Long-Term Paleoseismology in Cascadia: Probabilities, Clustering, and patterns of Energy Release

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Discovery of the 1700 AD earthquake is a triumph of sleuthing!

In 1984, Canadian Geologist John Adams was the first to suggest that direct evidence of Cascadia earthquakes existed in the form of "turbidites", deep sea deposits sometimes triggered by earthquakes.
Geologic evidence of great earthquakes is abundant in the form of trees killed by saline incursion, and the peat-bay mud couplets formed by each earthquake.
Cascadia submarine canyon systems traverse the locked zone, making them sensitive to ground shaking. They are, for the most part, isolated from river systems during high-stand conditions.

From Goldfinger et al., 1997 JGR
What actually happens during the earthquake?

Synchronous turbidity currents are triggered within a few minutes of each other along the length of the margin.
Turbidites are easy to capture, but what do they mean?
So our primary criteria for distinguishing earthquakes are
1) Aerial extent
2) Synchrony, and
3) Sedimentology.

Synchronous means within a few minutes to hours at most...

$^{14}$C dating gets us only to within a few decades at best, usually not that good.

So how do we constrain relative timing to within a few hours?

Cheat!
Detailed correlations are constructed from high-resolution physical property data collected from the cores, including magnetic susceptibility (high and low), gamma density, P-wave velocity, resistivity, and CT imagery.
In addition to the confluence test, we correlate turbidites between remote sites to establish continuity, and test for synchronous triggering.

Correlations are made on the basis of grain-size/physical property “fingerprints” within a $^{14}$C age framework.
CT imagery is invaluable for understanding turbidite structure and defining stratigraphic boundaries in detail. This image breaks out the sand fraction, the silt fraction, and the hemipelagic clay by their respective CT density values.

The CT can reveal such subtle features as a worm burrow which is apparently lined with material slightly more dense than its surroundings (biogenic clay).
Correlation is done using oil industry techniques such as stretching and squeezing “ghost traces” to examine correlations, and flattening the correlation diagram to event horizons.

Correlations supported by numerous radiocarbon ages.
Linking Onshore and Offshore:

Exploring inland turbidites and ground motions.
Inland Evidence...
This sequence shows the Cascadia Holocene earthquake sequence.

The slides are timed at 1 sec ~ 200 years.

Event pulses that correlate at all sites are shown by flashes of the “locked zone” in red. Event “size” shown by intensity of red shading
T14 Crater Lake (Mt. Mazama) Goes off!! ~7625 BP
Biggest Cascadia Earthquake! ~ 5900 BP
End of a 1200 year Gap in the North ~ 4800 BP
Another ~ 1000 year Gap (north only) Ends ~ 1500 BP
The penultimate earthquake ~ 480 BP
Rupture lengths from paleoseismic data, past 10,000 years. Segment boundaries are roughly compatible with ETS segment boundaries proposed by Brudzinski et al., 2007, though both sets of boundaries are quite crude.
For the northern margin, probabilities are relatively low, many intervals longer than 360 years are in the paleoseismic record.

The reliability analysis suggests at 360 years, 25% of repeat times will have been exceeded. Conditional probability in 50 years is 14% (12-17%).

(slight revision of repeat times and probabilities, in 2016 Marine Geology paper).
For the southern margin, if our interpretation is correct, 70-93% of repeat times will have been exceeded.

Conditional probability in 50 years is 37% (32-42%).

Portland is in between these extremes, with a recurrence of ~340 years, and 50 year probability of ~20%. (This is a slight increase, 2016 Marine Geology paper)
What about clustering?

There seems to be a poorly developed clustering, suggested here.

It certainly makes a difference whether the next expected event is part of a cluster or not, if clusters exist, and if the next event reflects a repeat of recent behavior.

In cluster 50 year probabilities are ~ 25%, not in a cluster, ~ 2%.

Clustering seems better developed in the latter half of the Holocene. If a repeat were to occur, a gap may be next.
Earthquake clusters you can see?

Longer records would help answer some of the obvious questions such as whether clustering is a long term feature, or if our “short” 10ka record is random.

The instrument already exists, and the experiment has already been run.

Goldfinger et al. 2013 *Superquakes and Super Cycles*, SRL v. 84 no.1 p. 24-32