TSUNAMIS – WHAT ARE THEY? and WHY DO THEY KILL SO MANY PEOPLE?

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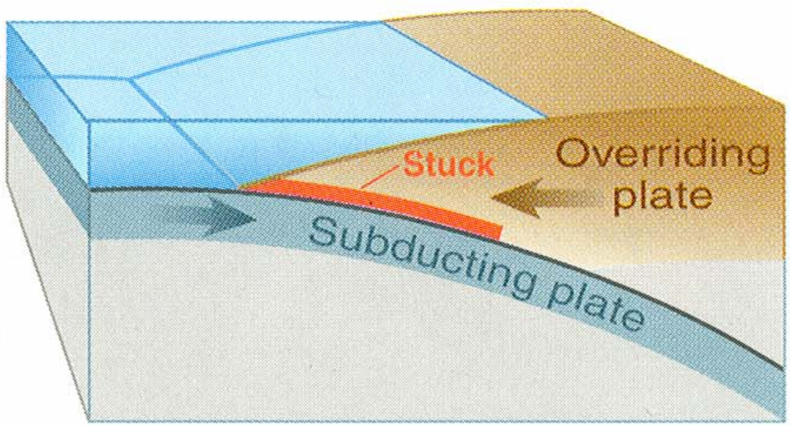
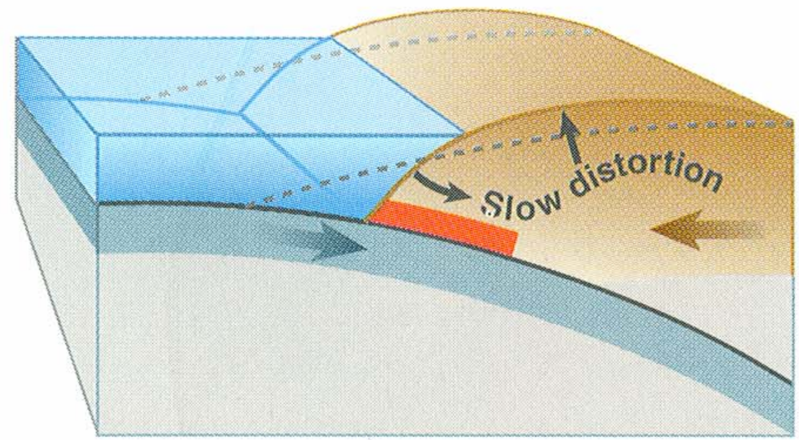
Tsunamis can be triggered by earthquakes or subaqueous landslides



Vertical Slice Through a Subduction Zone

One of the many tectonic plates that make up Earth's outer shell descends, or "subducts," under an adjacent plate. This kind of boundary between plates is called a "subduction zone." When the plates move suddenly in an area where they are usually stuck, an earthquake happens.



A. Between Earthquakes

Stuck to the subducting plate, the overriding plate gets squeezed. Its leading edge is dragged down, while an area behind bulges upward. This movement goes on for decades or centuries, slowly building up stress.

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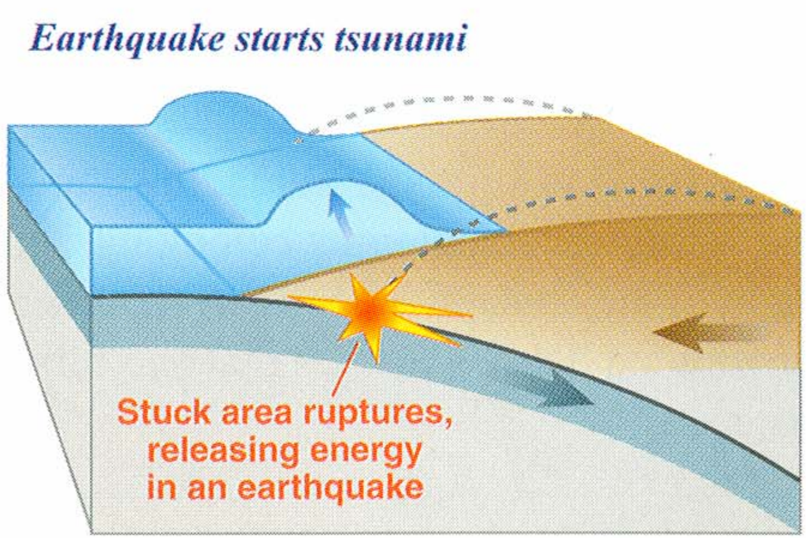
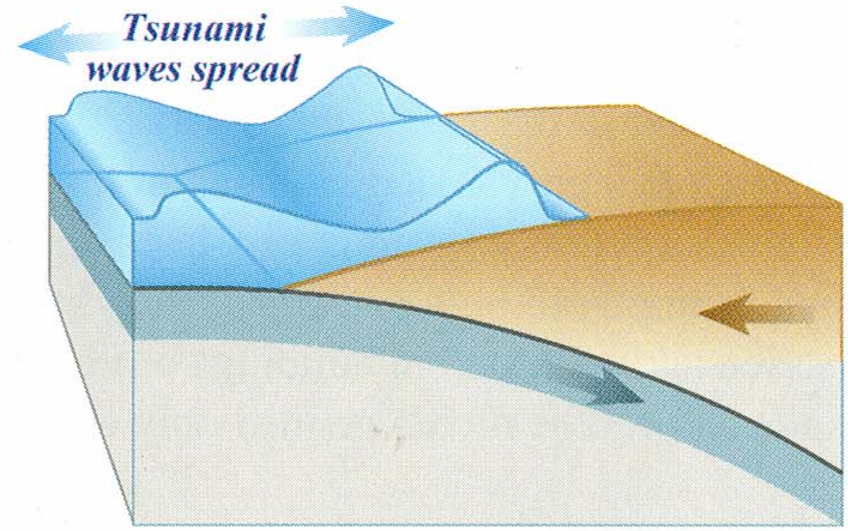


B. During an Earthquake

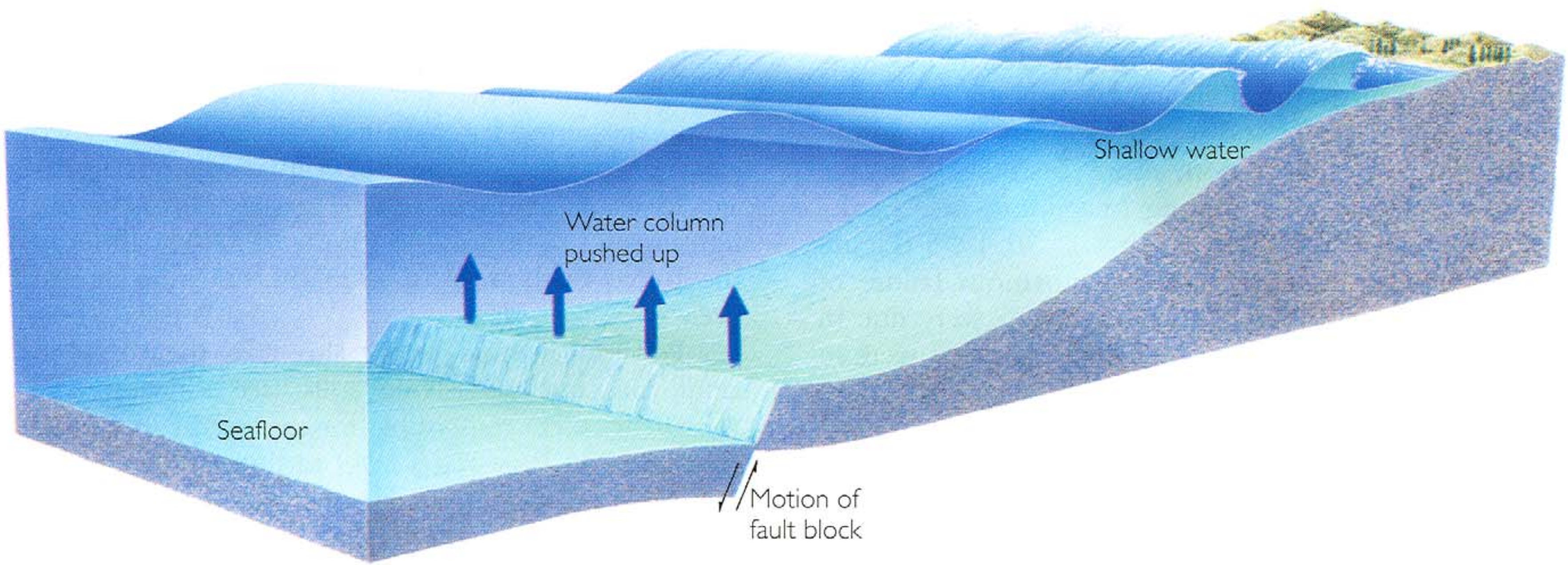
An earthquake along a subduction zone happens when the leading edge of the overriding plate breaks free and springs seaward, raising the sea floor and the water above it. This uplift starts a tsunami. Meanwhile, the bulge behind the leading edge collapses, thinning the plate and lowering coastal areas.



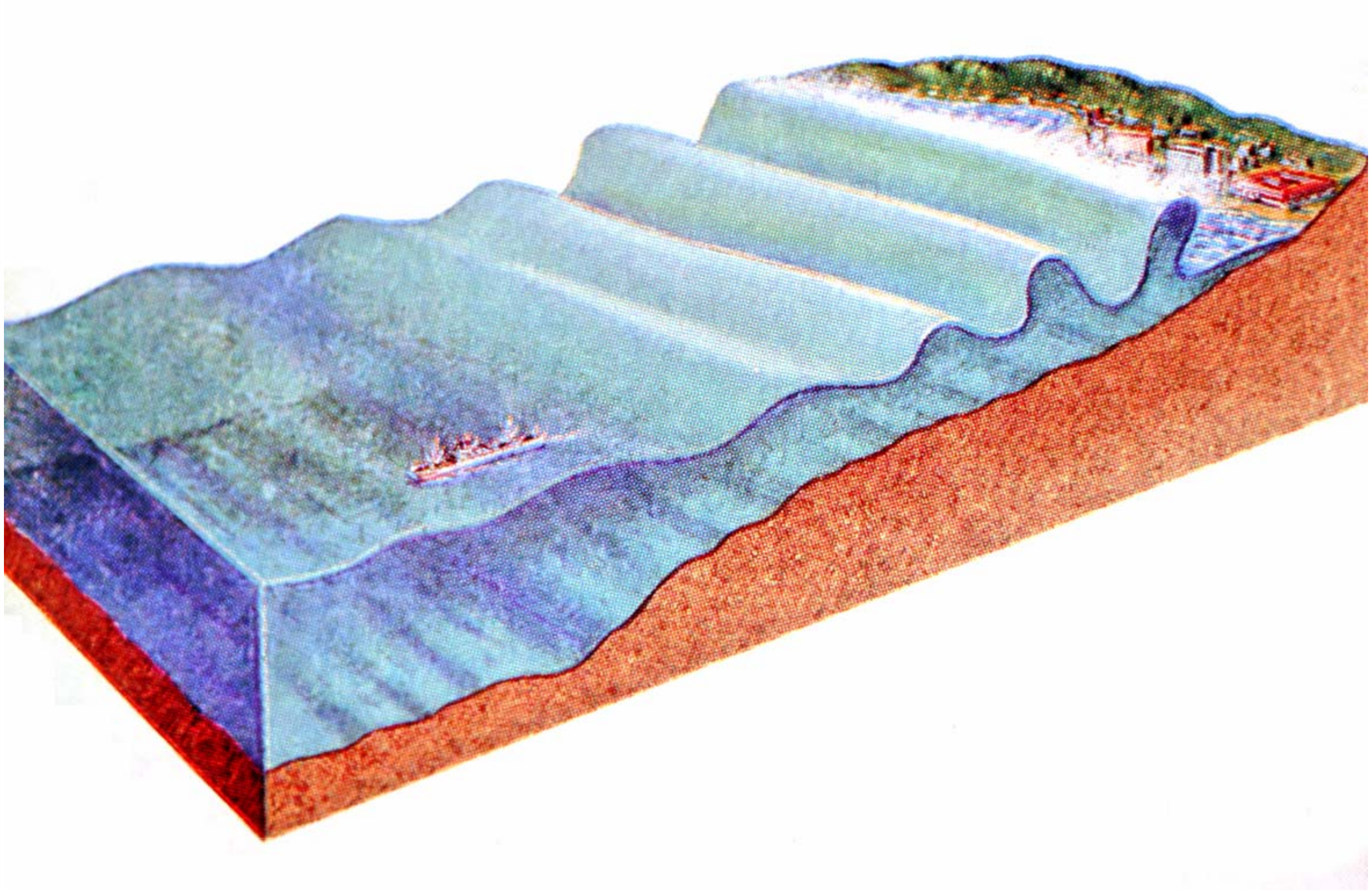
C. Minutes Later

Part of the tsunami races toward nearby land, growing taller as it comes in to shore. Another part heads across the ocean toward distant shores.

