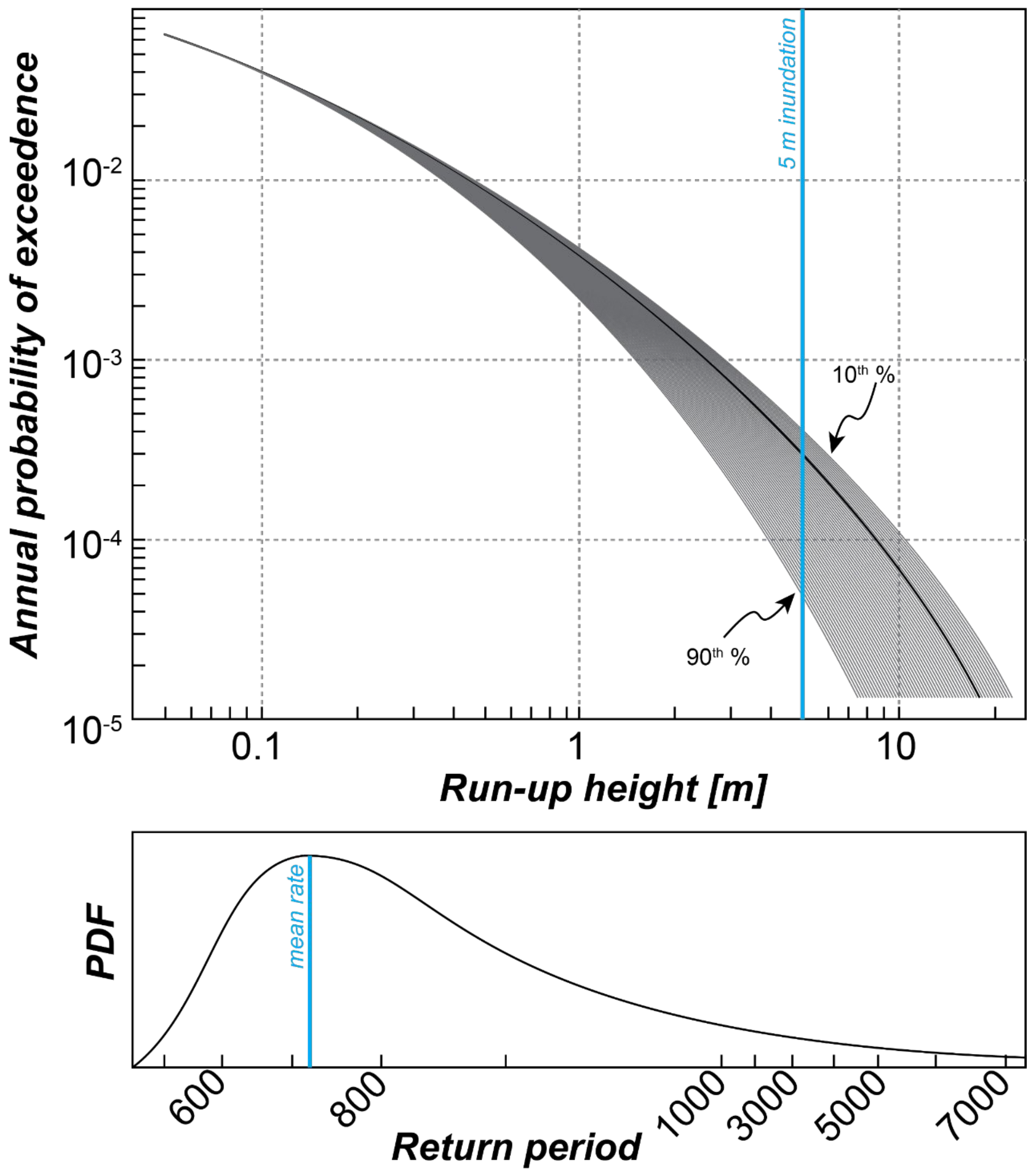
The intrinsic variability of a system

Best guess of exceedance frequency (black line)

Accurate hazard analyses can improve by reducing epistemic uncertainty

Improve what we know about plausible scenarios

This can be addressed with further geologic and geophysical research



PALEOSEISMOLOGY

Understanding of earthquake timing and extent primarily comes from geologic earthquake proxies

tsunami inundations

evidence of coseismic land level changes

strong shaking found in onshore and marine environments

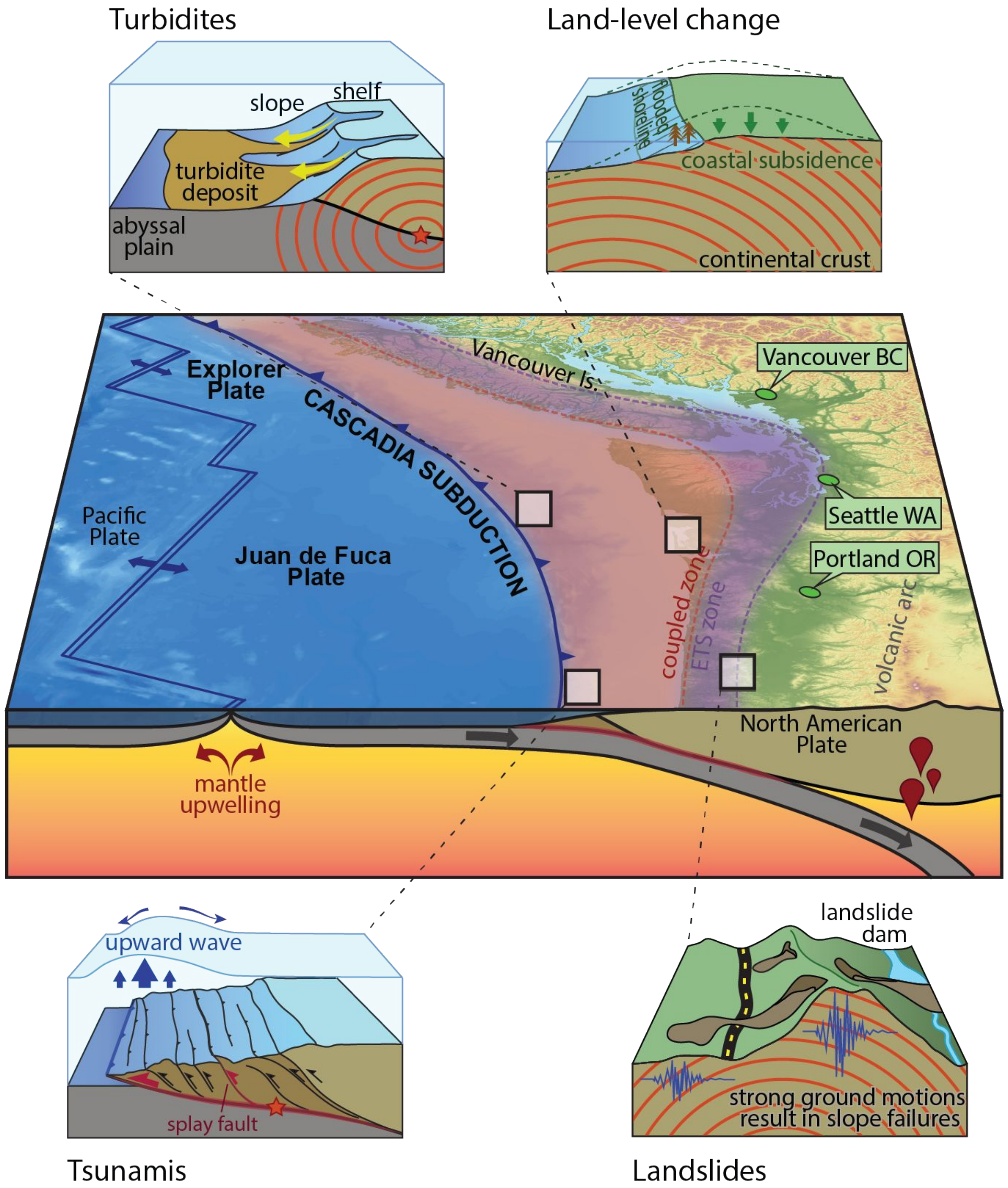
Geologic proxies provide unique insight into specific rupture characteristics

