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Finding 'Good Friday'

An explorative study into the sedimentary structures left from the Good Friday tsunami

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NONTECHNICAL SUMMARY

In 1964 the small logging town of Port Alberni, Vancouver Island B.C., was struck by the tsunami generated by the Good Friday earthquake ($M_w = 9.2$) originating near Anchorage, Alaska. This is Canada's most destructive tsunami to date, resulting in nearly $72,000,000 in damages (adjusted for inflation). The destructive nature of the tsunami is the result of tsunami 'ringing' inside of Alberni Inlet, a narrow 42 km long inlet on the west side of Vancouver Island. The trapped energy of the tsunami oscillated for at least 2 days which at times exceeded wave heights of 8 m (Fine et al. 2008).

In attempts to find evidence left from this tsunami on the seabed of Alberni Inlet a tsunamite, any sedimentary structure deposited from a tsunami, was recovered in one of the inlets deep basins. This tsunamite was identified as being deposited close to the year 1964 through the use of core sampling, x-radiography, and Cesium (^{137}Cs) dating. The structure found is comprised of a thick layer of sand and gravel sandwiched between two layers of mud. The findings support the theory that low wave energy at the bottom of several of Alberni Inlet's deep basins (>200m) that are separated by sills ensured that any tsunamite deposited there was not remobilized, re-suspended, and thus destroyed. This should help to guide those looking for tsunamites in marine environments by focusing on feasible search areas.

ABSTRACT

In 1964 the small logging town of Port Alberni, Vancouver Island B.C., was struck by the tsunami generated by the Good Friday earthquake ($M_w = 9.2$) originating near Anchorage, Alaska. The destructive nature of this tsunami is the result of tsunami 'ringing' inside of Alberni Inlet, a narrow 42 km long inlet on the west side of the island. The trapped energy of the tsunami oscillated for at least 2 days with wave heights exceeding 8 m at times (Fine et al. 2008). The extreme duration of tsunami waves greatly increases the chance of erosional processes transporting large terrestrial sediment into the water column to be deposited in several of the inlets deep basins. As such, Alberni Inlet provides an ideal location that is now known to contain well preserved tsunamites, sedimentary structures deposited from a tsunami.

Several Kasten cores taken in Alberni Inlet were analyzed for grain size, Cesium 137 activity and X-ray imaged to reveal the sediment structures within. Analysis of one of the cores provides evidence of a sediment structure atypical of what would normally be found in this location suggesting that an event had mechanically changed the deposition pattern for a period of time. The structure is 15 cm thick and is comprised largely of mud (<63 µm) though 40% is a sand/gravel mix. The first appearance of ^{137}Cs in a sediment column correlates to the year 1952, and is used to calculate a sedimentation rate of 0.82 cm yr^{-1}, similar to the methods outlined in Hill, 1994. Applying the sedimentation rate to the depth of the atypical structure strongly suggests that it was deposited during the early 1960's. Occam's razor dictates that the tsunami wave that occurred here in 1964 is the most likely cause of the unique structure.

Previous scientific studies have been conducted searching for sedimentalogical evidence of tsunamis in the terrestrial environment, however, the literature on sediment structures left in the marine environment is currently lacking. These findings help to fill a gap in what is known about tsunami sediment structures in the marine environment. This study will aide future researchers in determining likely locations where tsunamites could be preserved in the marine environment.

At the edge of the North American continental shelf on Vancouver Island B.C., lies Barkley Sound. Connected to Barkley Sound is Alberni Inlet; at 42km long, this is the island's longest inlet. At the head of Alberni Inlet is the small logging town of Port Alberni (Figure 1). On March 28, 1964, Port Alberni was hit by the most destructive tsunami waves in Canadian history, causing about $72,000,000 (adjusted for inflation) in damages. The tsunami was generated by an earthquake located 20 km north of Prince William Sound and 125 km east of Anchorage, Alaska. The "Good Friday" earthquake ($M_w = 9.2$) is the second most powerful earthquake ever recorded by a seismograph. The resulting tsunami waves crested as high as 8 m at Port Alberni (Fine et al. 2008). What made this event unique, however, was not just the height of the waves, but the duration over which Alberni Inlet was subject to their destructive power.

