# SUBMARINE LANDSLIDES & SEISMOTURBIDITES IN THE CASCADIA SUBDUCTION ZONE

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science for a changing world

# USGS RESEARCH PLAN

**Key scientific questions:**

To what extent and how frequently do potentially tsunamigenic upper plate structures rupture with the megathrust?

- *Evaluating seismic evidence for slip to the trench with detailed AUV/ROV surveys*
- *Examining Quaternary deformation in outer wedge*
- *Characterizing recent deformation on shoreline crossing faults in southern Cascadia*

How do along strike variations in the morphology and structure of the overriding plate relate to possible segmentation of the megathrust?

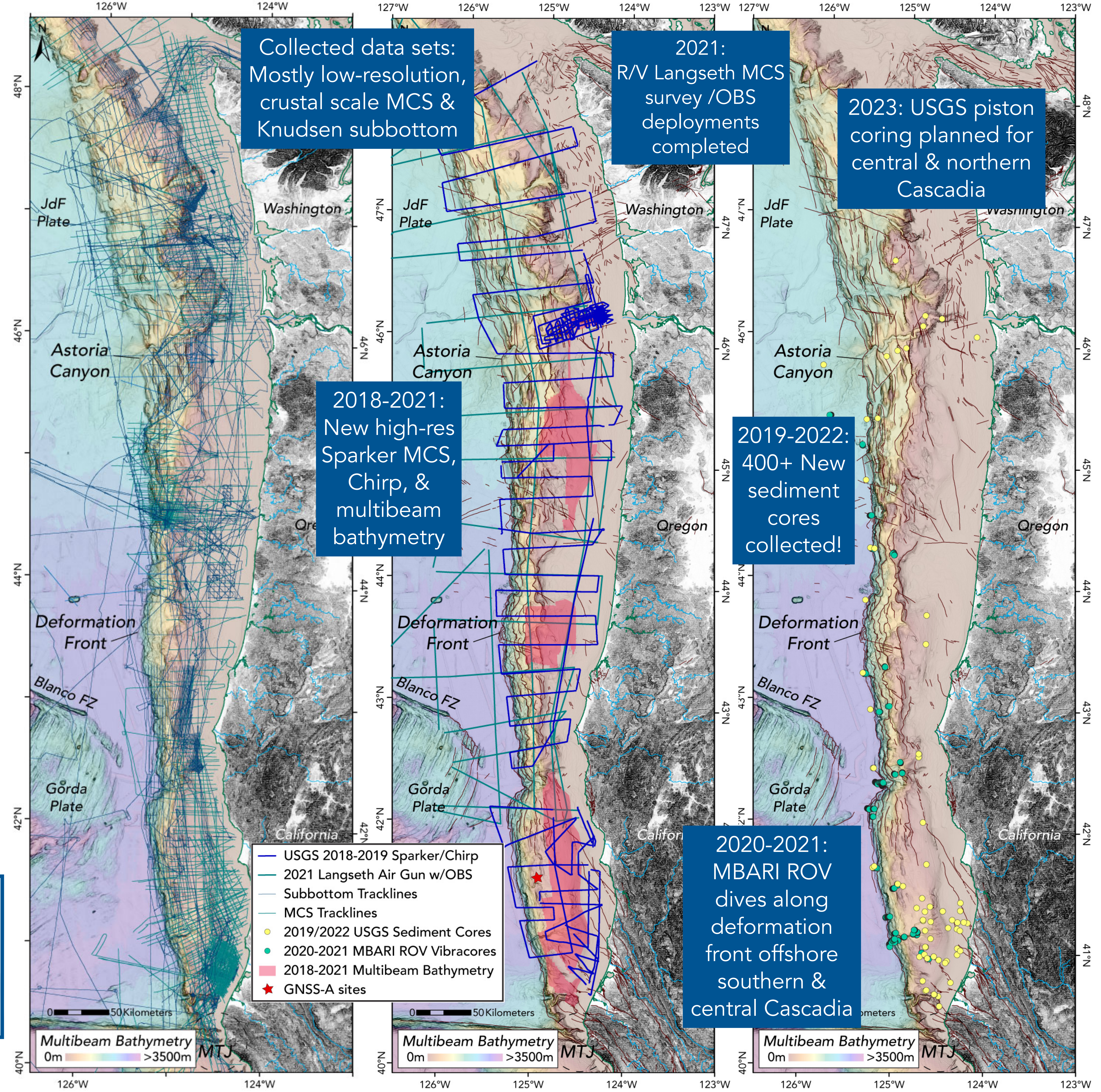
- *Watt and Brothers (2021): Systematic characterization of morphotectonic variability…*

What is the role of fluids in subduction zone processes?

- *Integrating seep mapping with regional structural characterization*

How is sediment delivered and redistributed across the continental shelf and slope?

How does earthquake shaking translate to slope failure?



Collected data sets: Mostly low-resolution, crustal scale MCS & Knudsen subbottom

2021: R/V Langseth MCS survey /OBS deployments completed

2023: USGS piston coring planned for central & northern Cascadia

2018-2021: New high-res Sparker MCS, Chirp, & multibeam bathymetry

2019-2022: 400+ New sediment cores collected!

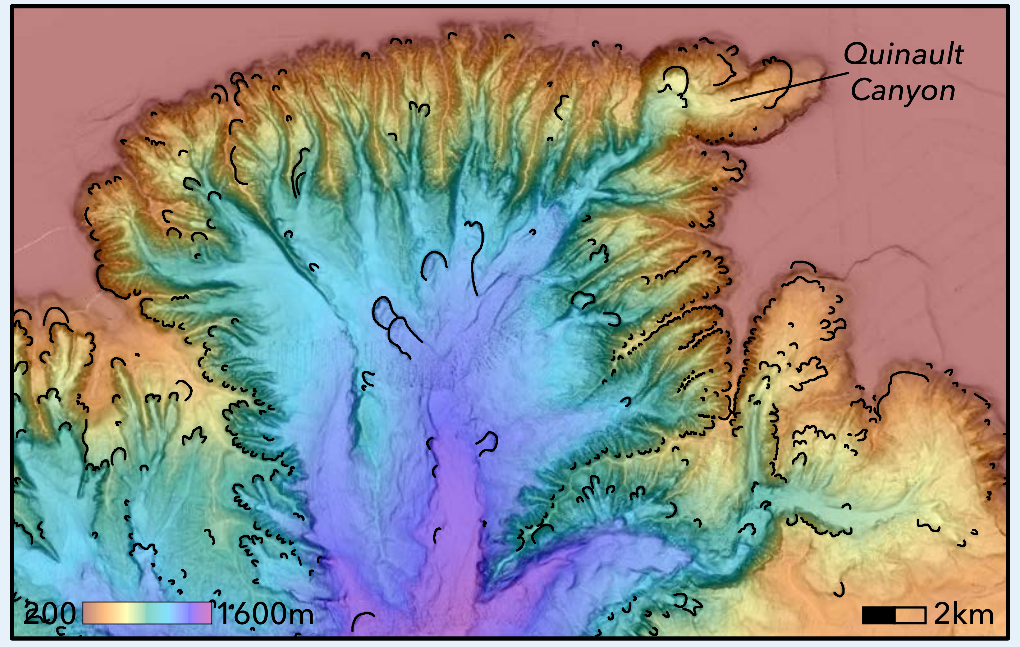
2020-2021: MBARI ROV dives along deformation front offshore southern & central Cascadia