tsunami*: location and magnitude of shallow deformation*

subsidence*: slip magnitude and heterogeneity*

turbidites & landslides*: location and magnitude of strong shaking*

Fig. modified from Walton & Staisch et al. (2021)



PALEOSEISMOLOGY

Fig. modified from Pearl & Staisch (2021)

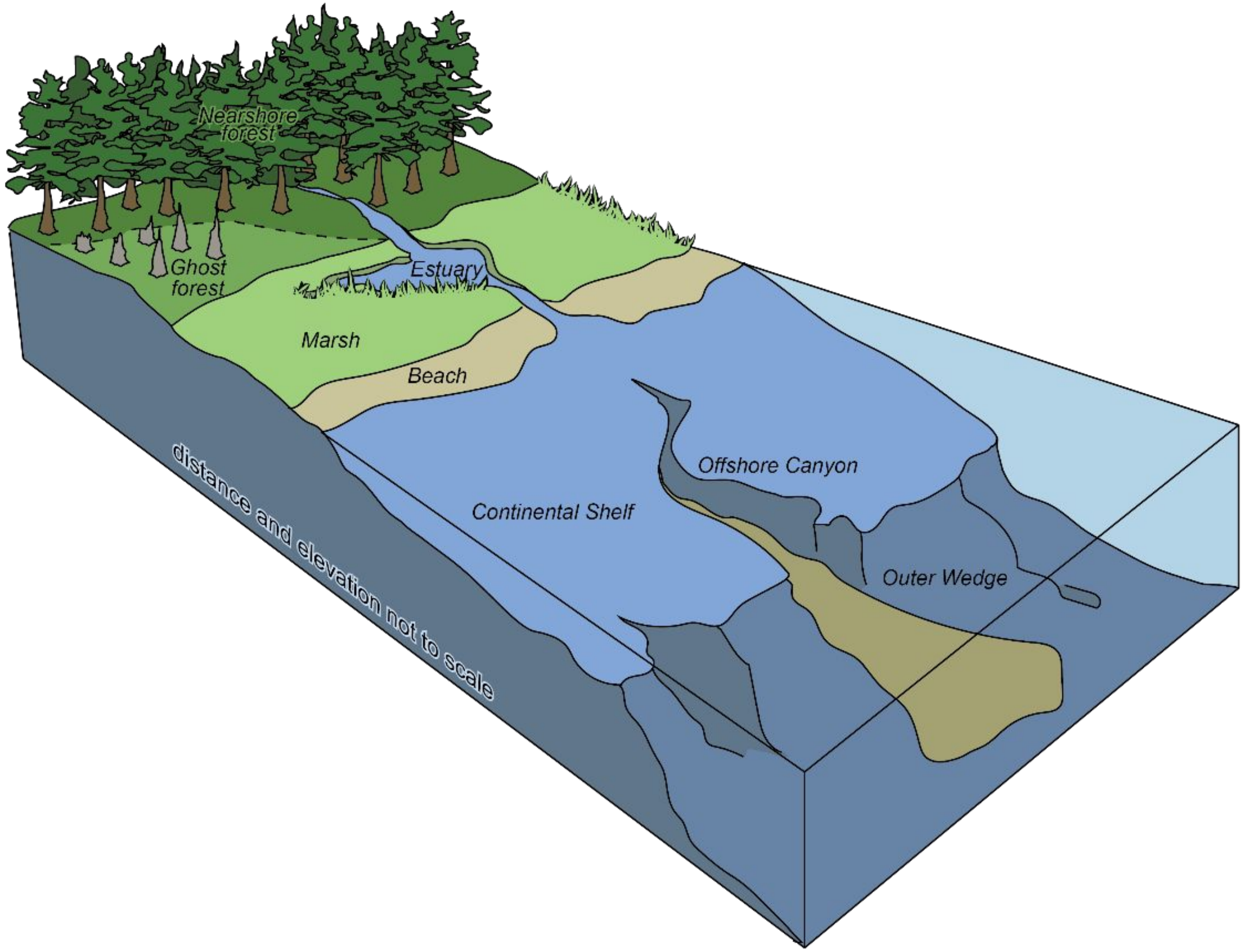
Coastal stratigraphy preserves decimeter-scale interseismic and coseismic deformation and tsunami inundation

Variations in the magnitude of coastal elevation indicative of heterogeneity of paleoseismic slip

Similarly, variations in tsunami inundation extent may be indicative of variable near-trench rupture