How Tsunami Waves Are Generated

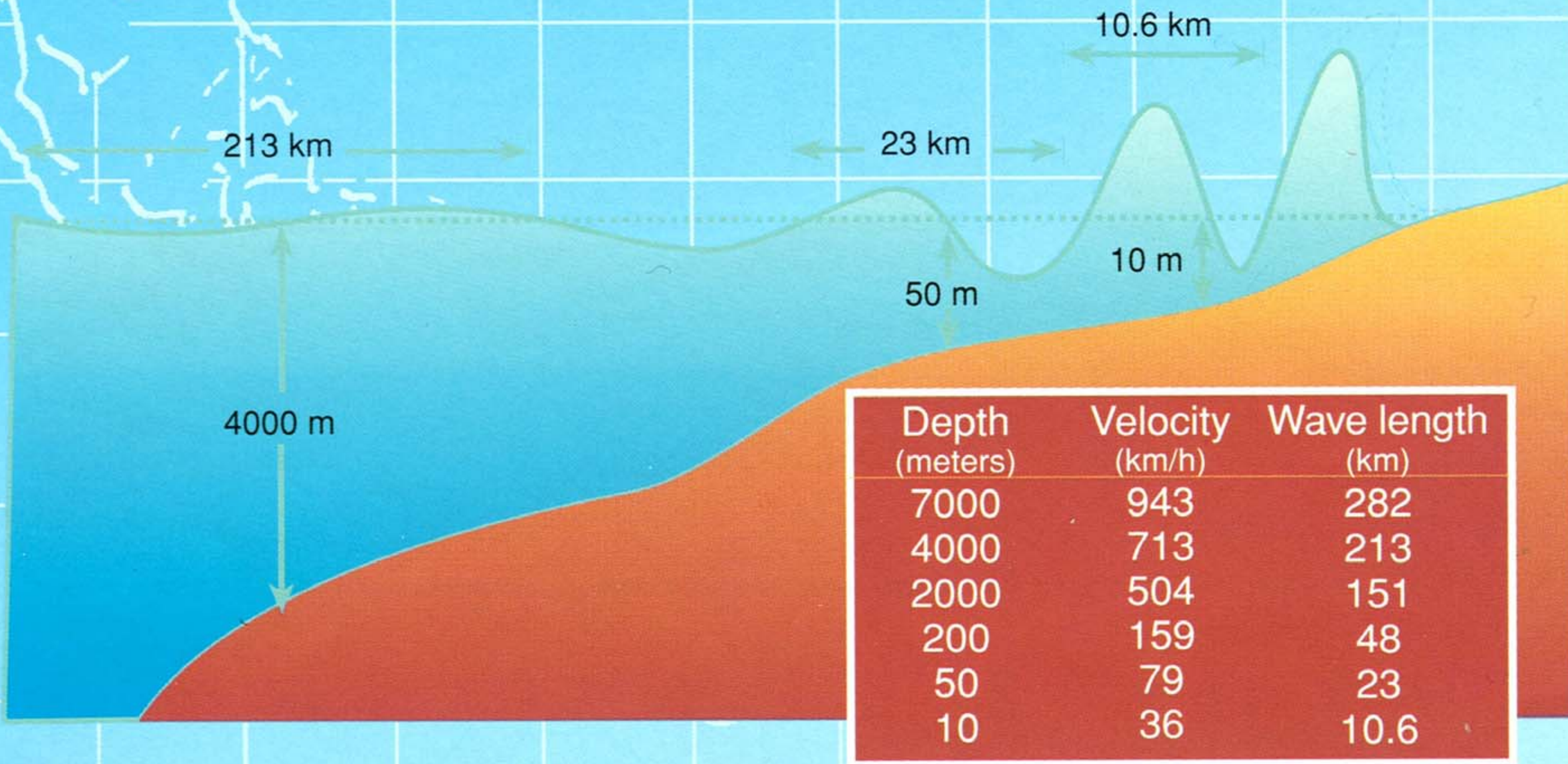


Large magnitude subduction zone earthquakes experience as much as 200 meters (656 feet) of crustal offset in the sea floor. Large scale subaqueous landslides can also create enormous wave energy.



- **Tsunamis travel at speeds between 425 and 500 miles per hour across open ocean, with wave lengths of about 200 kilometers!** **Ships in the open ocean can not discern the waves as the pass by because of their extreme wavelength.**

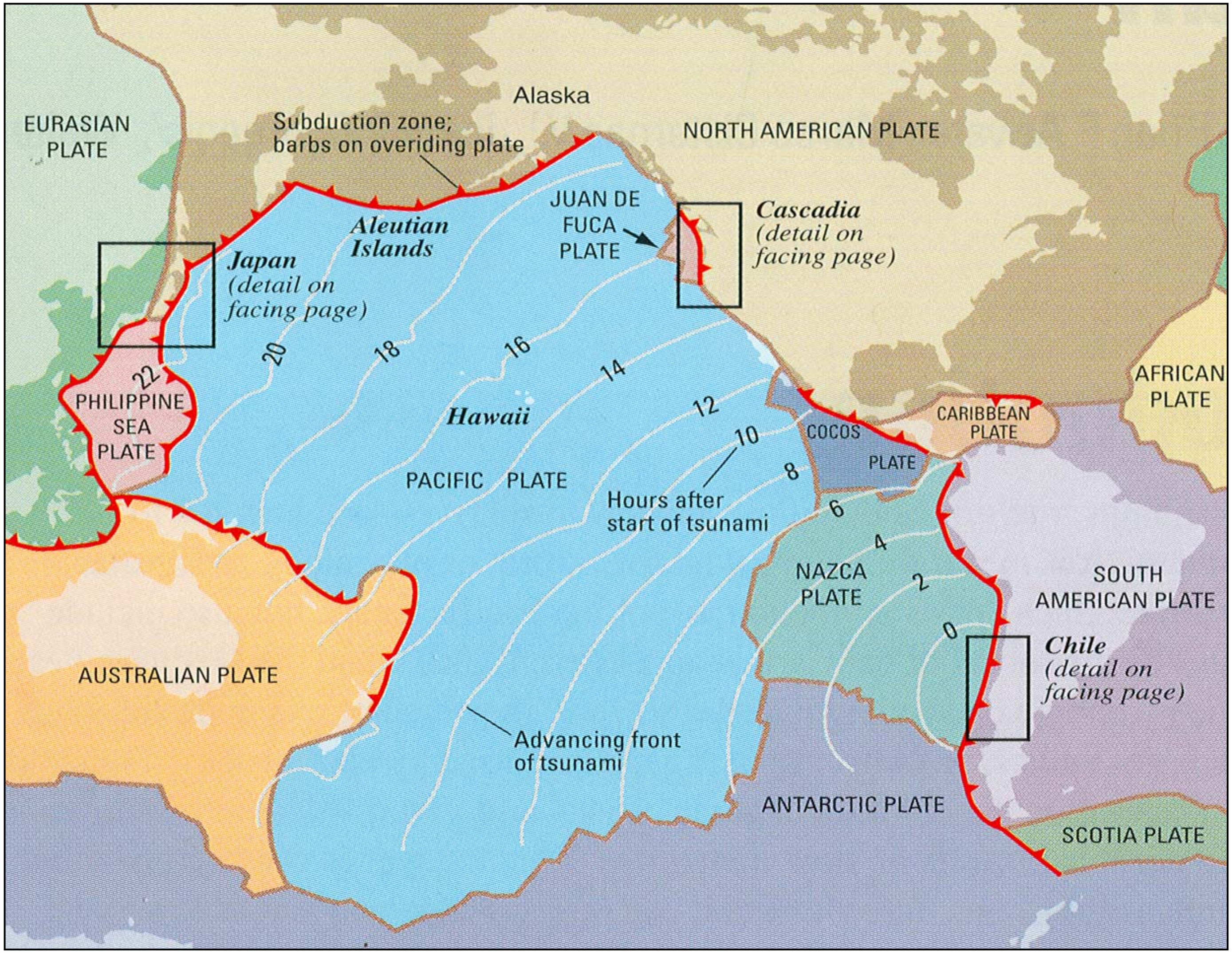
Tsunami Speed is reduced in shallow water as wave height increases rapidly.



Depth (meters)	Velocity (km/h)	Wave length (km)
7000	943	282
4000	713	213
2000	504	151
200	159	48
50	79	23
10	36	10.6

In the open ocean a tsunami is less than a few tens of centimeters high at the surface, but its wave height increases rapidly in shallow water. Tsunami wave energy extends from the surface to the bottom in even the deepest waters. As the tsunami attacks the coastline, the wave energy is compressed into a much shorter distance and a much shallower depth, creating destructive, life-threatening waves.

- **The transit speed of tsunamis is reduced in shallow water and the wave height increases rapidly. The wave is an inexorable force, which can easily pass over breakwater structures or man-made harbor moles.**

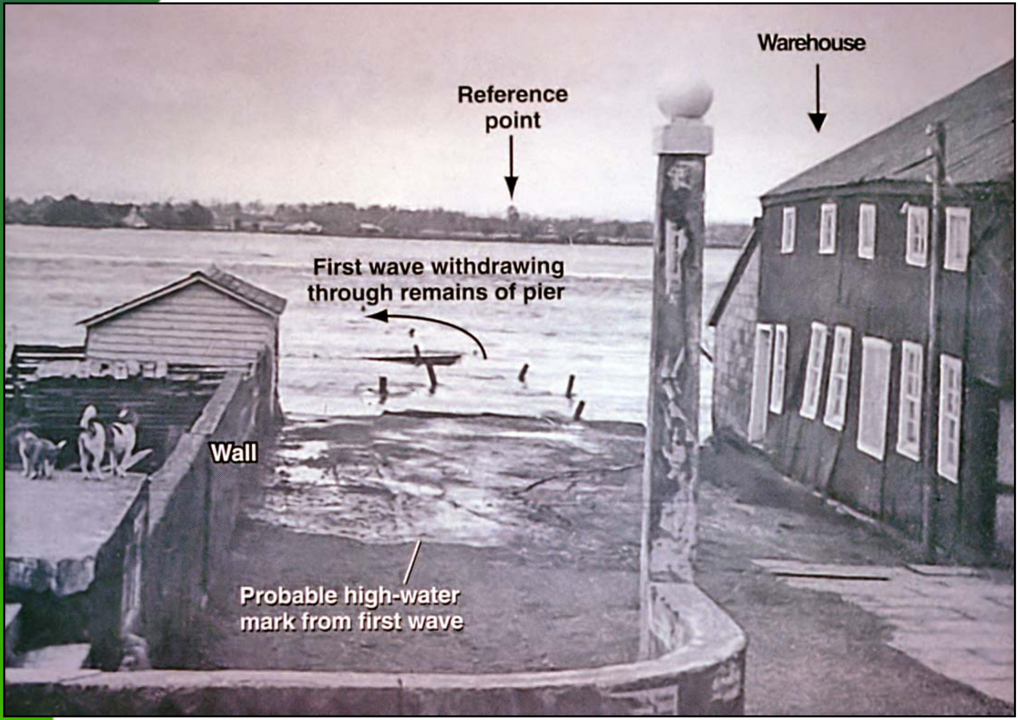


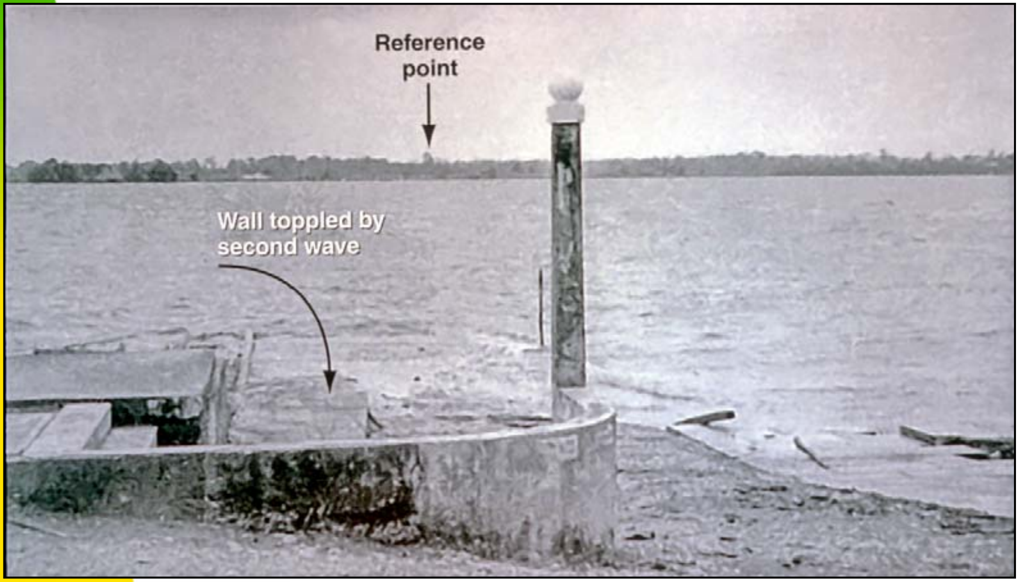
The largest tsunamis have historically emanated from the Pacific “Ring of Fire”, formed by thin oceanic plates being subducted beneath thicker continental crust. The Magnitude 9 Sumatra quake occurred along the boundary between the Eurasian and Australian Plates, an area known for high seismicity and vulcanism.

