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TSUAMI: WHAT IS IT?

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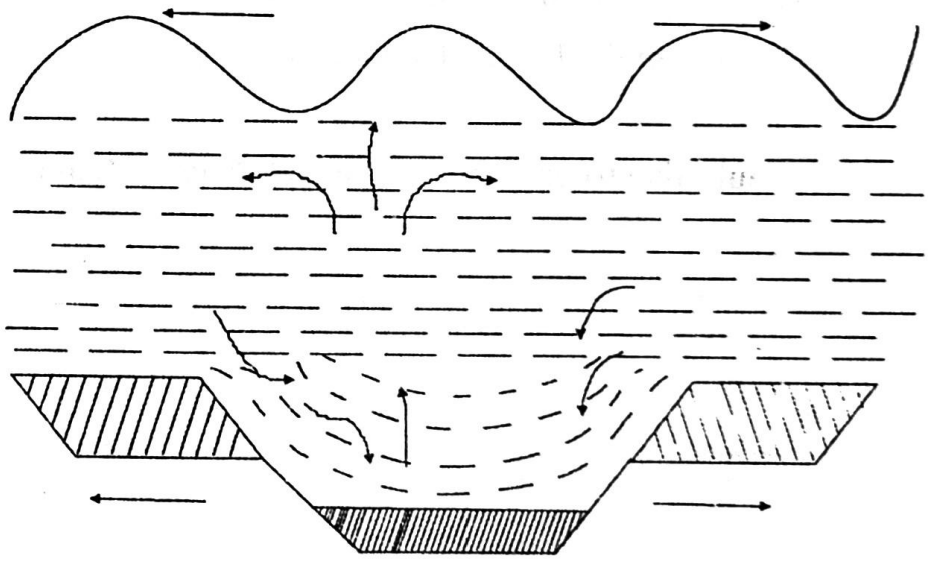
I. Tsunami: An Effect of Earthquake

An important secondary effect of a major earthquake is the seismic sea wave or tsunami as known to the Japanese.

An earthquake below the sea floor generates seismic sea waves or tsunamis. They often have catastrophic consequences such as devastation of the coastal regions. They are usually caused by earthquakes below the sea floor submarine landslides or volcanic explosions. The diagram of generation of tsunamis is given below.



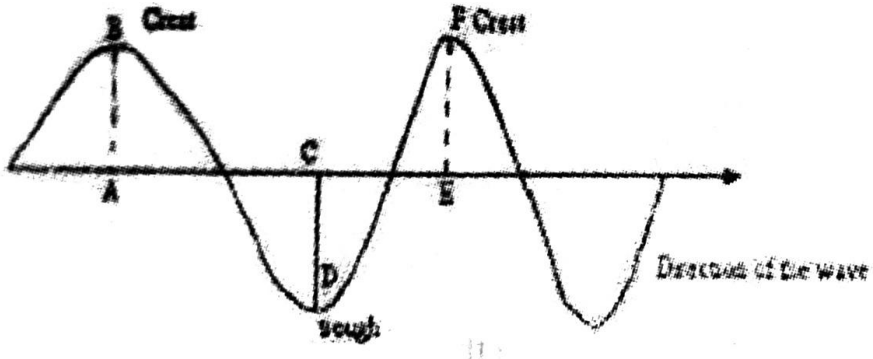
During an earth quake there is sudden subsidence or upheaval of the sea floor due to displacement of blocks. Accordingly all the water at

the epicentre of the earthquake is lifted or dropped for an instant giving rise to sea waves, several hundred-kilometers long but only few meters high in the open sea. These sea waves move at a speed of 750-800km/hr. inside the sea. Even though the speed of waves slow down drastically as they move through shallow coastal water, the height of the waves rise to 30 or 40 meters on approaching the coast. These very large and fast waves hit the shore. But because of their extremely long wavelength they do not withdraw quickly as the normal waves do. This long duration and great height cause great damage to the entire coast and many deaths by drowning low-lying coastal areas. It is thought that coastal flooding which occurred in Japan in 1703 with an estimated loss of life of 1, 00,000 persons may have been caused by seismic sea waves or tsunami.

