TSUNAMI

CHAPTER 4

TSUNAMIS

The earth is covered like an armored reptile with enormous stony slabs which drift on the denser material of the mantle, slabs that are constantly being destroyed and renewed in the processes of "plate tectonics" which we studied in Chapter 2. Nowhere are these processes more in evidence than along the belt of frequent earthquakes and volcanic eruptions that rings the Pacific Ocean.

These earthquakes, the destructive offspring of larger forces shaping and reshaping planet earth, have destructive oceanic offspring of their own - the great waves of the Pacific.

Every island and coastal settlement in the Pacific Ocean area are vulnerable to the onslaught of the great waves.

Some people call them “tidal waves", a name as misleading as it has been persistent. The great waves are not related to the tides. The Japanese, whose islands have felt their destructive power for generations, gave us the name used internationally: tsunami (pronounced " soo-nah’-me")

CHAPTER OBJECTIVES

1. Describe the tsunami waves.
2. Explain the origin of the phenomenon’s name.
3. Define the generation mechanisms.
4. Define transformations of a tsunami along its path from the origin area.
5. Describe tsunami effects on the coast.
6. Describe the Tsunami Warning System.

4.1 WHAT IS A TSUNAMI?

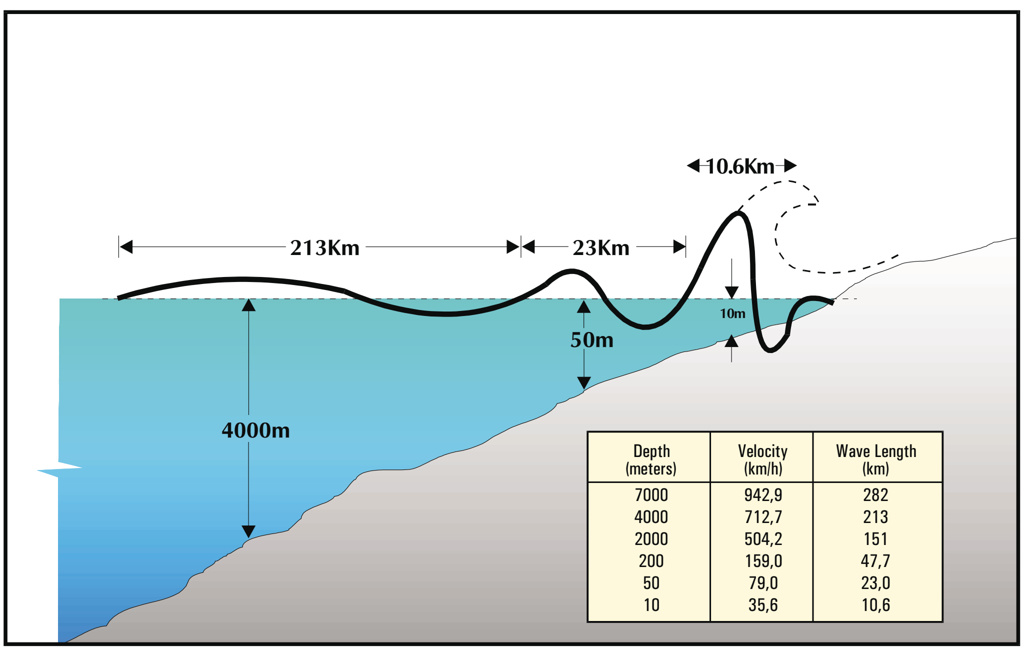
Unlike exaggerated or fictionalized accounts, a tsunami is NOT a single, monstrous wall of water that rises mysteriously out of nowhere to engulf a ship or a coastal community. It is, however, one of nature's most awesome forces - a series of sea waves capable of racing across an entire ocean at speeds up to 900 km per hour.

At sea, tsunami waves are less than 60 cm high - not even perceptible from ships or planes. By contrast, their length is often more than 160 km long, much greater than the water depth over which they travel.

There is no such thing as a typical tsunami. Each one is different. Still, tsunamis are collectively unique in the amount of energy they contain, even when compared to the most powerful, wind-driven waves.

A tsunami "feels the bottom" even in the deepest ocean, and it appears that the progress of this imperceptible series of waves represents the movement of the entire vertical section of ocean through which the tsunami passes.

As the tsunami enters the shoaling water of coastlines in its path, the velocity of its waves diminishes and the wave heights increases as seen in the diagram.



Depth (meters)	Velocity (km/h)	Wave Length (km)
7000	942,9	282
4000	712,7	213
2000	504,2	151
200	159,0	47,7
50	79,0	23,0
10	35,6	10,6

Tsunami wave modifications.

The arrival of a tsunami is often heralded by a gradual recession of coastal water, when the trough precedes the first crest; or by a rise in water level of about one-half the amplitude of the subsequent recession. This is nature's warning that more severe tsunami waves are approaching. It is a warning to be heeded, for tsunami waves can crest to heights of more than 30 meters, and strike with devastating force.

DO YOU KNOW ... ?

Tsunami is a Japanese word. You say it: soo-nah'-me. Break it in half: "tsu" means harbor and "nami" means wave.

Japanese scientists were the first to conduct specialized studies of tsunamis. Their eastern coast receives the most tsunami activity in the world, and that likely explains why the Japanese word is adopted internationally.

Other lesser used words for tsunami are:

- flutwellen (German)

- vloedgolven (Dutch)

- hai-i (Chinese)

- maremoto (Spanish)

- raz de maree (French)

- vagues sismiques (French)

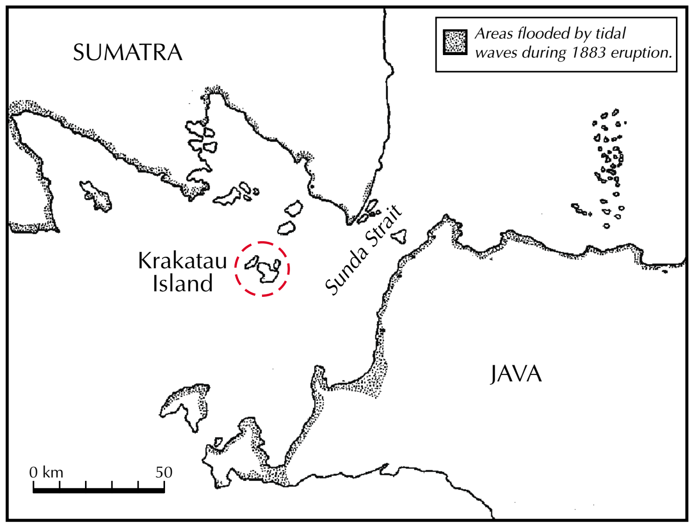
- tidal waves (English)

- seismic sea waves (English)

4.2 WHAT CAUSES A TSUNAMI?

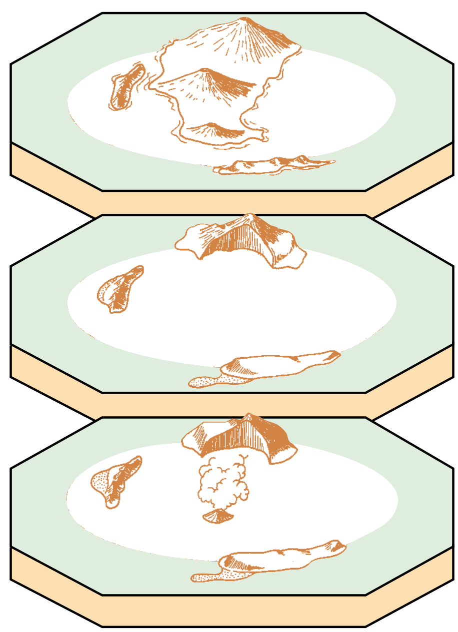
Natural disturbances, like earthquakes, volcanic eruptions and landslides, may cause tsunamis. Man-made disturbances, such as the underwater atomic explosions of 1946, can also set off the powerful waves, but the most frequent cause, by far, is the earthquake.