1960 M 9.5 CHILE EARTHQUAKE

- Before and after views of the coastal village of Queule, Chile, which was devastated by the tsunami that followed the Magnitude 9.5 earthquake in May 1960, the largest ever recorded.
- The residents who fled for the hills immediately after the quake survived, but those who remained were killed.

Save your life, not your possessions





Scenes from May 1960 tsunami waves in Maullín, Chile. Upper view shows withdrawal of the first wave, which destroyed the town's pier.

The buildings in the foreground were destroyed during the much higher second wave. Many people were killed who returned to their buildings to retrieve belongings.

Most of the bodies were never recovered because they were washed out to sea.

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- **1944 image of the mouth of the Río Maullín along the coast of Chile. The 1960 tsunami flowed 2 miles inland from the beach line, reaching a height of 15 feet above sea level. Those who survived did so by climbing onto anything that was floating.**

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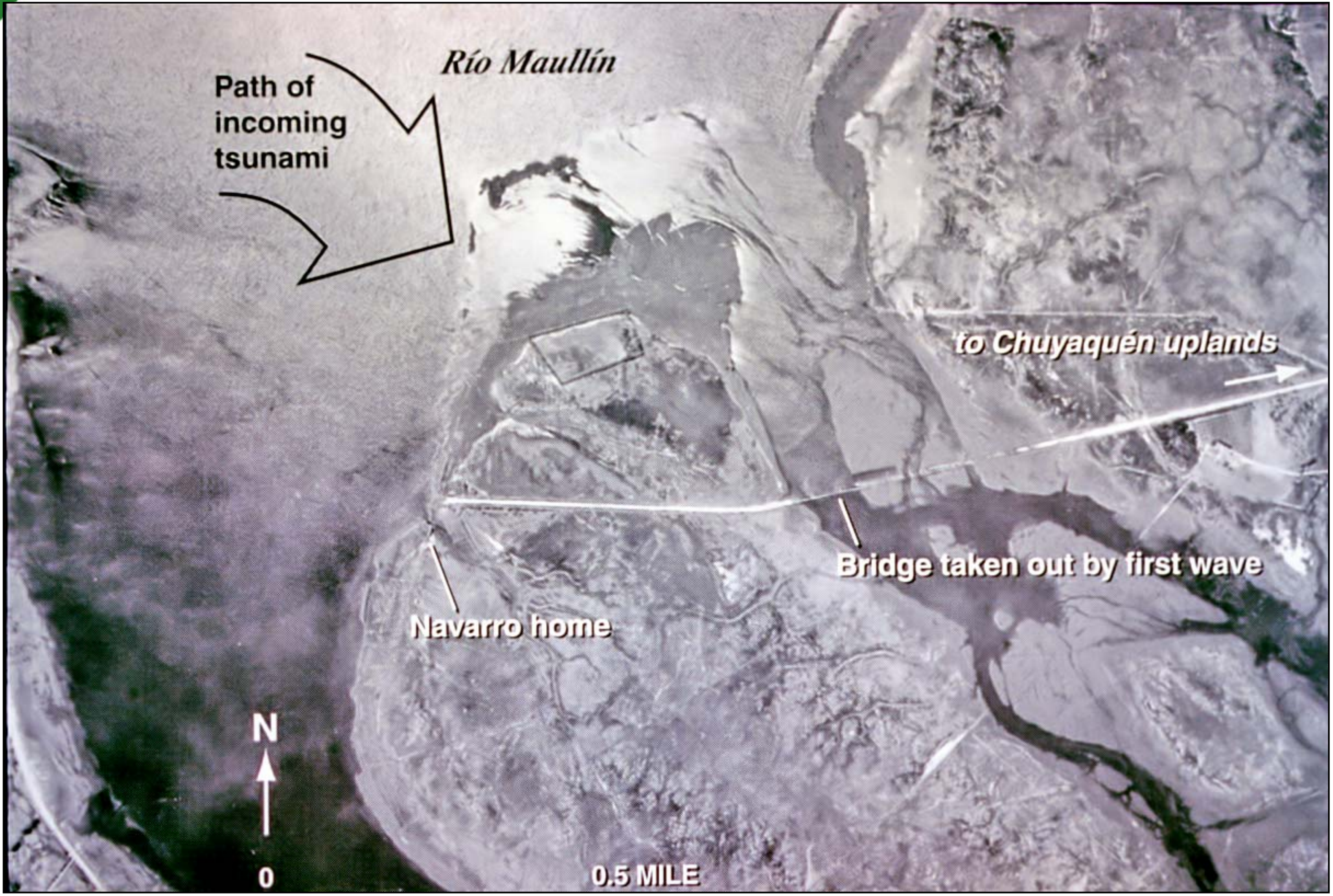

Post-quake view of the mouth of the Río Maullín in Chile in 1960. Occupants of this area survived by climbing up onto the roofs of sturdy structures.

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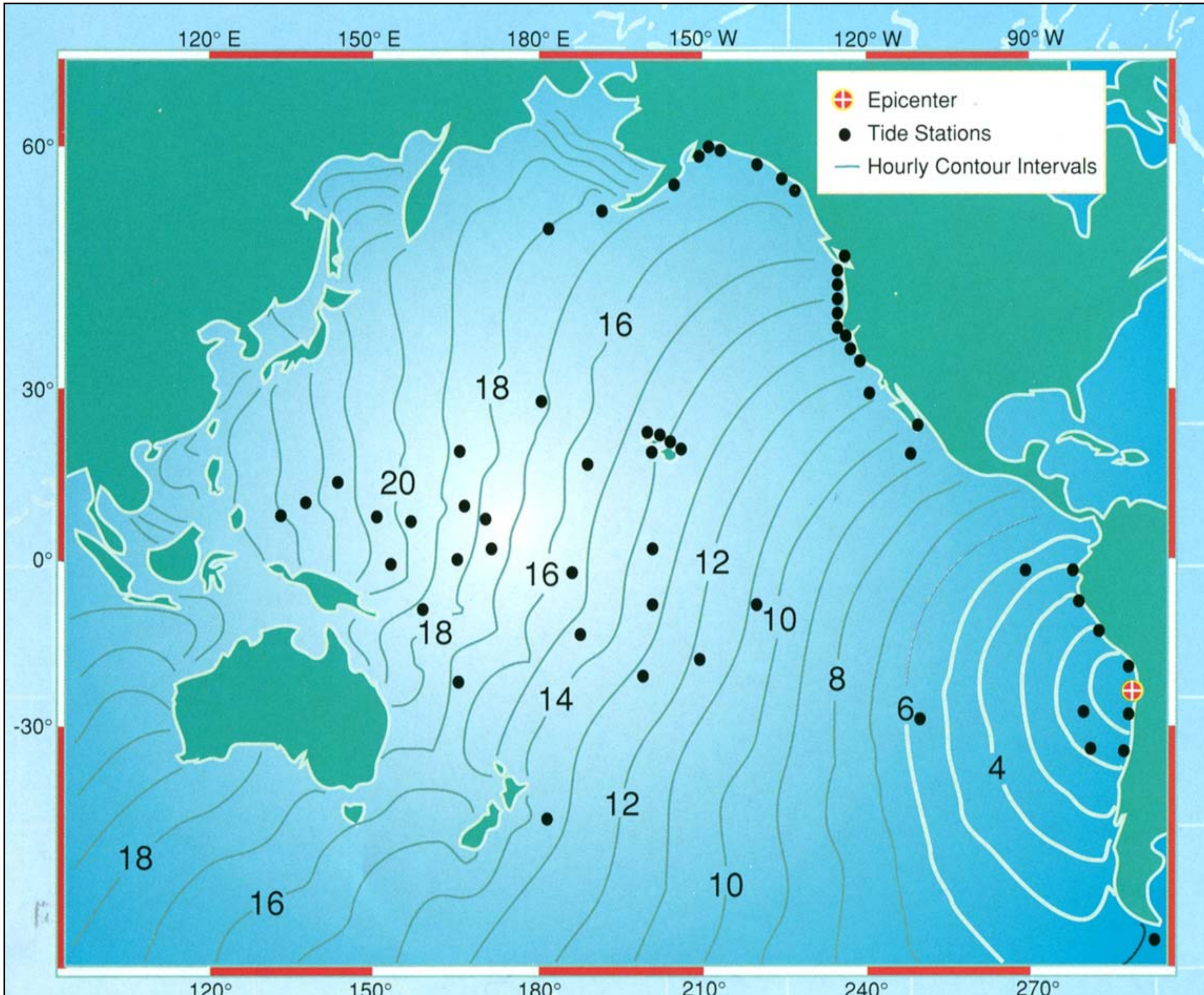
- Coastal areas struck repeatedly by tsunamis leave telltale traces of past wave runup. This image shows the Chilean coastline near Quenuir, which provides ample evidence of past tsunamis



Calculated tsunami travel times for an earthquake occurring off the coast of Chile. Each concentric curve represents one hour of tsunami travel time.

