Paleoseismologic data as constraints on subduction zone earthquake recurrence and rupture characteristics

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From hazard to risk: The science of planning for future tsunamis

November 7, 2024 || Eugene OR

Paleoseismology

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

Long records that span several earthquake cycles are vital

Paleoseismology focused on just timing provides a limiting view of the system

Geologic proxies provide unique insight into specific rupture characteristics

> ***subsidence**: slip magnitude and heterogeneity*
>
> ***tsunami**: location and magnitude of shallow deformation*
>
> ***turbidites & landslides**: location and magnitude of strong shaking*

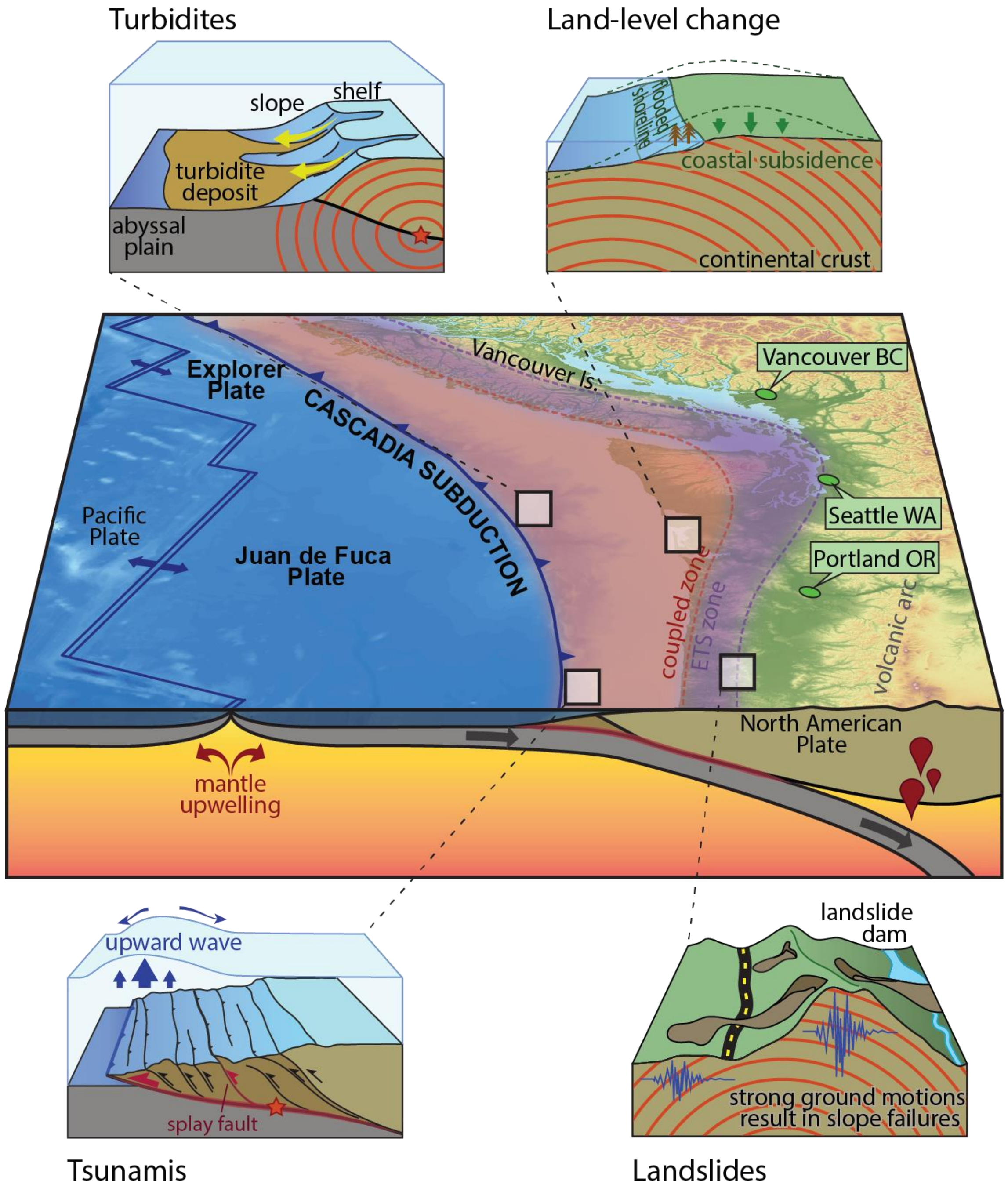


Fig. modified from Walton & Staisch et al. (2021)

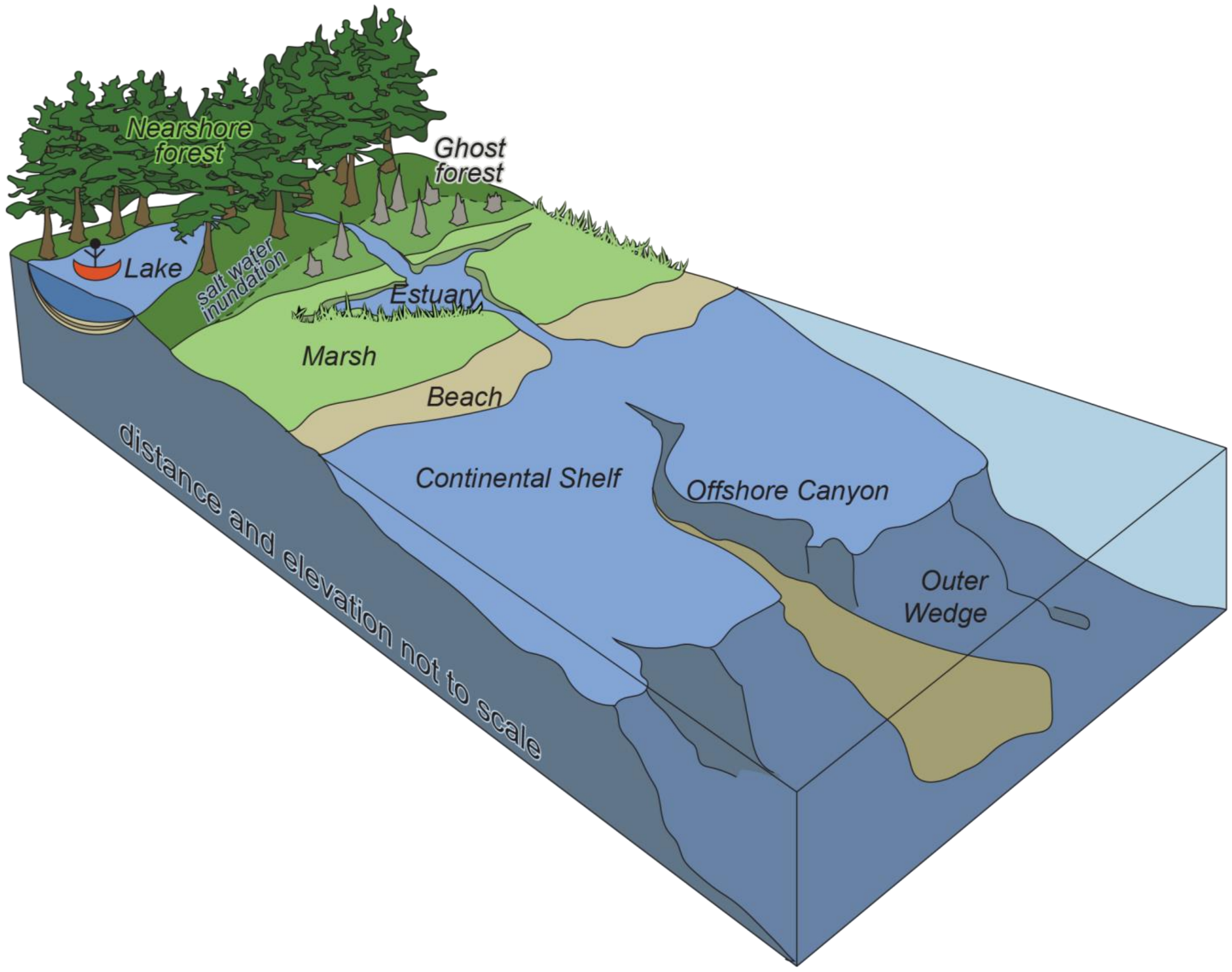
Environmental recorders

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

> *Variable slip magnitude and location leads to variable land-level change*
>
> *Similarly, variations in tsunami inundation extent may be indicative of variable near-trench rupture*

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

Terrestrial lakes are similarly sensitive shaking proxies, and some show evidence for tsunami inundation, too



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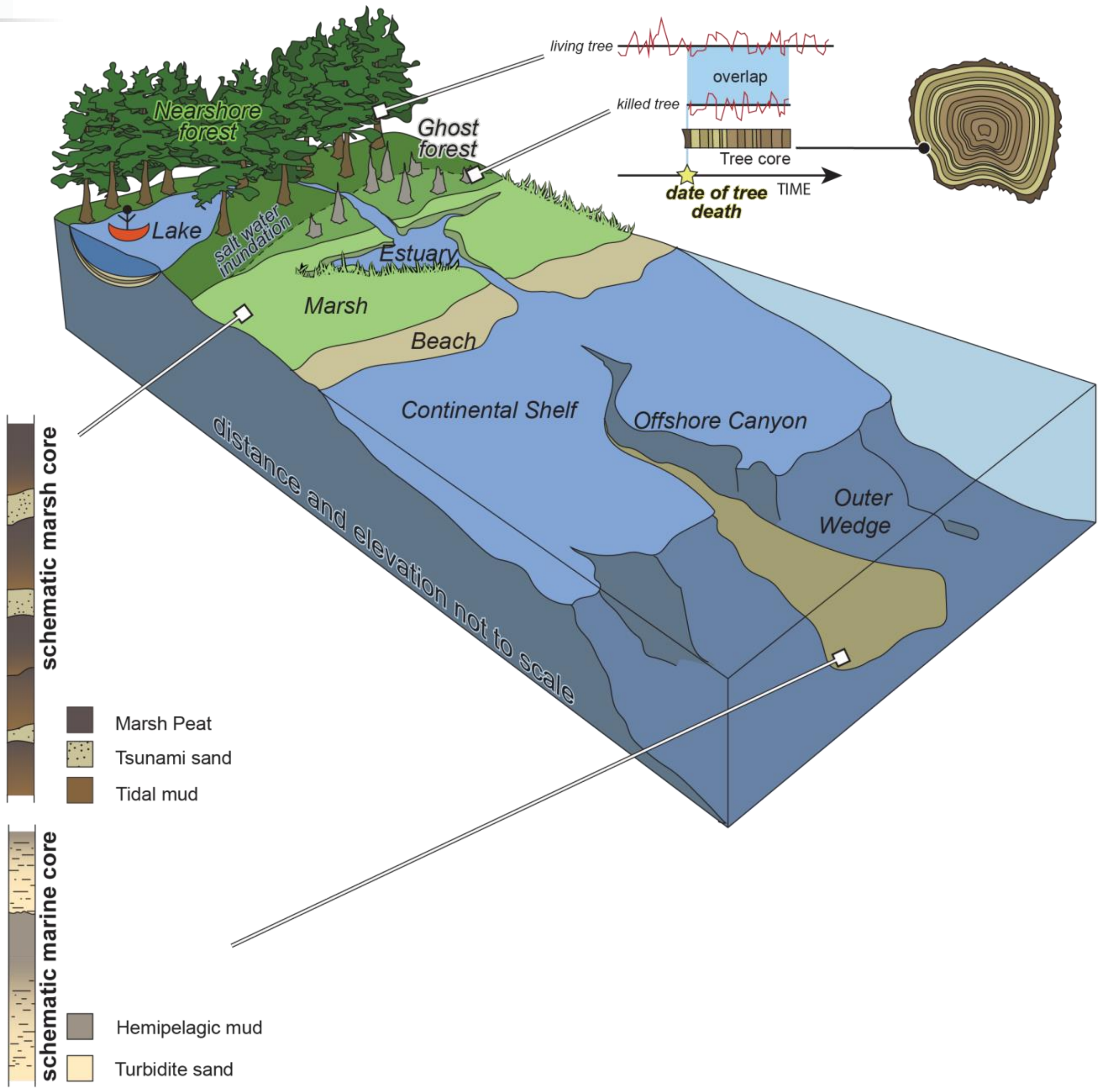

