Relationship of Submarine Canyon Morphology and Tsunami Propagation for the Northeast Pacific Continental Margin

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ABSTRACT: Multibeam sonar data for four submarine canyons from the Washington (US) and Vancouver (Canada) continental margin were used to examine the effect of tsunami propagation. Depths from canyon cross-section profiles were used to calculate wave amplitude and wave celerity for a potential tsunami. The seafloor flanking the canyons shows an increase in tsunami wave amplitude in comparison to amplitude along the canyon axes. Canyon flanks also show a decrease in wave celerity in comparison to celerity at canyon axes. Observations show correlation with prior studies confirming that the presence of a submarine canyon prevents an increase in wave amplitude along the canyon axis and increases tsunami arrival time to the shore relative to non-canyon areas.

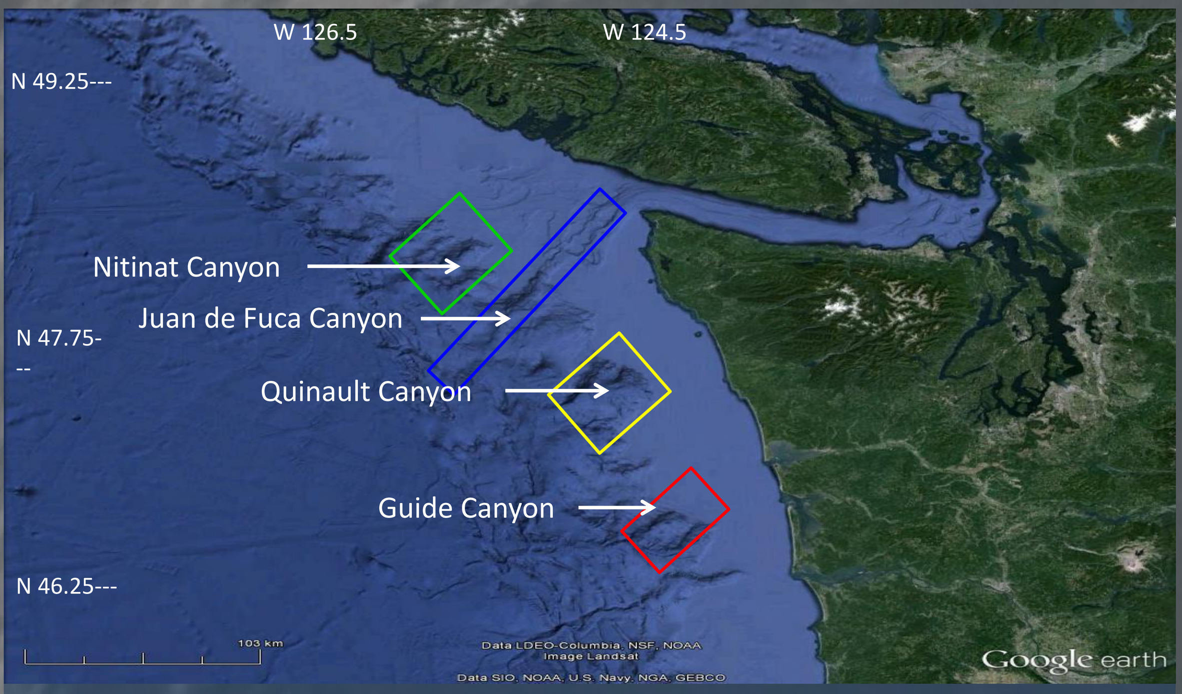

Figure 1: Location of the four submarine canyons examined in this study, along the Vancouver and Washington margins.