# TURBIDITY CURRENTS: SOURCE AREAS & DEPOSITS

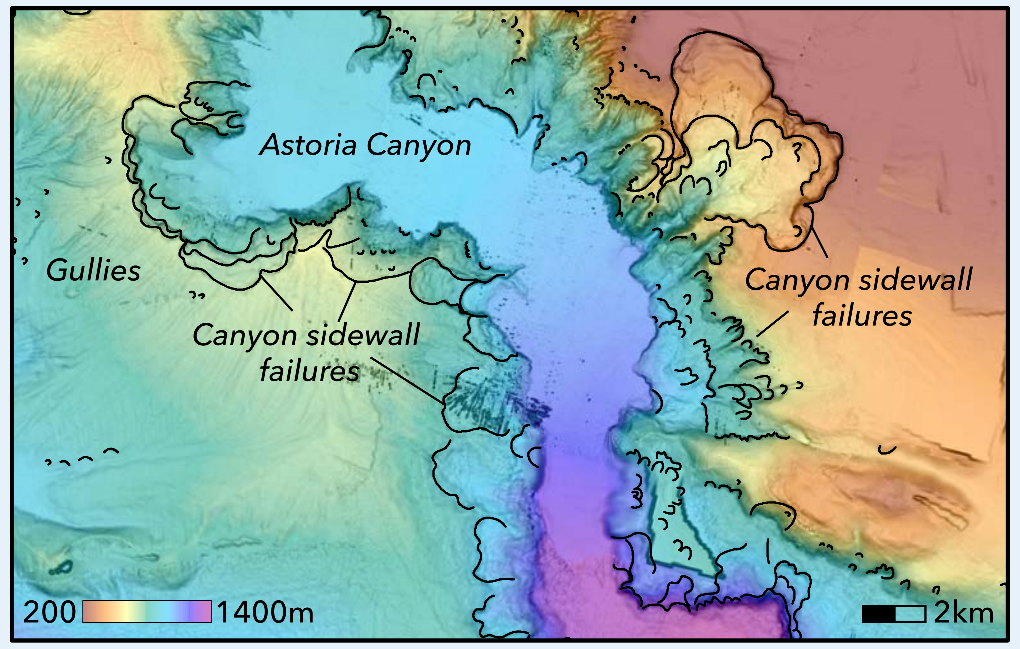
When earthquake shaking occurs, sediment is remobilized along different parts of the slope:

## Within submarine canyon systems

### *Canyon heads with fluvial inputs*

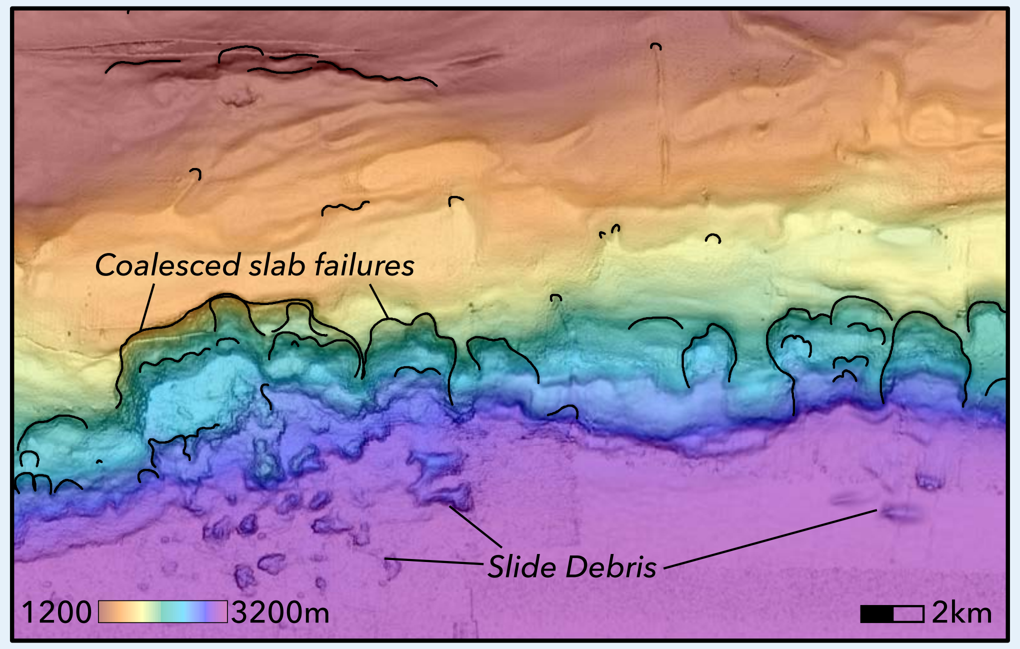


### *Canyon/channel levees & sidewalls*

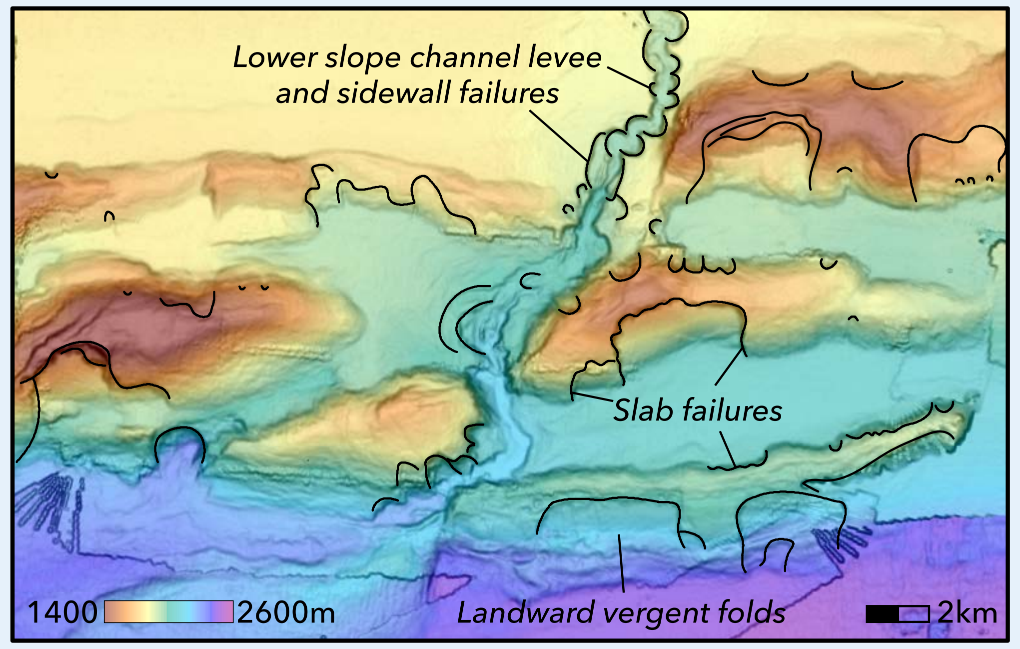


## Open slope failures

### *Steep seaward outer wedge*



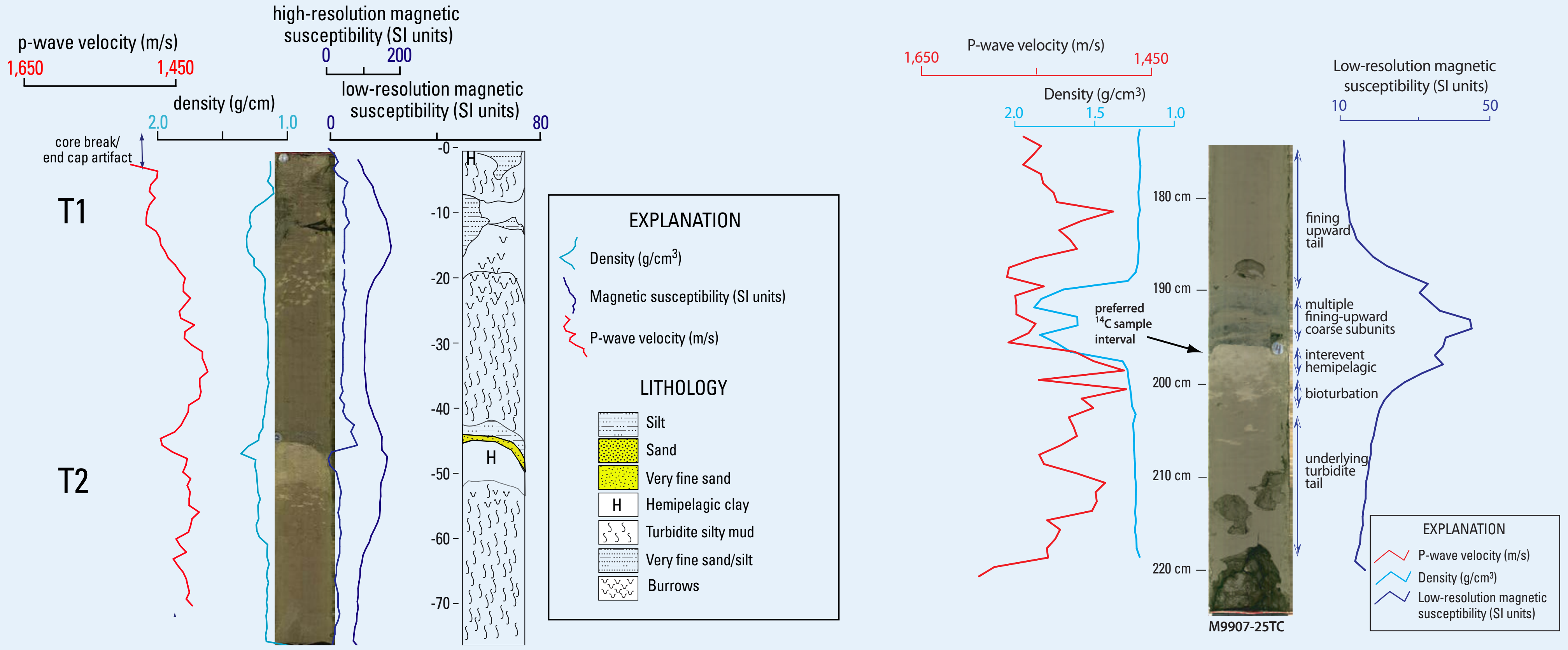
### *Flanks of anticlinal ridges*



*From Hill et al., 2022*

**Sandy abyssal turbidites:**

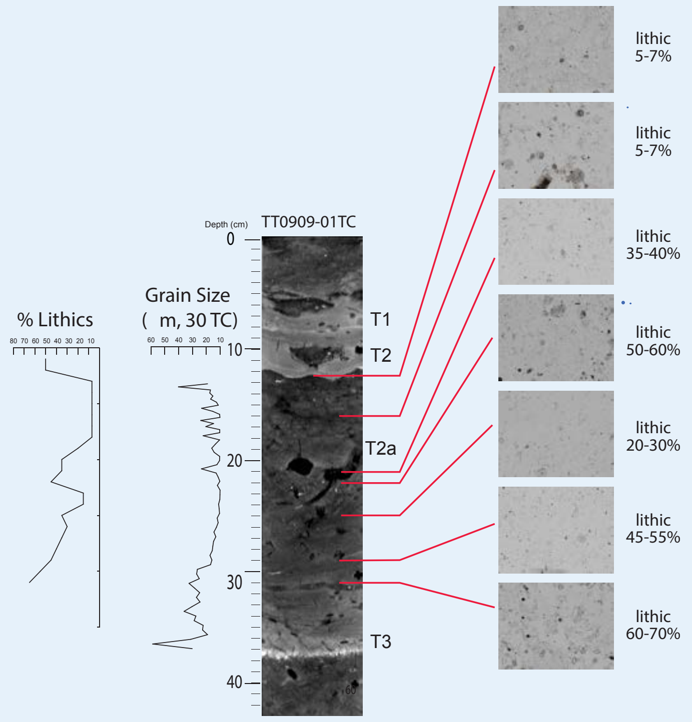
Multiple fining-upward Bouma $T_{A\text{–}C}$ sequences, capped by a fine-grained fining-upward tail associated with the waning turbidity current (Bouma $T_D$).



*Physical properties (density, magnetic susceptibility) often increase with grain size and can serve as proxies*

**"Mud turbidites":**

Thinner mud-silt beds with more subtle grain size and color variations; increased bioturbation; similar structures to sandier turbidites; high lithic content



*From Goldfinger et al., 2012*

# MARINE TURBIDITE RECORD: CORRELATION

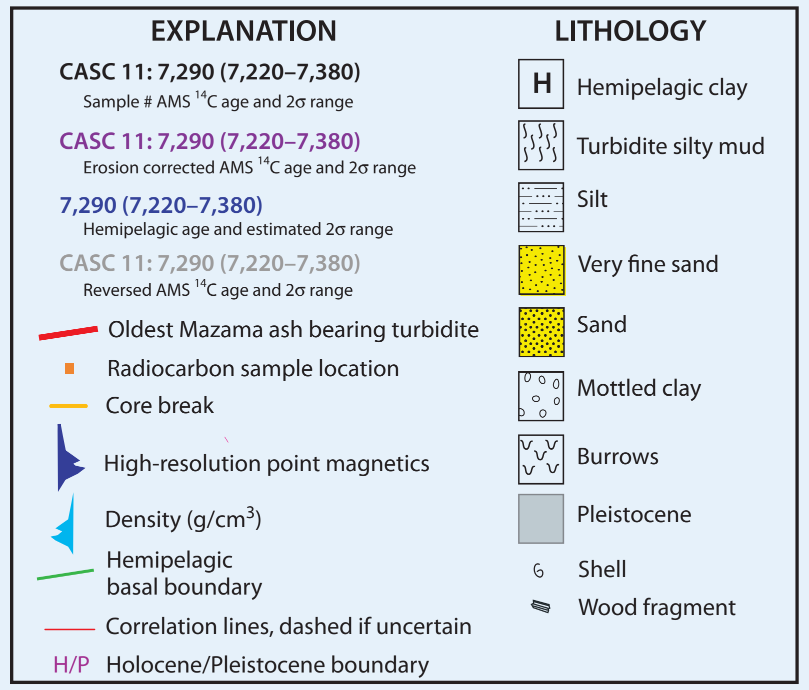
## STRATIGRAPHIC "FINGERPRINTING"