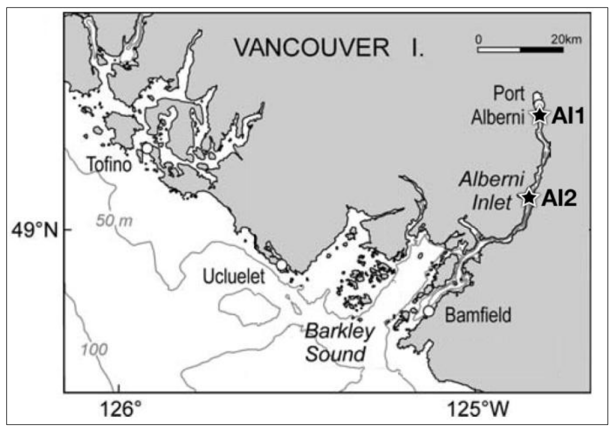

Figure 1
Map of Barkley Sound and Alberni Inlet on Vancouver Island B.C. Core sampling locations are indicated in the figure. The open circles on the map indicate locations of sea-level measuring devices (Fine et al. 2008).

Sea level data recorded by a tidal gauge at Port Alberni reveal a pattern of oscillating wave heights over a 48 hour period beginning when the town was first hit by the tsunami (Figure 2). Sea level heights experienced during this period differ significantly from the projected heights that were expected based on normal tidal fluctuations (Figure 2). Immediately after the tsunami entered Alberni Inlet, wave heights approached four meters above tidal datum (Figure 2). The largest of these waves hit Port Alberni and were greater than 8 m above tidal datum, but occurred during a time when the tidal gauge stopped recording between 4 a.m.

and 8 a.m. on March 28 (Figure 2). Wave heights during the gauge's downtime have been confirmed by eyewitness reports and water marks measured from surrounding buildings (Fine et al. 2008).

Due to the duration and strength of this tsunami event, it is hypothesized that large volumes of sediment and debris were entrained from the shoreline and pulled into the water column to be deposited on the seafloor. It is likely that the majority of sediment that was mobilized came from several of the river deltas inside of Alberni Inlet, the largest of which is located at the town of Port Alberni. Kasten cores taken throughout Alberni Inlet were analyzed for grain size, Cesium 137 activity and X-ray imaged to reveal the sediment structures within, in hopes of finding remnants of the tsunami. Analysis of one of the cores provides evidence of a sediment structure atypical of what would normally be found in this location, suggesting that an event had mechanically changed the deposition pattern for a period of time. It is possible that the position and thickness of these tsunamites (any sediment deposit related directly to a tsunami) can help to assess the magnitude of a tsunami and may help to further characterize tsunamites in similar environments elsewhere (Van den Bergh et al. 2003).

While many studies evaluating the sedimentological effects of tsunamis have been conducted, most of these have dealt with deposition on land (Dawson et al. 1988; Atwater 1992; Minoura et al. 1996; Hindson and Andrade 1999; Dawson 2000; Zong et al. 2003; van den Bergh et al. 2003). Fewer studies have focused on the characteristics of tsunamites in marine environments (Bondevik et al. 1996; Fujiwara et al. 2000; van den Bergh et al. 2003). Consequently, the geologic record of tsunamites includes, almost exclusively, data from terrestrial locations such as marsh deposits and coastal lakes.

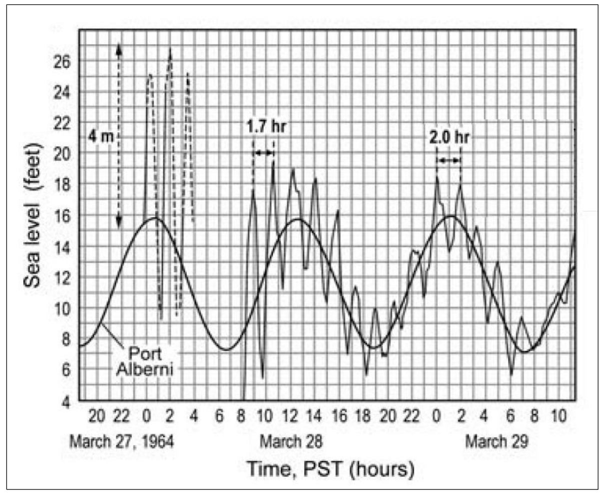

Figure 2
Tide gauge record at Port Alberni of the Alaska tsunami of March 28, 1964. The solid black line is the expected wave height due to tidal changes. The thinner lines are observed wave height. The tidal gauge stopped operating for 4 hours from about 4 a.m. until 8 a.m. (Fine et al. 2008).