• VOLCANO-GENERATED TSUNAMI



Krakatau island place.

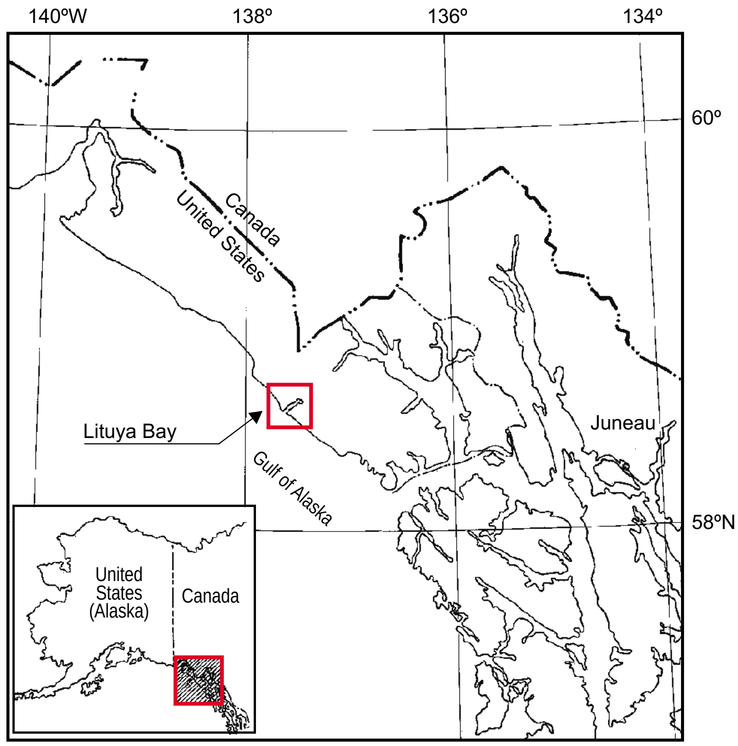
In 1883, a series of volcanic eruptions at Krakatau in Indonesia created a powerful tsunami. As it rushed towards the islands of Java and Sumatra, it sank more than 5,000 boats and washed away many small islands. Waves as high as a 12-story buildings wiped out nearly 300 villages and killed more than 36,000 people. Scientist believe that the seismic waves traveled two or three times around the Earth.



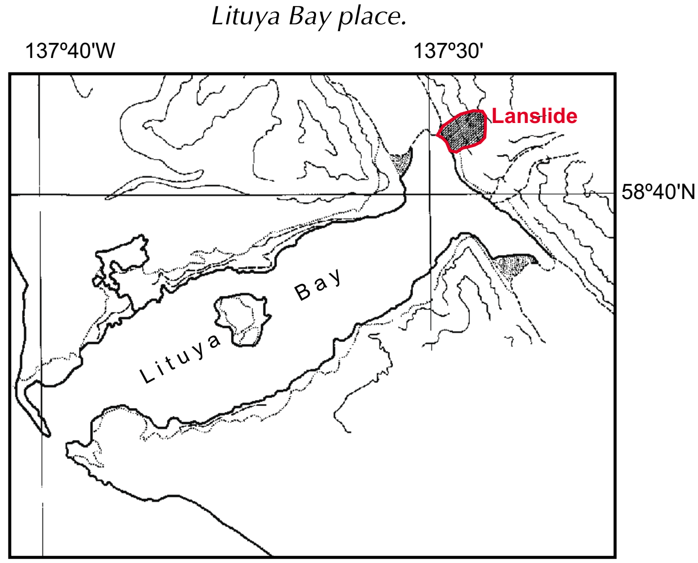
Krakatau island evolution during 1883 eruption.

• LANDSLIDE-GENERATED TSUNAMI

About 81 million tones of ice and rock crashed into Lituya Bay, Alaska in 1958. An earthquake had shaken the enormous mass loose. The landslide created a tsunami which sped across the bay. Waves splashed up to an astonishing height of 350 to 500 metres - the highest waves ever recorded. They scrubbed the mountain slope clean of all trees and shrubs. Miraculously, only two fishermen were killed.



Lituya Bay place.



Lituya bay.

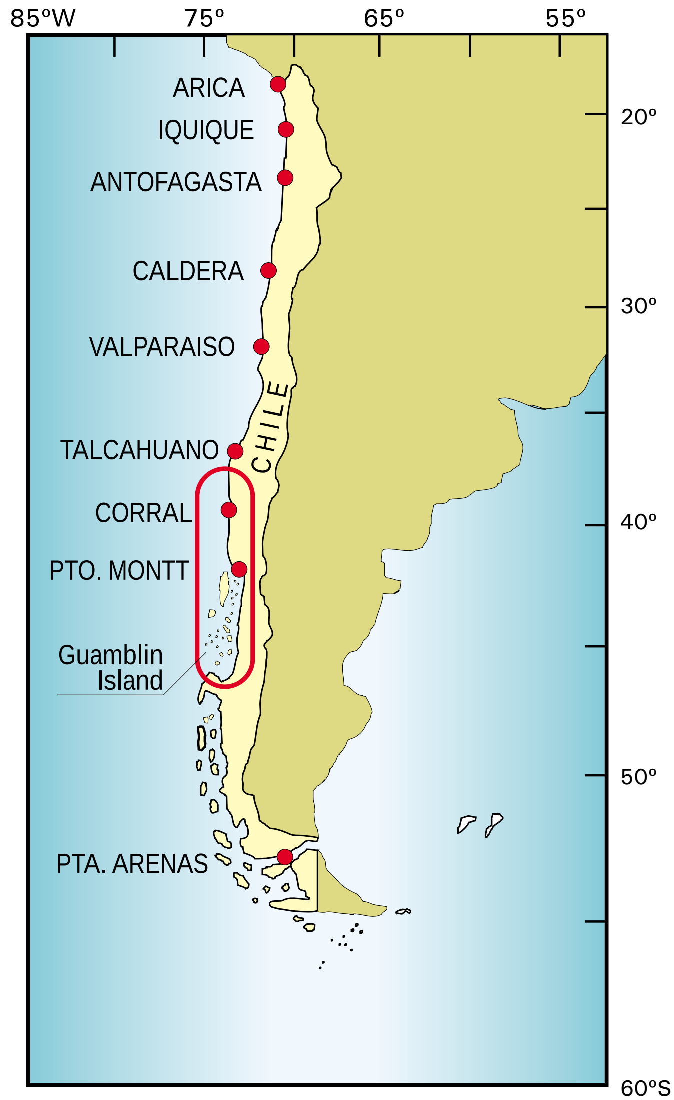
• EARTHQUAKE-GENERATED TSUNAMI

The most destructive tsunami in recent history was generated along Chile's coast by an earthquake in May 22, 1960.