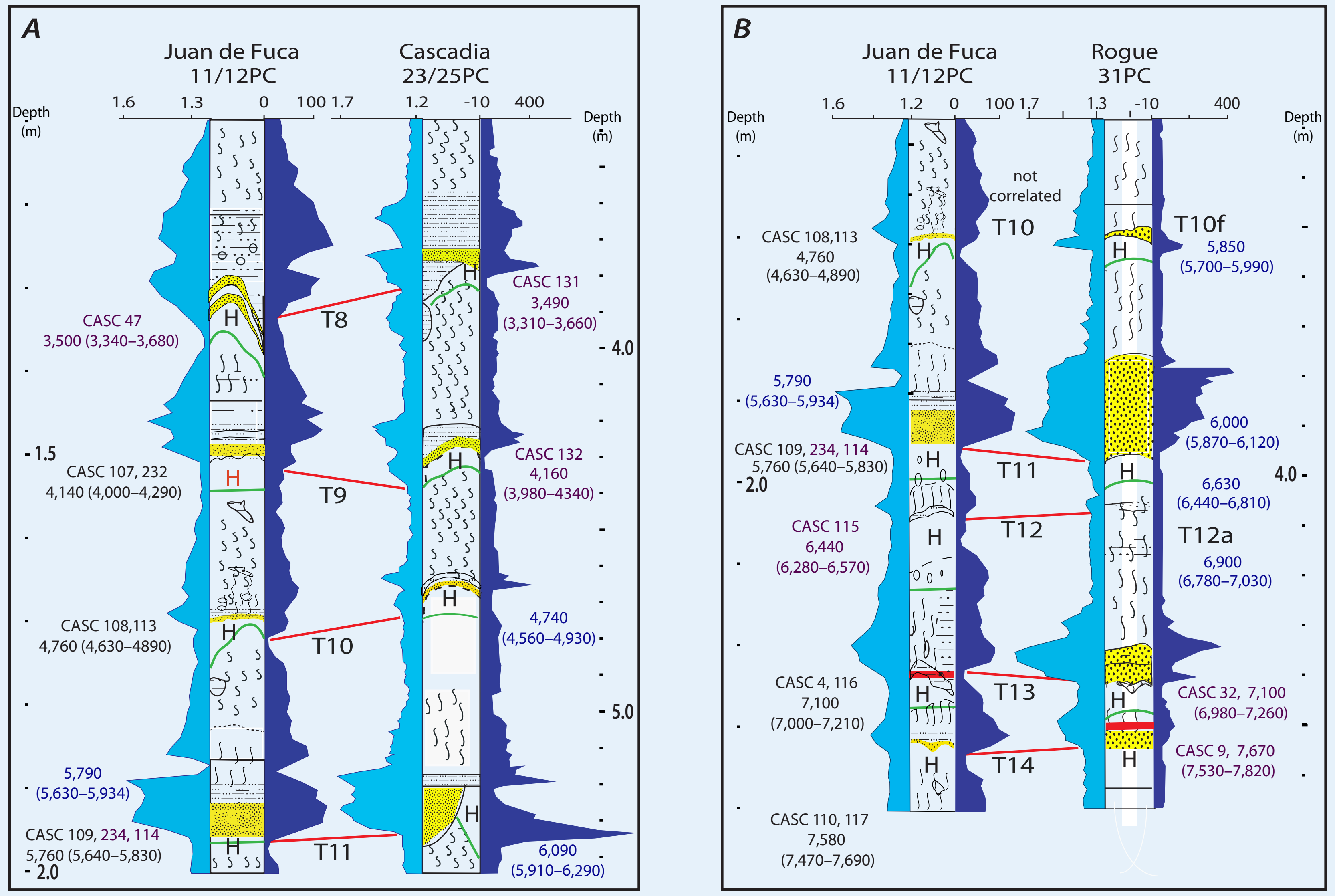
Stratigraphic correlation of turbidites within and between systems, over 100s of kms, relies primarily on the comparison of:

**Physical properties** *(Magnetic susceptibility and gamma density as proxies for grain size, supported by direct grain size subsample measurements, RGB color, P-wave velocity, CT and X-ray imagery)*

and is guided or bounded by age constraints from:

**Marker beds** *(Pleistocene/Holocene; Mazama Ash datum)* and **Radiometric dating methods** *($^{14}$C; $^{210}$Pb)*

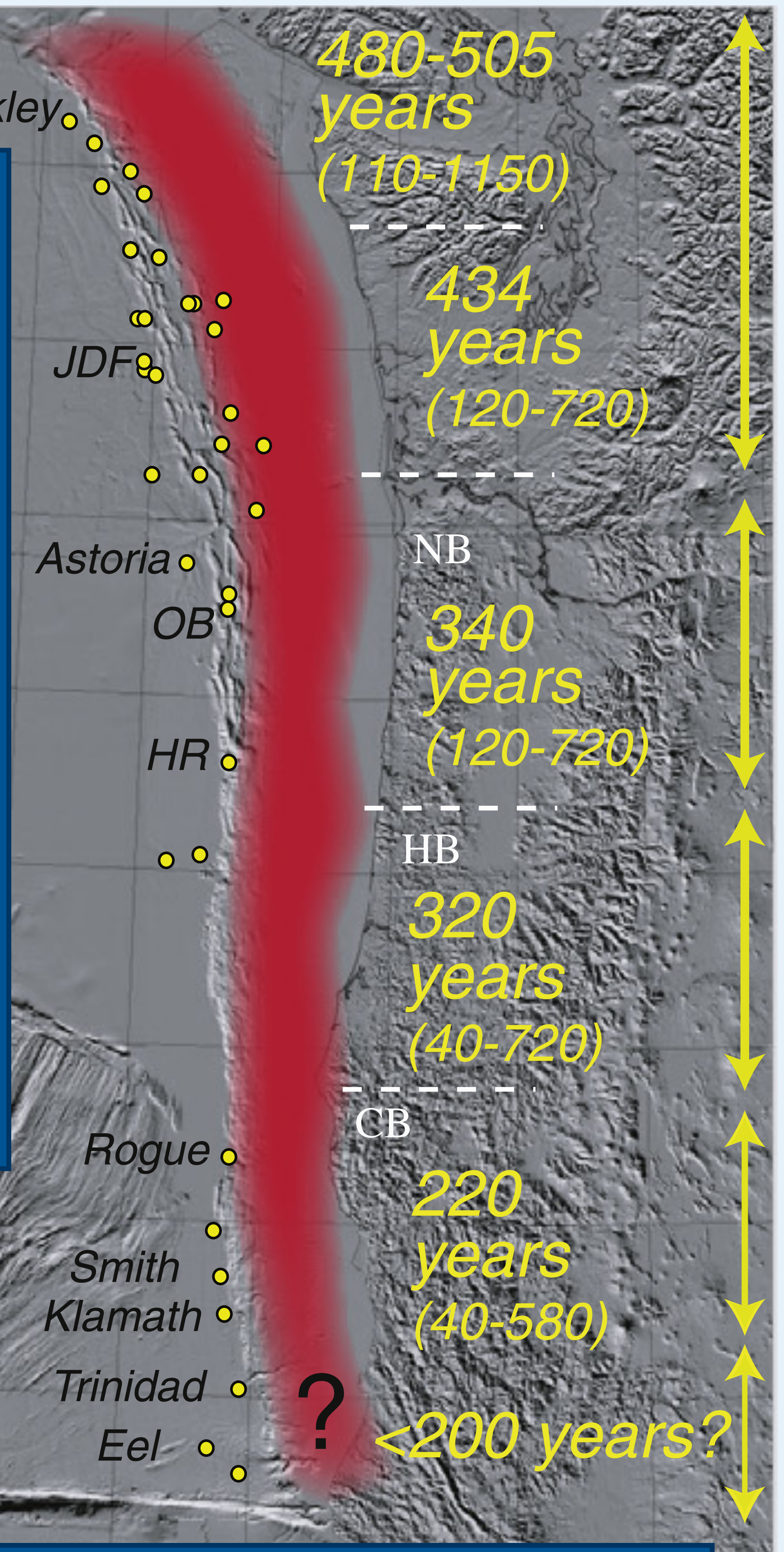




*From Goldfinger et al., 2012*

Full margin rupture recurrence ~500 yrs;

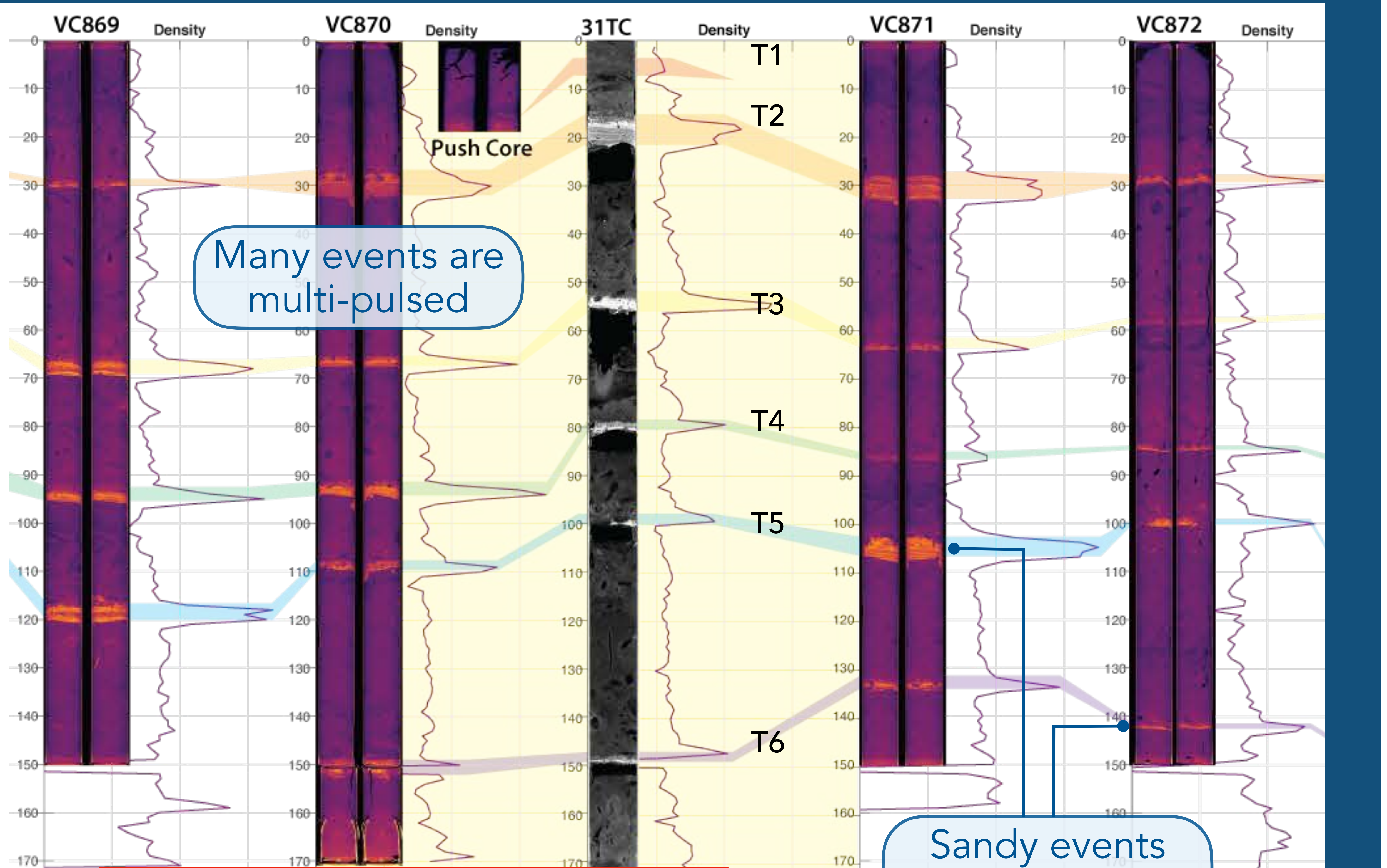
Increasing number of turbidites, correlated over shorter distances, suggests shorter recurrence times in the south