Tsunamis are very rare in the Indian Ocean. Most tsunamis, nearly 86%, occur in the Pacific Ocean triggered off by the under-sea-earthquakes around the Pacific rim by forming subduction due to the collision of tectonic plates. During the 1990's 82 tsunamis were reported worldwide, which is much higher than worldwide average of 57 tsunamis in a decade.

Tsunamis from Sumatra coast in Indonesia affected the countries in the Indian Ocean region including India, Srilanka and Thailand and claimed more lives than the last 16 tsunamis put together.

Here I would like to present a wave and its important parts.



λ - The wavelength of a wave, i.e. the distance between two consecutive crests.

c - Velocity of the wave

n -Frequency of the wave

Then $c = n \lambda$

AB, CD and EF are the amplitude of the wave.

Tsunami has nothing in common with normal wind-driven sea waves. Breezes flowing across the ocean cause waves of short wavelength on the surface of the sea. These wave currents are mainly confined to a shallow oceanic layer beneath which there is relatively calm water. Strong winds may be able to generate 30-metre waves in the open ocean. But even these do not move the deep waters. Tides occur allover the earth twice a day. They produce wave currents which reach bottom of the ocean just as tsunamis do but these too are shorter wavelengths when compared to the tsunamis.

Tsunamis are not generated by the gravitational pull of the moon or sun: Tsunamis are produced by (i) under sea earthquake, (ii) volcanic eruptions (iii) meteorite impacts (iv) underwater landslides. They set off waves with long wavelength in water. Most of the destructive tsunamis are caused by subduction zone earthquake.

Subduction zone is where two of the earth's rigid tectonic plates are moving towards one another and one plate composed of heavier oceanic material, dives beneath the other lighter plate of continent material. At the boundary of the two plates they rub against each other the lower one drags and flexes the top one slightly downward. When there is excessive frictional force between the two plates the upper plate rebounds its original position causing sea floor displacement. This happens so quickly that the sea surface is assumed to sea floor displacements. .

The potential energy of displacement is converted into kinetic energy of horizontal motion. This disturbance propagates outward as tsunami and the wave height will be just 2 metres. Unlike a tidal wave, a tsunami extends deep down into the ocean water. That is, tsunami crest is just the tip of a very vast watering motion. Within several minutes of the earthquake the initial tsunami will be split into two parts. One part is called distant tsunami that travels out the deep ocean. Another called local tsunami that travels towards the nearby coast. The speed at which both tsunamis travel varies according to the square root of the water depth. Therefore deep ocean tsunamis travel faster than local tsunamis. In the deep ocean this wave at the speed of 500-1000km/hr, is so gentle that even ships travel atop a tsunami with great velocity and with little loss of energy. The 1990 Chilean tsunami had enough force to travel for 22 hrs across thousands of kilometers to kill the people in Japan.

While both the tsunamis local and distant approach the shallow coastal waters, the wavelength decreases and amplitude increases several fold. As the waves hit the slope of the coastal line the long waves pile on one another and the wavelength is reduced while the amplitude increases. As the waves travel in the near shore region, a tsunami run-up occurs. Run-up is the height of water observed on shore above mean sea level.

After run-up part of the tsunami energy is reflected back on the open ocean. In addition tsunami can generate a particular type of waves called edge waves which travel back and forth parallel to the shore. The geometry of the sea floor warping near the coast has a significant influence on this. These effects result in repetitive arrivals of tsunami waves at particular points on the coast. Because of the complicated behaviour of the phenomenon of the waves near the coast, the first run up of a tsunami is often not the largest. In certain cases, the sea may seem to withdraw. Within minutes a wall of water may inundate the coast!

