Earthquakes as driving mechanism behind tsunamis

Introduction

Around Christmas 2004 two big earthquakes occurred in the Indian Ocean but with very different impacts on society. The earthquake from December 26 west of Sumatra, with a magnitude of 9.0, caused a devastating tsunami resulting in many death people all around the Indian Ocean till as far as Africa. Three days earlier an earthquake occurred 400 km south of New Zealand with a magnitude of 8.2. No tsunami is reported originating from this earthquake. What is the driving mechanism behind earthquakes that sometimes causes a tsunami but most of the time not the slightest elevation of the sea level?

Tectonic processes

To understand why one earthquake is causing a tsunami where others are not we have to understand the driving mechanism behind earthquakes (Figure 1). This driving mechanism is initiated deep down in the Earth where a source of heat is inducing convective currents between 100 and 2900 km depth. These currents have such enormous strength that they can break up the rigid and hard crust of the Earth, the top 50-100 km on which we are living. At ridges these floating plates of crust will move away from each other and new crust will be formed, at trenches two plates might collide or slide along each other (Figure 1).

These variations allow for a separation into three different types of plate boundaries: transform faulting, and divergent and convergent plate boundaries (Figure 2). Mainly at convergent boundaries earthquakes occur that might cause tsunamis like the Sumatra earthquake. The New Zealand earthquake was of the transform type and therefore did not cause a tsunami although the magnitude of the earthquake was almost as large as the Sumatra earthquake.

Earthquake characteristics

So the earthquake in Sumatra had the right mechanism to produce a tsunami. But there were additional factors that strongly influenced the devastating force of the tsunami. The earthquake had a very large magnitude, one of the largest in the last 100 years. The total length of rupture was over 1200 km (see yellow area, Figure 3) with a lateral displacement of 20-30 meters. However, lateral displacements are not of any influence on the occurrence of tsunamis. It is the vertical displacement on the fault that triggers a tsunami (Figure 4). And this earthquake had an unprecedented vertical displacement of approx. 15-20 meters in the zone of highest intensity!

How can earthquakes generate tsunamis?

Tsunamis can be generated when the sea floor abruptly deforms and vertically displaces the overlying water (Figure 4). The entire water column is disturbed by the uplift or subsidence of the sea floor. Waves are formed as the displaced water mass attempts to regain its equilibrium. These waves affect the whole column of water between the surface and the sea floor as they move, from the region of origin in the middle of the sea, towards the coast.

Summary:
We have seen that earthquakes do not always cause tsunamis
The reason why this earthquake caused such a devastating tsunami:
* Right mechanism (convergent plate boundary)
* Very large magnitude
* Occurred off coast in deeper water
* Extreme large vertical displacement of 15 meter or more!

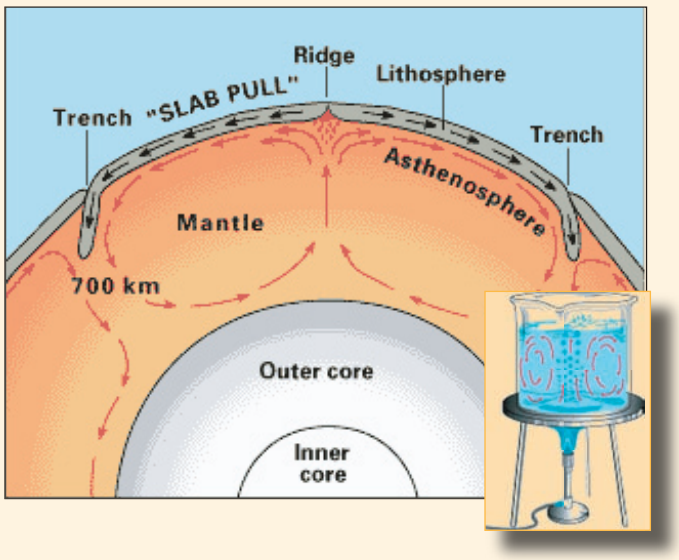

Figure 1: In a rather simplistic view the Earth can be considered to be build up by three different layers. The rigid top-layer we are living on (the crust), a warm thick layer with fluid properties (the mantle) and the deepest layer which is warming up the overlaying layers (the core). This source of heat initiates convective currents in the mantle that make the crust break into plates that will start floating over the Earth. Tectonic processes will take place at these plate boundaries; new crust is formed at ridges, old crust is disappearing at subduction zones (trenches).