METHODS:

- The R/V *Thomas G. Thompson* was equipped with a Kongsberg EM302 multibeam sonar.
- Canyons along the Washington and Vancouver margins were surveyed by the University of Victoria and Oregon State.
- Data from cruises TN 265 (2011) and TN 282 (2012) were imported from the NOAA/NGDC website.
- CARIS HIPS and SIPS 8.1 was used to post-process the data and create 10m-resolution CUBE BASE surfaces of the submarine canyons.
- Measurements of canyon head and sides of canyon width, depth, length, and slope were made.
- Wave Celerity (c) or velocity was calculated in Table 2 using the equation: $c = \sqrt{gd}$ where d = depth & g = $9.8m/s^2$ (gravity)
- Wave Amplitude (A) or height was calculated in Table 2 using the equation: $A_2 = A_1 \frac{[\sqrt{gd_1}]}{[\sqrt{gd_2}]}$ for $d_1 = 5{,}000m$ & $A_1 = 1m$

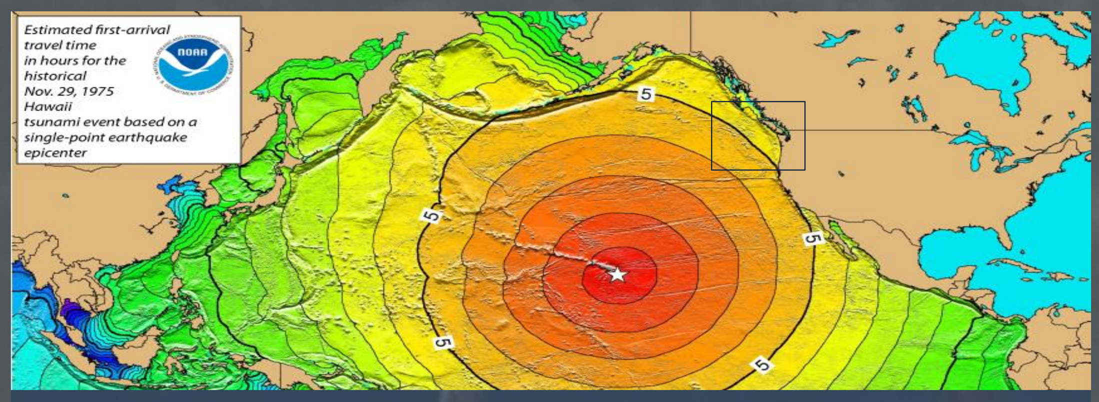

Figure 2: General direction of a predicted tsunami path for the case study. Epicenter location in Hilo, Hawaii USA with an arrival time of 5.5 hours to study area.(NOAA)

INTRODUCTION:

Geoscientists from Oregon State University and the University of Victoria mapped submarine canyons from aboard the University of Washington's R/V *Thomas G. Thompson,* along the Washington and Vancouver margins in 2011 and 2012, respectively (figure 1). Submarine canyons are transport areas for sediments and nutrients from the continental shelf to the deep ocean. The canyons along the Washington and Vancouver margins range in depth from 200 m at the shelf to1500 m at the continental rise. The change in depth occurs from a distance of 16,000 to 30,000 meters from the continental shelf to the rise. Submarine canyons are studied for sediment transportation, marine habitats, productivity, upwelling and gas hydrates.

Only recently, submarine canyons have been studied in relation to tsunami propagation. The shape, width, depth, incision length, distance to shore and orientation with respect to the shoreline are factors that can manipulate, increase or decrease the effect of a tsunami (Iglesias et al., 2014). Our study focuses on how submarine canyons have an affect on the amplitude, direction, arrival times and surge of a tsunami for four canyons: Nitinat, Juan De Fuca, Quinault and Guide.

In general when a tsunami approaches land and crosses over a submarine canyon, the wave amplitude and surge will decrease on the section of land shoreward of the canyon head because of the canyon's increased depth. The arrival time is also decreased in this area. By contrast, the two sections of land that lie shoreward of the shallow, flanking sides of the canyon, will have much greater wave amplitude and surge with an increased arrival time (Iglesias et al., 2014). This study will help to highlight areas of potential risk along the Vancouver and Washington shorelines in relation to wave size, arrival time, and surge in proximity to tsunami direction. A tsunami that hit Papua New Guinea in 1998 showed that wave heights (10 m) and run-ups (500 m inland) were greater shoreward of the canyon flanks than shoreward of the canyon head, where wave heights were 4 m, and only structures near the beach were destroyed (Davies et al., 2014). For our study, we have used the example of a tsunami generated near Hawaii (Figure 2), approaching each canyon from its foot towards its head, along the canyon's axis.