Conducting this survey in Alberni Inlet provides an excellent chance of finding tsunamites because of the long duration of the tsunami wave activity and the presence of several deep (~200 – 300 m) basins. The discovery of tsunamites deposited from the 'Good Friday' tsunami in Alberni Inlet therefore provides a unique opportunity to study the effects of a tsunami on the bottom sediments of a long, deep, narrow fjord and expands knowledge on a topic that is severely lacking from the geologic record.

METHODS

Field Methods:

Kasten cores were collected from selected locations in Alberni Inlet from aboard the R.V. Thompson in January 2013 (Figure 1). The Kasten core has 12.7 x 12.7 cm cross-section and is 300 cm long with a square steel barrel with one removable side which allows for samples to be extracted using Plexiglas trays for X-radiographic analysis (Mullenbach and Nittrouer 2006). The remainder of the sediment within the barrel was sampled for radiochemical analysis at 5 cm intervals (Mullenbach and Nittrouer 2006). Both Kasten cores were stored in the R.V. Thompson's walk-in refrigerator at 1˚C for preservation until transferred to a walk-in freezer on the U.W. campus. The location and depth of the two Kasten cores are as follows: AI1, 49˚11'34.37" N; 124˚48'57.21" W, at a depth of 78.5 m. AI2, 49˚3'30.93" N; 124˚51'21.73" W, at a depth of 245 m.

Laboratory Methods:

The cores were subsampled in 30-cm sections using Plexiglas trays 2.5-cm thick to allow for X-radiograph imaging using a Madison Medical Corporation Model VR 1020 portable X-ray machine under differing exposures and were recorded onto a Flashscan 35 digital X-ray imaging subsystem (Mullenbach and Nittrouer 2006). All images are presented as negatives with the variations between light and dark gray corresponding to the density of the sediment where lighter color means more dense material and darker material is less dense (Mullenbach and Nittrouer 2006). It is hypothesized that a tsunamite would be comprised of sand and coarser sediments than the mud which makes up the majority of the seafloor in Alberni Inlet (Dawson 2000). As an X-ray image, this will look like a dark layer sandwiched between two white layers because a sample of sand is less dense than a sample of mud.

After X-ray imaging, 2-cm subsections were collected every 10-cm. A portion of this material was set aside for porosity and grain-size analysis, while the remainder was dried, crushed and analyzed using gamma spectroscopy for ^{137}Cs by determining activity from the 662-keV γ-spectrum photopeak (Mullenbach and Nittrouer 2006).

Samples selected for grain size were soaked in a dispersant solution (NaPO4) and sonicated for >15 m, before sieving 63 µm to remove the sand fraction. The mud fraction was analyzed using a Micromeritics Sedigraph 5100, using a method modified from that of Drexler et al., 2000 (Hale et al. 2012).

RESULTS

Sand fraction analysis for core AI1 has a nearly vertical distribution (Figure 3). This distribution indicates that the ratio of sand to mud at any depth is nearly homogenous throughout the depth of the core (Figure 3). Grain size analysis, ^{137}Cs activity, and the X-ray image of AI1 do not indicate the presence of any sedimentary structures that could be characterized as a tsunamite (Figure 3).

Sand fraction analysis for core AI2 shows a varying degree of grain size throughout the depth of the core (Figure 4). At 40cm in the core, sand accounts for 33.2% of the sediment and increases to 39.7% at 30cm (Figure 4). The sand fraction above 20 cm and below 50 cm is more similar in proportions to those found in core AI1 (Figure 4).

