

Submarine slope failures in the Winona Basin and subduction earthquakes, northern Cascadia Margin

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Introduction

The SO294 - CLOCKS project collected a suite of sediment cores to study the paleoseismology of the Winona Basin, NW of Vancouver Island, British Columbia, Canada.

The Winona Basin spans the transition zone from the Cascadia Subduction Zone with M9 earthquakes every ~500 yrs and the Queen Charlotte transform fault with M8 earthquakes every few decades.

Earthquake recurrence rates were determined using turbidite events at local slope failure deposits, following methods developed by Goldfinger et al. (2012) and Hamilton et al. (2015).

The Winona Basin features several en-echelon NW-striking folds and ridges which uplifted Plio-Pleistocene sediments. The whole region was blanketed with glaciomarine sediments deposited during the recent deglaciation, 25-12 ka. Subsequently, several local slumps formed along the edges of these ridges, likely triggered by earthquake shaking. Their amphitheatre faces steepened and remained unstable and continued to fail each time sufficient seismic shaking was felt, depositing turbidites downslope for a few km.

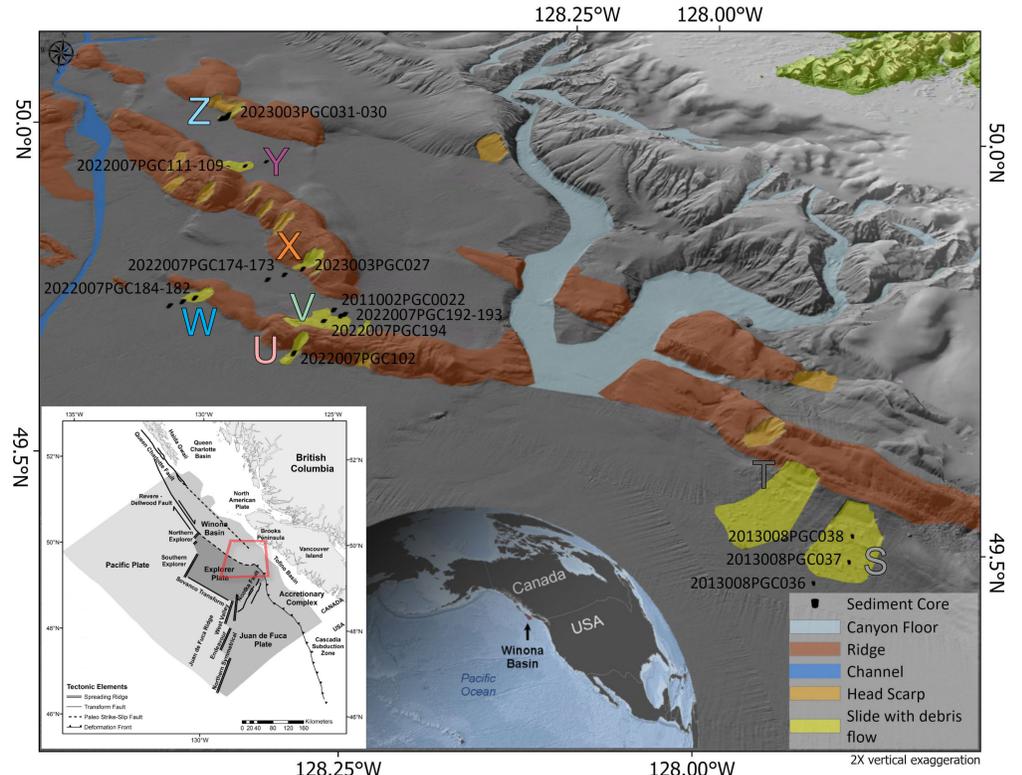
Between 2011 and 2023, transects through 7 slope failures off transpressional ridges in the Winona Basin have been sampled with 1 to 4

piston or gravity cores. The core locations are distal from the coast (~70 km) and not within canyons, which excludes sediment input directly from land. In addition, all positions are at a water depth of >1900 m, well below the wave excitation limit for turbidites, so that they can only be triggered by shaking of the unstable sediments by large earthquakes.

Cores were analyzed with multisensor core loggers, X-ray and visible imaging, and direct sedimentological descriptions. The study examines the NW extent of the Cascadia Subduction Zone, and the extent to which the Explorer Plate and Winona Basin are decoupled from the Juan de Fuca Plate.

Specifically, we are testing 3 hypotheses:

1. Earthquakes in Winona Basin are temporally correlated and likely caused by Cascadia subduction earthquakes.
2. Earthquakes in Winona Basin are temporally correlated and likely caused by Queen Charlotte Fault earthquakes.
3. Earthquakes in Winona Basin follow their own timing distribution, because its earthquake cycle is decoupled from adjacent major plate boundary faults.