It is not possible to describe in detail the damaged and death related to this tsunami along the coast of Chile, however, every coastal town between latitudes 36S and 44S was destroyed or severely damaged by the action of the tsunami and the earthquake.

In Chile, the double combination of earthquake and tsunami produced more than 2,000 deaths, 3,000 injured, two million homeless, and damage worth $550 million (US). The tsunami caused 61 deaths in Hawaii, 20 in the Philippines, 3 in Okinawa, and more than 100 in Japan.

Estimated damages were $50 million in Japan, $24 million in Hawaii, and$ 1million along the coast of the United States.

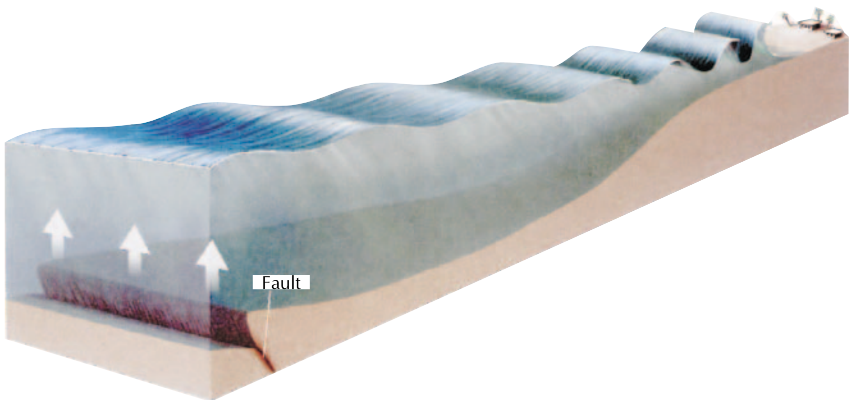


Area afected by the tsunami of may 22, 1960.

The height of the waves ranged from 13 meters at Pitcairn Islands, 12 meters at Hilo, Hawaii, and 7 meters at several places in Japan, to minor oscillations in other areas.

4.3 GENERATION OF TSUNAMIS

Current thinking is that tsunamis are generated by a sudden vertical motion along faults during major earthquakes, as seen in the diagram.



Tsunami generation by vertical movement of the ocean floor.

In the case of submarine earthquakes, the generation mechanism of the tsunami waves is as follows: when the earthquake occurs there is a noticeable displacement of the oceanic crust; a sudden upheaval or subsidence of the ocean floor may be produced; if this happens, the sea surface over the ocean floor deformation area will show a similar deformation, but while the ocean floor deformation is permanent, the sea surface deformation is not.

Although earthquakes that occur along horizontal faults sometimes generate tsunamis, they are local and generally do not propagate long distances. Some scientists pointed out that major earthquakes along horizontal faults near the coast of Alaska and British Columbia generated tsunamis that were observable at distances no greater than 100 km.

As already mentioned, tsunamis usually occur following a large shallow earthquake beneath the ocean. However, there are a number of instances where the earthquake (that produced the tsunami) occurred inland. Hence, one must deduce that tsunamis can be generated either by changes of sea bottom (i.e. faulting) or by the seismic surface waves passing across the shallow continental shelf. The long-period, surface waves (the so-called Rayleigh waves) have a vertical component and transmit a significant portion of the earthquake energy.

The return of the sea level to its normal position generates a series of waves propagating in all directions from the initially deformed area.

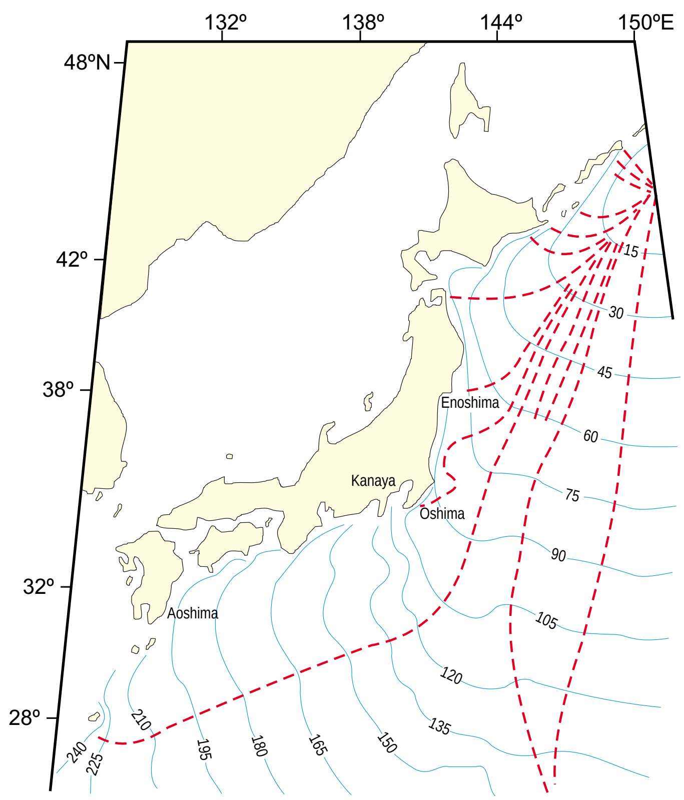
4.4 TSUNAMI PROPAGATION

The speed at which the tsunami travels depends on the water depth. If the water depth decreases, tsunami speed decreases. In the mid-Pacific, where the water depths reach 4.5 kilometers, tsunami speeds can be more than 900 kilometers per hour.

Some general concepts regarding refraction, and diffraction of water waves will be considered. These phenomena are important to the tsunami propagation problem.

WAVE REFRACTION. Consider progressive waves with wavelengths much larger than the water depths over which they propagate. These are called shallow-water or long waves. Because the waves are long, different parts of the wave might be over widely varying depths (especially in coastal areas) at a given instant.

As depth determines the velocity of long waves, different parts travel with different velocities, causing the waves to bend, and this is called wave refraction.