II The December 26 Earth Quake and the Consequent Tsunami

At 06.28 hours 1ST on the morning of December 26, 2004 an earthquake with focus at a depth of 10 km and magnitude of 9 on the Richter scale occurred with the epicentre located at 3.298 on 95.779°E off Sumatra, Indonesia. The earthquake's epicentre the was located at 257 km south - south East of Banda Aceh, Sumatra, Indonesia, 990 km SSE of Port Blair, South Andaman sea, India, 1806 km ESE of Colombo, Srilanka, and 2028 km SEE of Chennai, India. Thereafter 11 earthquakes were recorded between 06.28 and 09.51 hours – four earthquakes in Sumatra region including the first killer earth quake and four in Andaman Islands and three in Nicobar Island. Most of the earth quakes in Andaman and Nicobar Islands had a magnitude of 6 Richter scale; the one that occurred at 9.51 hrs in the Nicobar Islands had a magnitude of 7.3 Richter scale.

1. Cause of Sumatra Earthquake

As regards the cause of the Sumatra earthquakes, we are indebted to the US geological survey which has furnished the following earthquake report immediately after the earthquake.

The devastating mega thrust earthquake of December 26, 2004 occurred on the interface of the India and Burma plates, caused by the release of stresses that develop as the India plate subducts beneath the overriding Burma plate. The India plate beginning its descent into the mantle at the Sunda trench lies to the west of the earthquake epicentre. The trench is the surface expression of the plate interface between the Australia and India plate, situated to the south west of trench and the Burma and Sunda plate situated to north east.

In the region of the earthquake, the India plate moves toward the northeast at a rate of about 6, cm per year relative to the Burma plate. This results in oblique convergence at the Sunda trench. The oblique

motion is partitioned into thrust faulting which occurs on the plate interface and which involves slip directed perpendicular to the trench and strike slip faulting, which occurs several hundred kilometers to the east of the trench and involves slip directed parallel to the trench. The December 26 earthquake occurred as the result of thrust faulting.

Preliminary locations of larger aftershocks following the mega thrust earthquake show that approximately one thousand two Hundred kilometers of the plate boundary slipped as a result of true earth quake. By comparison with other large mega thrust earthquakes, the width of the causative fault rupture was likely over one hundred kilometers. From the size of the earthquake, it is likely that the average displacement on the fault plate was about 15 metres. The sea floor overlying the thrust fault would have been uplifted by several metres as a result of the earth quake. The above estimates of the fault dimensions and displacement could be refined in the future as the result of detailed analysis of the result of earthquake waves.

The world's largest recorded earthquakes have been all mega thrust events. These includes:

(i) The magnitude 9.5 Richter 1960 Chilean earth quake

(ii) The magnitude 9.2 Richter 1964 Alaska earthquake.

(iii) The magnitude 9.1 Richter 1957 Alaska earthquake.

(iv) The magnitude 9.0 Richter 1952 Kamchatka earthquake.

There was widespread damage and loss of property and human lives as the tsunami generated by the Sumatra earthquake, hit the Andaman and Nicobar group of Islands and later hit the east coast of India. It is estimated that more than 2,00,000 people including 20,000 of the east coast of India have been killed by the Tsunami.