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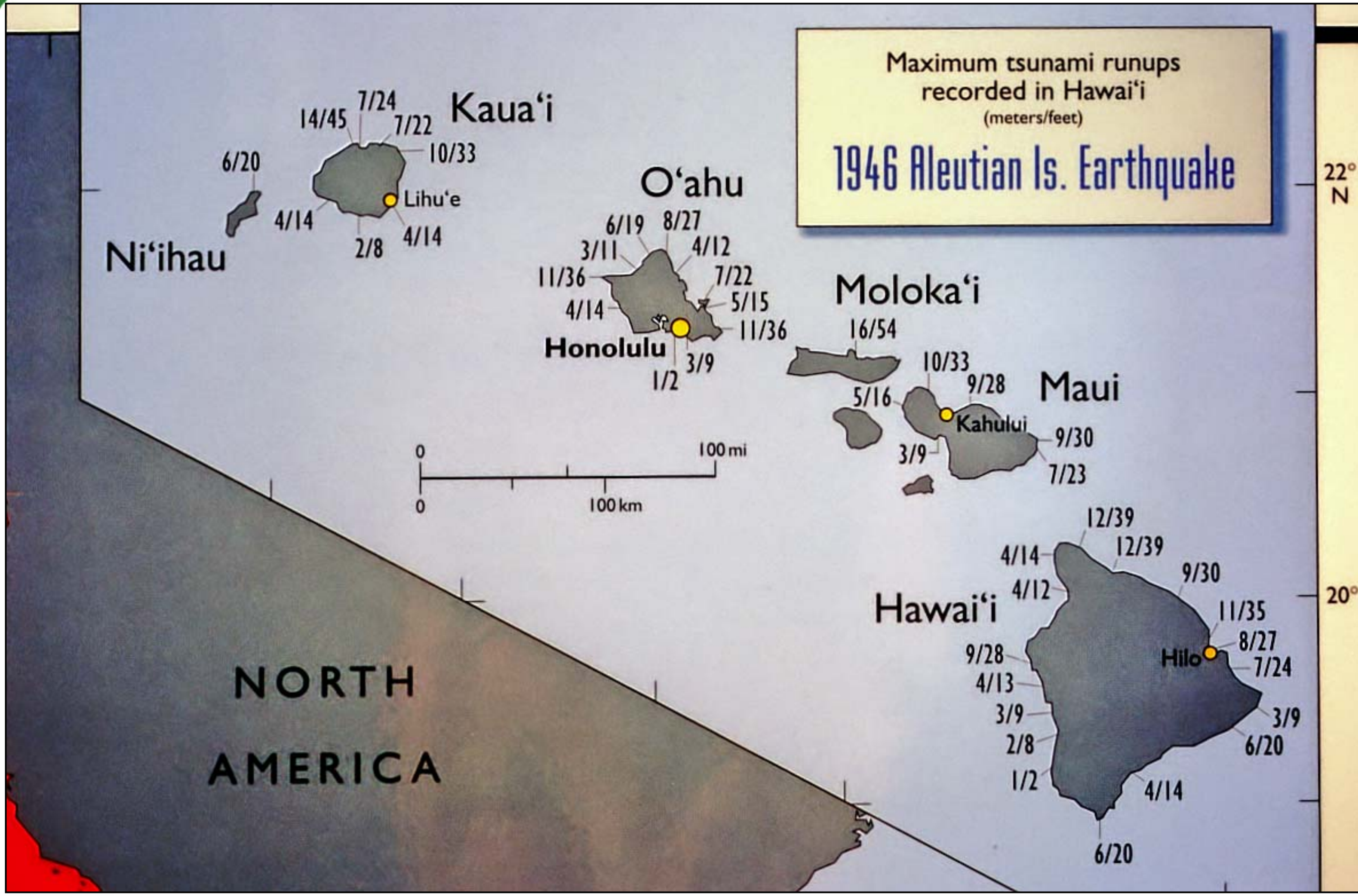
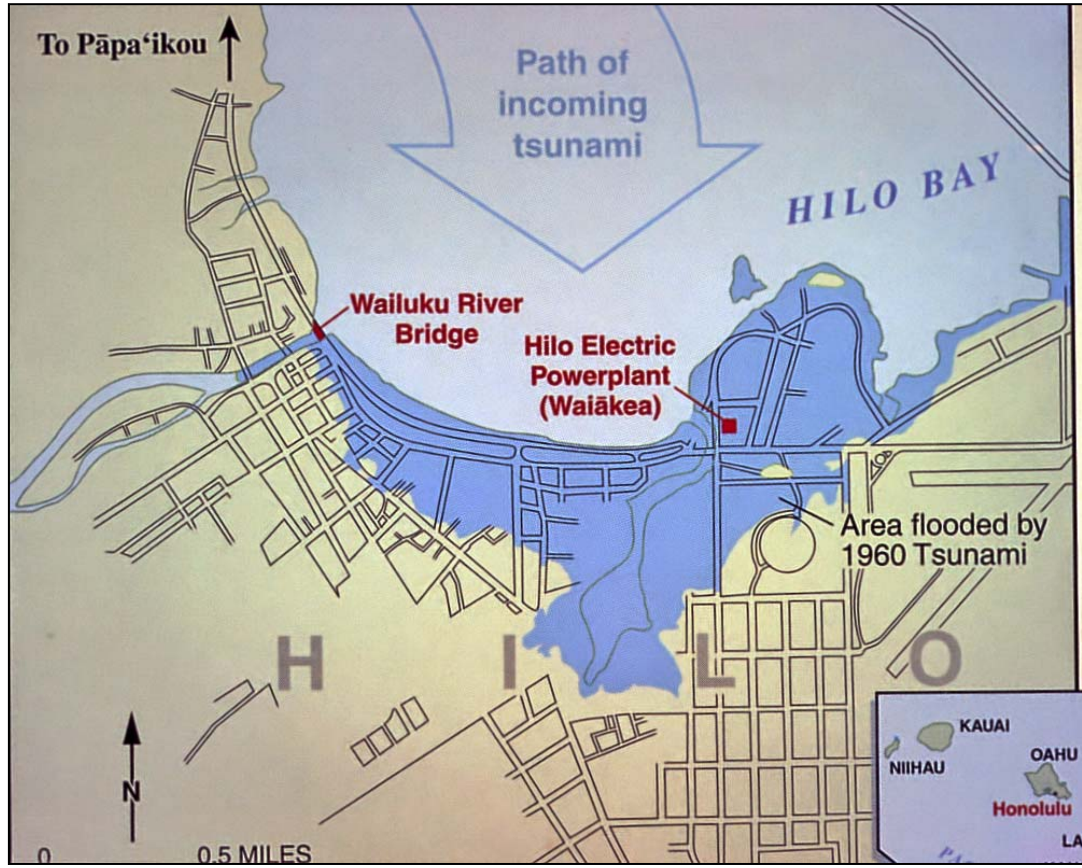


- **The deadliest tsunami in American history was triggered by the M 8.6 Unimak earthquake in the Aleutian Islands on April 1, 1946. Five hours later it s waves struck the coastal city of Hilo, Hawaii, rising as much as 35 m above sea level. 159 people were killed.**

April 1, 1946 tsunami in Hilo, Hawaii

159 people were killed

May 1960 tsunami in Hilo



Hilo, Hawaii has been hit by tsunamis more than any other location in the United States because of it's trumpet-shaped bay, which serves to concentrate and magnify the heights of incoming wave trains.

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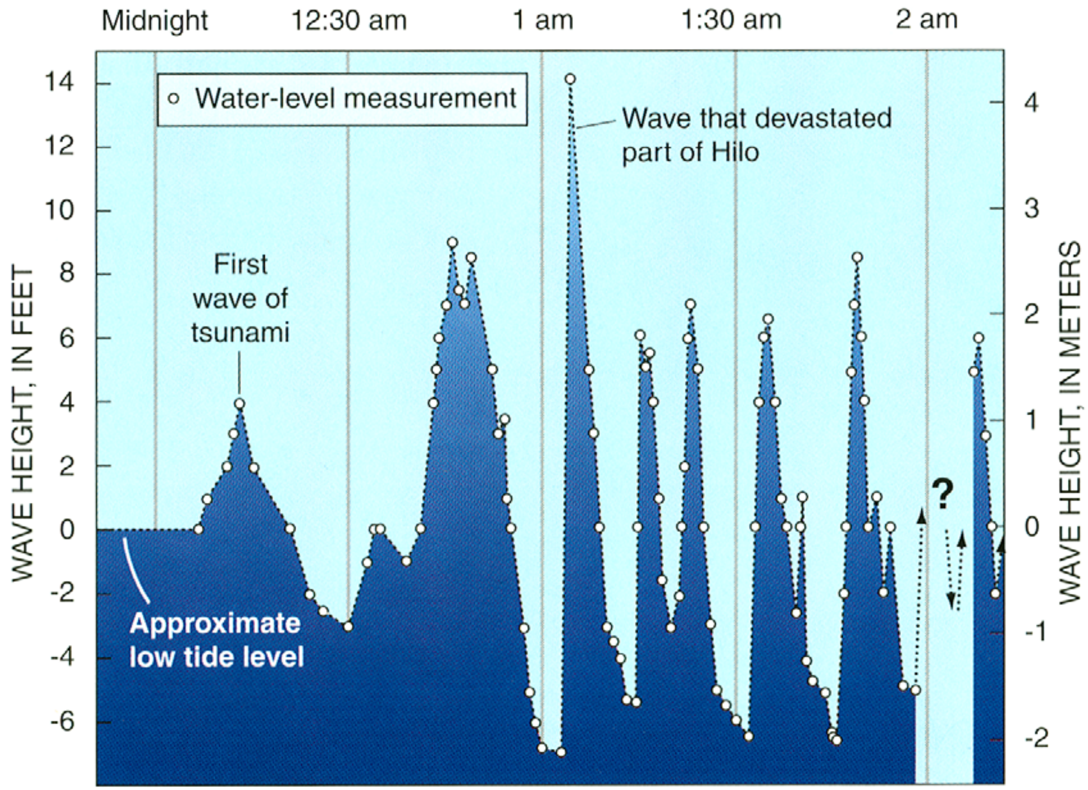
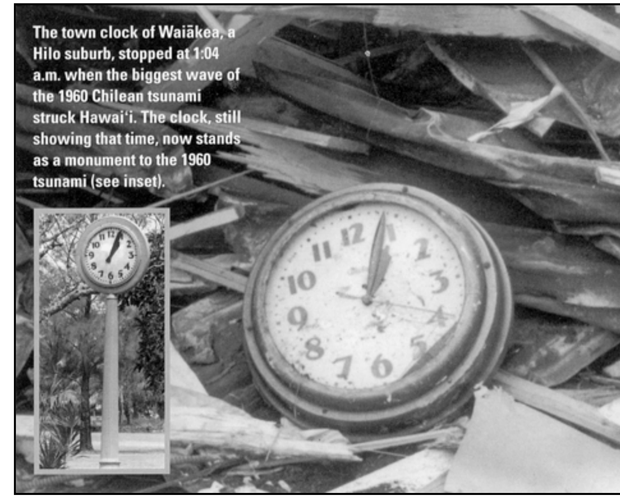


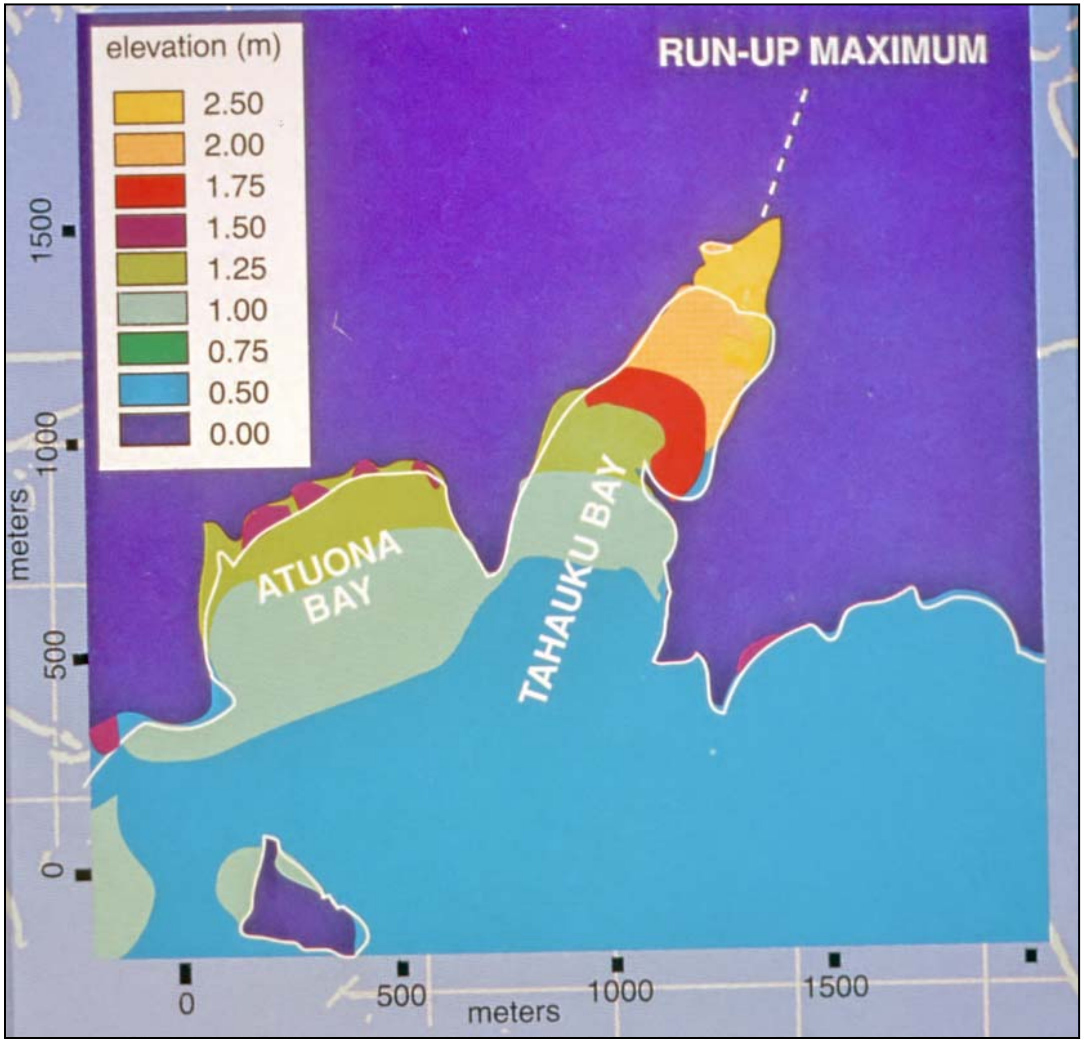
TSUNAMI OF MAY 23, 1960, ON THE ISLAND OF HAWAII