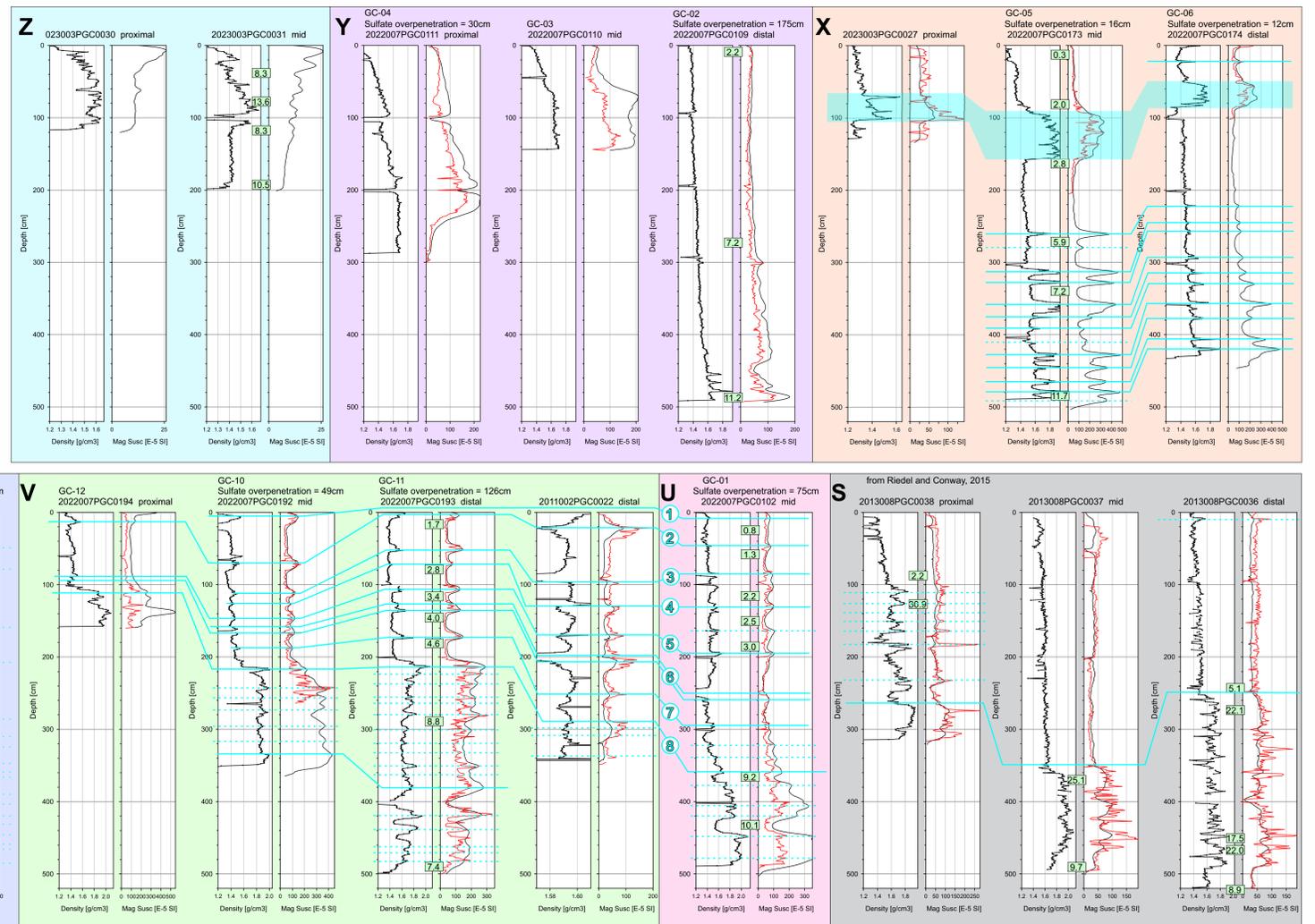
Physical Properties Logs and Turbidite Record

Density and magnetic susceptibility (MS) logs are optimal for distinguishing instantaneous high-energy turbidite sediments from continuous hemipelagic sediments.

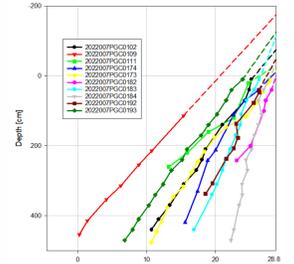
The core logs are arranged from NW to SE by slide transect. The black MS traces were measured with a 14cm coil, which smooths the curves, whereas the complementary red traces have 3mm resolution.

Radiocarbon ages of planktonic foraminifera are reported in green boxes (ka BP, calibrated with Oxcal, using Marine 2020 calibration curve, and reservoir corrections following Schmuck, et al., 2021)

Suspected turbidite horizons are indicated with cyan lines, and correlated between cores where possible. Slides U and V are on either side of the same transpressional ridge, and appear to have correlated turbidites.



Pore Water Geochemistry



Pore water was collected just after core recovery with Rhizon Soil Water Samplers.