2. List of Large Tsunamis in the Historical Past.

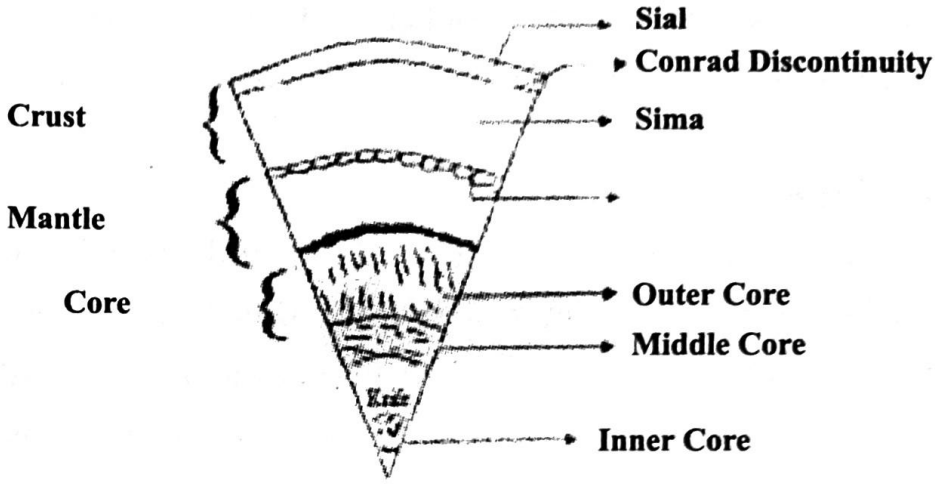
1.	November, 1775	The Great Lisbon earthquake generated a wave up to 20 feet high that struck coastal Portugal, Spain and Morocco.
2.	August 27, 1883	The eruption of the volcano krakatau generated a massive wave that swept over the shores of nearby Java and Sumatra killing 36,000 people.
3.	June 15,1896	The Sanriku tsunami struck Japan without warning. A wave estimated 75 feet high hit a crowd gathered to celebrate a religious festival killing more than 26,000 people.
4.	December 17, 1896	Tsunami washed away part of the embankment and main boulevard of Santa Barbara, California.
5.	January 13 1906	A devastating off shore quake submerged part of Tumaco, Colombia, and washed away all the houses, on the coast between Rioverde Ecuador and Micay, Colombia with the death toll estimated between 500 to 1500.
6.	April I, 1946	Alaskan quake generated a tsunami that destroyed North cape light house killing 5. Hours later the waves arrived, at Hilo, Hawai, killing 159 people and causing millions of dollars in damage.
7.	May 22, 1960	A wave reported 32 feet high killed 1000 in Chile and caused damages in Hawai including 61 deaths. It also caused damages in the Philippines, Okinawai and Japan as it swept across the Pacific.

8.	March 29, 1964	Good Friday earthquake in Alaska sent out a wave swamping much of the Alaskan coast and destroyed 3 villages. The wave killed 107 people in Alaska, 4 in Oregon and 11 in California as it swept through the west coast.
9.	August 16, 1976	Tsunami killed more than 5000 people in the Morogulf region of the Philippines.
10.	May 17, 1998	An off shore quake, triggered a wave that struck the north coast of Papua New guniea killing some 2000 people and leaving thousands homeless.

3. Tsunamis on the Coast Lines of India

	Date	Remarks
1.	Between 1st April and 9th May, 1008	Tsunami on the Iranian coast from local earthquake
2.	August 27, 1883	Krakatoa 1.5m tsunami at Madras.
3.	1884	Earthquake in the western part of the Bay of Bengal. Tsunamis at Port Blair.
4.	June 26, 1941	8.1 Richter quake in the Andaman sea at 12.9° North, 92.5° East. Tsunami in the east coast of India with amplitudes from 0.75 to 1.5m.
5.	November 27, 1945	8.2 Richter quake 70 km south of Karachi at 24.5° N 63.0° E. Tsunami amplitude at Kutch was 11.02 to 11.5m

III. Internal Structure of Earth



On the seismic investigation the earth's interior is broadly divided into 3 major parts. They are

i) The Crust
ii) The Mantle
iii) The Core

1. The Crust

It is the uppermost shell of the earth that covers the rocks of the interior thinly. There are two types of areas on the surface of the crust. They are the oceanic areas and the continental areas. The thickness over the oceanic areas is generally 5 – 10 kilometres whereas the continental area is about 35 kms. The overall thickness ranges from 55 to 70 kms in orogenic belts.

At its lower boundary there is a discontinuity called the Mohorovicic discontinuity. The crust can be divided in 2 layers. The upper layer is called sial and lower one is sima. The boundary between sial and sima is called Conrad discontinuity. The sial layer is rich in silica and aluminium. It consists of all types of rocks: igneous, sedimentary and metamorphic. The thickness of sial layer is 11 kilometres.

Sima layer is rich in silica and magnesium and basaltic in composition. It's thickness is 22 kms. A change from continental to oceanic crust, takes place at the peripheries of the major continents where there are marginal seas and islands.