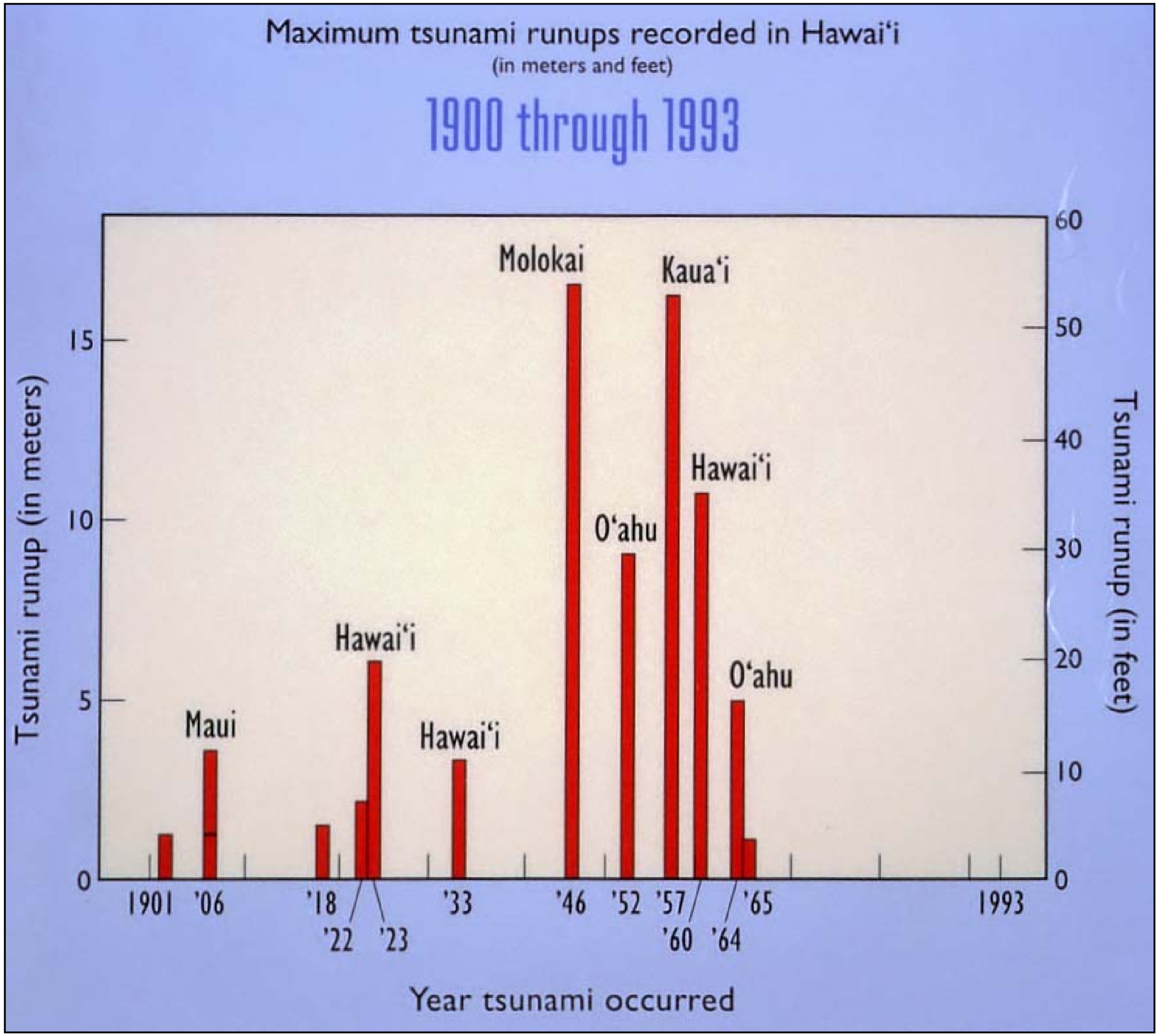
The 1960 Chile earthquake produced a series of tsunami waves that crossed the Pacific Ocean. This record shows measurements of water levels beneath the Wailuku River Bridge made by seismologist Jerry Eaton and his companions during the first few hours of the tsunami in Hilo, Hawaii.

Tsunamis arrive as a series of waves, separated by a few minutes to a few hours. The waves can last for up to three days. The third wave was the most deadly, reaching a height of 14 m above mean sea level.

Tsunami awareness is very high in Hilo because 159 people were killed in 1946 and another 61 in 1960. Warnings were issued in 1960, but people returned to the downtown area after the first two waves.



- **Maximum wave run-up is controlled by azimuth of the oncoming wave train and the shape of the coastline. Trumpet shaped with converging shorelines are the worst condition. Breakwaters do not mitigate run-up.**



- **Maximum tsunami wave runups recorded in Hawaiian Islands between 1900-1993.**

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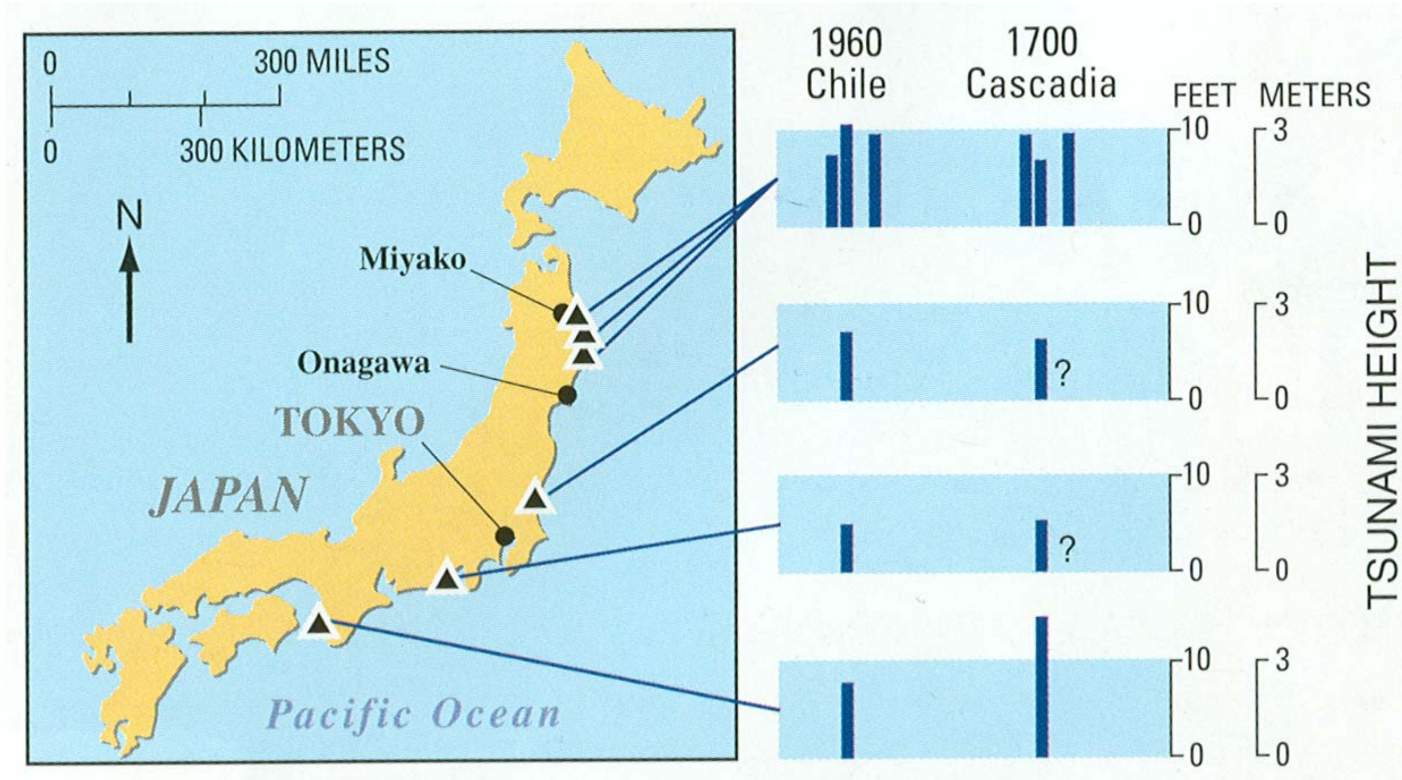
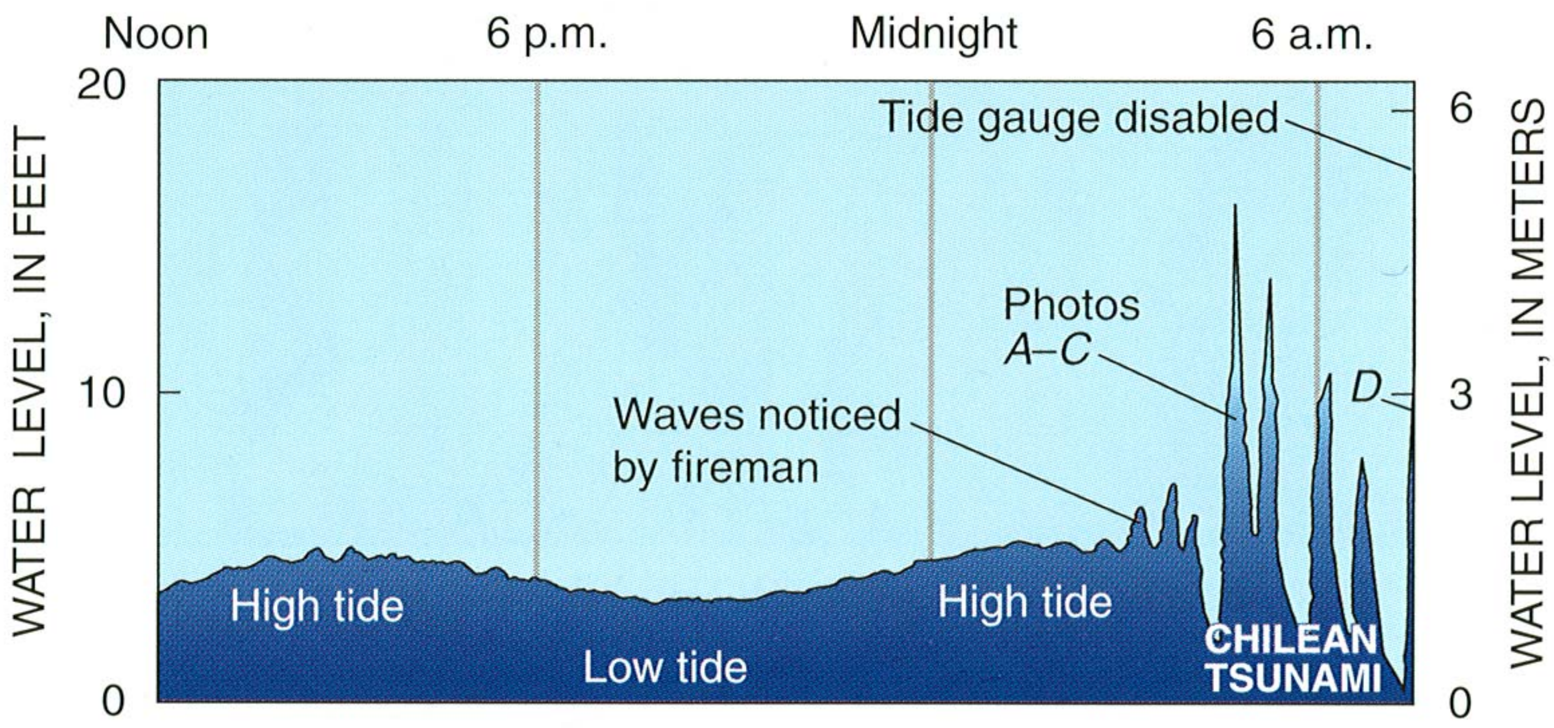


As shown by wave heights observed in Japan, subduction-zone earthquakes in Chile and Cascadia have caused tsunamis that were large even after crossing the Pacific Ocean.