*Goldfinger et al., 2017*

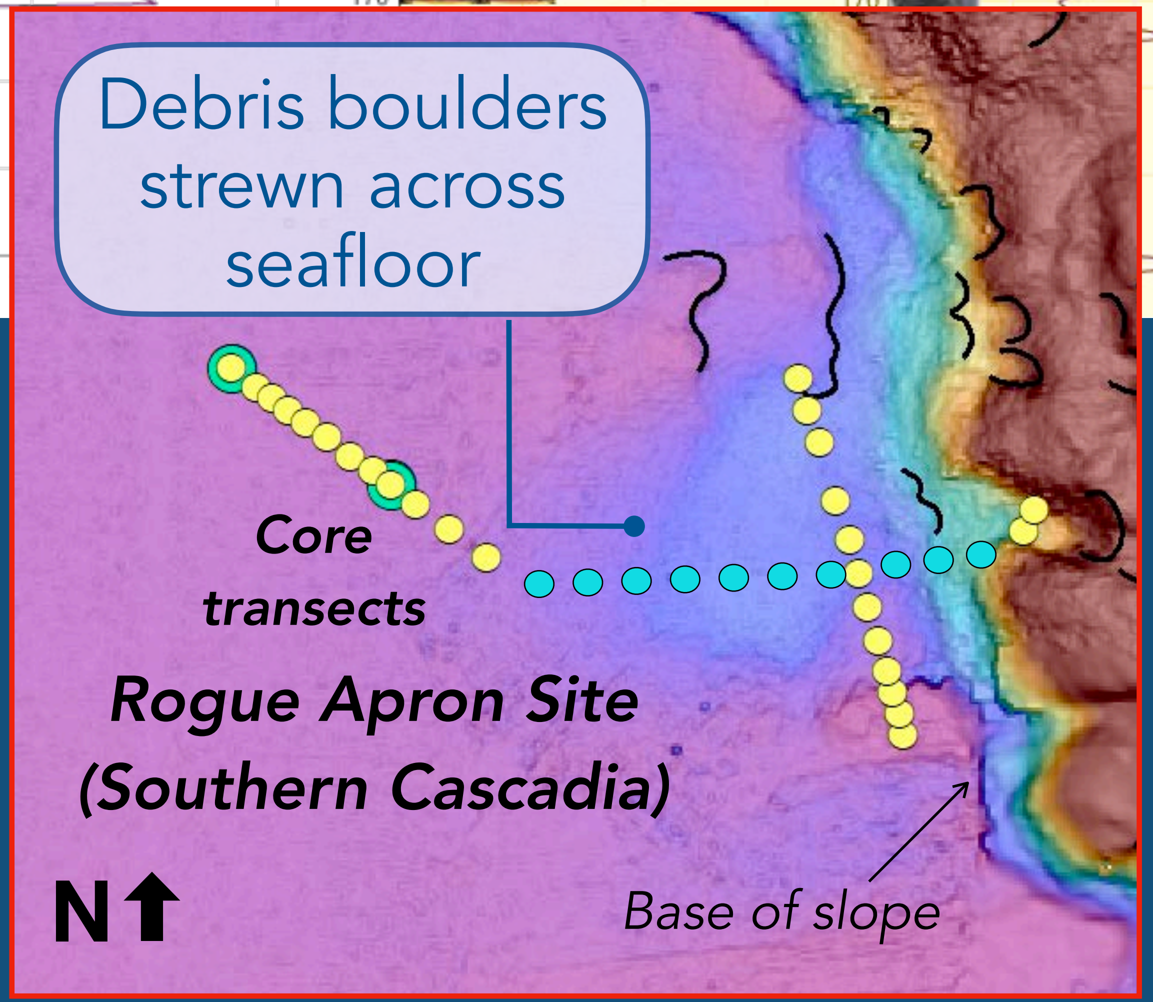
Uncertainties (ages, robustness of long distance correlation, interpretation of deposits) make it difficult to distinguish the length of ruptures, as well as the spatial extent and magnitude of shaking — requires better understanding of turbidite generating systems in Cascadia

# VARIABILITY WITHIN TURBIDITE SYSTEMS



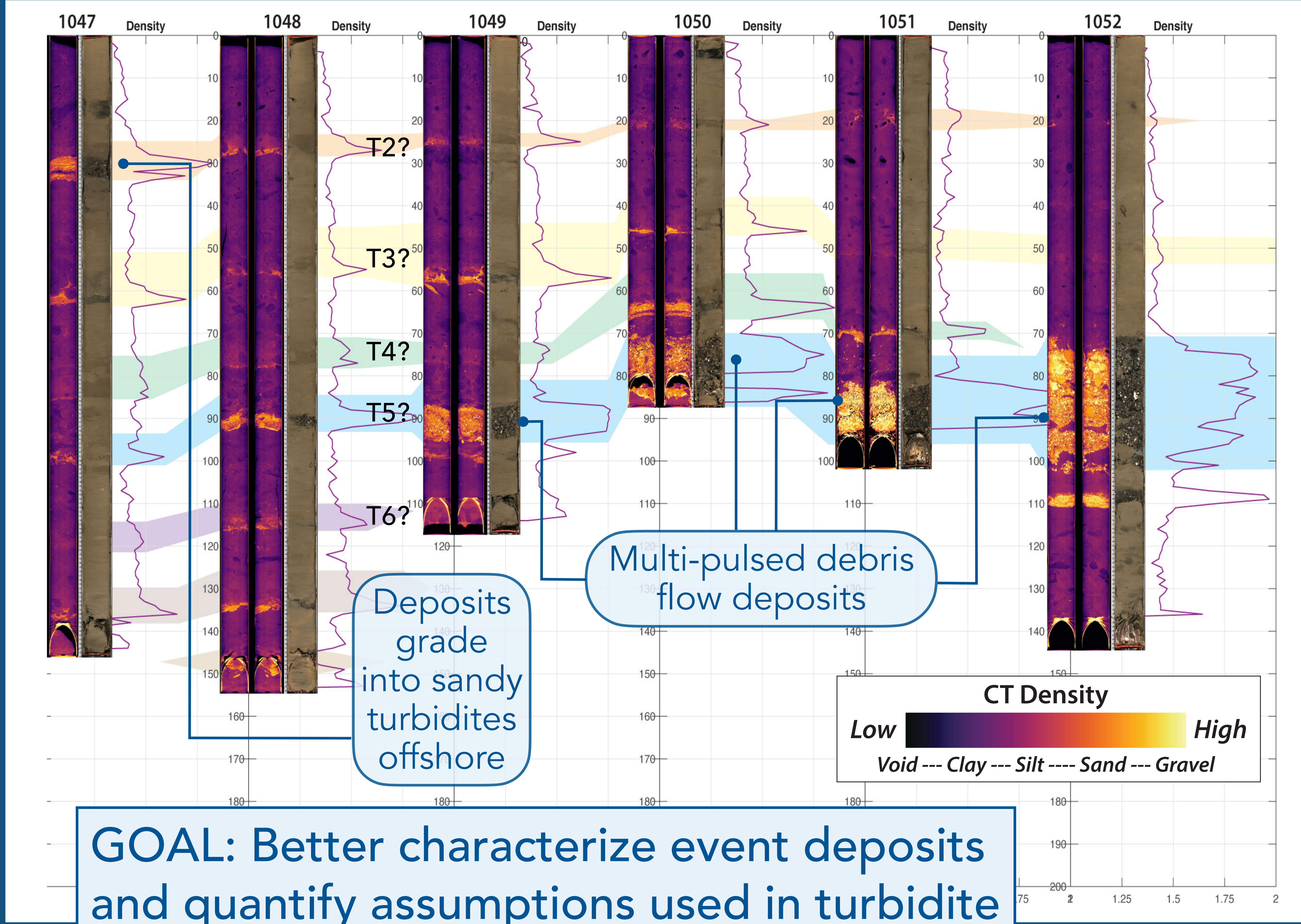
Many events are multi-pulsed

Sandy events on abyssal plain



Debris boulders strewn across seafloor

*31TC and T-events from Goldfinger et al., 2012*



Deposits grade into sandy turbidites offshore

Multi-pulsed debris flow deposits

GOAL: Better characterize event deposits and quantify assumptions used in turbidite age models to reduce uncertainties

Vibracore transects (200-400m spacing), paired with push cores to collect undisturbed sediment-water interface, and ROV video observations, show *significant variability both between and within turbidite systems*