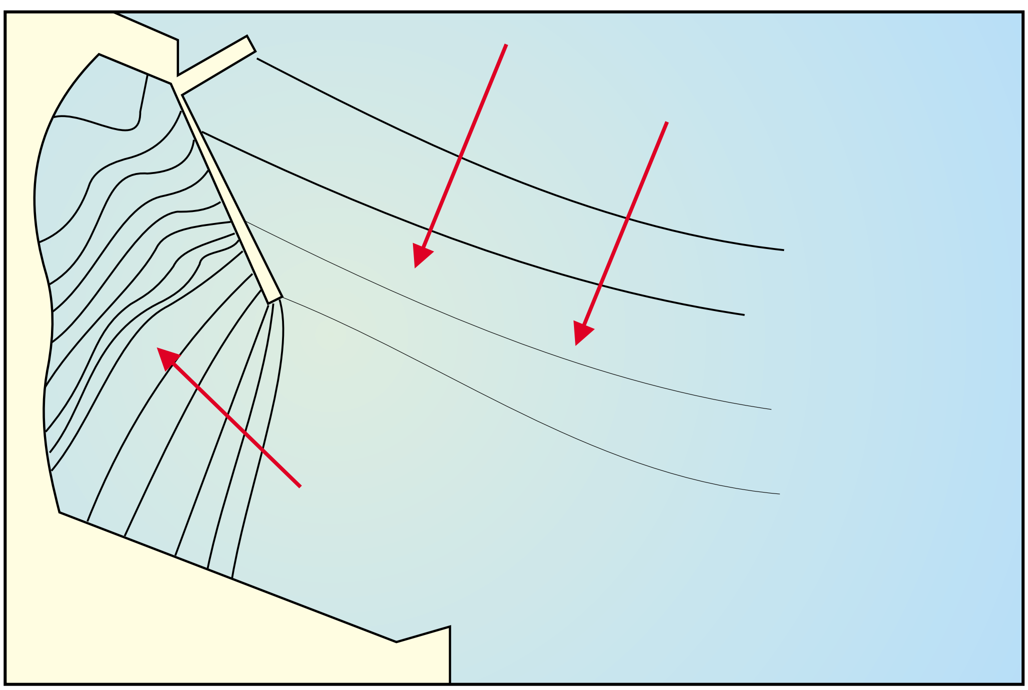
Examples of refraction of tsunami waves.

DIFFRACTION OF WATER WAVES. Diffraction is a well-known phenomenon, especially concerning optics and acoustics. This phenomenon can be considered as the bending of waves around objects. It is this kind of movement that allows waves to move past barriers into harbors as energy moves laterally along the crest of the wave as shown in the drawing below. This bending is on a much smaller scale and is less easily explained than the bending discussed in refraction which is a simple response to changes in velocity.

• DISTANTLY GENERATED TSUNAMIS

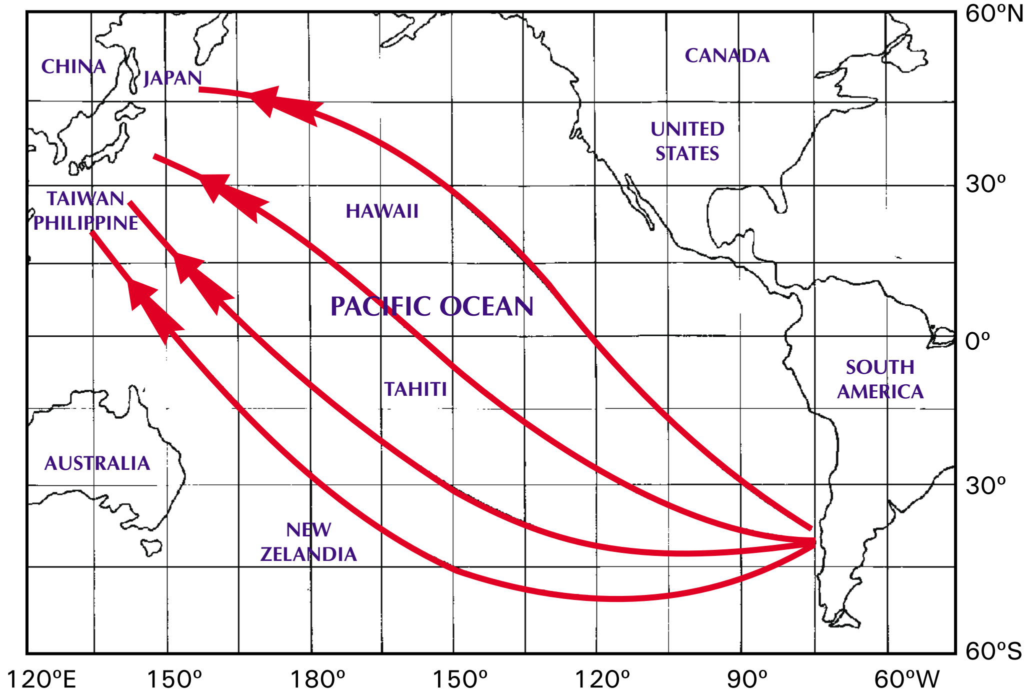
When a tsunami travels a long distance across the ocean, the sphericity of the Earth must be considered to determine the effects of the tsunami on a distant shoreline. Waves which diverge near their source will converge again at a point on the opposite side of the ocean. An example of this was the 1960 tsunami whose source was on the Chilean coastline, 39.5S., 74.5 W. The coast of japan lies between 30 and 45N. and about 135 to 140 E., a difference of 145 to 150 longitude from the source area. As a result of the convergence of unrefracted wave rays, the coast of japan suffered substantial damage and many deaths occurred. Next figure illustrates the convergence of the wave rays due to the Earth's sphericity.

Remember that besides the already mentioned effect, the rays of the tsunami waves are also deviated from their natural path along maximum circles, due to



Examples of difraction of waves.

refraction of the rays because of depth differences, to paths given by deeper places. The effect of this refraction over long distance generated tsunami waves is that not always the tsunami waves will converge on the other side of the ocean.

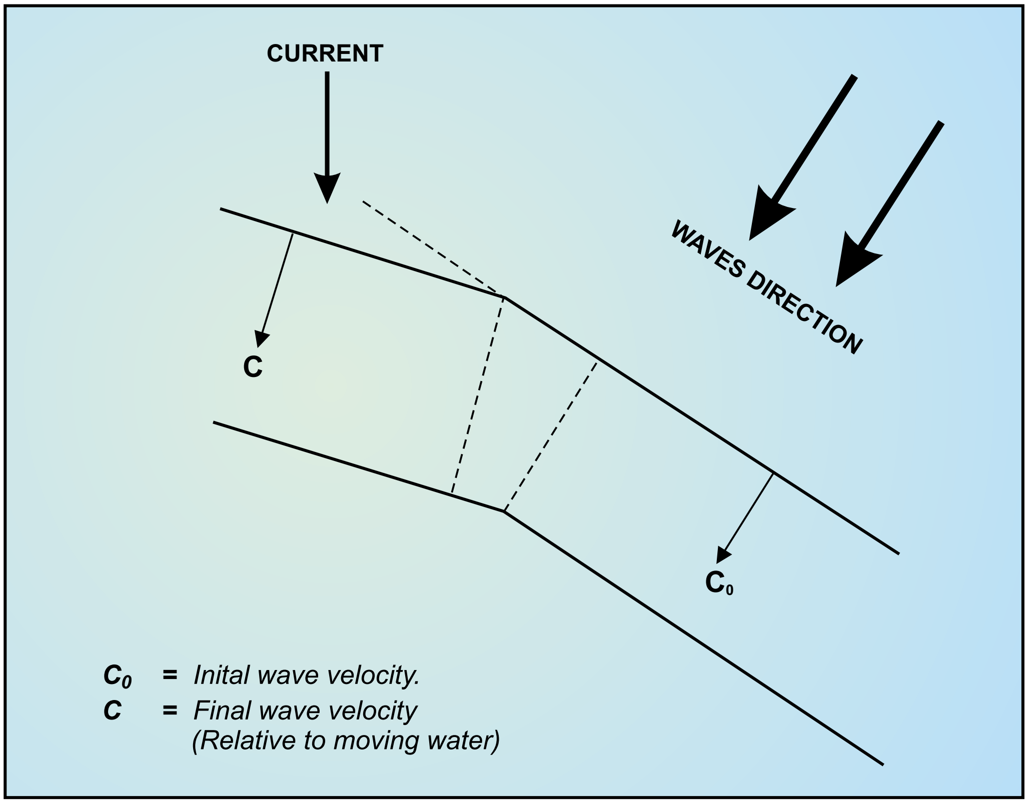


Convergence of tsunami wave rays generated by the 1960 Chilean earthquake.