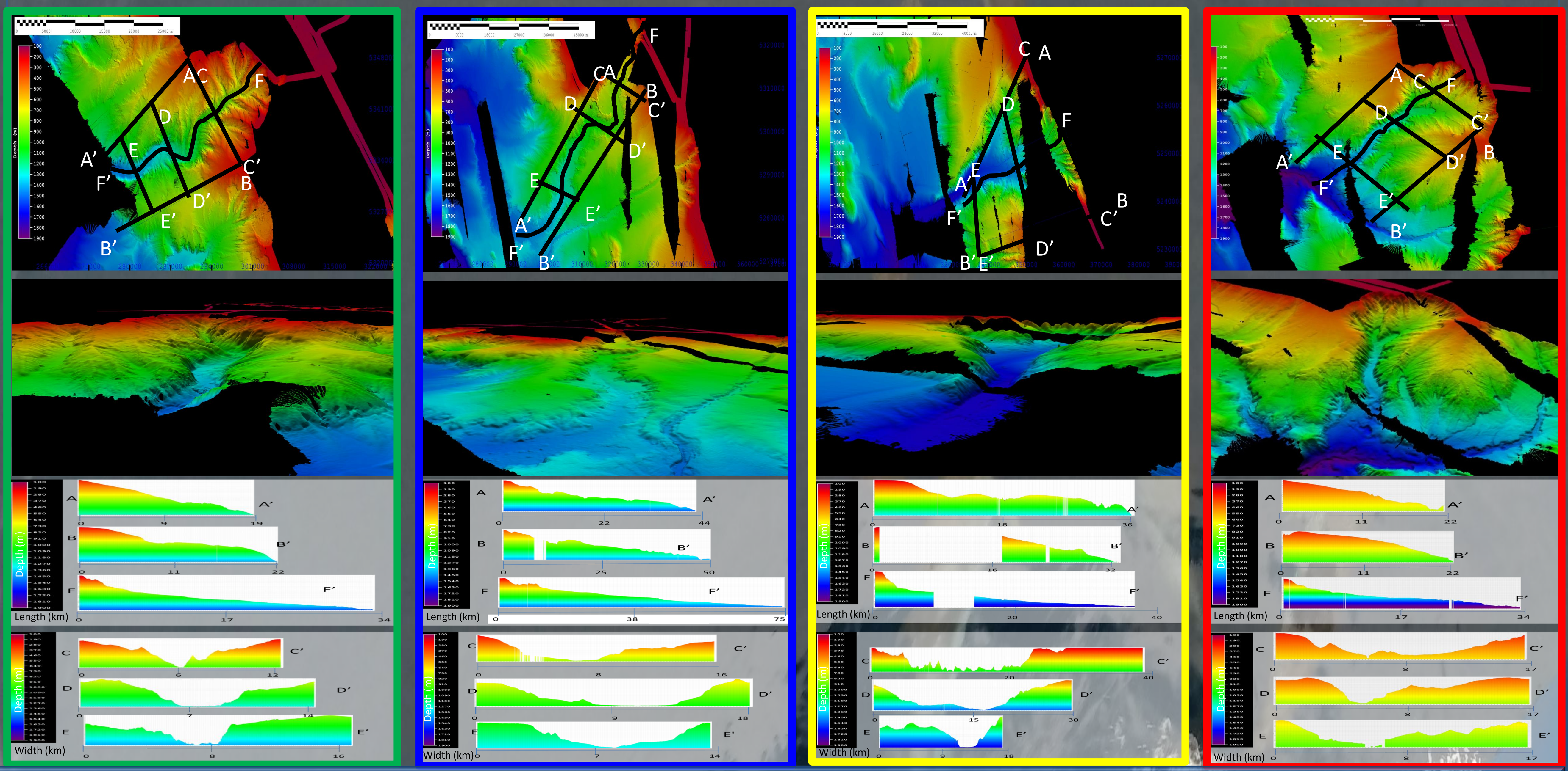

Figure 3. Nitinat, Juan De Fuca, Quinault and Guide Canyons shown in CUBE 2D (top images) and 3D (middle) with an exaggeration of 3.5x to emphasize the submarine canyon relief. Lines down canyon axes show location of profiles for length, and other lines show locations of width profiles (bottom images).