The first appearance of ^{137}Cs in a sediment column correlates to the year 1952 (Hill 1994; Zong et al. 2003). In AI2, the first appearance of this isotope is at a depth of 50cm. The difference in time between 1952 and when the Kasten core was taken is 61 years. Over this period, 50cm of sediment accumulated in this location giving an average sedimentation rate of 0.82 cm yr^{-1}.

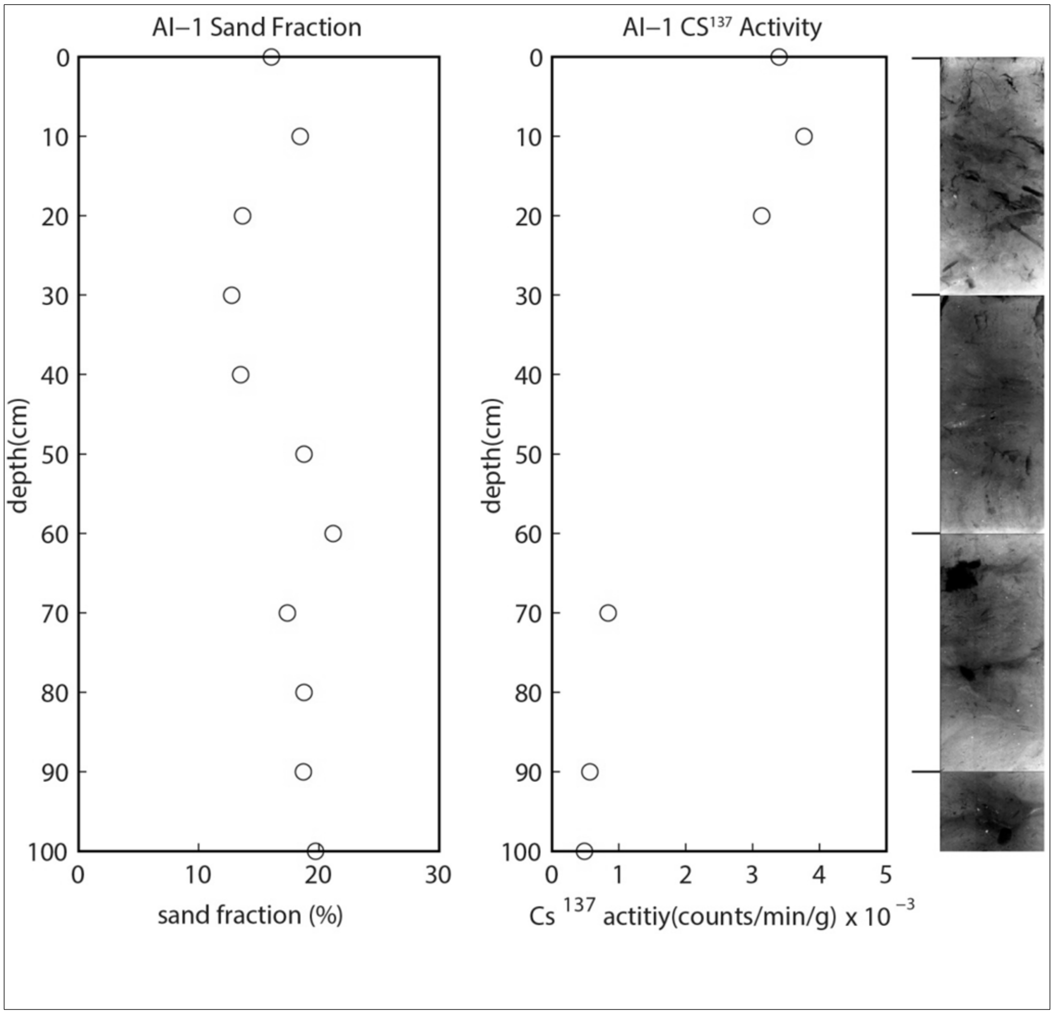

Figure 3

Sand Fraction, Corrected Cesium 137 and X-ray image of core AI1.

Multiplying the sedimentation rate by the time since the tsunami hit Alberni Inlet (2013-1964=49 yrs) gives an approximate depth of 40.1 cm in the core where a tsunamite should be expected.