- **There is a substantive historic record of devastating tsunamis in Japan, dating back a thousand years**

May 1960 tsunami in Onagawa, Japan



Tide-Gauge Record for May 23 and 24, 1960, at Onagawa, Japan

The Chilean tsunami waves began hitting Japan around 4:40 AM on May 23rd, about 22 hours after the massive earthquake. Despite an efficient warning network, it killed 122 people in Japan

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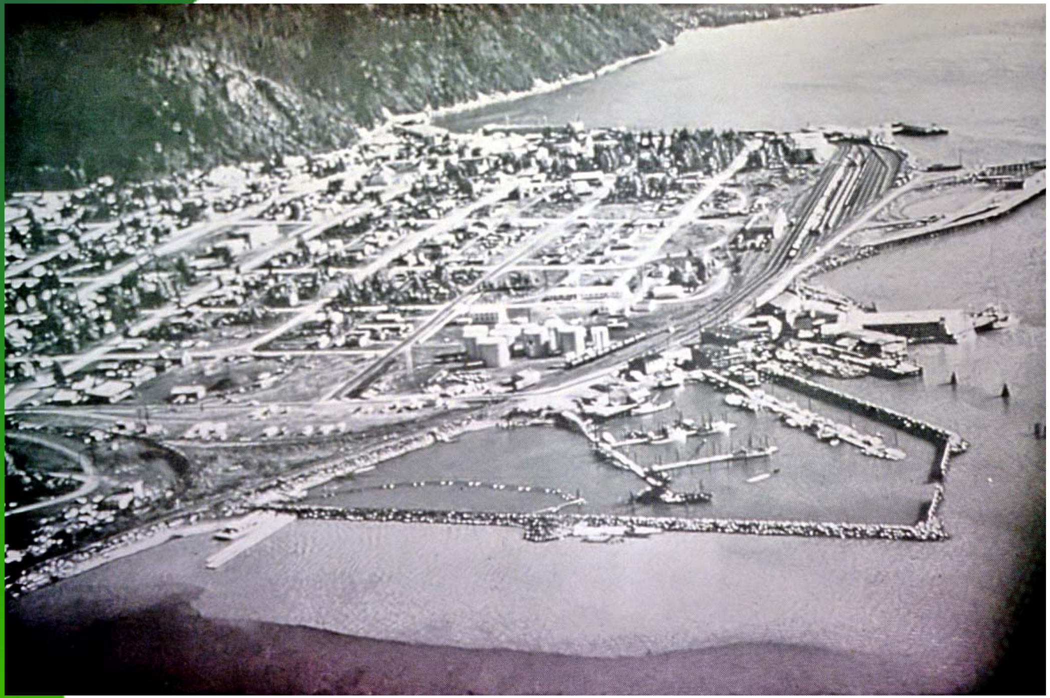
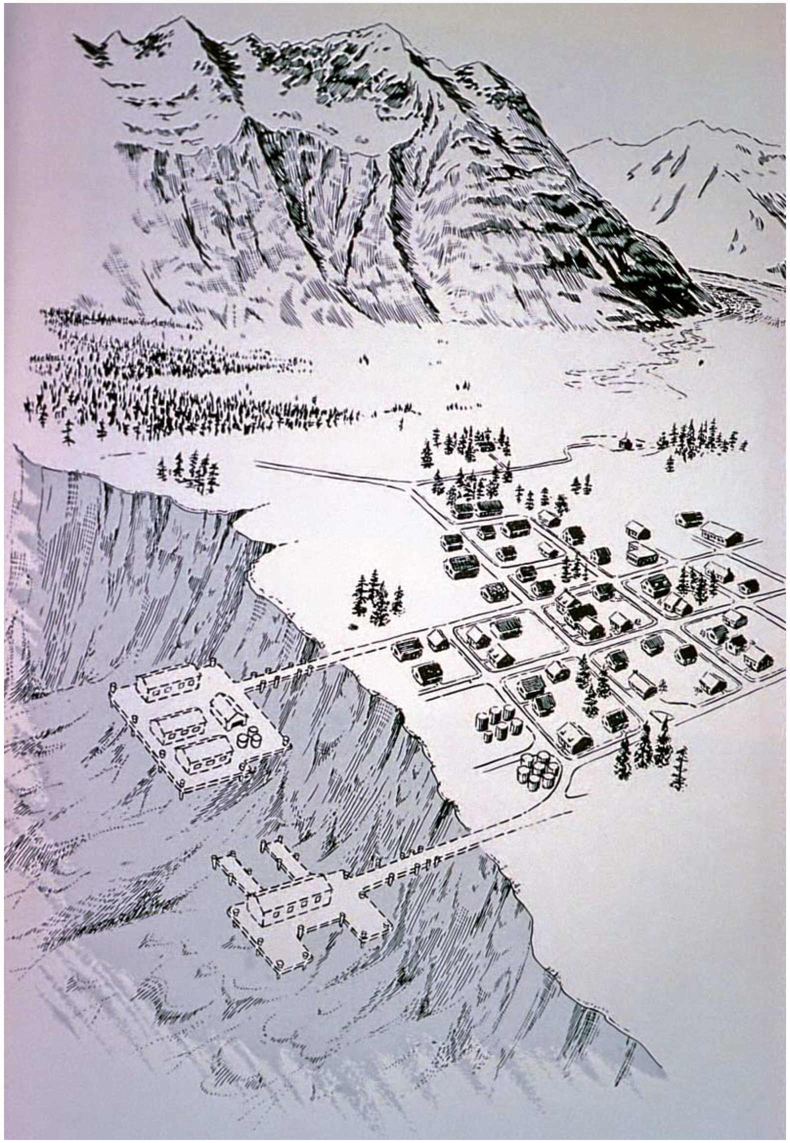
Sequence of images taken in Onagawa, Japan during the May 1960 tsunami. No one was lost in Onagawa, even though the highest wave was 14 feet.

Erecting Protective Walls

The Japanese employ protective seawalls at many of their most vulnerable coastal communities. These views show a 1993 tsunami that splashed over a protective wall and wrecked havoc on the "protected" community. Note dead fish in street at lower left.

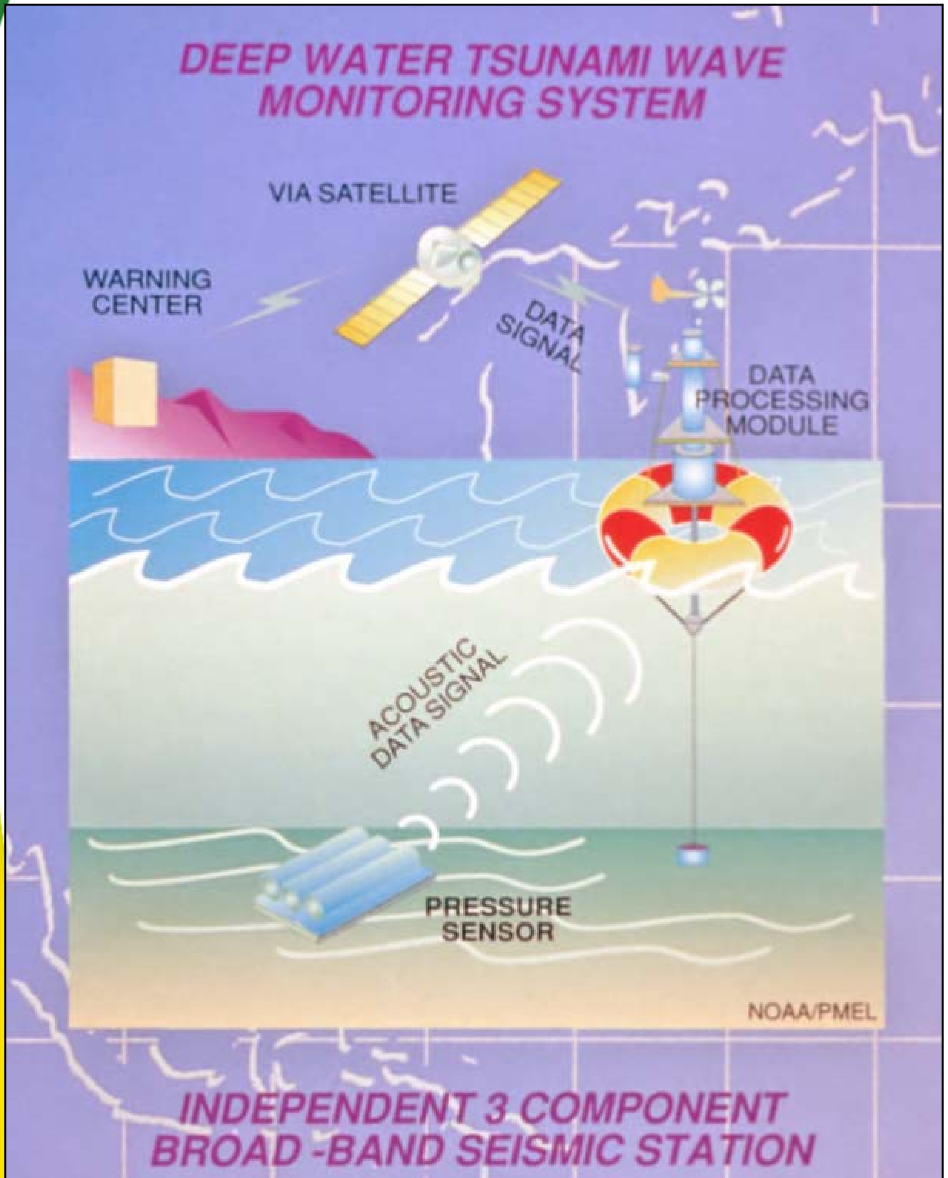




Before and after views of Valdez Harbor, M 8.4 Alaska earthquake March 23, 1964

Images showing damage to coastal wharves and fishing fleet – 1964 Alaska earthquake