RESULTS:

The four submarine canyons studied along the Washington and Vancouver margins have deep incisions and wide shelves that decrease wave amplitude and increase wave celerity which manipulates arrival time and surge of a tsunami. Table 2 shows that each mid-canyon depth, taken at each width profile, shows an increased speed averaging 20 m/s and a decreased wave height of 0.40 m in comparison to the canyon flanks. In contrast, the flanks of these canyons appear to be areas showing increased amplification of wave amplitude and decreased wave celerity which manipulates surge and arrival time of the tsunami wave. The flanks of each canyon have an increased wave height averaging 0.40 m and a decreased wave speed averaging 20 m/s (Table 2). However, this change is just for when the tsunami first reaches the canyon, at the canyon foot. When the tsunami reaches the canyon head the wave height is increased by an average of 2.085 m and wave speed is decreased by an average of 46.45 m/s on the canyon flanks. This difference of 1.685 m in wave height and 26.45 m/s in celerity between the canyon flank and canyon head will cause major wave refraction and can change where the major damage will occur when the surge of the tsunami finally reaches land. The canyons' increased distance from land will also have an effect on the impact of the tsunami on land.

Table 1. Data from profiles for the four canyons with depth range and total distance for the canyon head and canyon shoulders.

	Nitinat	Juan de Fuca	Quinault	Guide
Canyon Head Depth Range (m)	165–1,525	230-1,466	210-1715	180-1,900
Canyon Total Distance (m)	29,575	63,100	31,405	31,000
North Shoulder Depth Range (m)	285–1,235	238-1,500	180-1,345	406-1,108
North Shoulder Total Distance (m)	18,935	43,265	36,530	21,272
South Shoulder Depth Range (m)	245–1,415	370-1,388	185-1,090	525-1,622
South Shoulder Total Distance (m)	21,690	49,795	33,000	22,333
Shallow Width Profile				
Start Depth (m)	285	232	180	395
Midpoint Depth (m)	968	802	1,060	822
End Depth (m)	245	375	185	570
Middle Width Profile				
Start Depth (m)	767	700	595	637
Midpoint Depth (m)	1,270	1,050	1,515	1,305
End Depth (m)	765	703	425	612
Deep Width Profile				
Start Depth (m)	1,025	1,050	800	1,027
Midpoint Depth (m)	1,397	1,287	1,685	1,500
End Depth (m)	893	1,054	1,130	1,143

Table 2: Wave speed and wave height change with canyon depth. Canyon heads show less height and more speed in comparison to canyon flanks which show more height and less speed.

	Nitinat Canyon			Juan de Fuca Canyon			Quinault Canyon			Guide Canyon		
	Depth (m)	Wave Speed (m/s)	Wave Height (m)	Depth (m)	Wave Speed (m/s)	Wave Height (m)	Depth (m)	Wave Speed (m/s)	Wave Height (m)	Depth (m)	Wave Speed (m/s)	Wave Height (m)
Deep Width Profile												
North Shoulder	1,025	100.22	2.21	1,050	101.44	2.18	800	88.54	2.50	1,027	100.32	2.21
Mid Canyon	1,397	117.01	1.89	1,287	112.31	1.97	1,685	128.50	1.72	1,500	121.24	1.83
South Shoulder	893	93.55	2.37	1,054	101.63	2.18	1,130	105.23	2.10	1,143	105.84	2.09
Middle Width Profile												
North Shoulder	767	86.70	2.55	700	82.83	2.67	595	76.36	2.90	637	79.01	2.80
Mid Canyon	1,270	111.56	1.98	1,050	101.44	2.18	1,515	121.85	1.82	1,305	113.09	1.96
South Shoulder	765	86.59	2.56	703	83.00	2.67	425	64.54	3.43	612	77.44	2.86
Shallow Width Profile												
North Canyon	285	52.85	4.19	232	47.68	4.64	180	42.00	5.27	395	62.22	3.56
Mid Canyon	968	97.40	2.27	802	88.65	2.50	1,060	101.92	2.17	1,305	113.09	1.96
South Shoulder	245	49.00	4.52	375	60.62	3.65	185	42.58	5.20	570	74.74	2.96