At the calculated depth of where the tsunamite was predicted to be found in the core, a drastic change in the sediment is seen in grain size and in the X-ray image. The sediment around this depth is comprised significantly more of sand (~35%) than all other depths in both AI1 and AI2 (Figure 4). The X-ray image reveals the bottom of a unique structure at around 40 cm depth which extends to about 25 cm (Figure 5). This sedimentary structure is comprised of larger grained sediment consisting of sand and gravel and is sandwiched between mud from both above and below.

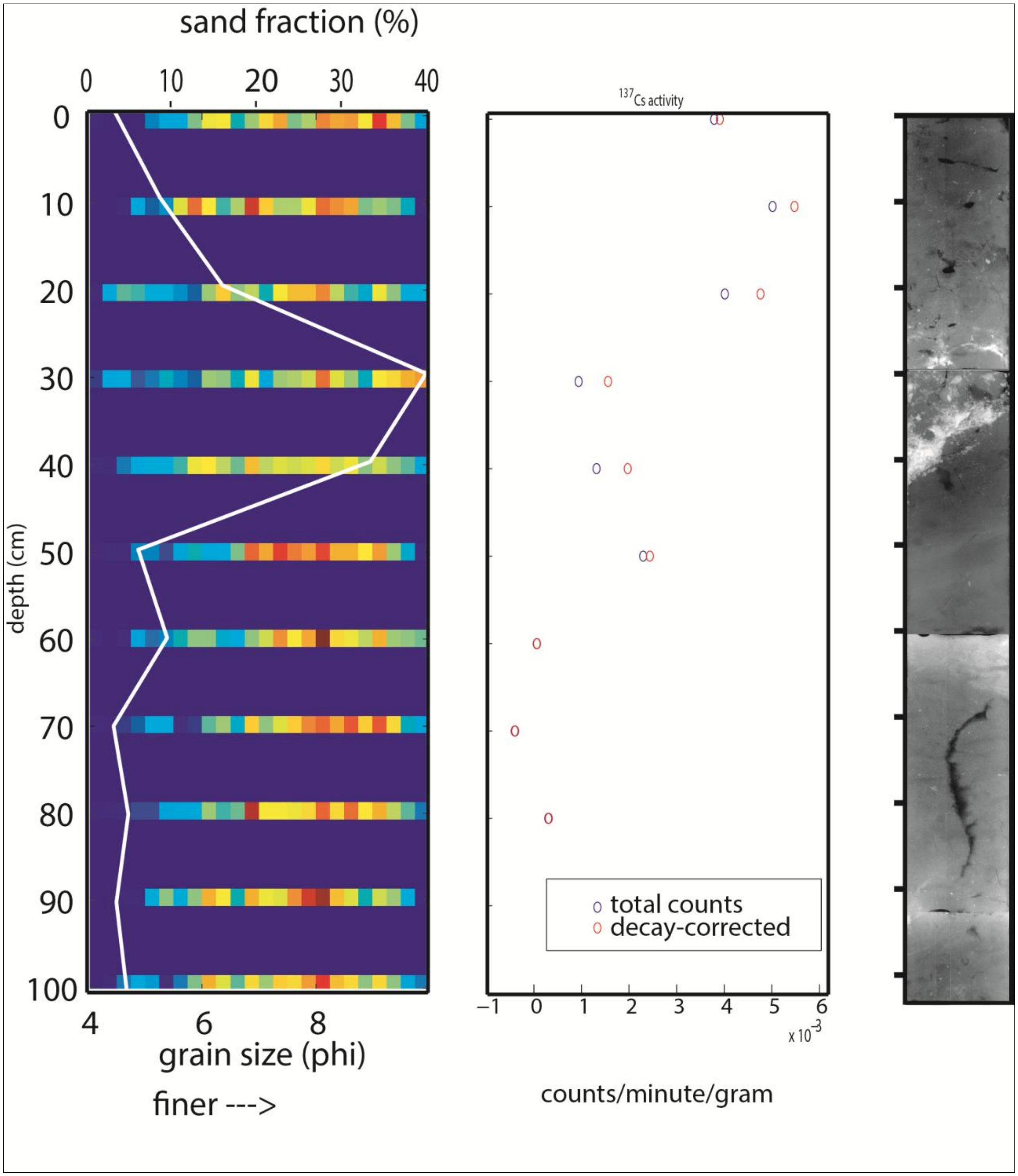

Figure 4

Sand Fraction, Grain Size, Corrected Cesium 137 and X-ray image of core AI2.