There are other mechanism that cause refraction of water waves, even in deep water and without topographical irregularities. It has been shown that a current moving obliquely to the waves can change their direction of propagation and wavelength.

As a tsunami approaches a coastline, the waves are modified by the various offshore and coastal features. Submerged ridges and reefs, the continental shelf, headlands, the shapes of bays, and the steepness of the beach slope may modify the wave period and wave height, cause wave resonance, reflect wave energy, and/or cause the waves to form bores which surge onto the shoreline.

Ocean ridges provide very little protection to a coastline. While some amount of the energy in a tsunami might reflect from the ridge, the major part of the energy will be transmitted across the ridge and onto the coastline. The 1960 tsunami which orignated along the coast of Chile is an example of this. That tsunami had large wave heights along the entire coast of japan, including the islands of Shikoku and Kyushu which lie behind the South Honshu Ridge.



Refraction by current.

• LOCAL TSUNAMIS

When a locally generated tsunami occurs, it impacts coastal areas a very short time after the event which produced the tsunami (earthquake, submarine volcanic eruption or landslide). Lapses as short as two minutes have been observed between the earthquake's occurrence and the tsunami arrival to the closest shore.

Because of this, a tsunami warning system is useless in this type of event and we should not expect instructions from an established system to react and keep us safe from the possible tsunami impact. This operation incapability of the warning systems is further increased by the communications and systems collapse generated by the earthquake. Hence, it is necessary to prepared in advance a proper response plan in case of a tsunami.

4.5 COASTAL EFFECTS

Tsunami wave action over the shore is variable and mainly dependent of the combination of both submarine and land topography in the area and the orientation of the arriving waves.

• WAVE HEIGHT

The height of the waves is also affected by the shore itself. The funneling effect of a bay, for instance, increases the height of the waves. On the other hand, a shoal or sandbar offshore decreases the height. This explains the wide variation in tsunami heights that usually occur along a single coast.

• TSUNAMI RUNUP ON A SHORELINE

The arrival of a tsunami at a shoreline may cause an increase in water level of 30 meters or more in extreme cases. Increases of 10 meters are not uncommon. This vertical increase in the height of the water level is called the tsunami runup height.

The height of a tsunami will vary from point to point along a coastline. Variations in tsunami height and shoreline topography will actually cause some variation in runup characteristics along any section of coastline.

An example of how extreme this variation can be is given by some scientists; on the island of Kauai, Hawaii, where there was a gentle rise of water level on the western side of the bay, but less than one mile to the east, waves rushed onshore, flattening groves of trees and destroying houses.

It should be noted that the characteristics of the waves may vary from one wave to another at the same coastal point. Some scientists cite a case in Hawaii where the first waves came in so gently that a man was able to wade through chest-high water ahead of the rising water. Later waves were so violent that they destroyed houses and left a line of debris against trees 150 meters inland.

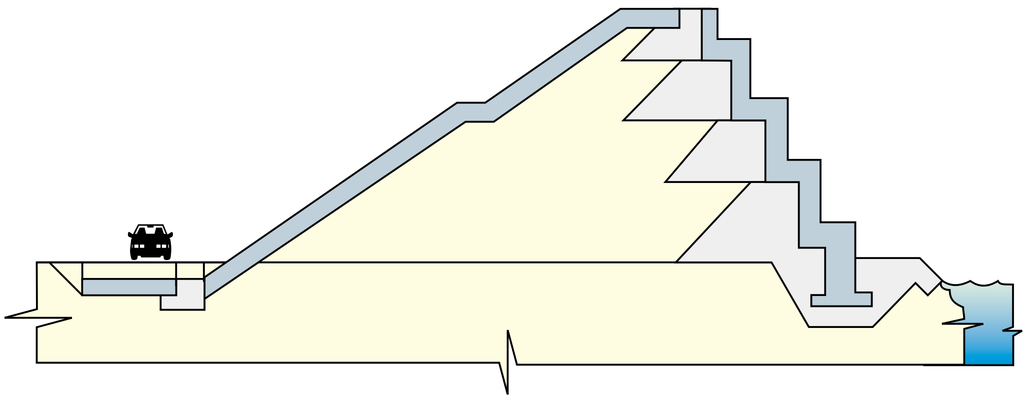
• TSUNAMI IMPACT

The destruction caused by tsunamis stems mainly from the impact of the waves, the flooding, and the erosion of foundations of buildings, bridges and roads. Damage is magnified by floating debris, boats, and cars that crash into buildings. Strong currents, sometimes associated with tsunamis, add to the destruction by freeing log booms, barges and boats at anchor.

Additional damage takes the form of fires from tsunami-related oil spills, and pollution from released sewage and chemicals.

4.6 PROTECTION FROM TSUNAMIS

It is impossible to fully protect any coast from the ravages of tsunamis. Countries have built breakwaters, dikes and various other structures to try to weaken the force of tsunamis afid to reduce their height. In Japan, engineers have built broad embankments to protect ports, and breakwaters to narrow harbor mouths in an effort to divert or reduce the energy of the powerful waves.



Type of breakwater designed as protection of low-lying coasts.

But no defense structures have been able to protect the low-lying coasts. In fact, barriers can even add to the destruction if a tsunami breaks through, hurtling chunks of cement about like missiles.

In some instances, trees may offer some protection against a tsunami surge. Groves of trees alone, or as supplements to shore protection structures, may dissipate tsunami energy and reduce surge heights.