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Age Control and Correlation

To be useful, proxies must be datable

Most paleoseismic datasets rely on radiocarbon dating

Typical age uncertainty is several decades to a few hundred years

However, dendrochronological analysis can provide annual to seasonal precision

Large age uncertainties allow for varying interpretations of the geologic record

> *Multiple magnitude 8 earthquakes that occur over a short period of time (years to decades) could be misidentified as a single full-margin event*

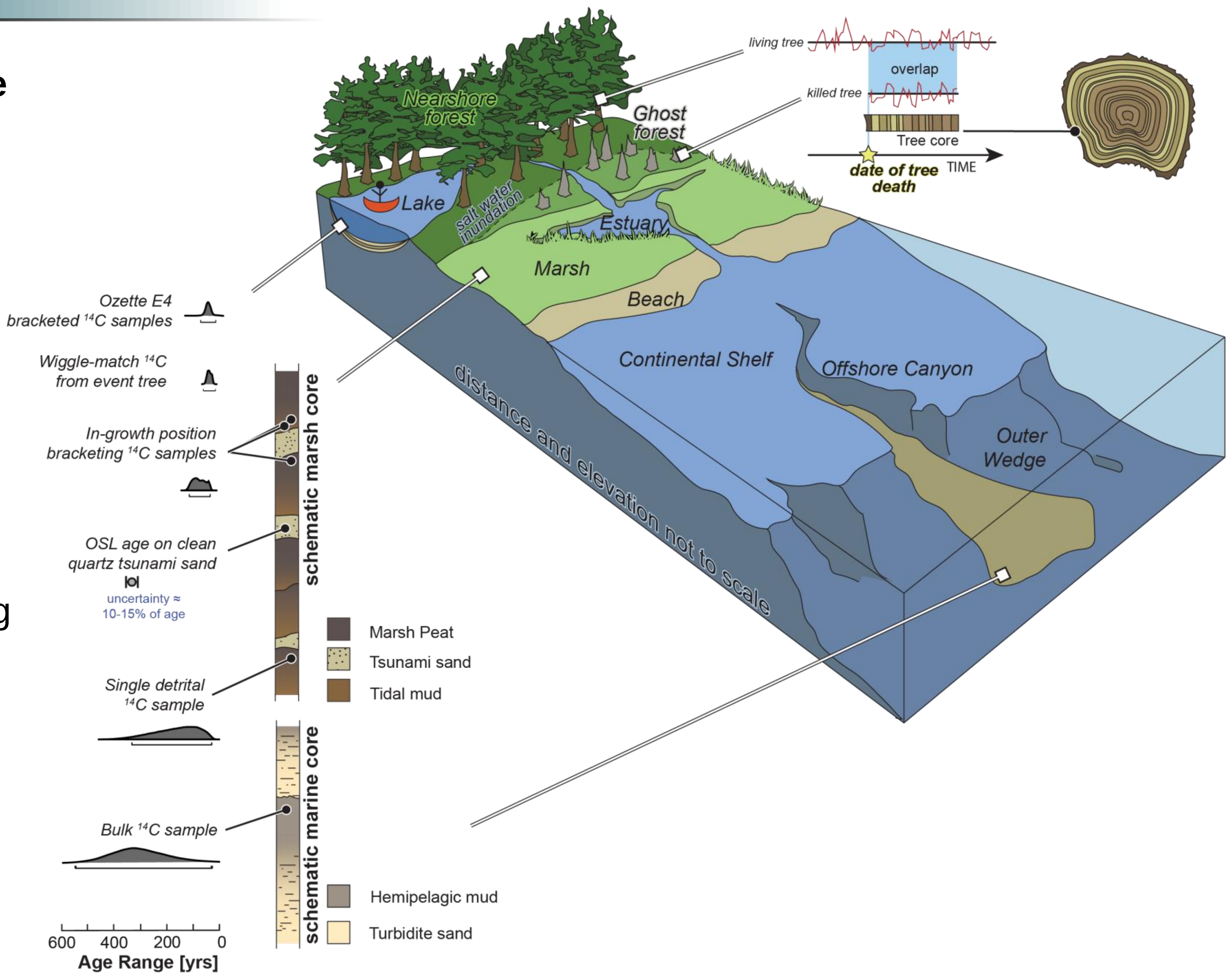


Fig. modified from Pearl & Staisch (2021)

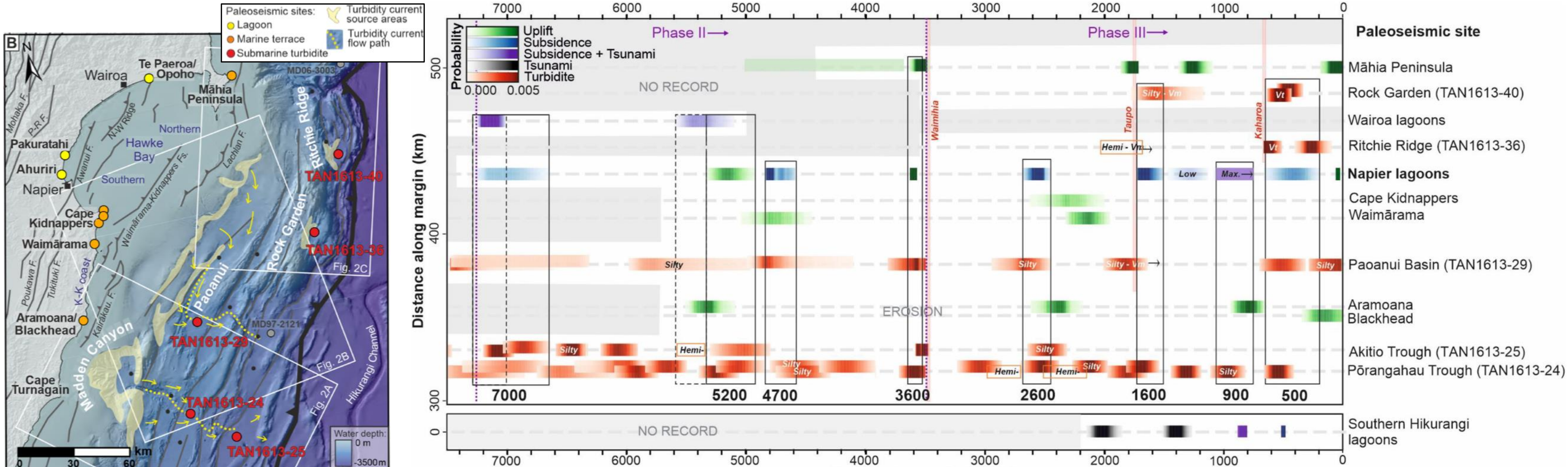
Age Control and Correlation

Multi-proxy approach to recurrence and source

Coastal evidence along Hikurangi margin is extremely complicated given multiple source mechanisms

Turbidite paleoseismology is particularly useful to examine spatiotemporal trends and that are otherwise difficult to tease out from onshore evidence *(Pizer et al., 2024)*

Success requires sufficient age precision and establish synchronous deposition



Figs. from Pizer et al. (2024)

Age Control and Correlation

Along-strike correlations

The age and overlap of paleoseismic events underpins our knowledge of CSZ earthquake size and frequency