# TURBIDITE SOURCES: CANYONS VS. OPEN SLOPE

## What are the sources and pathways of turbidity flows across Cascadia?

← Northern → ← Central → ← Southern →

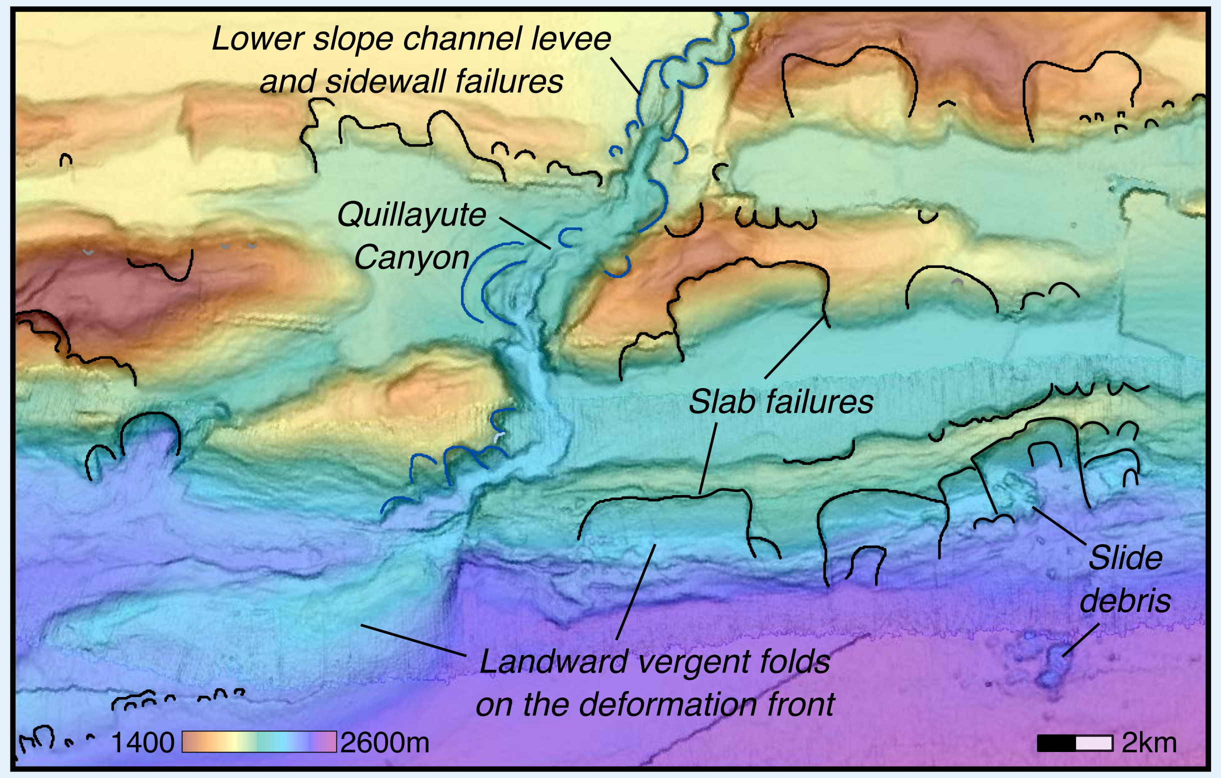
Failures in steep canyon heads, sidewalls and levees;
On the steep faces of landward vergent folds

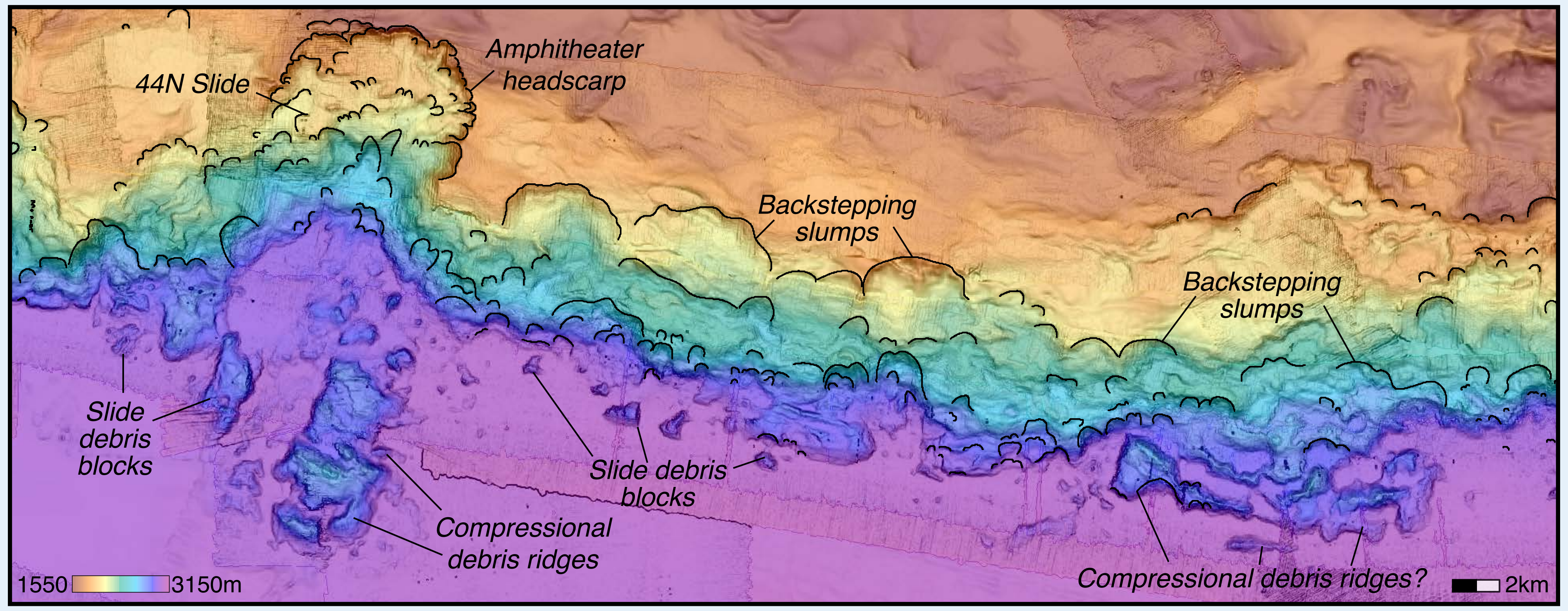
Blocky failures concentrated around steep,
stepped terrace morphology of the lower slope