Extrapolation of sulfate trend up to seawater concentration (28.8 mmol/l) estimates how much stratigraphy is missing above the core tops from losses during coring

The excellent correlation with the age model tops demonstrates the utility of pore water measurements.

Age Models

Radiocarbon ages, collected on pelagic foraminifera, are calibrated with Oxcal, using Marine 2020 calibration curve, and reservoir corrections following Schmuck, et al., 2021).

Remarkably, the slides have constant sedimentation rates between 2 and 4 times the regional hemipelagic rate of 0.02 cm/yr. The slides appear to have initiated in late glacial times ~12 ka, and deposited consistently since.

Discussion and Conclusions

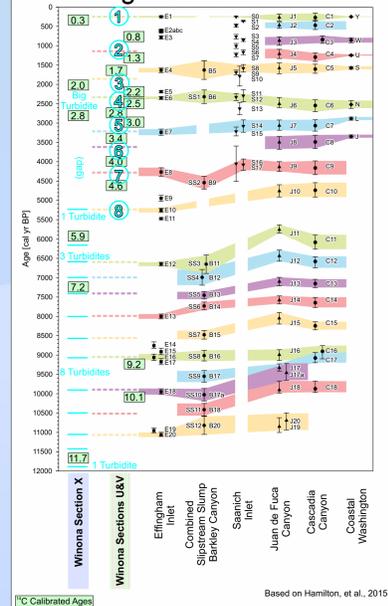
Turbidites, likely due to major earthquake shaking, are observed to occur in the Winona Basin with a ~500-year cadence, suggesting Cascadia subduction earthquake rupture either extends NW to the basin, or stress-changes caused by subduction earthquakes further south trigger local earthquakes.

1. The Winona Basin sits at the transition between the Cascadia Subduction Fault where the young Juan de Fuca plate subducts below North America, and the Queen Charlotte Fault where the Pacific Plate moves NW with right-lateral transpressive motion for the last 10 m.y., against North America.
2. The basin has oceanic basement with up to 7km of (Plio-) Pleistocene sedimentary cover (Davis and Riddiough, 1982). These young sediments are folded and faulted in a series of NW striking ridges which outcrop at the seafloor due to transpressional stresses in the interaction between the Pacific and North American plates.
3. The entire basin is blanketed by a thick layer of Wisconsin glacio-marine sediments

4. The ridges have several slope failures identifiable with multibeam bathymetry, and at least 8 slide deposits which we label S to Z.
5. We have collected 19 piston or gravity cores from 7 slides.
6. The cores all recovered Holocene olive-green hemipelagic mud, often interrupted by coarser sand layers. No cores have yet been collected which pierce through the Holocene to the typically grey sediments of deglacial Pleistocene times.
7. Planktonic foraminifera, collected from uniform mud beneath sand horizons, reveal a surprisingly constant sedimentation-rate (0.041 to 0.075 cm/yr). No dates (other than reworked shells collected from turbidites) are older than 12ka BP.
8. The oldest slope failures appear to have initiated shortly after the deglacial sediment transportation and deposition finished, ~12ka.
9. Cores from 5 of the 7 slides contain turbidites, recognizable by peaks in density, magnetic susceptibility and P-wave velocity, and coarse materials or clasts seen in X-ray and visual images. Often, the sand deposits display clear fining-upwards trends.
10. The most likely trigger mechanism is seismic shaking. At water depths below 1900m, no storm activity can be felt. There are no tractive sediment pathways possible from terrestrial or shallow marine sources and all coarse failed materials are very locally derived from the adjacent ridges. The observation of correlated turbidites (both time and magnitude) argues against random triggering.
11. Slides U and V are situated on opposite sides of the same ridge. It is possible to

12. Slide X is notably similar to the Slipstream slide off Barkley Sound (Hamilton et al., 2015). Thirteen turbidites are observed between 12 and 5 ka, followed by a gap of 3 k.y. Later at X, a large turbidite was deposited, between 2.0 and 2.8 ka BP calib., correlated with the youngest turbidite observed at Slipstream. Our interpretation for the Slipstream sequence, which we extend here, is that earthquakes continued to occur, however the slump scarp stabilized such that subsequent ground-shaking was insufficient to dislodge further material.
13. The correlation with Cascadia subduction earthquakes suggests three possible mechanisms.
 - a. Subduction of the Juan de Fuca Plate, >100 km to the south, creates sufficient ground shaking to trigger turbidites.
 - b. The closer Explorer Plate subducts along with the Juan de Fuca Plate. The implication is that the locked zone is larger than previously estimated thus making the total magnitude of Cascadia subduction earthquakes even larger.
 - c. The recent analysis of the south tip of the Cascadia Subduction Zone (Goldfinger et al., 2025) demonstrates that strike-slip earthquakes on the San Andreas Fault are apparently triggered by Cascadia subduction earthquakes after a delay of 63±53 years. If similar stress transfer occurs across the en-echelon faults in Winona Basin, local earthquakes may be triggered by the stress changes caused by Cascadia Subduction earthquakes.

Age Correlations



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