Most work on assessing recurrence often relies on a Maximum Rupture Model

Largest rupture possible given age overlap

Turbidite datasets previously tied the onshore evidence together

Interpreted to suggest 19-20 full margin events over 10 kyr

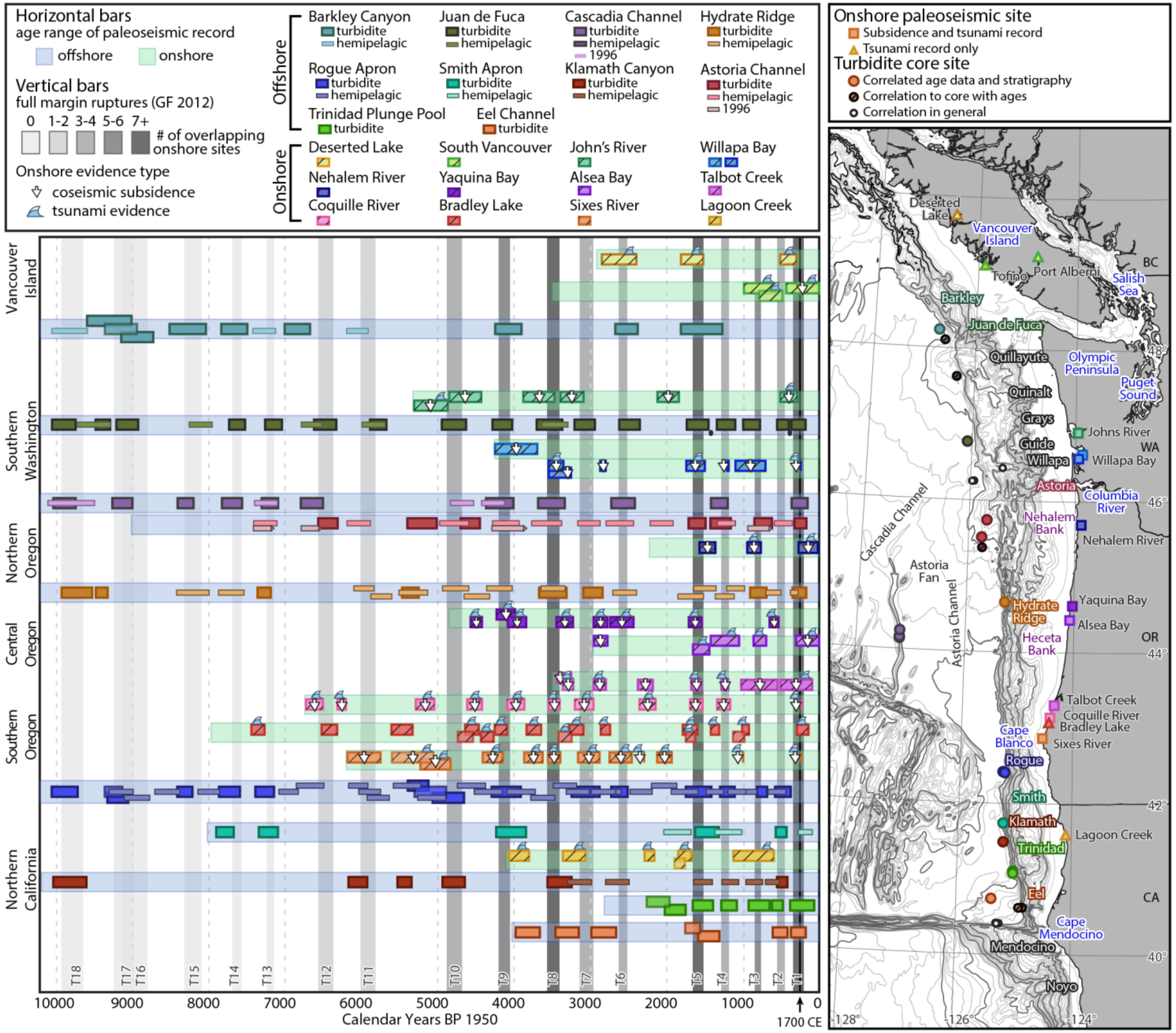


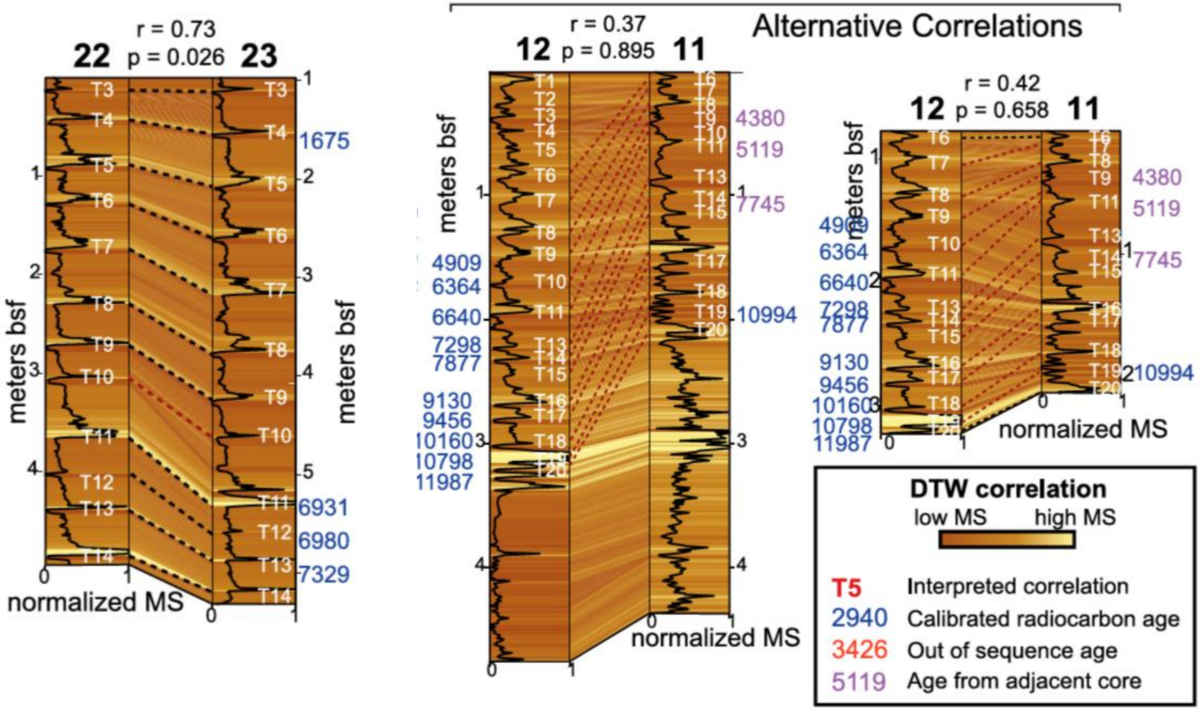
Fig. modified from Walton & Staisch et al. (2021)

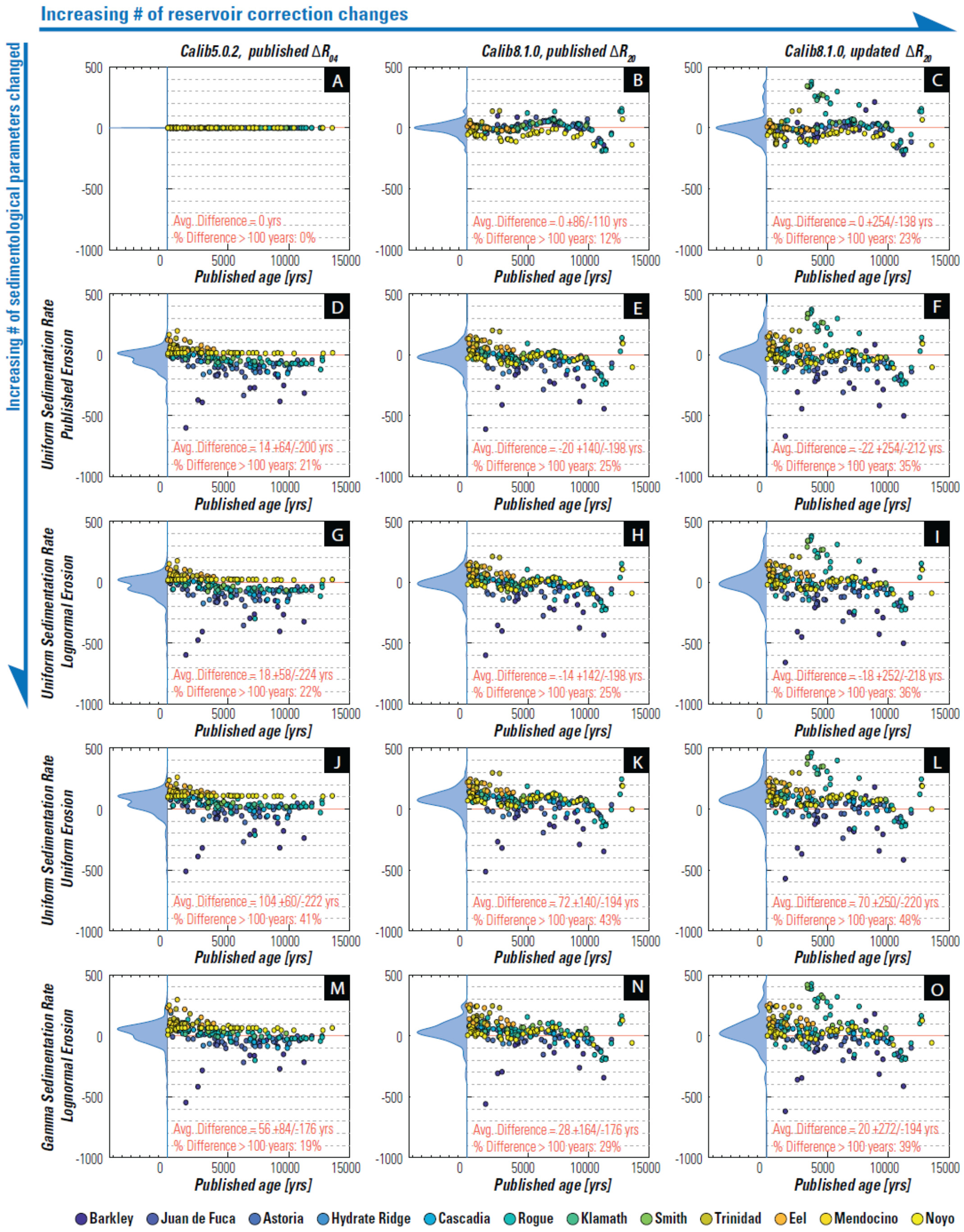
Age Control and Correlation

Age control
Require independent constraints on sedimentation rate and marine reservoir corrections for precise turbidite ages *(Staisch, 2024)*

Synchronous deposition
Significant correlation of turbidites only between nearby cores, <100 m apart *(Nieminksi et al., 2024)*

Cascadia Channel ***Juan de Fuca Channel***





Figs. from Nieminski et al. (2024) and Staisch (2024)

Age Control and Correlation

Variable rupture length

Correlation using a Maximum Rupture Model for terrestrial ages indicates variable rupture length and frequency through time *(Nelson et al., 2021)*

- *Persistent rupture barrier ~Nehalem Bank*
- *More frequent rupture in southern CSZ, particularly in last 1.6 kyr*

> " ...more precise but discordant ages might show that soils [evidence] at different sites are not the same age. "
>
> —Nelson (1992)