PACIFIC Tsunami Warning Network



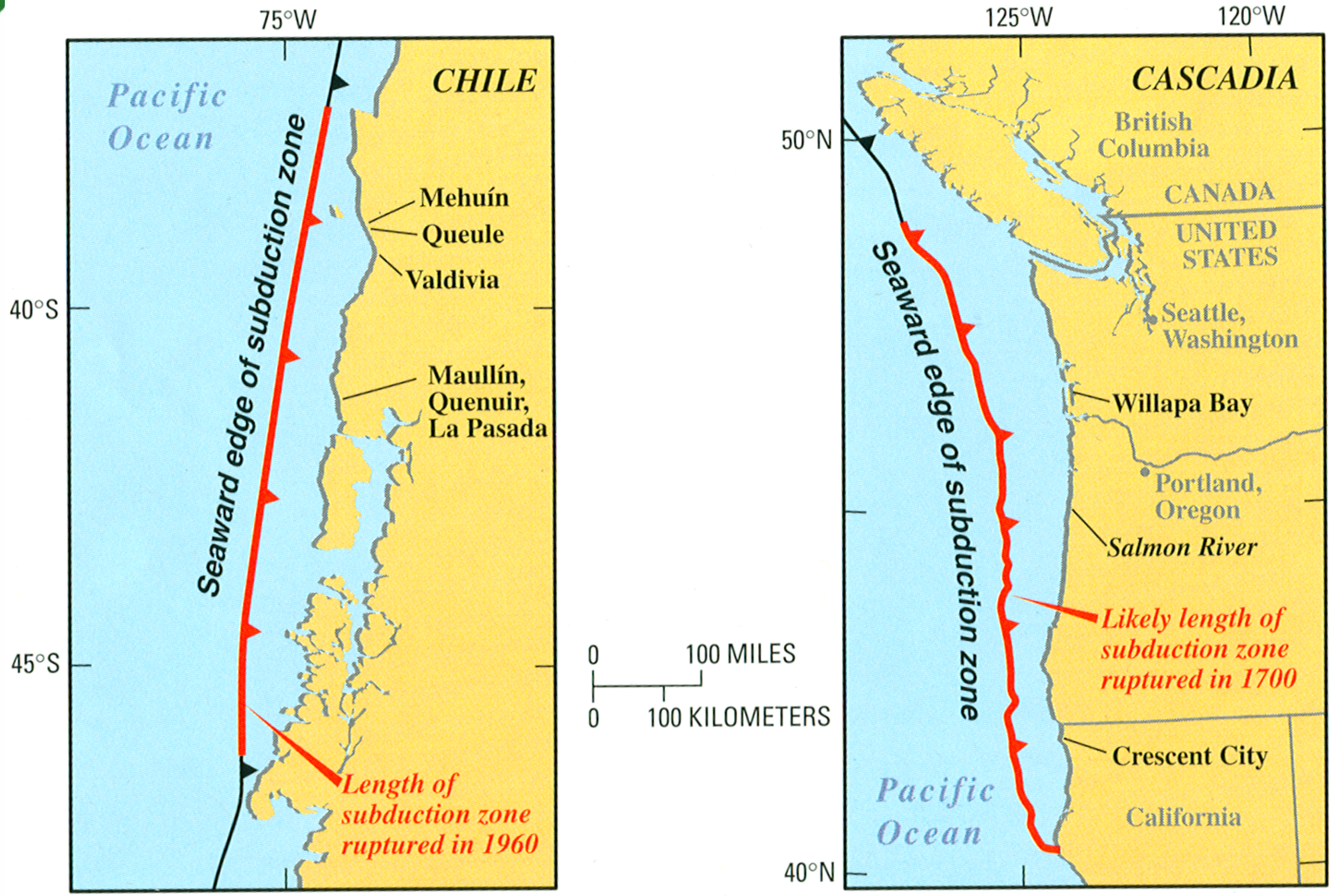
NOAA's monitors are tethered to pressure sensors resting on the ocean floor. They can detect subtle changes in wave height using pressure sensors, transmitting this data to satellite. Ships on the open ocean cannot detect traveling tsunami waves because of their great wavelength (usually greater than 200 km).

Warnings Must be Heeded

- **One of the problems with warnings is providing the requisite education about what to do when warned. This shows spectators gathering along the Ali Wai Canal on Oahu to witness the May 1960 tsunami**

Retreating shorelines are a common precursor of devastating tsunamis. These views are from the New Guinea coast in 1995

Despite all manner of warnings, young men invariably believe they can out-run the waves when they come in, like some sort of sporting event



Both the 1960 Chile earthquake and the 1700 Cascadia earthquake were caused by sudden ruptures of long segments of subduction zones. Each of these quakes generated a tsunami that not only struck nearby coastal areas but also caused damage in coastal areas as far away as Japan.

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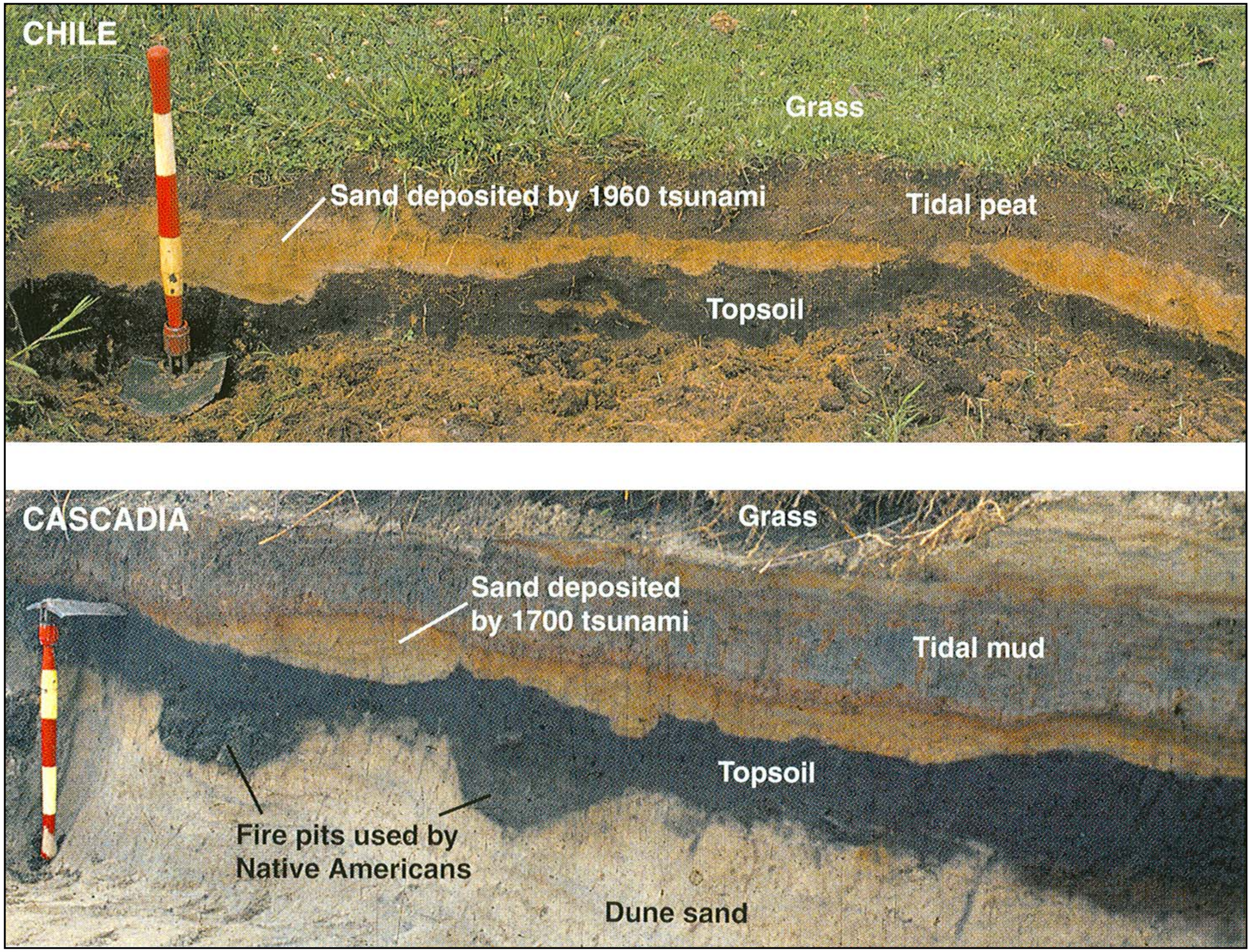

Sand deposited by major tsunamis emanating from coastal Chile in May 1960 (upper photo) and off the coast of what is now Oregon and Washington in 1700 (lower photo).

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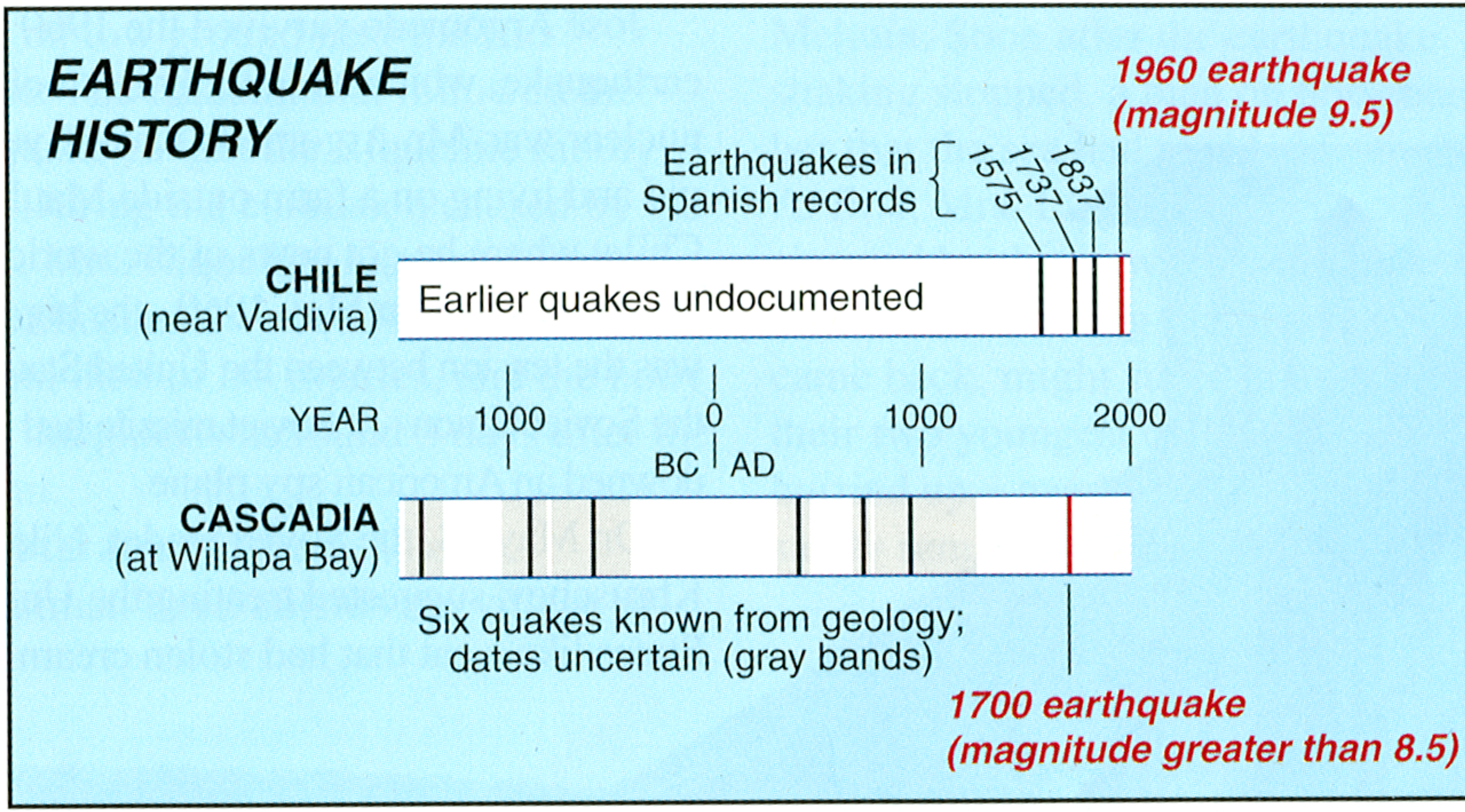

Long times between earthquakes can erase memories of how to survive their tsunamis. The region of the 1960 Chile earthquake had gone without such a quake since 1837. Except for Native American legends, memory of the 1700 Cascadia earthquake is limited to written records of its tsunami in Japan.