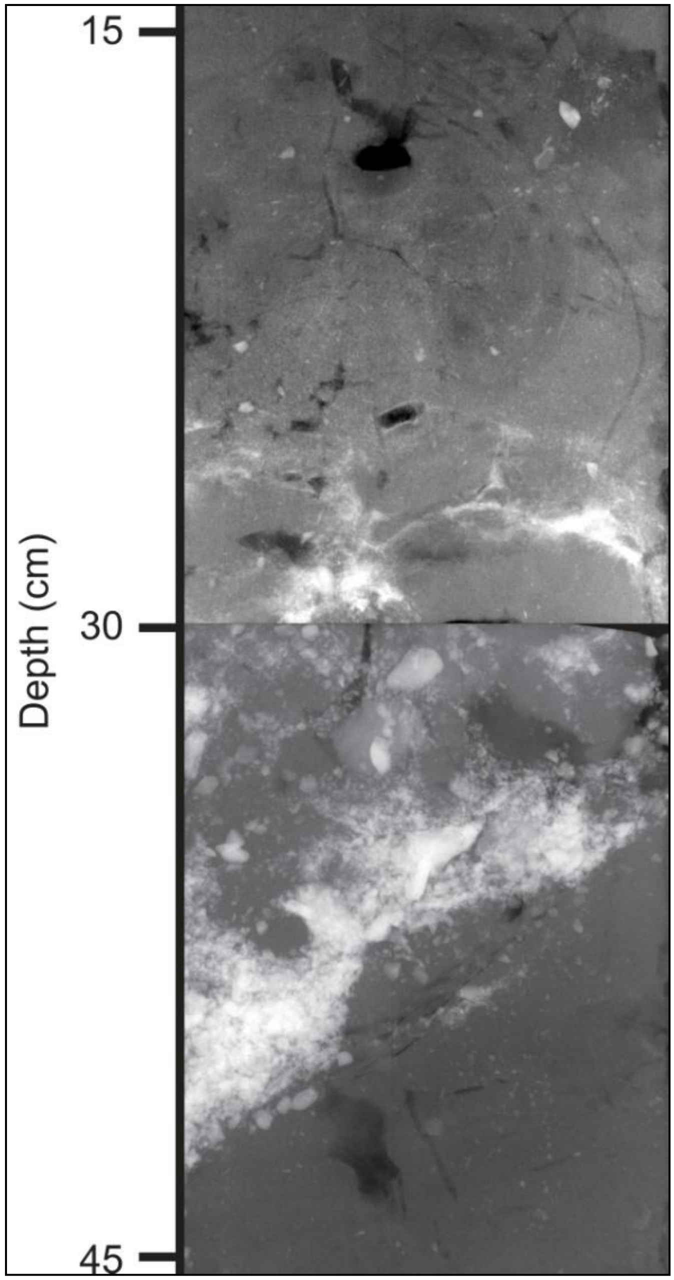

Figure 5

X-ray image of the suspected tsunamite in core AI2. White color indicates more dense material whereas darker color indicates less dense material.

CONCLUSIONS

The homogeneity in the vertical distribution of the sand fraction for core AI1 does not show evidence of a mechanical change in the sediment distribution system. Additionally, the X-ray image of core AI1 does not show any evidence of a tsunamite. The X-ray of AI1 reveals a sediment structure comprised heavily of wood fragments. If, at the time of the tsunami, when sand and gravel should have been deposited into soft mud but the bottom was comprised instead of tightly packed wood, the tsunamite would be more subject to re-suspension. This is a likely reason why evidence of a tsunamite at this coring location was not found despite a large source of erodible material from a nearby river delta Somass River. The comparatively shallower depth of 78.5 m also makes resuspension in this location more likely.