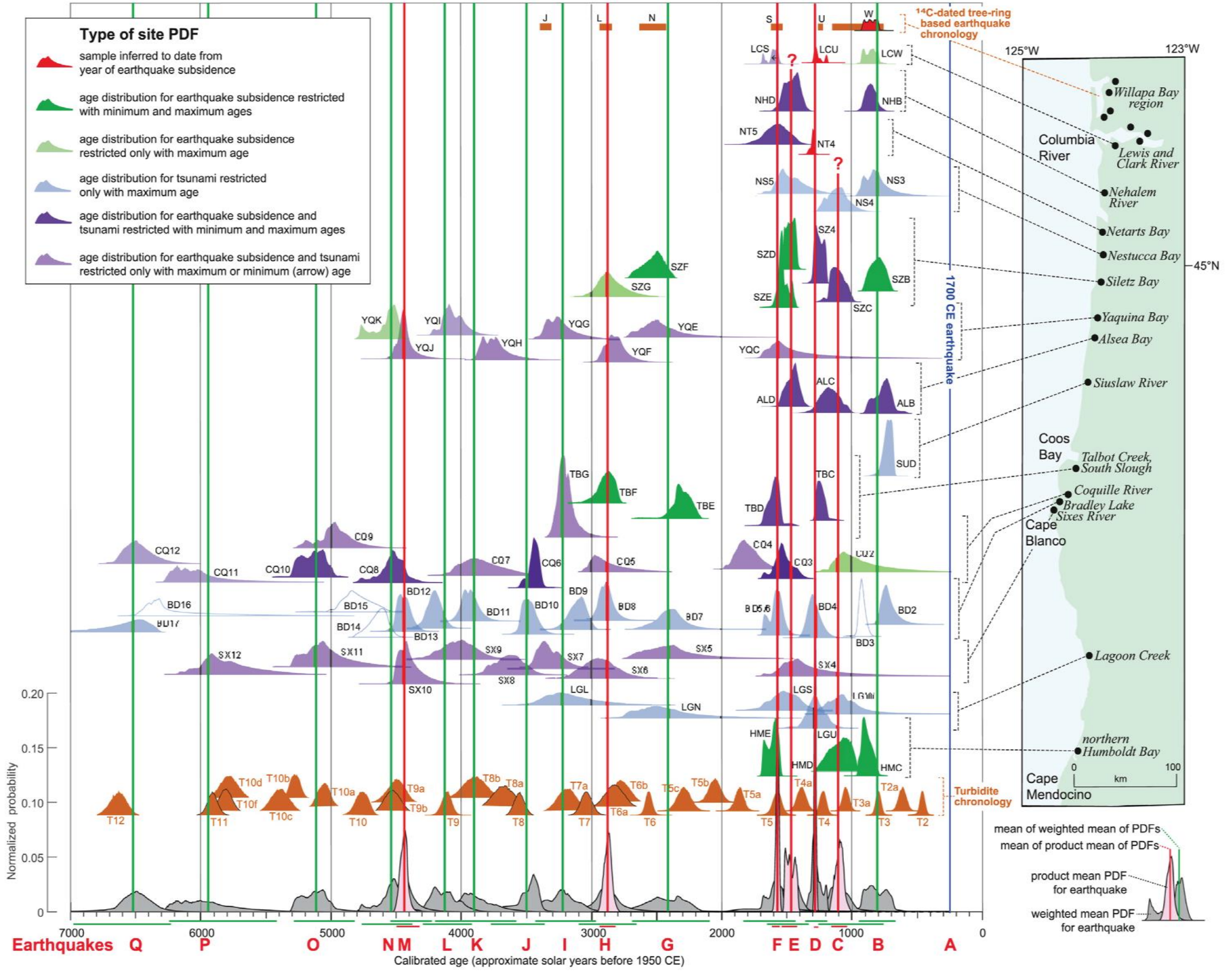


Fig. modified from Nelson et al. (2021)

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Discordance in the details
Ages from the penultimate "full-margin" event may actually show evidence for a sequence of three partial ruptures

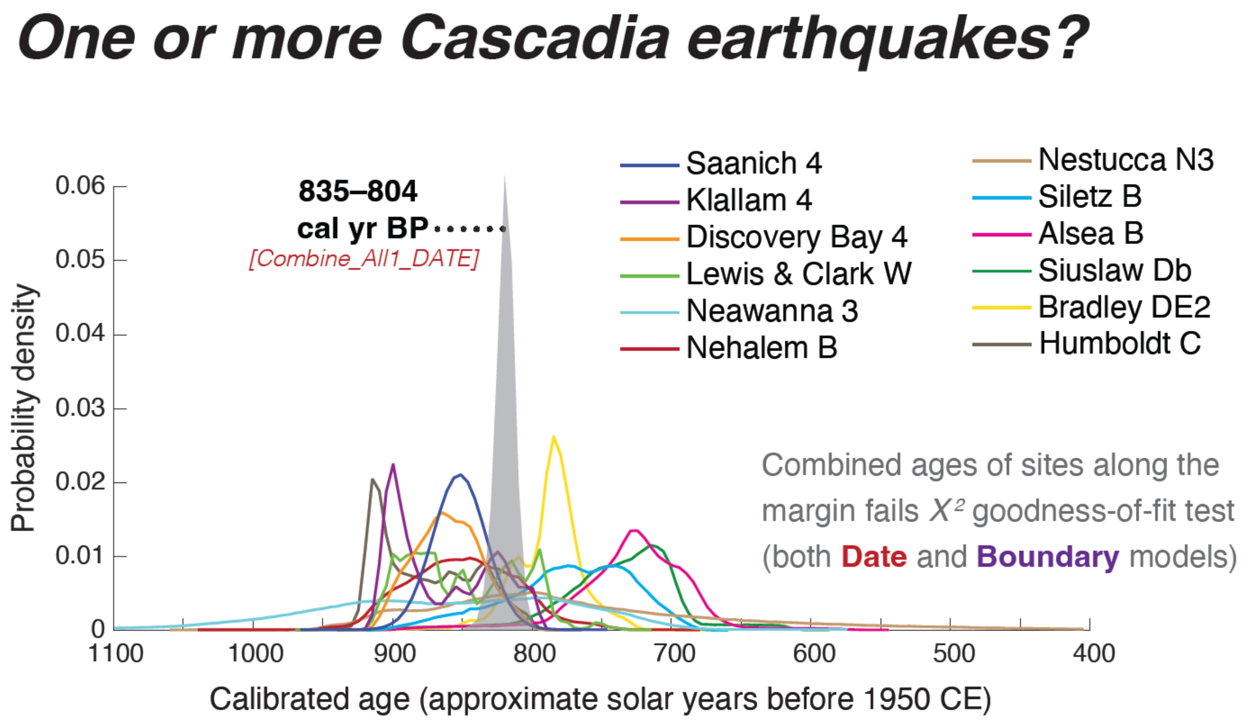

Fig. modified from Witter et al. (2024)

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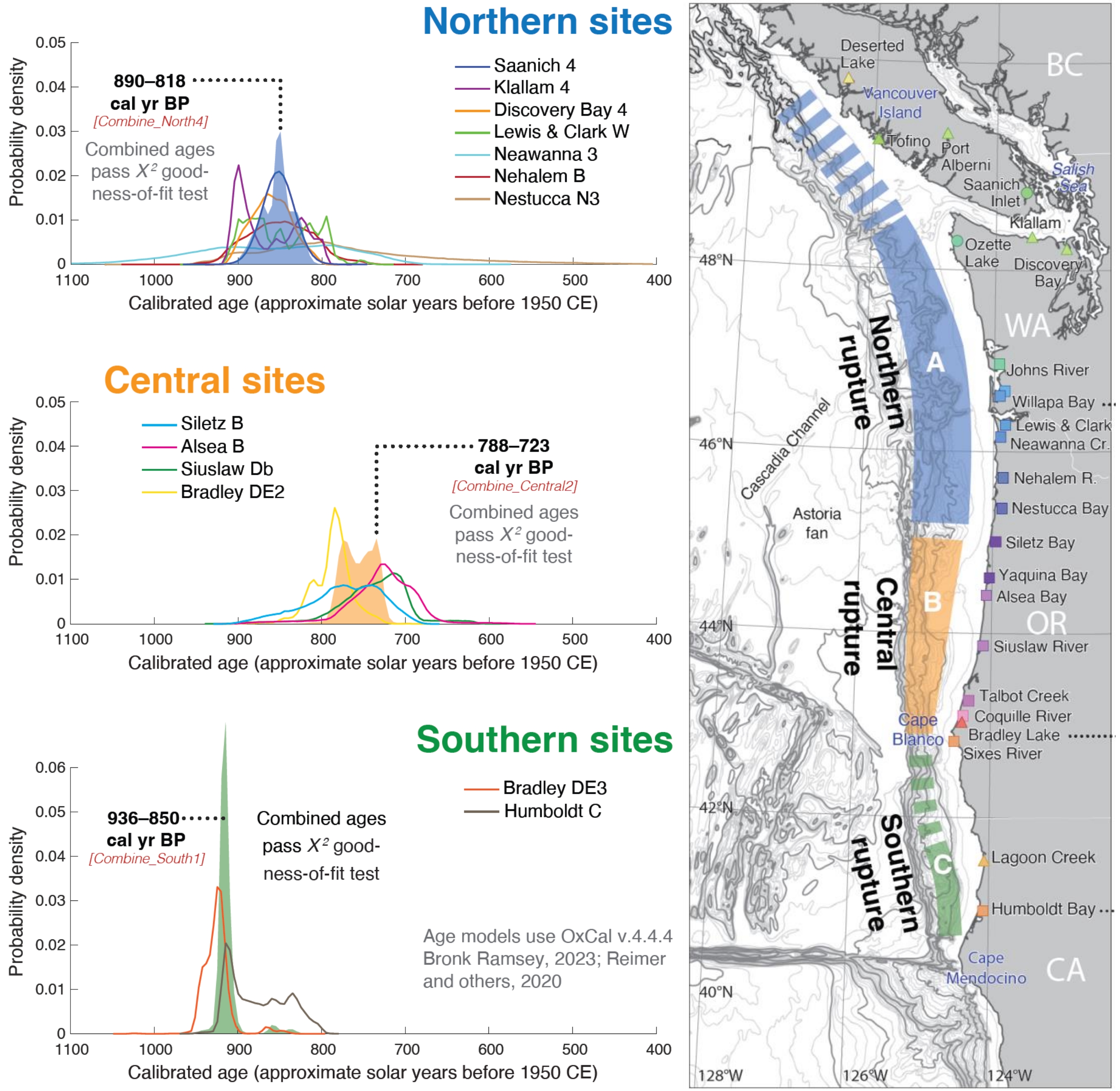
Discordance in the details
Ages from the penultimate "full-margin" event may actually show evidence for a sequence of three partial ruptures

- *Geographically and statistically distinct age groups*
- *Bradley Lake record suggests two events*
- *Current ^{14}C data and age models lack the precision to disprove either hypothesis*