Nearshore marine environments receive ample sediment supply for the generation and preservation of seismically triggered turbidites

Coseismic turbidites result when earthquake shaking causes unstable, steep, submarine canyon walls to fail, creating coarse, turbulent sediment flows



PALEOSEISMOLOGY

Fig. modified from Pearl & Staisch (2021)

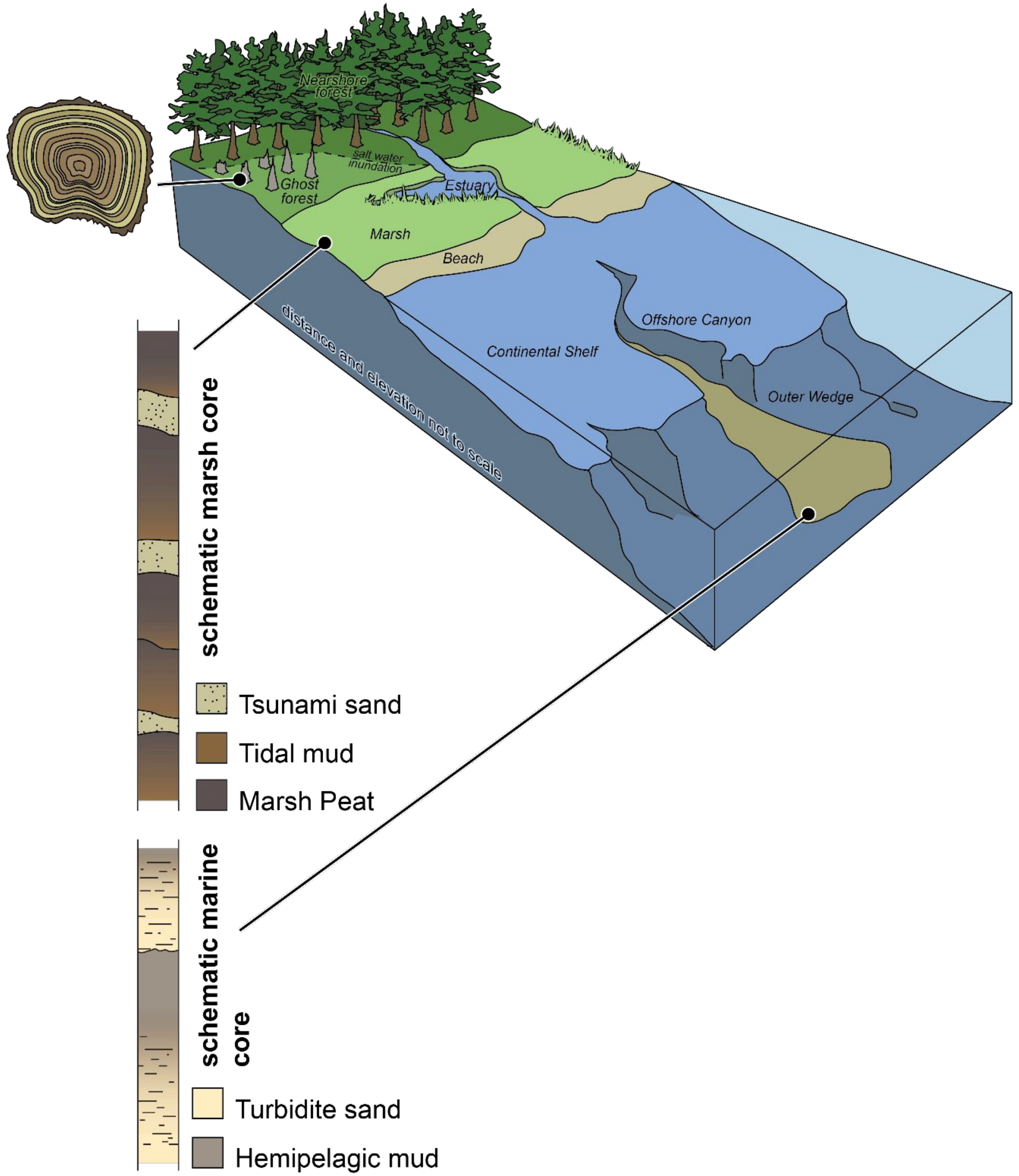
Coastal stratigraphy preserves decimeter-scale interseismic and coseismic deformation and tsunami inundation

Variations in the magnitude of coastal elevation indicative of heterogeneity of paleoseismic slip

Similarly, variations in tsunami inundation extent may be indicative of variable near-trench rupture

Nearshore marine environments receive ample sediment supply for the generation and preservation of seismically triggered turbidites

Coseismic turbidites result when earthquake shaking causes unstable, steep, submarine canyon walls to fail, creating coarse, turbulent sediment flows



PALEOSEISMOLOGY

To be useful, proxies must be datable

Most paleoseismic datasets rely on radiocarbon or optically stimulated luminescence dating