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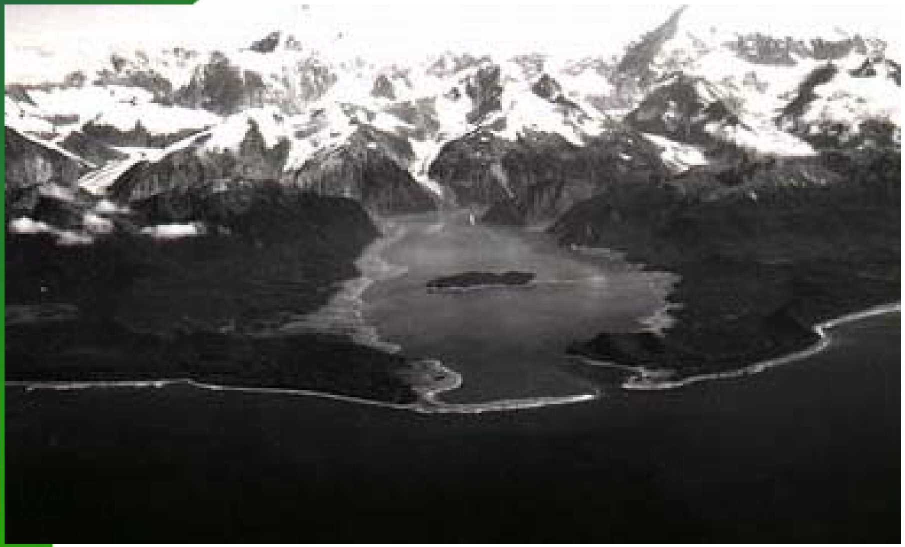
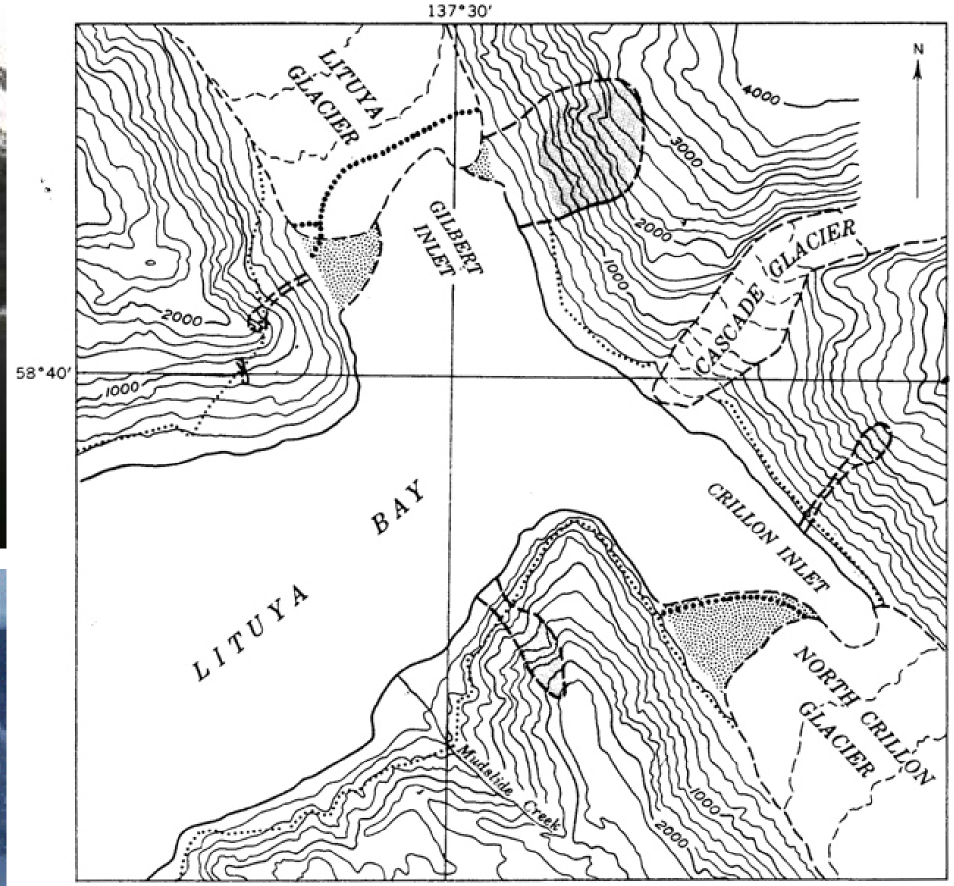
- **Local tsunamis are often be associated with tsunami generation by submarine or subaerial landslides or volcanic explosions.**





Map showing outline of the rockslide at mouth of the Lituya Glacier that generated destructive waves in Lituya Bay in 1958

- **The worst landslide-generated tsunami wave in modern time occurred on July 9, 1958 at Lituya Bay, Alaska, where wave run-up from a subaqueous landslide exceeded 485 meters, seen on slope in photo at lower left.**

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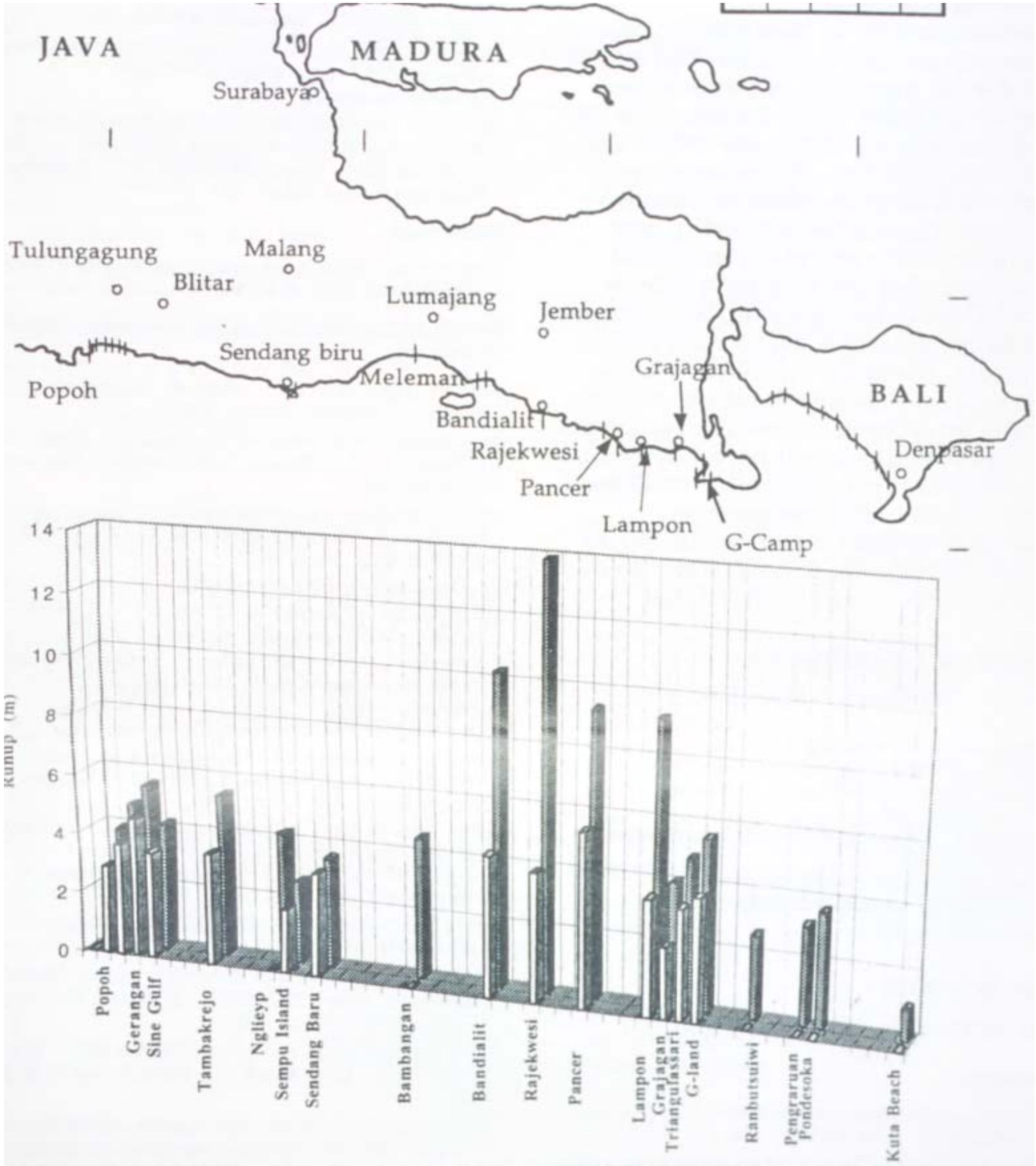
Subaqueous slump blocks seen off Indonesian coast near Lewobele and Leworahang on Dec 12, 1992.

ASYMMETRIC WAVE RUNUP

A common occurrence with tsunamis is asymmetric wave run-up, as shown in the plot.

An earthquake in eastern Java on June 3, 1994 caused a wave 14 meters high to obliterate the village of Rajekwesi, killing 33 people. None of the other towns recorded run-ups much over 5.5 meters.

This problem has to do with constructive interference of converging wavetrains



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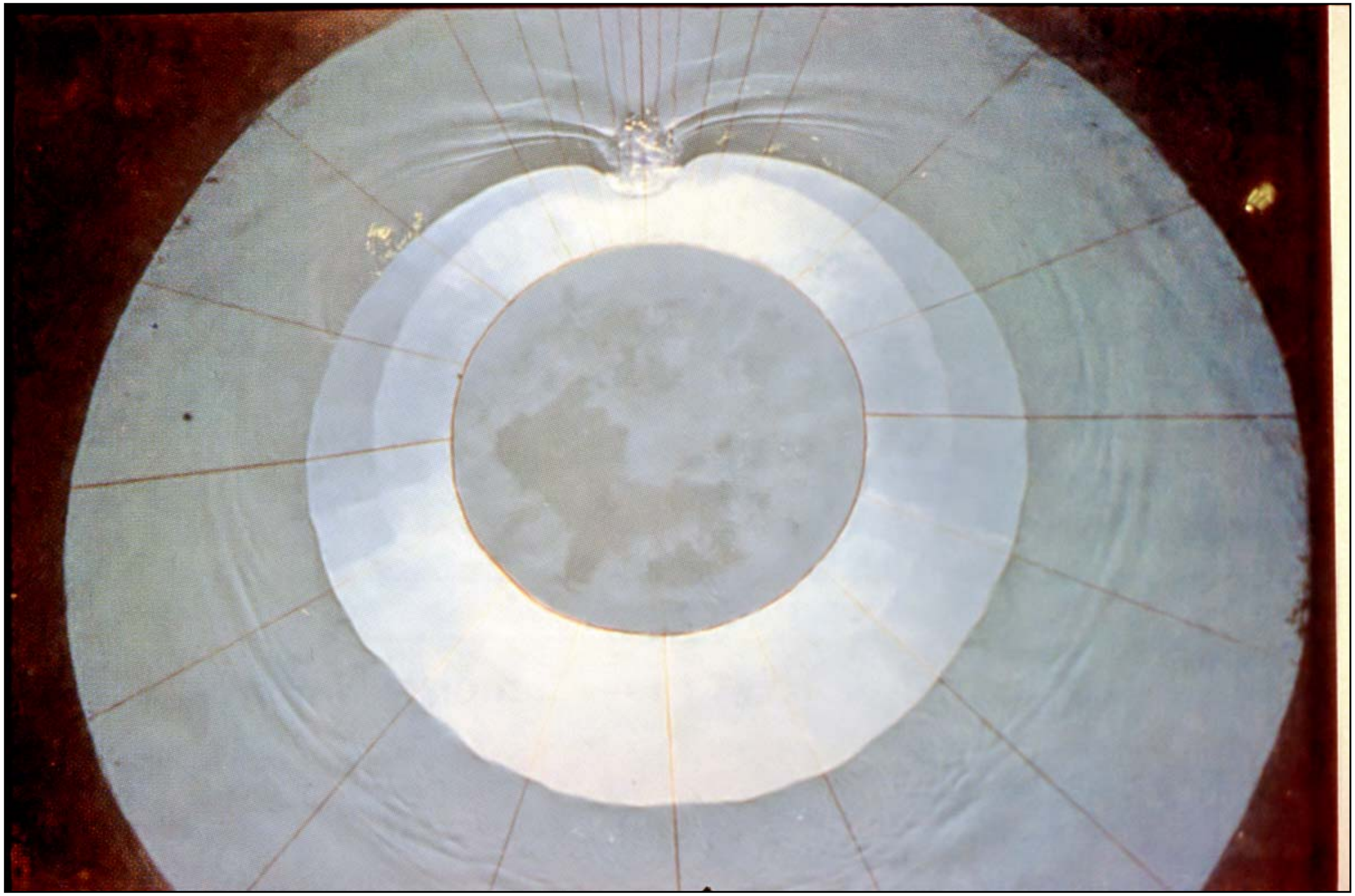

- **Convergent interference of reflected waves around a perfectly circular island in wave tank at ERDC-Vicksburg. This is what causes some locations to be hit with so-called "killer waves".**

CONCLUSIONS

- **Tsunamis are much more frequent than most people realize**
- **Can be caused by earthquakes, volcanic eruptions, subaqueous landslides and subaerial landslides**
- **Coastal bathymetry, shape of coastline, onshore topography, and aspect to advancing wave fronts impact severity of tsunami runup.**
- **People living in low lying coastal plains are most at risk; must have awareness training and evacuation plan in place to survive a tsunami**

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