4.7 THE TSUNAMI WARNING SYSTEM

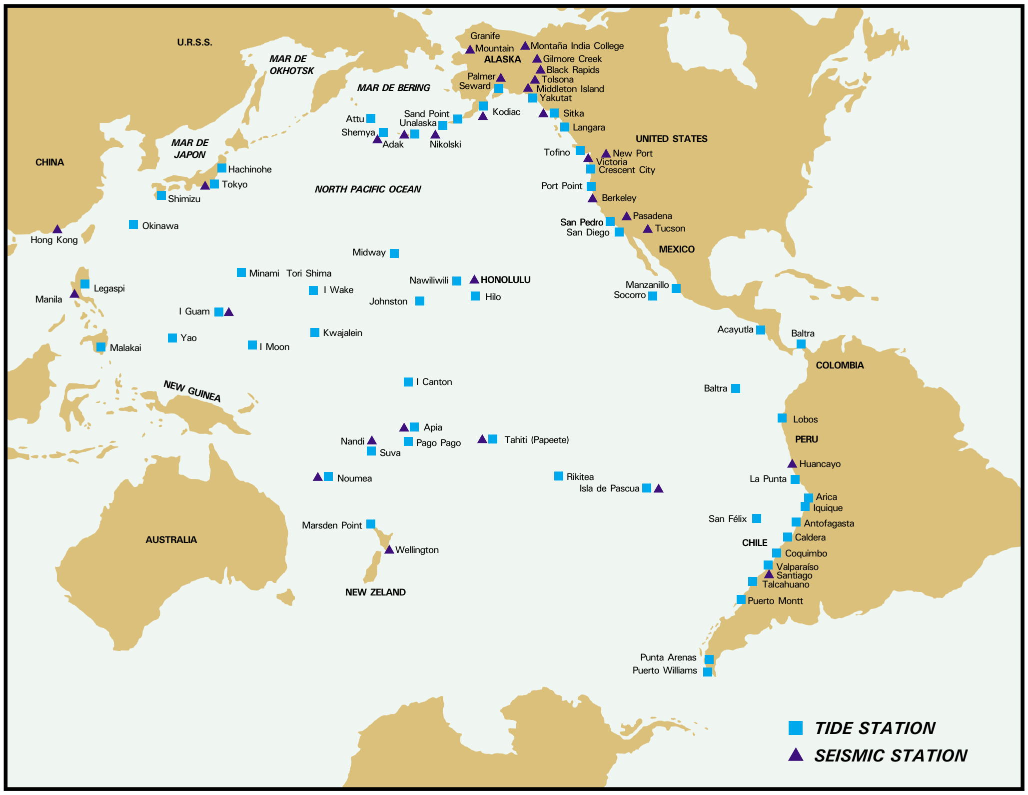
• OBJECTIVE

The operational objective of the Tsunami Warning System (TWS) in the Pacific is to detect and locate major earthquakes in the Pacific Region, to determine whether they have generated tsunamis, and to provide timely and effective tsunami information and warnings to the population of the Pacific to minimize the hazards of tsunamis - especially to human life and well being. To achieve this objective, the TWS continuously monitors the seismic activity and ocean surface level of the Pacific Basin.

• DESCRIPTION

The TWS is an international program requiring the participation of many seismic, tidal, communication, and dissemination facilities operated by most of the nations bordering the Pacific Ocean. Administratively, participating nations are organized under the Intergovernmental Oceanographic Commission as the International Coordination Group for the Tsunami Warning System in the Pacific (ICG/ITSU). The International Tsunami Information Center was established upon request of IOC and serves many roles in assisting ICC/ITSU member nations in mitigating the effects of tsunamis throughout the Pacific. The Pacific Tsunami Warning Center (PTWC serves as the operational center for the Tsunami Warning System of the Pacific.

PTWC collects and evaluates data provided by participant countries, and issues appropriate informational bulletins to all participants regarding the occurrence of a major earthquake and possible or confirmed tsunami generation.



Seismic and tide stations of the Tsunami Warning System of the Pacific.

• OPERATIONAL PROCEDURES

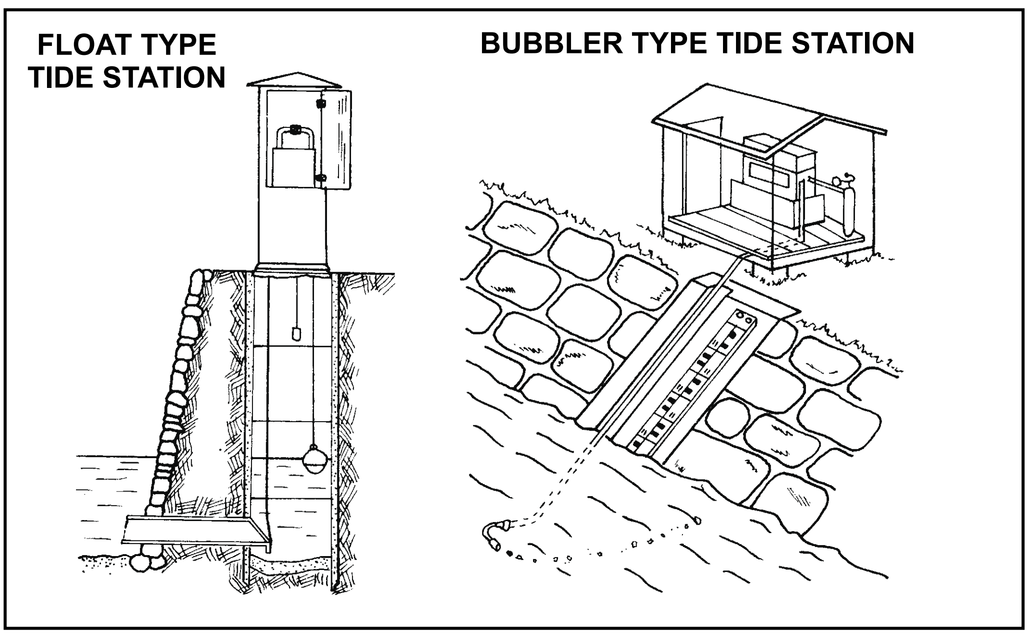
The functioning of the System begins with the detection, by any participating seismic observatory, of an earthquake of sufficient size to trigger the alarm attached to the seismograph at that station. Personnel at the station immediately interpret their seismograms and send their readings to PTWC. Upon receipt of a report from one of the participating seismic observatories or as a consequence of the triggering of their own seismic alarm, PTWC send messages requesting data to other observatories in the System.

When sufficient data have been received for PTWC to locate the earthquake and compute its magnitude, a decision is made concerning further action. If the earthquake is strong enough to cause a tsunami and is located in an area where tsunami generation is possible, PTWC will request participating tidal stations located near the epicenter to monitor their gauges for evidence of a tsunami.

Tsunami Warning/Watch Bulletins are issued to the dissemination agencies for earthquakes of magnitude 7.5 or greater (7.0 or greater in the Aleutian Island region), alerting them to the possibility that a tsunami has been generated and providing data that can be relayed to the public so that necessary preliminary precautions can be taken.

Reports received from tidal stations are evaluated; if they show that a tsunami has been generated that poses a threat to the population in part or all of the Pacific, the Tsunami Warning/Watch Bulletin is extended or upgraded to a Warning for the whole Pacific. The dissemination agencies then implement predetermined plans to evacuate people from endangered areas. If the tidal station reports indicate that either a negligible tsunami or no tsunami has been generated, PTWC issues a cancellation of its previously disseminated Tsunami Warning/Watch.

In some areas of the Pacific Basin national or regional tsunarni warning systems function to provide timely and effective tsunarni information and warnings to affected populations. For those coastal areas nearest the tsunami source region, the need for rapid data handling and communications becomes obvious. Because of the time spent in collecting seismic and tidal data, the warnings issued by PTWC cannot protect all areas in the Pacific against tsunamis generated in adjacent waters. To provide some measure of protection within the first hour after generation of a tsunami in the local area, national and regional warnings systems have been established by some countries. Regional systems provide the earliest possible alert to the population within the immediate vicinity of the earthquake epicenter by issuing immediate warnings based on earthquake information without waiting for tsunarni confirmation.



Tide Gauges.