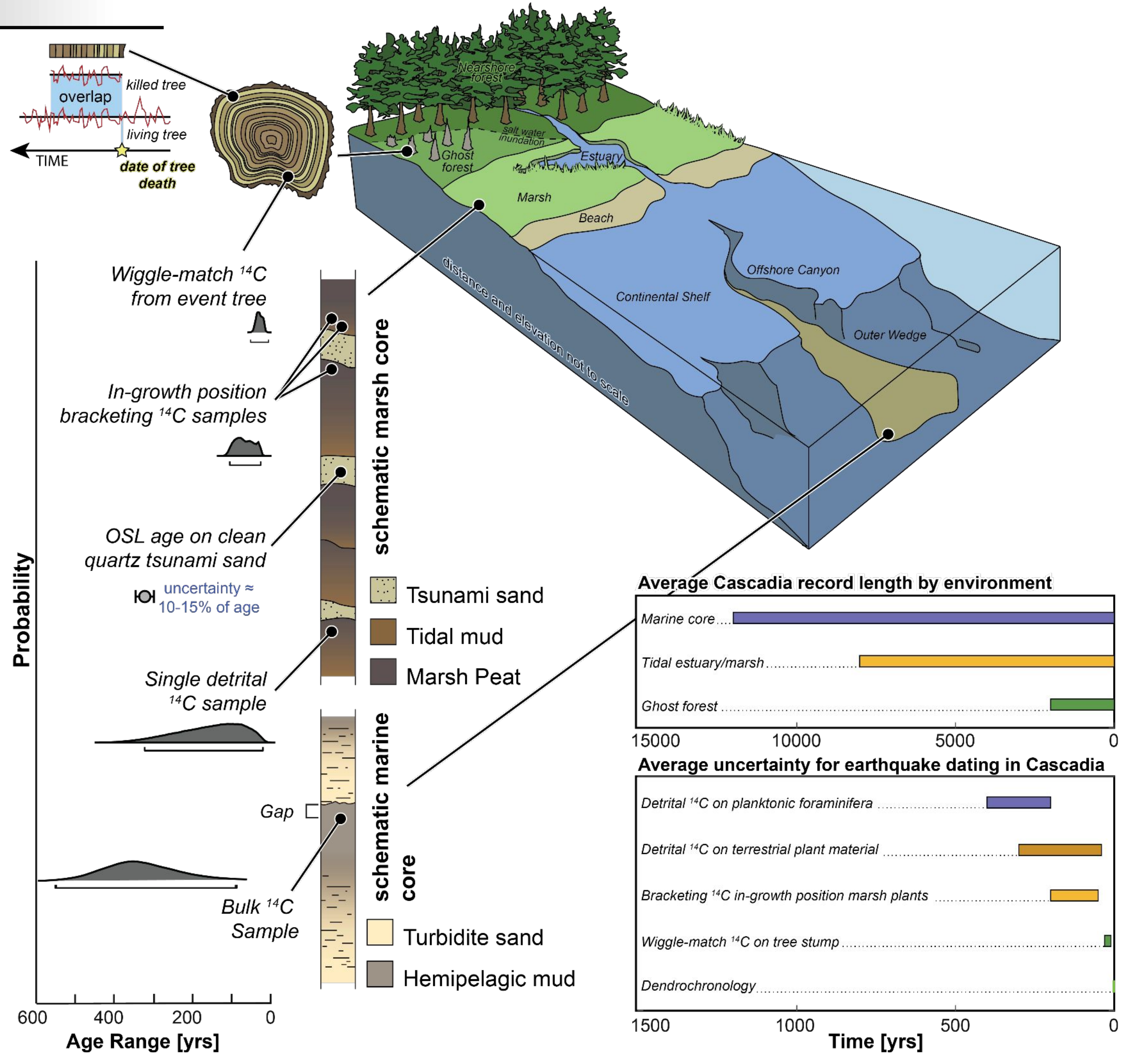
Typical age uncertainty is on the order of several decades to a few hundred years

However, dendrochronological analysis of trees killed by rapid coseismic subsidence and marine inundation, can provide annual to seasonal precision

Large age uncertainties allow for varying interpretations of the geologic record

> *Multiple magnitude 8 or magnitude 7 earthquakes that occur over a short period of time (years to decades) could be misidentified as a single huge earthquake*

Fig. modified from Pearl & Staisch (2021)



PALEOSEISMOLOGY

Fig. modified from Pearl & Staisch (2021)

To be useful, proxies must be datable

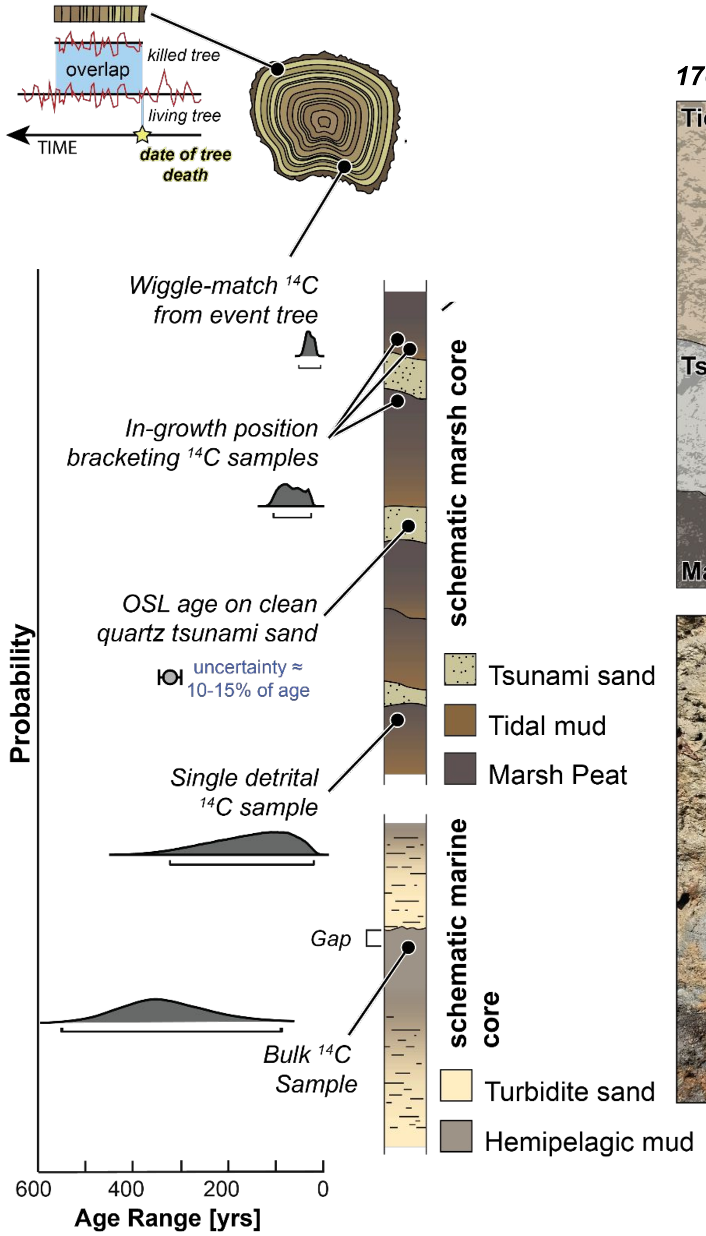
Most paleoseismic datasets rely on radiocarbon or optically stimulated luminescence dating

Typical age uncertainty is on the order of several decades to a few hundred years