Sedimentation rates calculated from the first appearance of ^{137}Cs in AI2 indicate that if any sedimentary evidence of the tsunami was deposited, it would be found at 40cm into the core. This is compelling evidence that some event during the early 1960's caused a mechanical change in the sediment distribution system. The evidence found in core AI2 is most likely a tsunamite structure left from the 'Good Friday' tsunami that Alberni Inlet experienced during 1964. The sediment seen in the X-ray image was likely re-deposited sand and gravel picked up from the Nahmint river delta which is less than 2 km from the coring location.

While the suspected tsunamite in AI2 is not near the greatest peak in ^{137}Cs concentration as expected, the usefulness of the isotope was no less diminished. A possible reason the tsunamite was not found near the ^{137}Cs peak may be a consequence of how this isotope settles out of the atmosphere. While it is indeed true that peak production of ^{137}Cs occurred during 1963-64, the same year as the Good Friday tsunami, the settling rate of the isotope is likely highly variable due to global wind patterns. What may have occurred here is that the tsunami entrained and deposited sediment yet to be attached with the ^{137}Cs isotope produced in 1964 as it was still predominately in the atmosphere, making the ^{137}Cs concentration low at this point in the sediment column. Additionally, the tsunami likely exposed and transported sediment that had been buried for some time, making the sediment unavailable for the atmospheric bound isotope to have ever even bonded too, further decreasing the ^{137}Cs activity at this depth in the sediment column.

In AI2 the peak in ^{137}Cs activity occurs at 10 cm. Dividing 10 cm by the sedimentation rate correlates the peak in ^{137}Cs activity to around the year 2000. Several reasons could account for this. Nuclear accidents like Chernobyl and Three Mile Island that occurred in the late 1970's and mid 80's would have greatly increased the output of ^{137}Cs into the atmosphere and may have settled on terrestrial based sediment in the Alberni Inlet region any time after. The town of Port Alberni is supported by its logging industry. If large-scale logging occurred in the Alberni Inlet's watershed during the late 1990's or early 2000's, the resulting increase in erosion of surface sediment, now high in ^{137}Cs concentration, would enter the water column where some of it would be deposited on the seabed.

Assuming the AI2 core is representative of the basin from which it was cored, the Good Friday tsunami deposited a huge amount of sediment into this basin during its two day period. The X-ray image reveals the tsunamite starting around 40 cm and extending to about 25 cm; making the thickness of the tsunamite about 15 cm (Figure 5). The area of the thalwag directly in front of the Nahmint river delta, where the tsunamite most likely settled, has an area of roughly 1 km. Assuming that the thickness of the tsunamite remains constant over this entire area, then it can be calculated that the tsunami deposited roughly 1.5 km^3 of coarse grained sediment into this relatively small basin. The large volume of material suspended by the tsunami is not unreasonable as steady state situations near coastal environments are often interrupted by episodic events in which the sediment accumulated may account for a significant portion of the sediment column (Hill 1994). It is likely that this seiching tsunami had grave consequences for the benthic organisms living in this basin.

The tsunamite found was a thick sedimentary layer of relatively coarser material sandwiched between fine mud as expected from Van den Bergh et al. 2003. The results of this study are dissimilar to the findings of Zong et al. 2003 who identified similar sedimentological events using ^{137}Cs as a marker but in a terrestrial environment. The results of study demonstrate that using the peak of ^{137}Cs activity to identify the year 1964 is insufficient in a marine environment where many more variables are at play. Additional analysis, such as 210-Pb dating, would be required to accurately assess what depths in a sediment column correspond to what age.

The advantage of finding a tsunamite in a marine environment is that the impact of a tsunami on the seabed can be estimated. For an area that annually receives <1 cm yr^{-1}, the instant addition of a 15 cm blanket of sand and gravel can be devastating to benthic organisms. These findings demonstrate the impact a seiching tsunami wave can have in a long, deep, narrow fjord system by its ability to suspend and distribute large amounts of coarse sediment. The results of this study also demonstrate how variable the impact on the seabed can be over a small spatial separation. The findings also identify several factors that may be used to determine benthic areas in a fjord system at high risk of being strongly impacted by a tsunami wave that are not traditionally thought of as being at risk areas. High risk areas are those located in a relatively deep basin and near an area of land where dominantly coarse sediment presides, such as a river delta.

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