2. The Mantle

The second major part of the earth is mantle, which is the source region of most of earth's internal energy and of forces responsible for ocean floor spreading continental drift, orogeny and major earth quakes. The thickness of mantle portion of the earth is about 2865 kms. It forms 83% of the earth volume and 68% by mass.

The upper mantle is consists of two layers, which are distinguished on the basis of velocity of propagation of seismic waves. The upper layer of the upper mantle lying between mohorovicic discontinuity and a boundary at a depth of 410 km is characterized by a decrease in the seismic velocity. This layer is called Gutenberg layer. The crust and the upper part of the Gutenberg layer together constitute Lithosphere. Below this is Asthenosphere, which is a layer with no strength and with low seismic velocity. Lithosphere is separated from the rest of the mantle by Asthenosphere. Lithosphere is used for the crust and the upper part of mantle. Lithosphere is elastically very strong. The thickness of Lithosphere is 50 to 100 kms. The Lithosphere consists of 95% igneous rocks, 4% shale, 0.75% sandstone and 0.25% Limestone.

The rigid Lithosphere is capable of moving over the Asthenosphere. Lithosphere is disjointed into large segments or blocks extensively by faults of thrusts. These blocks are known as Lithosphere plates, which are in motion relative to each other. The total thickness of the mantle portion of the earth is 2900 kms.

3. The Core

Beneath the mantle lies the earth's core, a sphere with a radius of 3475 kms.The pressure and the temperature of the core are both very

high. The pressure is assumed to be over three million atmosphere. The temperature of the core is around 6000°c. The density varies from I0.6x10³ kg/m³ in the outer core to 13x10³kg/m³ in the inner core of the earth. The core consists of three parts.

i) Outer core
ii) Middle core and
iii) Inner- core

i; Outer Core

It extends from 2900 kms to 4982 kms. It is considered to be in a state of homogeneous fluid. It does not transmit secondary waves (transverse waves)

ii) Middle Core

It is a transition layer that extends from 4982 kms to 5121 kms. The material is in a fluid to semifluid state.

iii) Inner Core

It extends from 512 kms up to the centre of the earth i.e., 637 kms. The inner core is assumed to be in a solid state, with a density of 13xl03 kg/m³. It is believed to contain metallic nickel and iron, which is called Nife. Its thickness is about 125 kms.

The recent discovery about the earth as published in the *Times of India*, 9-6-1988 reads as follows: "Scientists have now found that the supposedly smooth hot ball of iron at the earth's core is not smooth but have vast mountain range sized bumps and valleys with upside down lakes of molten rocks between them".

4. Tectonic Movements

The process that involves the breaking and bending of the earth's crust under internal earth forces is known as tectonic movement. Rocks do not always behave in the way as they do at the surface.

5. Earthquake

An earthquake is a sudden and temporary vibration set-up on earth's surface, ranging from a faint tremor to a wild motion due to the sudden release of energy stored in the rocks beneath the surface. Earthquake is a form of energy of wave motion, which originates in a limited region, then spreads out in all directions from the source of disturbance.

Earthquakes usually last for a few seconds to minutes. Sometimes the vibrations are so feeble that we cannot feel them whereas the violent earthquakes result in huge loss of human life and property.

The point within the earth where earthquake waves originate is called the focus and from the focus the vibrations spread in all directions. First they reach the surface at the point immediately above the focus and this point is called the epicentre. It is at the epicentre the shock of the earthquake is first experienced. It is, however, evident, that no earthquake can possibly originate at a mere point alone. Earthquakes occur beneath the surface of the earth, where the rocks yield suddenly, of course, after prolonged build-up of stresses. They are often associated with fault-lines, which provide a zone of fracture and earthquake energies at various depths, which may be anywhere in the crust or as far as 700 km down into the mantle.

Due to the sudden yielding of rocks to stresses, waves of energy are sent out through the earth. These waves of energy are called seismic waves. The seismic waves emerge in the form of an earthquake and radiate outward like ripples produced when a stone is thrown into a pool of water, gradually losing energy.