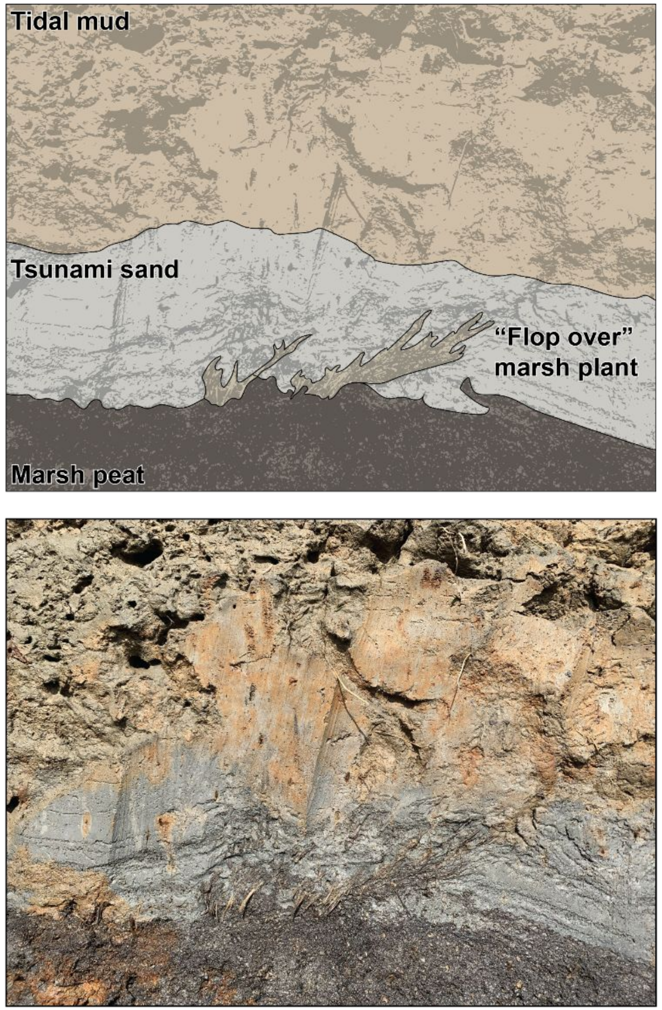
However, dendrochronological analysis of trees killed by rapid coseismic subsidence and marine inundation, can provide annual to seasonal precision

Large age uncertainties allow for varying interpretations of the geologic record

> *Multiple magnitude 8 or magnitude 7 earthquakes that occur over a short period of time (years to decades) could be misidentified as a single huge earthquake*



1700 CE tsunami sand – Niawiakum River, Washington



FULL MARGIN INTEGRATION

1. Compile and evaluate dataset quality

Compile sedimentological characteristics of paleoseismic and paleo-tsunami evidence along the entire margin

Quasi-quantitative ranking to assess:

- Confidence in geochronologic data
- Confidence of recorded event

2. Event correlation between sites

Systematically remodel all age data

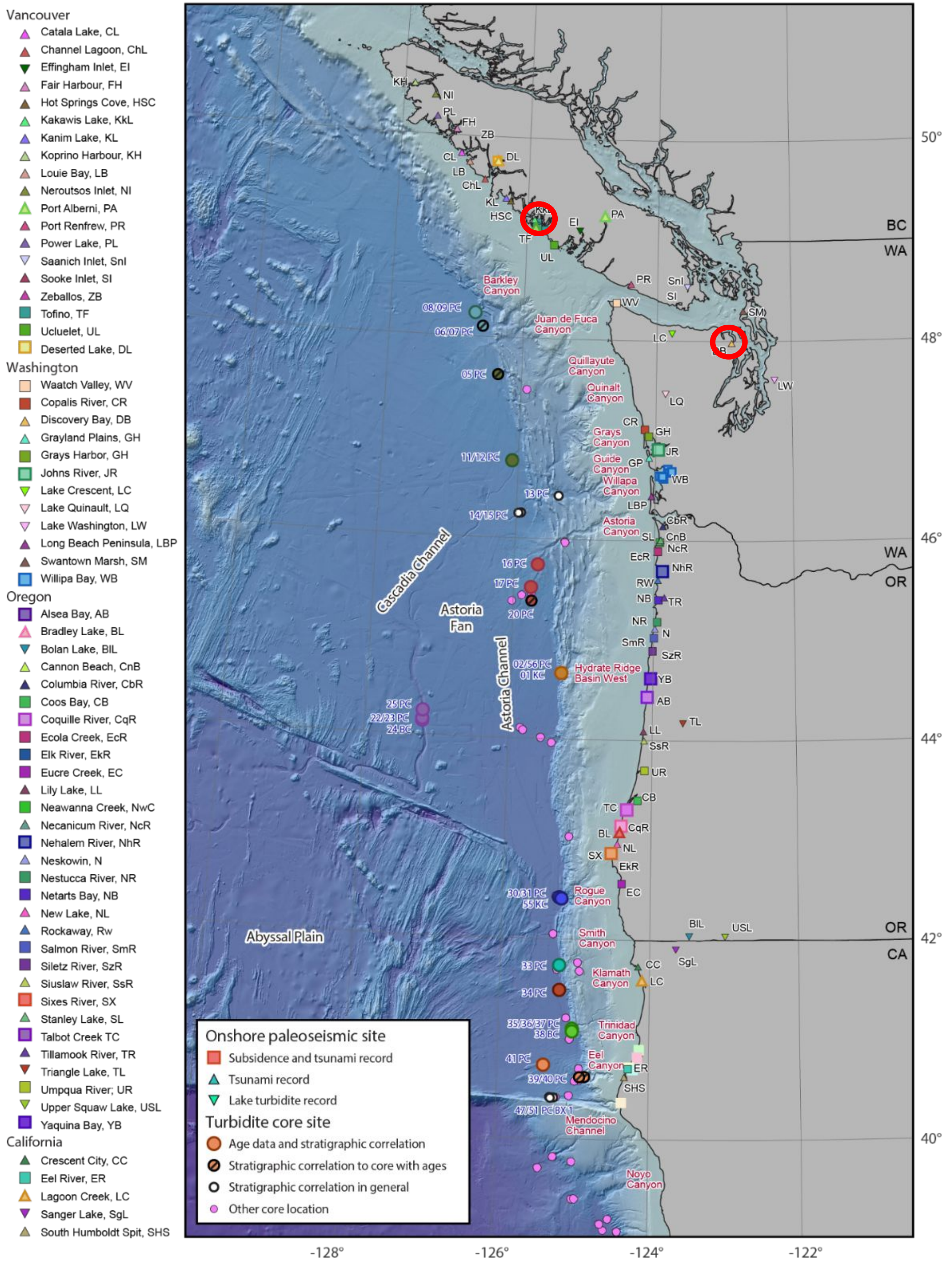
- Browning Passage example
- Discovery Bay example