To function effectively, these regional systems generally have data from a number of seismic and tidal stations telemetered to a central headquarter. Nearby earthquakes are located, usually in 15 minutes or less, and a warning based on seismological evidence is released to the population of the area. Since the warning is issued on the basis of seismic data alone, one may anticipate that warnings occasionally will be issued when tsunamis have not been generated. Since the warnings are issued only to a restricted area and confirmation of the existence or nonexistence of a tsunami is obtained rapidly, disruptions are minimized while a higher level of protection is obtained.

Among the most sophisticated of the national systems are, those of France, Japan, Russia, and the U.S.A. For the United States, PTWC and the Alaska Tsunami Warning Center (ATWC have responsibility as the U.S. National Tsunami Warning Centers to provide tsunami warning services for any tsunami impacting U.S. national interests. In addition, PTWC acts as the Hawaii Regional Tsunami Warning Center for tsunamis generated within the Hawaiian Islands.

A) REPORTS

TWO TSUNAMIS OUT OF THE PAST

(Extracted from DISCOVER/August 1983)

Probably the greatest tsunami of all time is shrouded in the myths of antiquity. It was born in about 1450 B.C., at the island of Thera, southeast of Greece. There, a brilliant royal city of the Minoan civilization flourished until one day the volcano on Thera exploded, blusting much of the island into the air. The resulting tsunami, some scholars have speculated, may have inspired the story of Moses' parting of the Red Sea, and the death of Thera may have been the factual basis for the fable of Atlantis related later by Plato.

A giant tsunami accompanied the catastrophic Lisbon earthquake of November 1, 1755. The quake was apprently centered in the ocean floor west of Lisbon. The waves and earthquake killed at least 60,000 people, many of whom were gathered in churches to worship on All Saint's Day. The tragedy evoked intense theological argument about the providence of God, prompted Rousseau to suggest that people would be better off out of doors, and provided a memorable episode in Voltaire's Candide.

• RIDING A TIDAL WAVE.

By U.S. Navyy Rear Admiral L.G. Billings
(Extracted from THE NATIONAL GEOGRAPHIC MAGAZINE, JANUARY 1915.)

It is the purpose of this article to record a thrilling experience in one of the modern earthquakes, in which a United States man-of-war was carried on the crest of a tidal wave 5 miles down the coast, 2 miles inland, and set down, entirely unharmed, upon the beach, within 100 feet of the Andes.

In 1868 I was attached to the U.S.S. "Wateree," then on duty in the South Pacific - one of a class of boats built at the close of our Civil War to ascend the narrow, tortuous rivers of the South; she was termed a "double tender," having a rudder at each end, and was quite flat-bottomed - a conformation which, while it did not add too her seaworthiness, enabled her to carry a large battery and crew, and eventually saved our lives, in the catastrophe which was soon to come upon us.

August, 1868, found us quietly at anchor off the pretty Peruvian (now Chilean) town of Arica, whiter we had towed the old United States store-ship "Fredonia" to escape the ravages of yellow fever, then desolating Callao and Lima. It was August 8, 1868, that the awful calamity came upon us, like a storm from a cloudless sky, overwhelming us all in one common ruin.

I was sitting in the cabin with our commanding officer, about 4 p.m., when we were startled by a violent trembling of the ship, similar to the effect produced by letting go the anchor. Knowing it could be that, we ran on deck. Looking shoreward, our attention was instantly arrested by a great cloud of dust rapidly approaching from the southeast, while a terrible rumbling grew in intensity, and before our astonished eyes the hills seemed to nod, and the ground swayed like the short, choppy waves of a troubled sea.

The cloud enveloped Arica. Instantly through its impenetrable veil arose cries for help, the crash of falling houses, and the thousand commingles noises of a great calamity, while the ship was shaken as if grasped by a giant hand; then the cloud passed on.

As the dust slowly settled we rubbed our eyes and looked again, believing they must be playing us a trick; for where but a few short moments before was a happy, prosperous city, busy with life and activity, we beheld but a mass of shattered ruins, hardly a house left standing; not one perfect; the streets blocked with debris, through which struggled frantically the least wounded of the unhappy wretches imprisoned in the ruins of their once happy homes; while groans, cries, and shrieks for help rent the air.

Over this horror the sun shone pitilessly from an unclouded sky; the sea rolled shoreward as steadily as before. How long did it last? No one took any note of time.

With the recollection in our minds of the tidal wave that followed the earthquake at Santa Cruz and stranded one of our proudest sloops-of-war, the "Monongahela", in the streets, we anxiously scanned the sea for any unusual appearance betokening the coming of that dreaded accompaniment; but all was as calm and serene as before.

Our prudent commander, however, gave the necessary orders to prepare for the worst. Additional anchors were let go, hatches pattened down, guns secured, life lines rove fore and aft, and for a few moments all was the orderly confusion of a well-disciplined man-of-war preparing for action. Many hands make short work, and in a few moments we were prepared for any emergency.

Looking shoreward again, we saw the uninjured thronging the beach and crowding the little pier, crying to the vessels to aid them in digging their loved ones from the ruins and to transport them to the apparent safety of the vessels riding so quietly at anchor. This was more than we could witness unmoved, and orders were given to prepare a landing party of 40 men, duly equipped with shovels, etc. The gig, a large, double-banked whaleboat, with a crew of 13 men shoved off at once. She reached the shore and landed her crew, leaving only the customary boat-keeper in charge.

Our attention was now distracted from the formation of our working party by a hoarse murmur. Looking shoreward, to our horror we saw vacancy where but a moment befores the pier had been black with a mass of humanity - all swallowed up in a moment. Amid the wreckage we saw the gig, bearing a single boat-keeper, borne by an irresistible tide toward the battlements from the front of the Morro, with the gallant seaman struggling to stem the current. Finding his efforts vain and certain death awaiting him, he laid in his useless oar, running aft to the coxswain's seat, grasped the boat flag and wave a last farewell to his shipmates as the boat dissapeared forever in the froth of the cruel rock at the foot of the Andes. Thus the "Wateree" lost the only one of her crew of 235 souls on that fatefull day.

But our troubles then commenced. We ere startled by a terrible noise on shore, as a tremendous roar of musketry, lasting several minutes. Again the trembling earth waved to and fro, and this time the sea receded until the shipping was left stranded, while as far seaward as our vision could reach, we saw the rocky bottom of the sea, never before exposed to human gaze, with struggling fish and monsters of the deep left high and dry. The round-bottomed ships keeled over on their beam ends, while the "Wateree" rested easily on her floor-like bottom; and when the returning sea, not like a wave, but rather like an enormous tide, came sweeping back, rolling our unfortunate companion ships over and over, leaving some boottom up and others masses of wreckage, the " Wateree" rose easily over the tossing waters, unharmed.

From this moment the sea seemed to defy the laws of nature. Currents ran in contrary directions, and we were borne here and there with a speed we could not have equaled had we been steaming for our lives. At irregular intervals the earthquakes shock recurred, but none of them so violent or long-continued as the first.

Facing the Morro, and a short distance away, a rocky islot rose some feet above the sea. On it the Peruvians had hewn a fort from the solid rock and had mounted herein two 15-inch guns, the garrison numbering some 100 souls. We were but a short distance from this fort and were fearing to be cast against its rocky sides, when suddenly we saw it dissapear beneath the waves. Whether it sank on the water rose we could not tell; we only knew it vanished; and when it reappeared, after a few moments, like a huge whale, not only were the unfortunate garrison gone, but the guns and carriages as well. Imagine, if you can, how the water lifted those inmense masses of iron, weighing many tons and offering no holding surface from their resting places and tumbled them out of the 8-foot parapet. It is a problem never to be solved.