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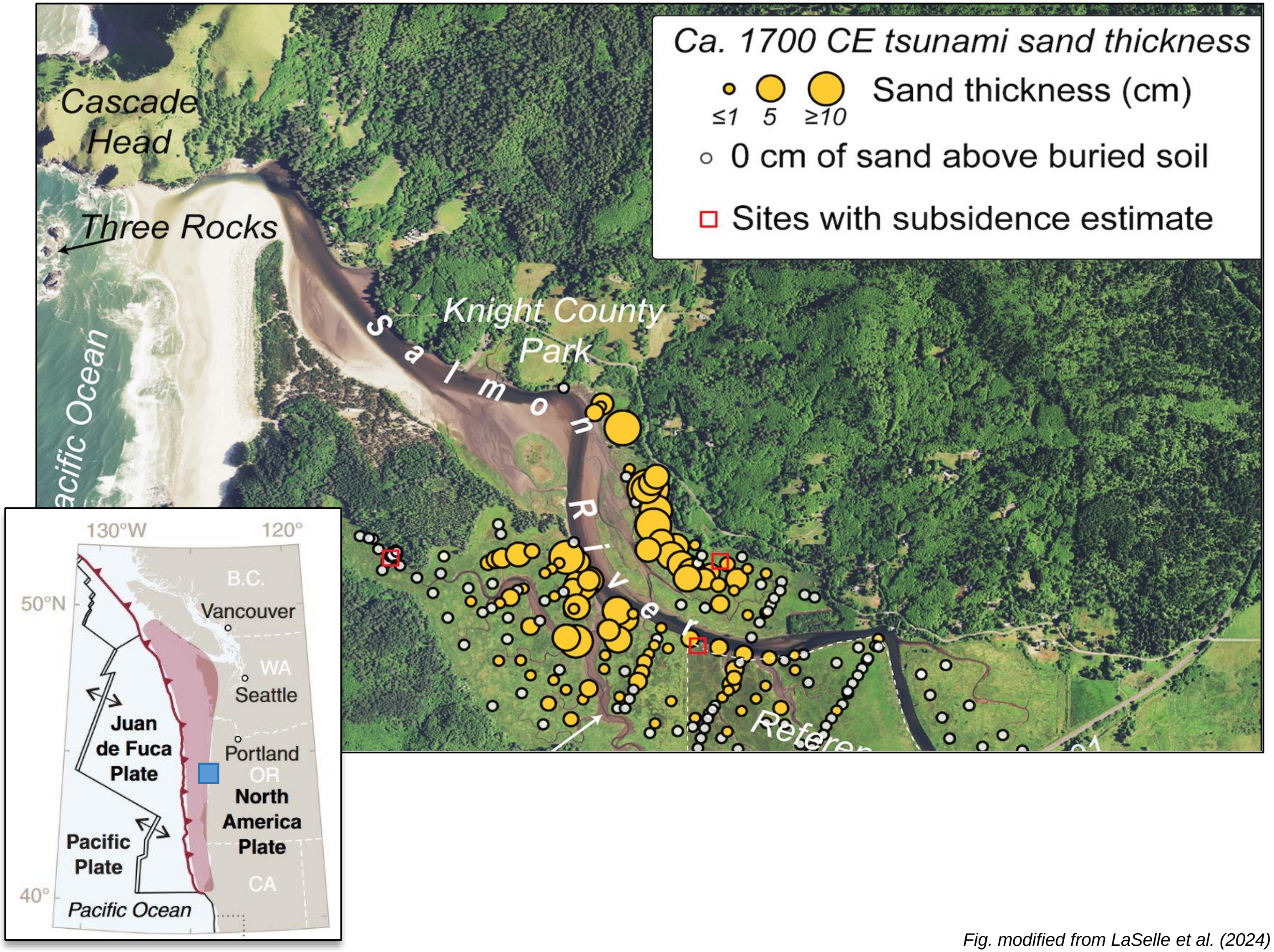
Tsunami mapping and models

Tsunami deposit mapping provides a key benchmark for rupture models

LaSelle et al. (2024) use previous sand inundation limits to constrain sediment transport models that arise from variable **rupture characteristics** and **tidal stage**

Best fit model suggests 0.8-1.0 m subsidence but tsunami must inundate at MHHW for the 1700 CE Cascadia event

Greater slip is permissible but the modeled sand is thicker and farther inland than observed



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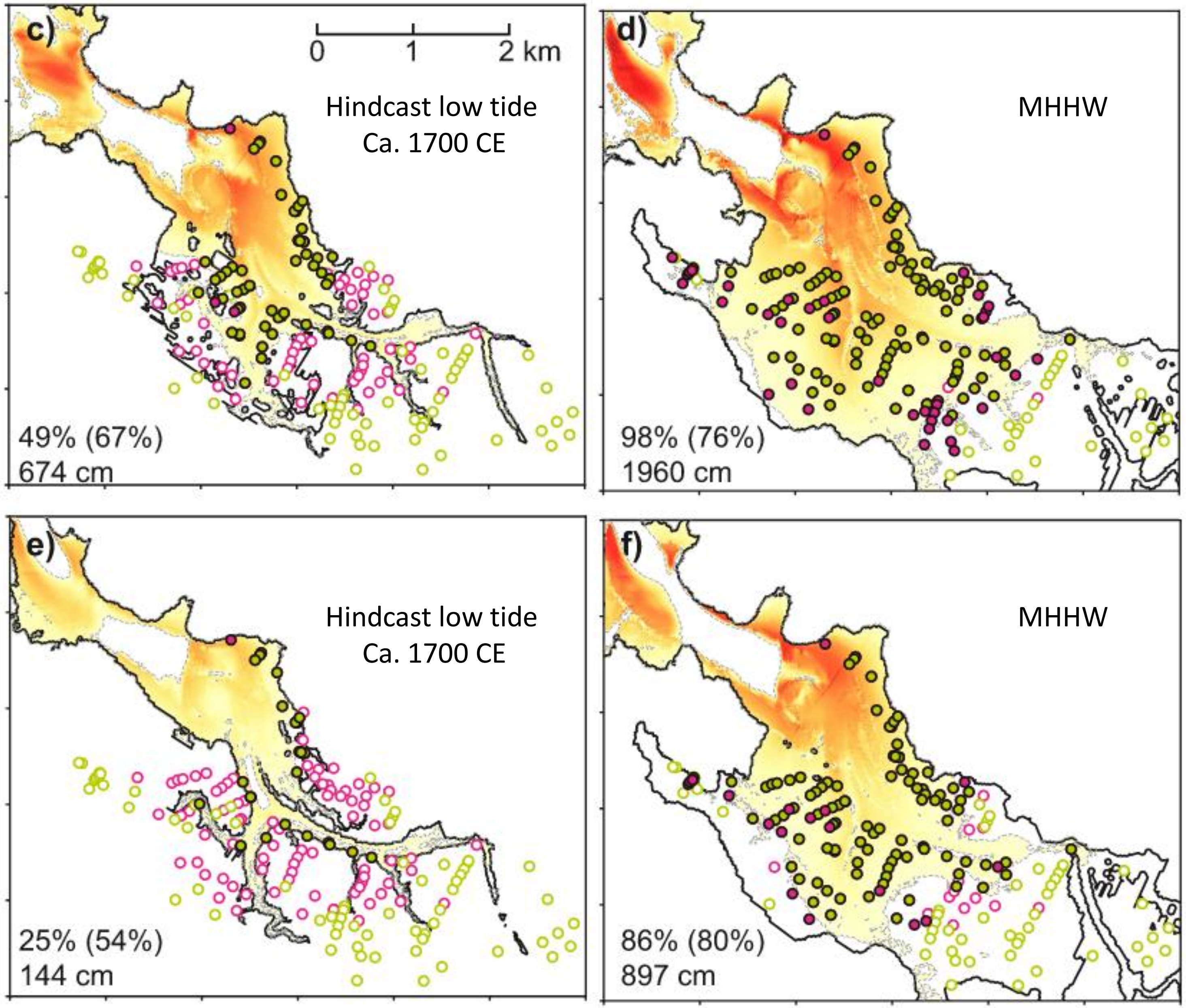

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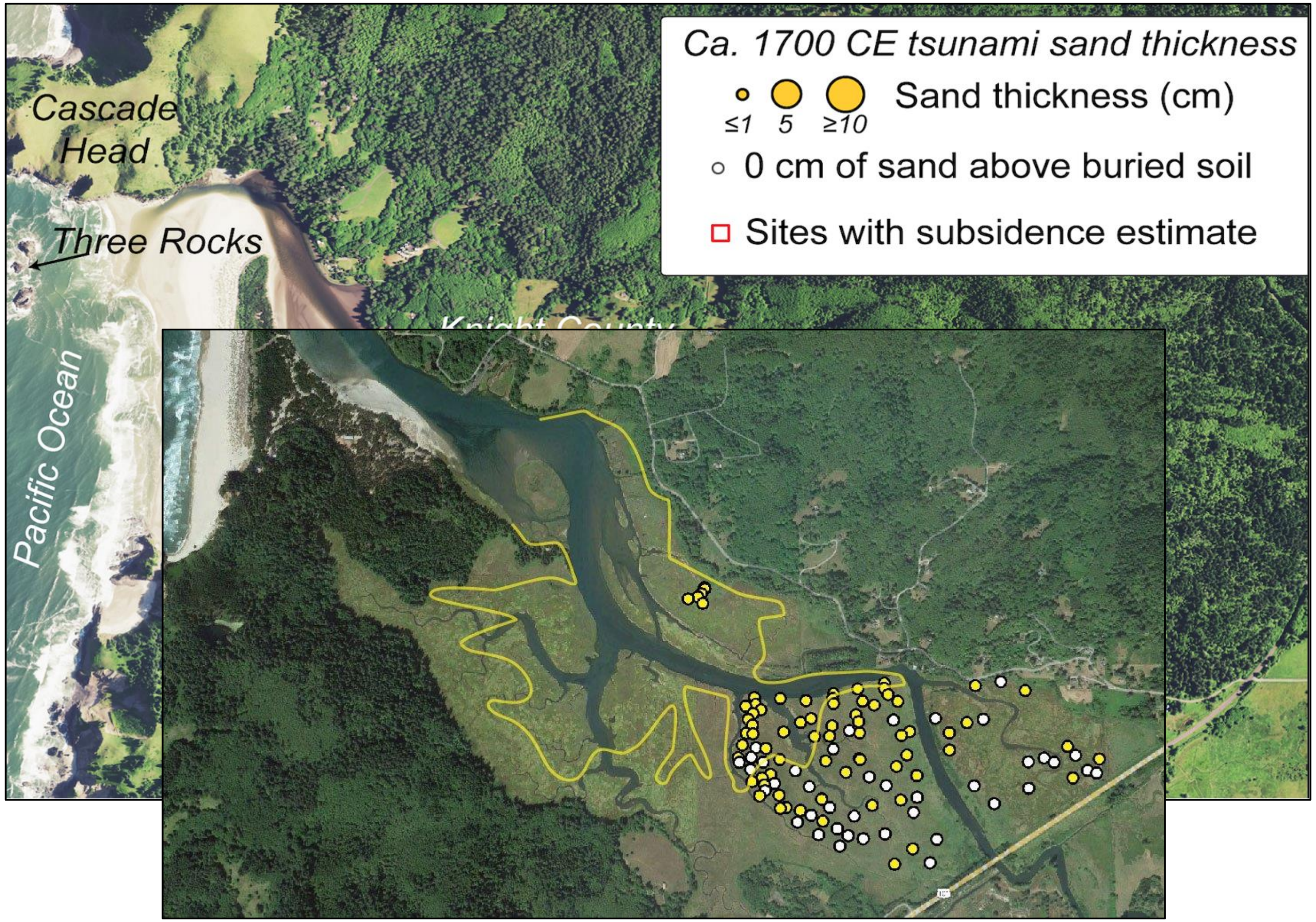