Correlation based on overlapping age data and ranking scheme

3. Estimate event timing

Combining ages between correlated sites

- Product of overlapping age probability functions
  Emphasizes overlapping time periods
- Summation (mean) of age probability functions
  Considers all age uncertainties



FALSE POSITIVES

Every paleoseismic dataset suffers from recording events that may not be Cascadia earthquakes

- storms
- distal earthquakes
- local crustal earthquakes
- stochastic mass-wasting

In several cases, we have good examples of non-local or non-seismic events in the record

- coastal estuaries record tsunamis from 1964 Alaska and 1960 Chile
- the San Andreas fault may trigger southern Cascadia turbidites

We targeted known false positive events to evaluate how a non-Cascadia records rank in our scheme

source: Lincoln County Historical Society in Newport
1964 debris at Ona Beach near Waldport

OXCAL MODELING TESTS

Radiocarbon ages vs. Earthquake ages

Age rank quality scheme was designed to highlight how well events might be dated at each site

How to model data properly to ensure uncertainty in age information is accurately represented?

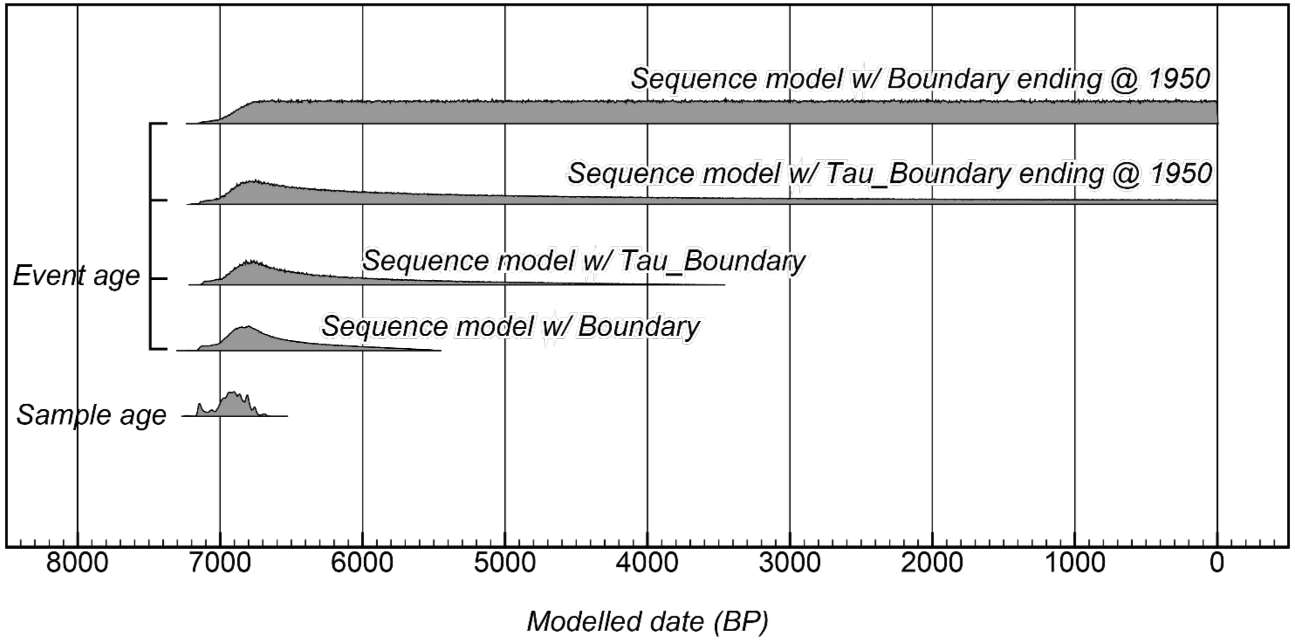
BROWNING PASSAGE EXAMPLE

A single detrital age was analyzed below the assumed 1700 CE tsunami sand

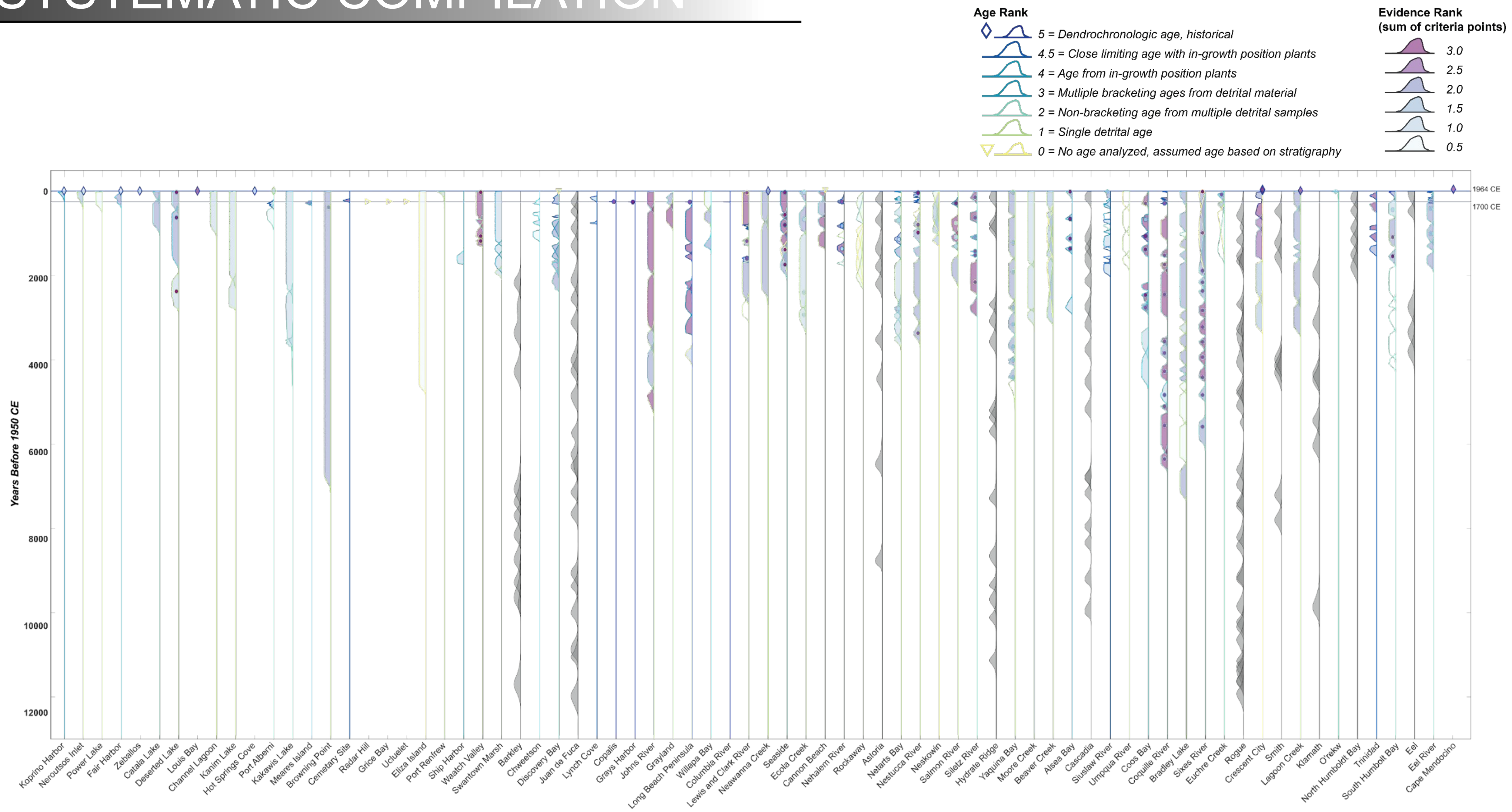
Uncalibrated age 6060 ± 70 cal yr BP

Several different OxCal modeling examples show very different age probabilities

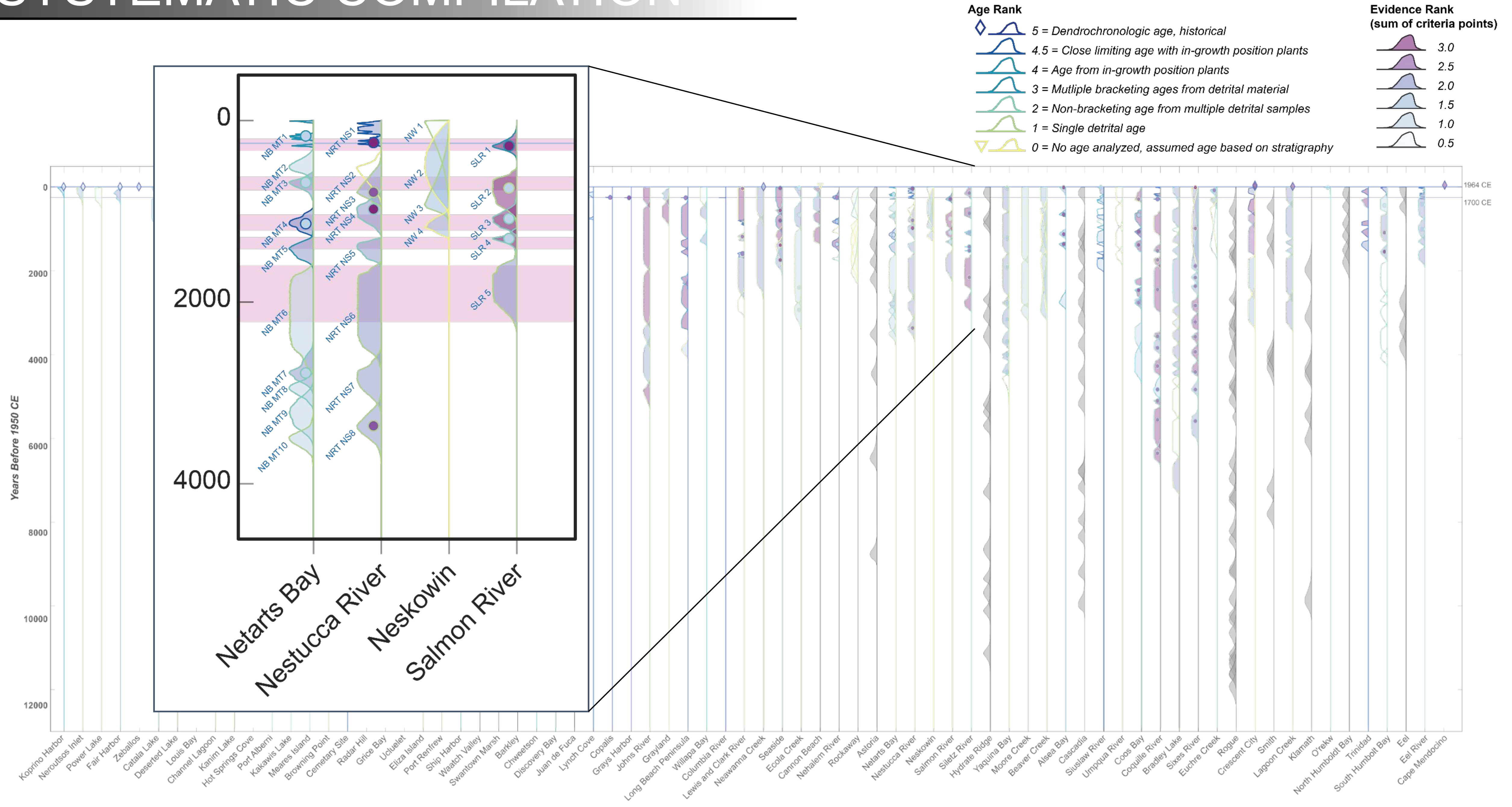
Browning Point, single radiocarbon age below inferred 1700 CE earthquake horizon