Before the earthquake Arica had one of the best and most modern machine-shops between Callao and Valparaiso. Many of the machines were ponderous and properly secured on cement foundations. There were also several locomotives, cars, and many heavy castings. These all disappeared; not a vestige was left. It seems impossible they could have been swept out to sea, but assuredly they could not be found on shore.

It had now been dark for some time and we knew not where we were, the absence of the usual beacon and shore lights adding to our confusion. About 8.30 p.m. the lookout hailed the deck and reported a breaker approaching. Looking seaward, we saw, first, a thin line of phosphorescent light, which loomed higher until it seemed to touch the sky; its crest, crowned with the death light of phosphorescent glow, showing the sullen masses of water below. Heralded by the thundering roar of a thousand breakers combined, the dreaded tidal wave was upon us at last. Of all the horrors of this dreadful time, this seemed the worst. Chained to the spot, helpless to escape, with all the preparations made which human skill could suggest, we could but watch the monster wave approach without the sustaining help of action. That the ship could ride through the masses of water about to overwhelm us seemed imposiblle. We could only grip the life-line and wait the coming catastrophe.

With a crash our gallant ship was overwhelmed and buried deep beneath a semisolid mass of sand and water. For a breathless eternity we were submerged; then, groaning in every timber, the staunch old "Wateree" struggled again to the surface, with her gasping still clinging to the life-lines - some few seriously wounded, bruised, and battered, none killed; not even one missing. A miracle it seemed to us then, and as I look back through the years it seems doubly miraculous now.

Undoubtedly our safety was due to the design of the ship. The ship was swept on rapidly for a time, but after a while the motion ceased, and, lowering a lantern over the side, we found ourselves on shores, but where, we knew not. Smaller waves washed about us for a time, but presently they ceased. For some time we remained at quarters; but as the ship remained stationary, and nothing new occurring, the order was given too "Pipe down," followed by the welcome order, "All hands stand by your hammocks," and such of the crew as were not on watch quietly made their way through the reopened hatches to the sodden berth deck - to sleep.

The morning sun broke on a scene of desolation seldom witnessed. We found ourselves high and dry in a little cove, or rather indentation in the coast-line. We had been carried some 3 miles up the coast and nearly 2 miles inland. The wave had carried us over the sand dunes bordering the ocean, across a valley, and over the railroad track, leaving us at the foot of the seacoast range of the Andes. On the nearly perpendicular front of the mountain our navigator discovered the marks of the tidal wave, and, by measurements, found it to have been 47 feet high, not including the comb. Had the wave carried us 200 feet further, we would inevitably have beendashed to pieces against the mountain-side.

We found near us the wreck of a large English bark, the "Chanacelia," which had one of her anchor chains wound around her as many times as it would go, thus showing she had been rolled over and over; a little nearer the sea lay the Peruvian ship, the "America," on her bilges; and the sand was strewn with the most heterogeneous mass of plunder that ever gladdened the heart of a wrecker. Grand pianos, bales of silk, casks of brandy, furniture, clothing, hardware; everything imaginable was there.

The earthquake shocks continued at varying intervals, but none of them so violent or long-continued as at first; some of them, however, were severe enough to shake the "Wateree" until she rattled like an old kettle, and caused us to abandon the ship and camp on a considerable plateau, some 100 feet high, and overlooking the ship and wreckage. Here we had an opportunity of seeing the disastrous results of the earthquake on land. We found in some places inmerses fissures, many of them over 100 feet wide and of unknown depths; others were mere cracks. Some of them proved the graves of the fleeing inhabitants. In one instance, I remember, we found the body of a lady sitting on her horse, both swallowed up while fleeing for their lives. At Arica we found but desolation and death. Where once had stood that pretty little city, a flat, sandy plain streched before us.

B) CHAPTER SUMMARY

- A tsunami is a series of ocean waves of extremely long length and period, generated by disturbances associated with earthquakes occurring below or near the ocean floor.

- Other causes of tsunamis are submarine volcanic eruptions, landslides and man-made disturbances like underwater atomic explosions.

- The speed of the tsunami waves depends on the water's depth.

- The propagation of tsunami waves is subject to refraction and diffraction.

- Tsunami waves are further modified when approaching a coastline by submerged ridges and reefs, continental shelves, headlands, the shapes of bays, and the steepness of the beach slope.

- The height of a tsunami will vary from point to point along a coastline.

- The sphericity of the Earth causes convergence of the wave rays coming from a distantly generated tsunami.

- The destruction caused by tsunamis stems mainly from the impact of the waves, the flooding and the erosion of foundations of buildings, bridges and roads.

- The operational objective of the Tsunami Warning System in the Pacific is to detect and locate major earthquakes in the Pacific Region, and to determine whether they have generated tsunamis.

C) QUESTIONS/PROBLEMS

1 . Describe a tsunami.

2. Explain how a tsunami can be generated.

3. Explain the differences between a landslide-generated tsunami and an earthquake-generated tsunami.

4. Describe the modifications a tsunami wave can have when traveling from its source region.

5. Describe the Tsunami Warning System.

D) CHAPTER TEST

A. Vocabulary. Match the definition in Column I with the term it defines in Column II, on the left margin between the brackets.

	Column I	Column II
( )	1. bending of the ocean waves	a. volcano-generated tsunami
( )	2. vertical distance between sea-level and flooded height	b. diffraction
( )	3. long-period surface waves	c. refraction
( )	4. tsunami produced by a submarine volcanic eruption	d. run-up
		e. Rayleigh waves
( )	5. bending of waves behind a breakwater	f. flooding

B. Multiple Choice

Choose and mark the letter that best completes the statements or answers the question.

1. A tsunami is:

   a) a sound wave
   b) a wind driven wave
   c) a single mountrous wall of water
   d) several long waves in the ocean

2. The word tsunami means:

   a) sea waves
   b) waves in a harbor
   c) sea tremor
   d) shallow waves

3. A tsunami can be caused by:

   I) big magnitude earthquake
   II) submarine volcanic eruption
   III) landslide close to shore
   IV) atomic explosion

   a) only I and III are correct
   b) only II and IV are correct
   c) I, II, III are correct
   d) all are correct

4. Tsunamis are generally produce at:

   a) mid-oceanic ridges
   b) colliding plates
   c) hot spots
   d) shield volcanoes

5. Tsunami waves are modified by:

   a) barometric pressure
   b) sea water temperature
   c) refraction
   d) hydrodynamic forces

6. Diffraction of waves is:

   a) an optical and acoustic phenomenon
   b) a change in the wave period
   c) the return of the sea level to its normal position
   d) a sea-bottom deformation

7. Good protection from tsunami impact comes from:

   a) an ocean ridge
   b) barriers
   c) groves of trees
   d) none of the above

8. The Tsunami Warning System issues a Tsunami Warning in case of:

   a) a big earthquake
   b) generation of a tsunami
   c) reports from news media
   d) a hurricane