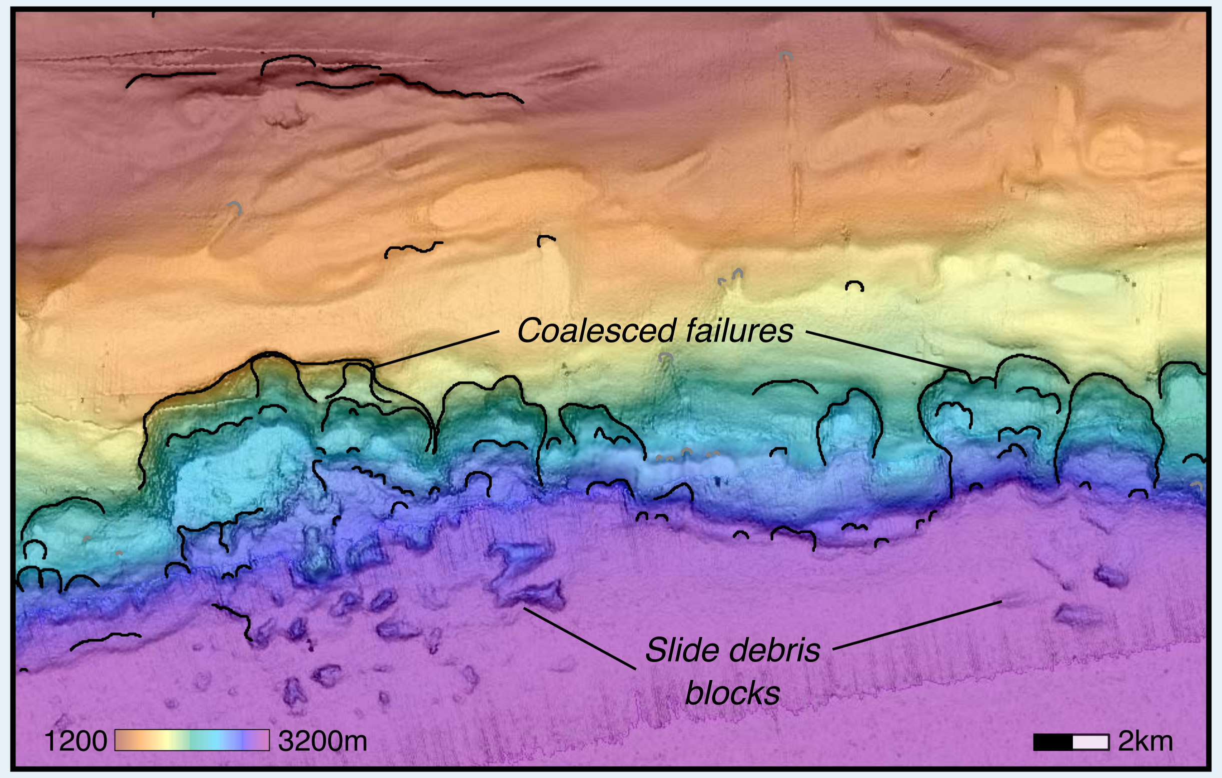
Upper slope sediment storage;
Failures on steep lower slope

Sediment storage on the upper slope and pervasive mass wasting along the steep lower slope suggests ***disintegration of the outer wedge is the primary source of turbidites in Cascadia***

*Hill et al., EPSL, 2022*







# SOUTHERN CASCADIA: LOWER SLOPE FAILURES

## Sediment storage on the upper slope and pervasive mass wasting along the steep lower slope

Very few upper slope failures despite high sediment flux from Eel & Klamath Rivers

**Eel Forearc Basin is a sediment sink** that inhibits shelf to deep sea transport

Upper Trinidad Canyon has ***>20m* Holocene**; failures in lower canyon contribute to turbidite record

Extensive failures in the lower canyon

Lack of canyons here suggest turbidites are likely sourced from *lower slope failures*

# Earthquake generated turbidites appear to be sourced from seafloor failures on the lower slope in southern Cascadia

Large failures destabilize the slope (*MTDs*); subsequent earthquakes produce a series of ***turbidites*** sourced from the failure zone

***Adjacent to*** failure zone: Poorly expressed turbidites

***Within*** failure zone: Well-defined turbidites

Turbidites correspond to reflectors above the MTD

Multiple large failures followed by smaller turbidity flows

# CENTRAL CASCADIA: NO SUBMARINE CANYONS

## Steep lower slope with stepped terrace morphology and extensive failure zones

⌒ Seafloor failure scarps, *Hill et al., 2022*

● Core Location, *Goldfinger et al., 2012*

● Archival/Additional Cores, *Goldfinger et al., 2017*

Lower sediment input than north and south

*With a steep lower slope, the proximal abyssal plain acts as an 'isolated basin' where all failures are local and earthquake triggered*

★ Isolated basins with no terrestrial input are key

Isolated basin; correlations with Hydrate Ridge

Key record - close to trench; isolated; deposits reflect local source

250km gap with no turbidite records ***(until now!)***

In Sept 2022, we collected a suite of piston cores ★ along the abyssal plain that provide new earthquake records spaced ~50km apart

# CENTRAL CASCADIA: ABYSSAL TURBIDITE RECORDS

Initial estimates suggest 20-23 Holocene events likely sourced from proximal failures of the lower slope

Turbidite event layers appear as spikes in MS / Density

Complex event with likely multiple failure sources

Graded sands and silts, crossbedding and flame structures

Thin bedded sands

Laminated silts and fine sands

Mud clasts, gravel & sand

Multi-pulse graded sands

# NORTHERN CASCADIA: WHAT IS THE ROLE OF CANYONS?

## Well developed canyons with limited Holocene sediment input & substantial lower slope inputs form sidewall failures

Relict, no Holocene sediment recharge, turbidite record starts mid-canyon,

*Some Holocene sediment recharge from Columbia River*

How much sediment are these systems contributing?

2019 - 2024: Geophysical surveys, coring & oceanographic instrumentation deployments to investigate ***oceanographic triggers of sediment gravity flows***

No confluence to test

2023: Coring along the deformation front (away from channels) to obtain new ‘untainted’ records from lower slope failures

*Most relevant confluence*

*References: Goldfinger et al., 2017*

# TURBIDITE SOURCES: LOWER SLOPE FAILURES

Earthquake generated turbidites appear to be sourced from seafloor failures on the lower slope in all regions of Cascadia

← Northern → ← Central → ← Southern →

>8700 landslide scarps mapped

Seafloor failure scarps are clustered along outer wedge, outside of submarine canyon catchment systems

From: Hill et al., EPSL, 2022

Steep seaward face of outer wedge: sediment bypass and slope failures

# TECTONIC OVERSTEEPENING & SLOPE FAILURE

Imbricate thrust faults create a stepped terrace morphology with steep ledges in Central Cascadia

Failures are pervasive along the deformation front — at all scales

*Failure occurs at the forelimb of the fold*

*Uplift and deformation of the outermost wedge leads to recurring, earthquake-triggered failures that are recorded in the abyssal turbidite record*

# TECTONIC OVERSTEEPENING & SLOPE FAILURE

Steeply dipping thrust faults create lower relief folds in southern Cascadia

Uplift with every earthquake cycle creates oversteepening that outpaces the effects of compaction strengthening and preconditions the slope for failure

Failures occur at wide variety of slope gradients; **average slope here: 4-6°**

*Accretion of abyssal sediment into the outer wedge provides unlimited recharge of sediment to produce abyssal seismoturbidites during slope failure*

# SUMMARY

**The abyssal turbidite record is a GREAT source of earthquake triggered event deposits.**

Local sources are best!

Abyssal turbidites sourced from lower slope failures (away from canyons and channels) avoid many of the pitfalls and arguments commonly made against turbidite stratigraphy:

(1) Many abyssal turbidites can be tied to mass transport deposits at the base of the slope — the only viable source for these abyssal turbidites is earthquake triggered ground failure

(2) Correlation should not be solely based on matching physical properties or counting the number of events — it is OK if events are missing or look different in different places — they are probably sourced locally

(3) Tectonic oversteepening along the lowermost slope provides infinite recharge of sediment to fail during earthquake shaking

**Better understanding of turbidite generating systems and refined chronologies from detailed core transects are key to interpreting the offshore record.**

*We need to better constrain the minimum threshold for shaking induced failure*

*The spatial distribution of landslides can inform where/how shaking occurs*