SYSTEMATIC COMPILATION



SYSTEMATIC COMPILATION



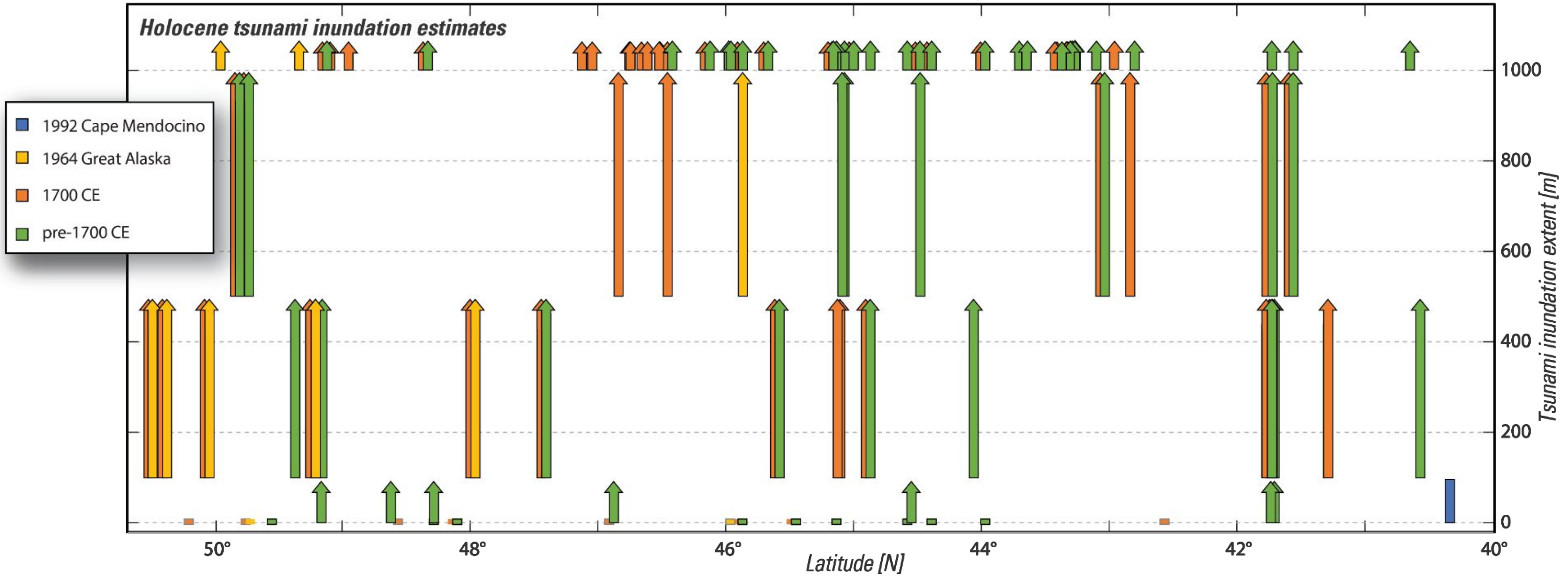
VARIABLE INUNDATION

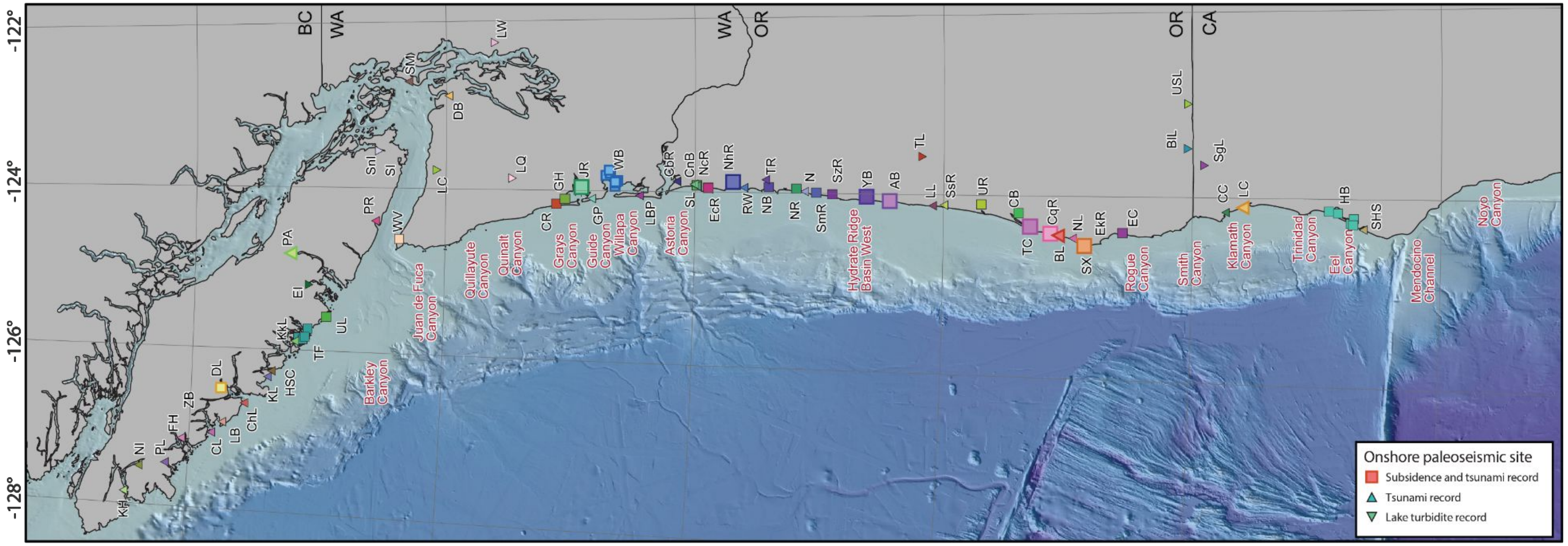
Holocene record
Compiled tsunami inundation extent along strike

Historic non-CSZ M9 events
Yellow bars show tsunami inundation from 1964 Great Alaska earthquake

Cape Mendocino experienced small (0-100 m) but noticeable tsunami inundation following 1992 event

Important to take note of “false positive” events that may not be Great CSZ earthquakes





FUTURE DIRECTIONS

Rupture characteristics and boundaries through time

Both paleoseismic and geophysical datasets hint at variable CSZ rupture scenarios

Systematic age analysis and correlation will help constrain event extent and timing

Paleoseismic proxies for rupture characteristics provide some clues to understanding coseismic processes

Integrate earthquake paleoseismic rupture proxies with 2-D and 3-D modeling of convergent margin at a variety of timescales

Constrain variability of great megathrust ruptures characteristics over the Holocene

Combine paleoseismic tsunami record and modeling to assess potential splay fault activity

Combine subsidence datasets to model slip heterogeneity

Combine shaking proxies to model ground motion characteristics

How does this translate to hazard?

Paleoseismic data gaps: which data gaps are most important for constraining rupture scenarios?