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Tsunami mapping and models

New mapping pushes the observed limit inland

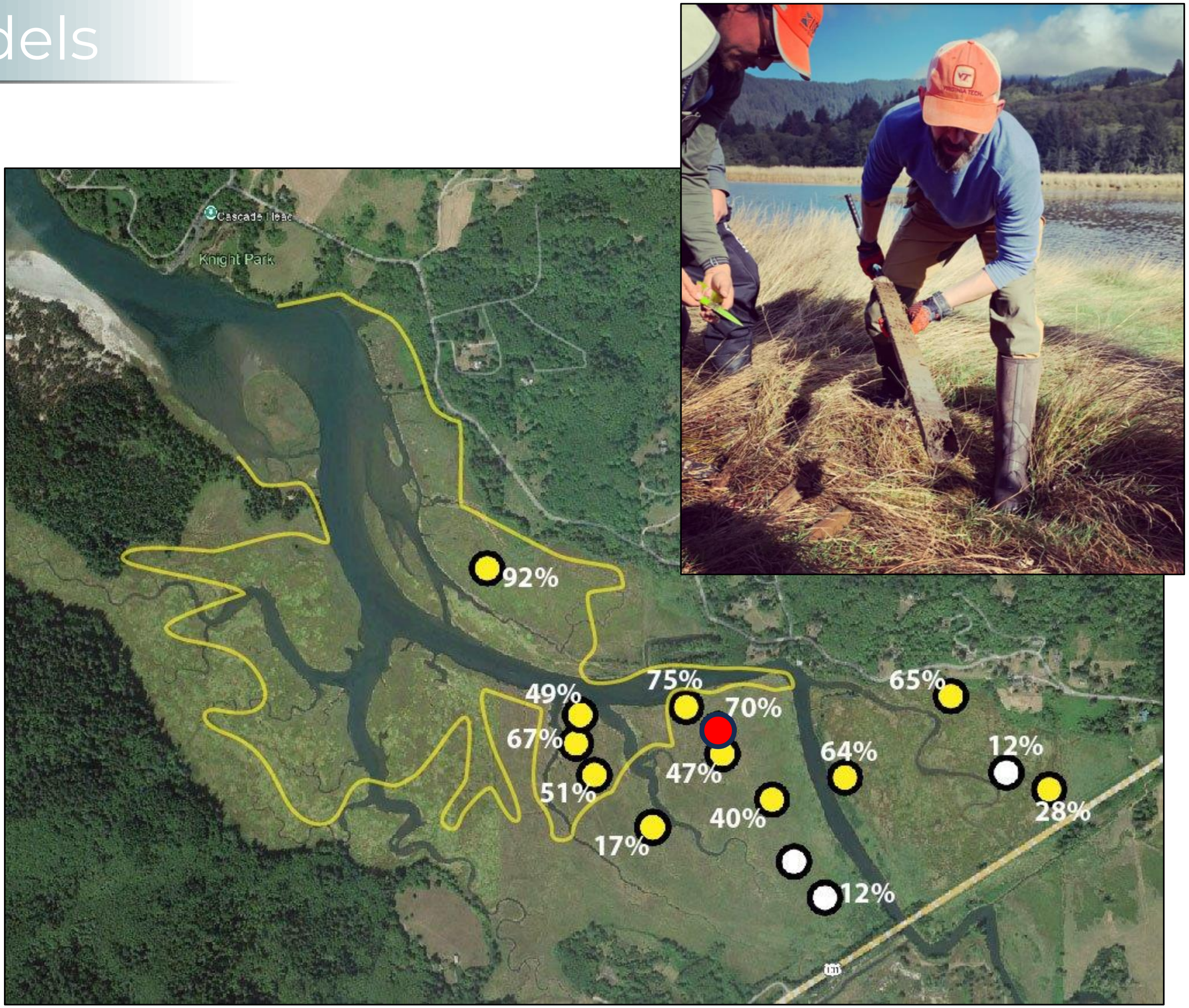
CRECENT CPAL fieldwork in Oct. 2023 and subsequent high resolution laser grain size analysis

Percentages are of sand-size particles across 1700 CE event horizon

Diatom analyses across the horizons also indicate marine incursion

Broken valves and marine provenance can be tracked farther inland than sand, giving a closer estimate of inundation extent

> *e.g., Tanigawa et al. (2018) observed marine diatoms ~2 km farther than sand in 2011 Tōkohu-oki tsunami*



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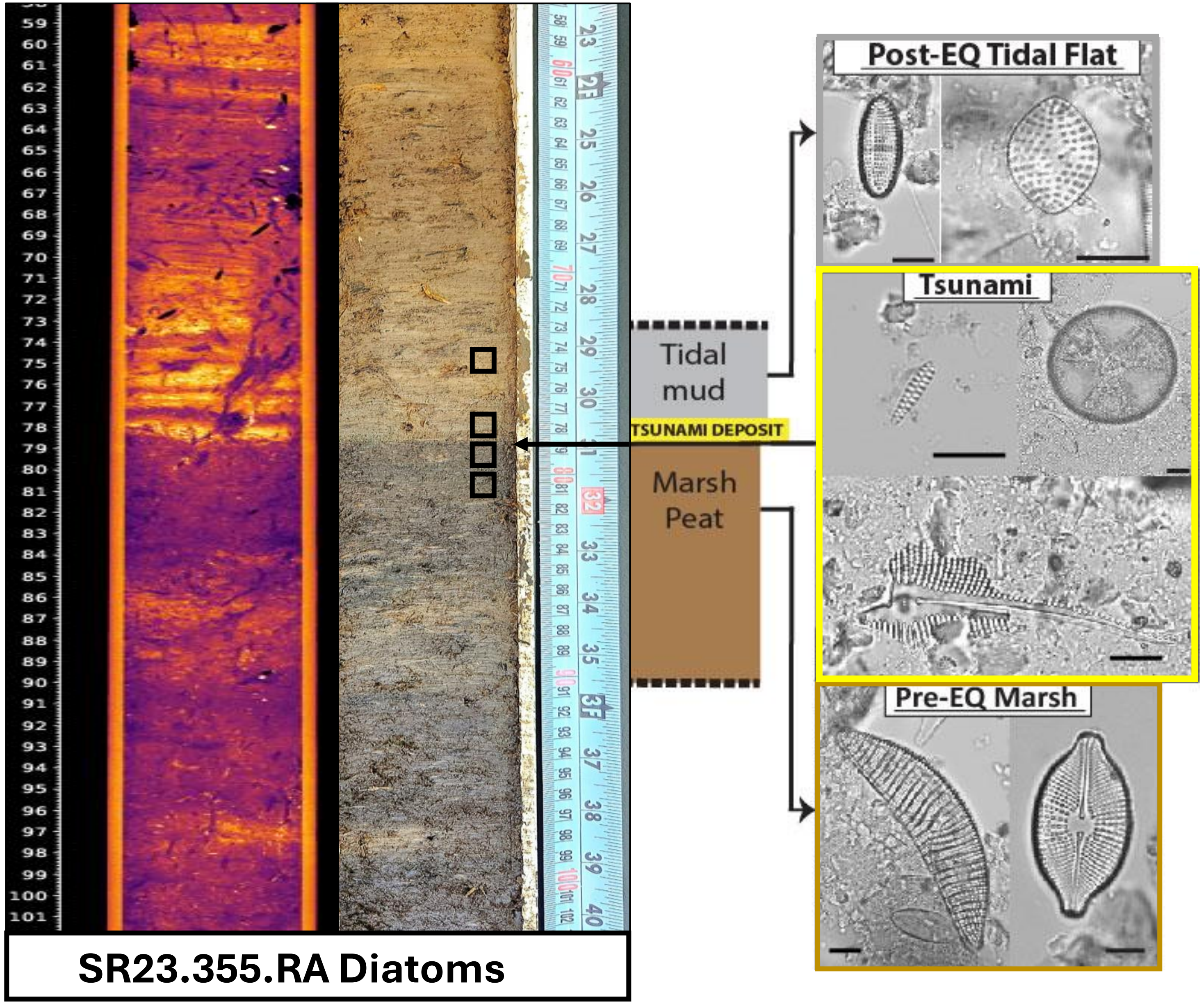

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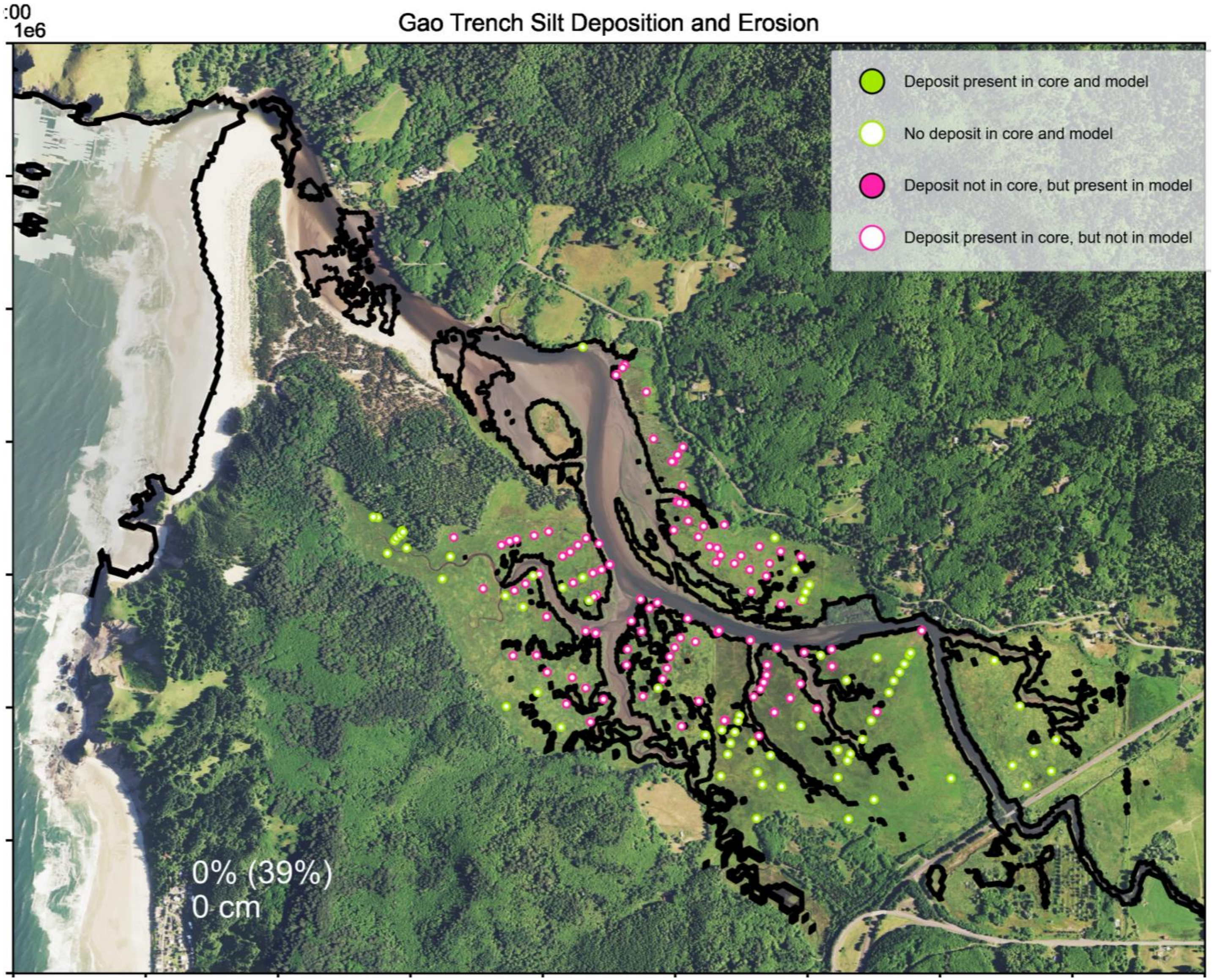