Discussion & Conclusion:

In correlation with the assumed tsunami path, the areas directly adjacent to the canyon heads will experience less wave amplitude and less surge than the areas adjacent to the flanks of the canyon heads. The width and depth of the canyons will suppress the effects of wave amplitude and surge (figure 5). Areas in red may be subject to increased wave amplitude and surge with respect to the tsunami wave direction used in this study, whereas areas highlighted in yellow should have decreased wave amplitude and surge. Submarine canyons have an effect on tsunami propagation in relation to inland communities. These effects are dependent on the tsunami's wave direction and canyon morphology, including width, depth, incision length, distance from land and orientation to land. More data on tsunami surge and wave heights in this region is needed to predict how the distance of the canyons will have an effect on the propagation of a specific tsunami.

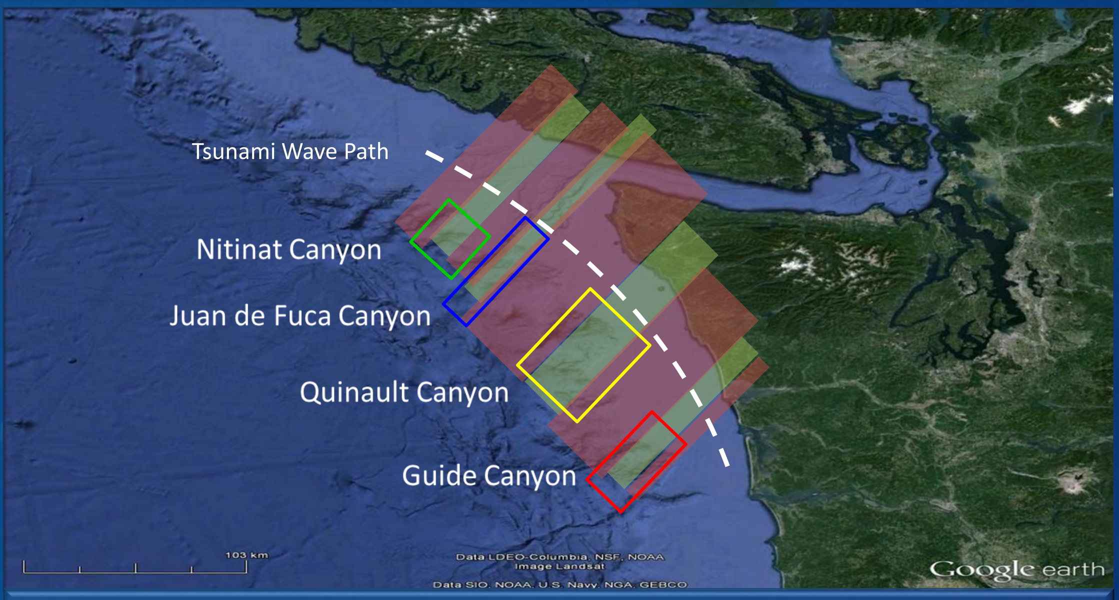

Figure 5. Green shaded zones show areas on land directly behind canyon head where wave amplitude and surge is minimal. Red shaded zones show locations of high risk where canyon flanks cause increase in wave amplitude and surge.

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References

- Aylsworth, J.,M., and Broome, J., 2011, Introduction to tsunamis, *Geological Survey of Canada, Natural Resources Canada, p.1-9.*
- Davies, H. L., Davies, J. M., Lus, W. Y., Perembo, R. C. B., Joku, N., Gedikile, H., and Nongkas, M., Learning from the Aitape Tsunami, *Geology Department, University of Papua New Guinea, University PO, NCD.*
- Iglesias, O., Lastras, G., Souto, C., Costa, S., and Canals, Ml., 2014, Effects of Coastal Submarine Canyons on Tsunami Propagation and Impact: *Marine Geology*, v. 350, p. 39-51.

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