6. Some Important Earthquakes in India

1. Kutch earthquake of 16 June, 1819
2. Bengal and Kashmir earthquake of 1885

3. Assam earthquakes of 1897, 1935, 1988 (6 August 1988)
4. Kangra earthquakes of 1905, 1975, 1987
5. Bihar earthquakes of 15 January 1934, 21 August 1988
6. Koyna earthquake of 11 December 1967

7. Earthquakes and Worldwide Damages

No	Date	Damages
1.	1920	Kansur (China) and Tokyo earthquake in which 1,80,000 people died.
2.	1923	Kansur (China) and Tokyo earthquake in which 143,000 people died.
3.	11 Oct 1737	The world's worst earthquake claimed 300,000 lives.
4.	1970	In Peru 67,000 people died due to earthquake.
5.	1976	Tangshan (China) earthquake in which 700,000 people died.
6.	1980	In Chile earthquake 20,000 people died
7.	1985	In Mexico earthquake 7,000 people died.
8.	March 1987	4000 people died in series of earthquakes in Equator.
9.	1950	In Assam, on the Independence day, earthquake killed 1530 people.

8. Plate Tectonics

According to the American scientists Hess and Dietz, the concept of plate tectonics involves the worldwide network of moving lithospheric plates. The main ideas underlying the hypothesis of plate tectonics are the outcome of the study of the structure of the oceans floor and the discovery of zones in the formation of young oceanic crust on mid oceanic ridges and zones of the absorption crust in structures. The total system of plate motion is commonly referred to as plate tectonics. Plate is a large rigid slab of rock which moves slowly through the Asthenosphere. The thickness of the plates is from 0 to 10 km at the ridge and 100 to 150 kms

elsewhere. Plates are of continental dimensions. Geological scientists believe that the earth is composed of 20 lithospheric plates.

Some scientists believe that the earth is composed of six major plates and small plates were incorporated into these six.

These major plates are as given below.

i) The Pacific Plate
ii) The American Plate
iii) The African Plate
iv) The Eurasian plate
v) The Indian plate
vi) The Antarctic plate

The plates are continuously in motion with respect to each other. Each plate is capable of moving independently of the surrounding plates. Each plate may contain continental as well as oceanic surface. Only the Pacific plate is made up of wholly oceanic sea floor. These plates are small and large separated by faults and thrusts, lying mostly across ridges or parallel to borders (trenches). Plates move with velocity ranging from I to 6 cm. per year. They move away from one another or past one another or towards one another.

Where two plates converge and one is thrust beneath the other, we find the Island arcs. Where two plates slide past each other there occurs transcurrent faults i.e., the large strike-slip faults, joining segments of ocean ridges or arcs. Plate boundary is the surface trace of the zone of motion between two plates. Plate margin is the marginal part of a particular plate. Two plate margins meet at a common plate boundary where three plate boundaries meet. It is termed as a triple junction.

The plate tectonic theory explains number of geological phenomena quite convincingly and it is considered to be a revolution in earth science.

Some Important Facts about the Earth

1. Shape of the earth is that of a spheroid.
2. Its equatorial radius is 6378.3 km.
3. Its polar radius is 6356.9 km.
4. Mean radius of the Earth is 6371.2 km.
5. Mass of the earth is 5.97x1024 kg.
6. Volume of the earth is 1.08x1027 CC.
7. Average density is 5.5 gm/CC.
8. Average density of surface rocks is 2.8 gm/CC.
9. Age of the earth is 4.5 billion years.
10. Total area of the earth surface is 510.08 million square kilometers.
11. Total land surface is 148.63 million square kilometers.
12. Total water surface is 361.45 million square kilometers.
13. The earth completes one full rotation around its axis in 23 hrs 56 minutes.
14. The earth completes the full revolution around the sun in 365.28 days.
15. Rotation velocity at equator is 465 m/sec.
16. Mean velocity in its orbit about the sun 29.78 km/sec.
17. 3.5 billion years ago the first life originated on the earth.
18. Human evolution took place around 1.5 billion years ago.