Fig. from LaSelle et al. (2024)

Recurrence and ruptures

Fig. from Walton and Staisch, et al. (2021)

What do we know?

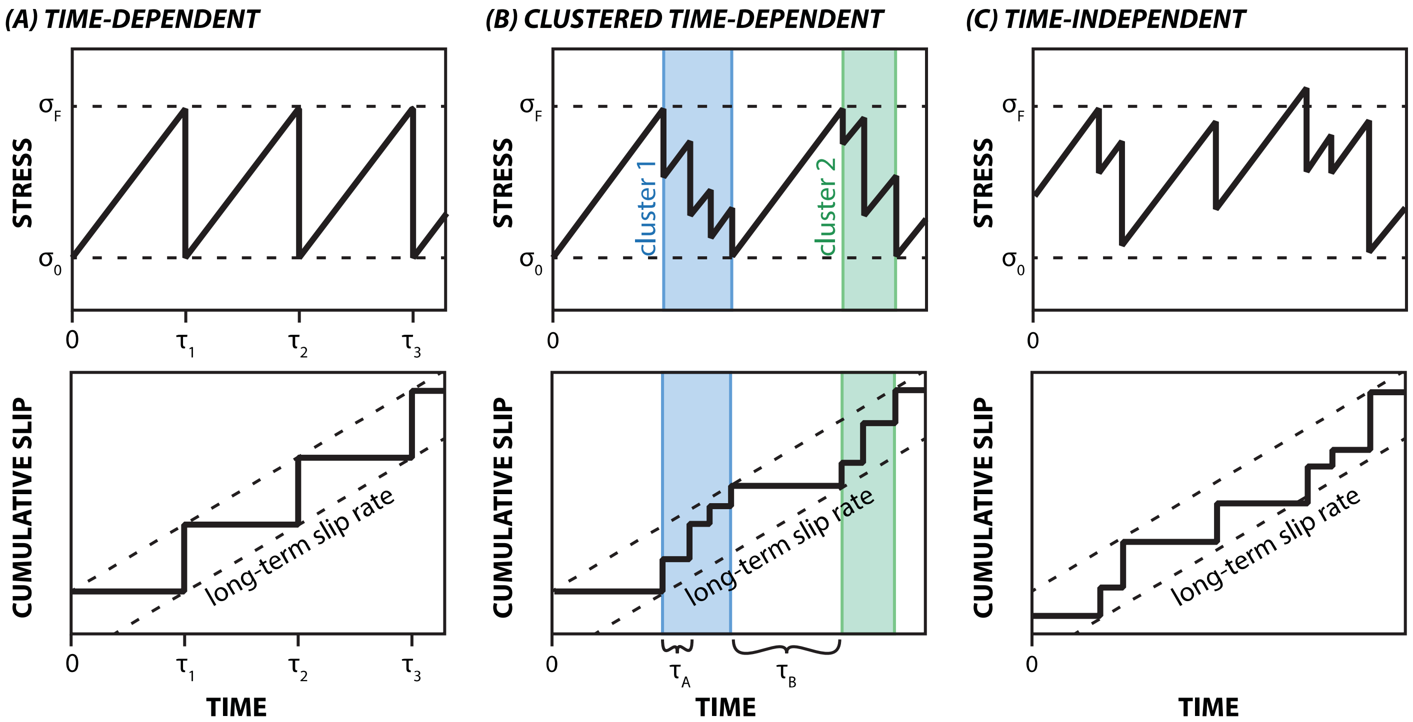
- A multi proxy approach to paleoseismology provides the best constraints for rupture source
- Coastal deformation and tsunami sand extent are excellent benchmarks for rupture models
- Precise ages really matter

What don't we know?

- In many cases, age uncertainty prohibits us from definitively identifying rupture extent and source
- Rupture characteristic variability over time

What do we need to <u>do</u> to know what we don't know?

- Better age control
  there are no bad ages, just bad context
- High resolution data on at more sites
  onshore and offshore, ideally
- More models of past events using paleoseismic benchmarks

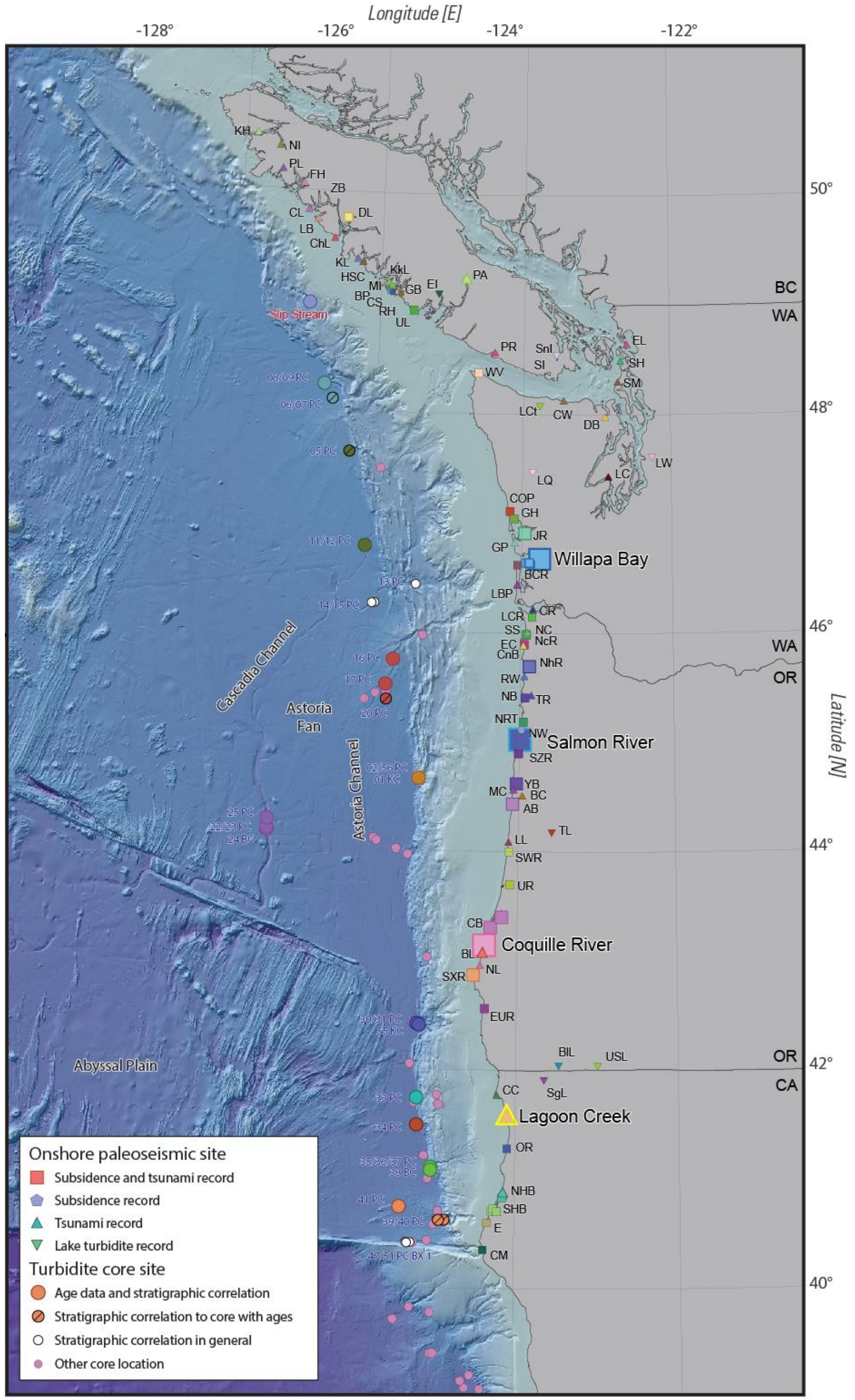


Ongoing field efforts

CPAL/CoPes/USGS fieldwork and analyses

Fieldwork in 2023-24 was targeting known paleoseismic sites with good evidence for subsidence and tsunami inundation

- **Tsunami inundation mapping (1700 CE)**
  - *Willapa Bay, Lagoon Creek, Salmon River, Coquille River*
- **Downcore age control**
  - *Lagoon Creek, Coquille River*



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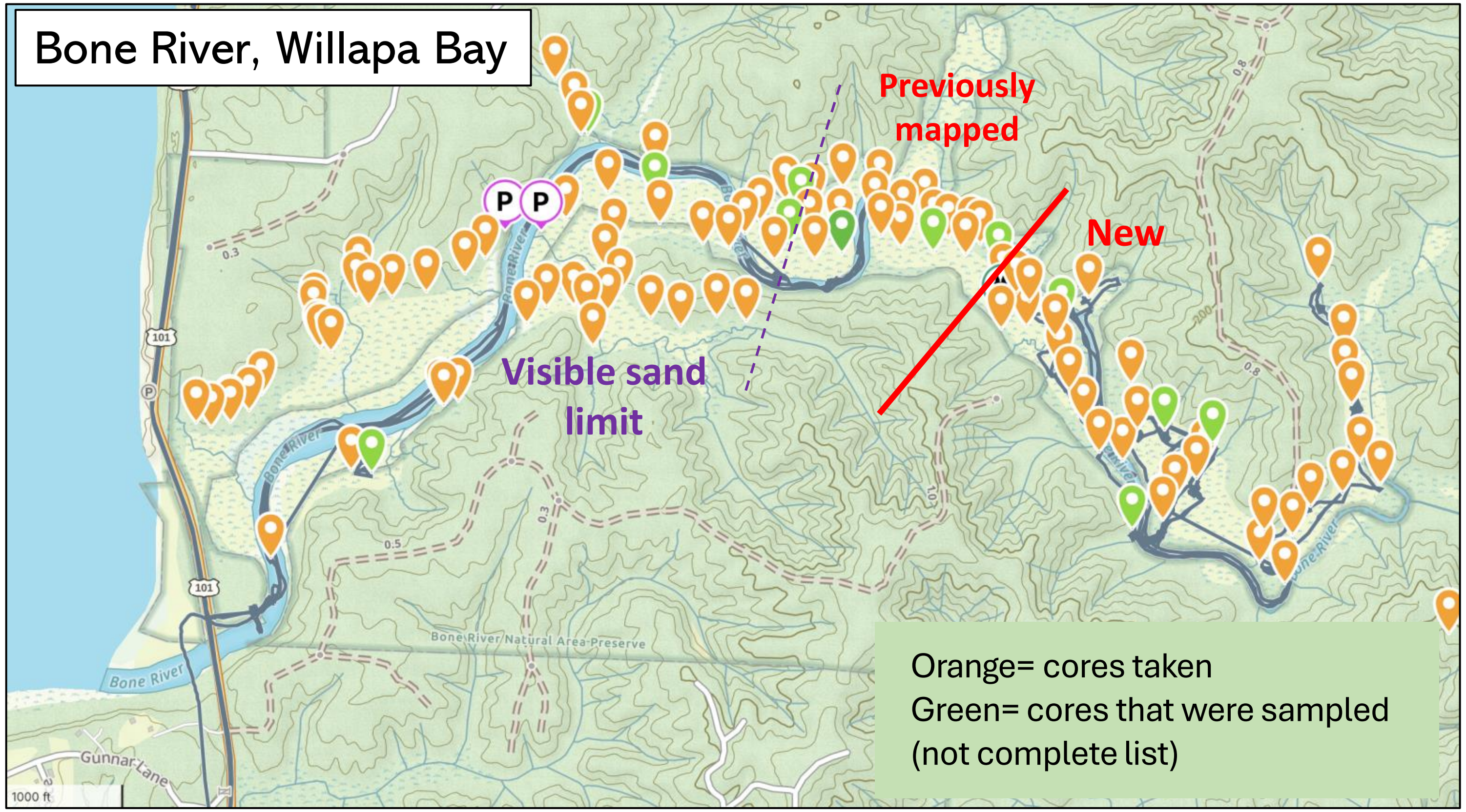
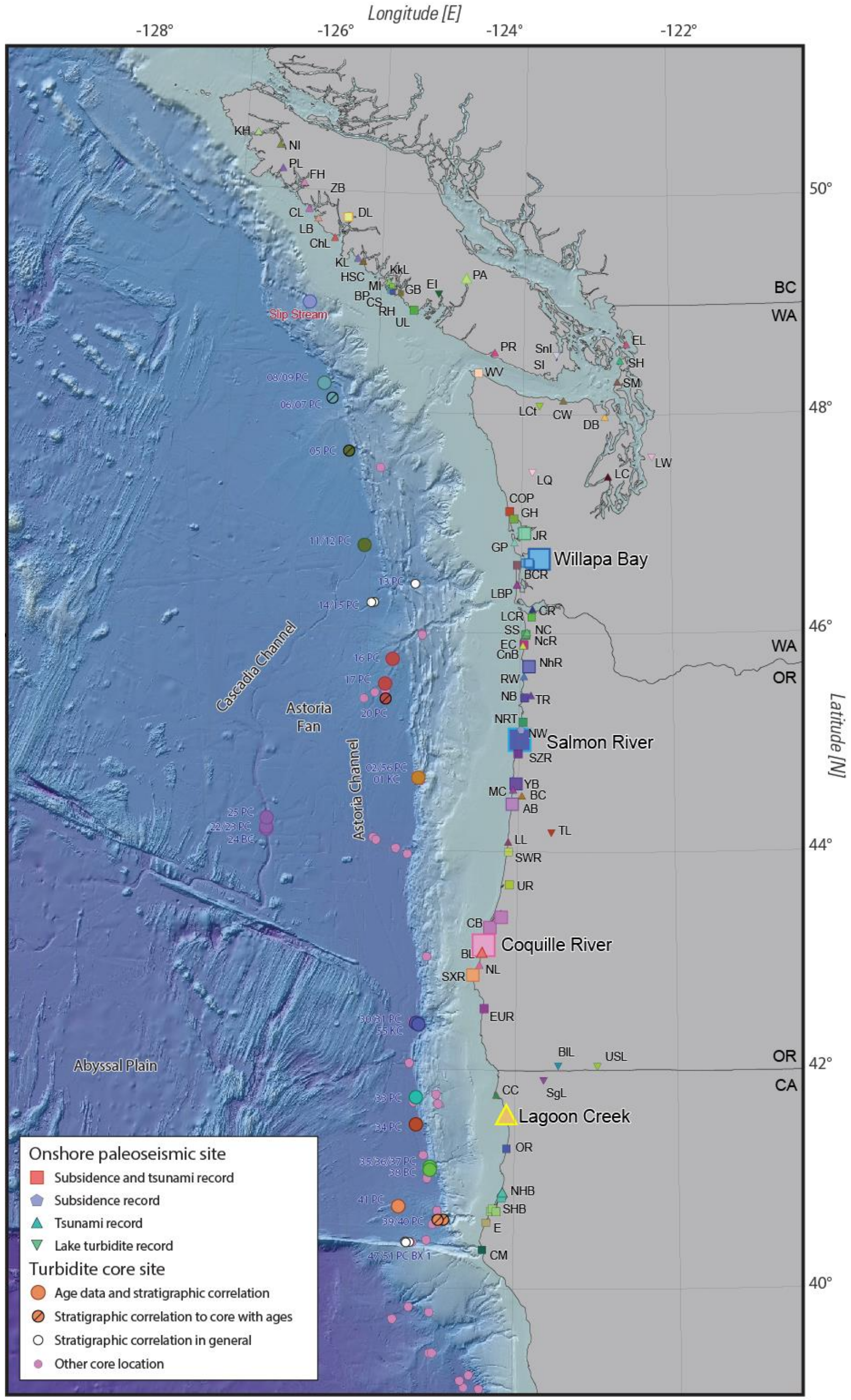
Downcore age control

Lagoon Creek, Coquille River





QUESTIONS?

Age Control and Correlation

Systematic reanalysis

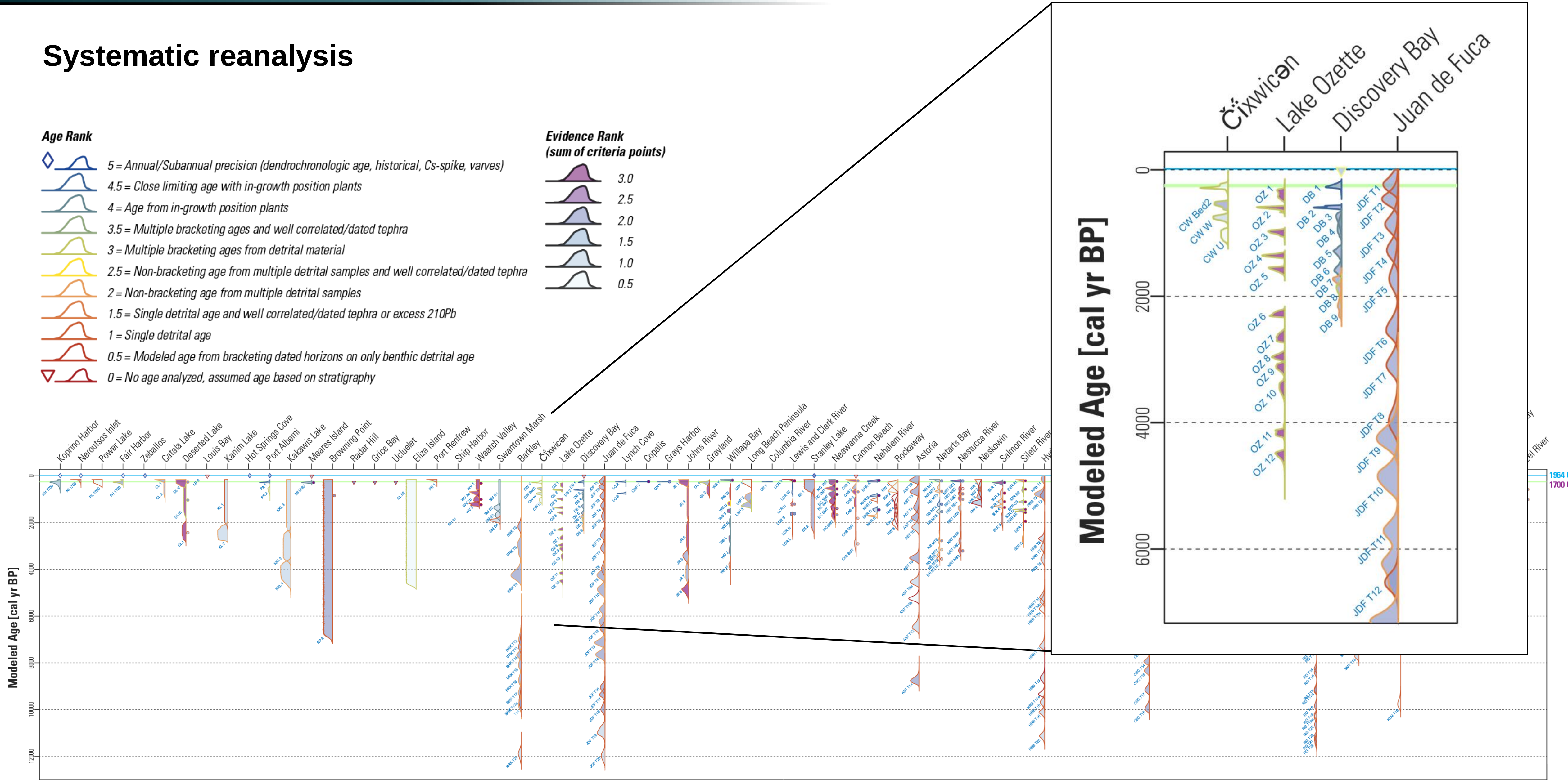


Fig. from Staisch et al. (in prep)