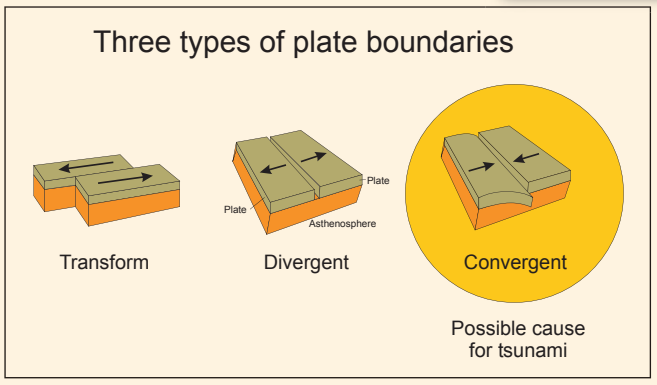

Figure 2: There are three different types of plate boundaries. The first type, transform faulting, describes two plates that are sliding along each other. Divergent plate boundaries are were new crust is formed and two plates are slowly getting separated. In subduction zones we see convergent plate boundaries where two plates are colliding with each other and one of the plates is subducting back into the Earth. This type of plate boundary is particularly effective for causing tsunamis.

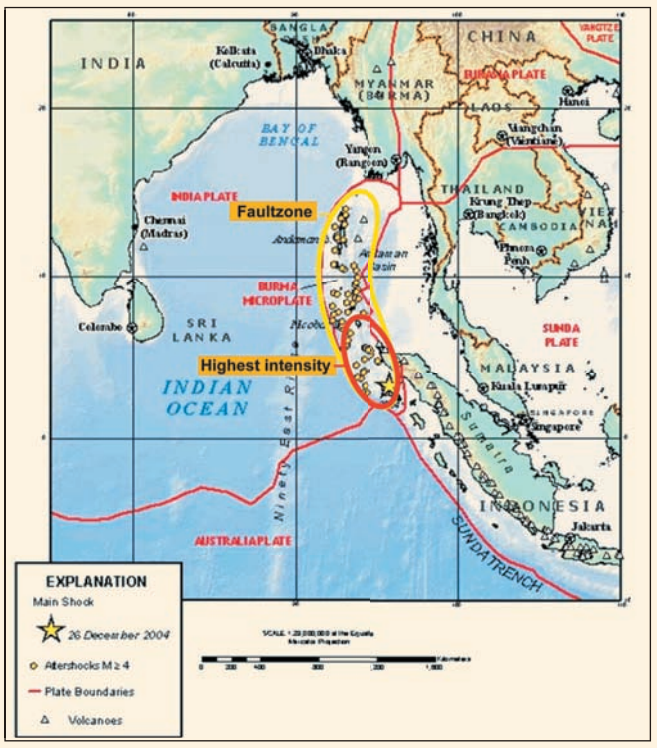

Figure 3: Tectonic overview of the Indian Ocean. The devastating megathrust earthquake of December 26, 2004, occurred on the interface of the India and Burma plates and was caused by the release of stresses that develop as the India plate subducts beneath the overriding Burma plate. The India plate begins its descent into the mantle at the Sunda trench, which lies to the west of the earthquake's epicenter. The trench is the surface expression of the plate interface between the Australia and India plates, situated to the southwest of the trench, and the Burma and Sunda plates, situated to the northeast.
In the region of the earthquake, the India plate moves toward the northeast at a rate of about 6 cm/year relative to the Burma plate. This results in oblique convergence at the Sunda trench. The oblique motion is partitioned into convergence and normal faulting. The December 26 earthquake occurred as the result of convergence. (source: USGS)

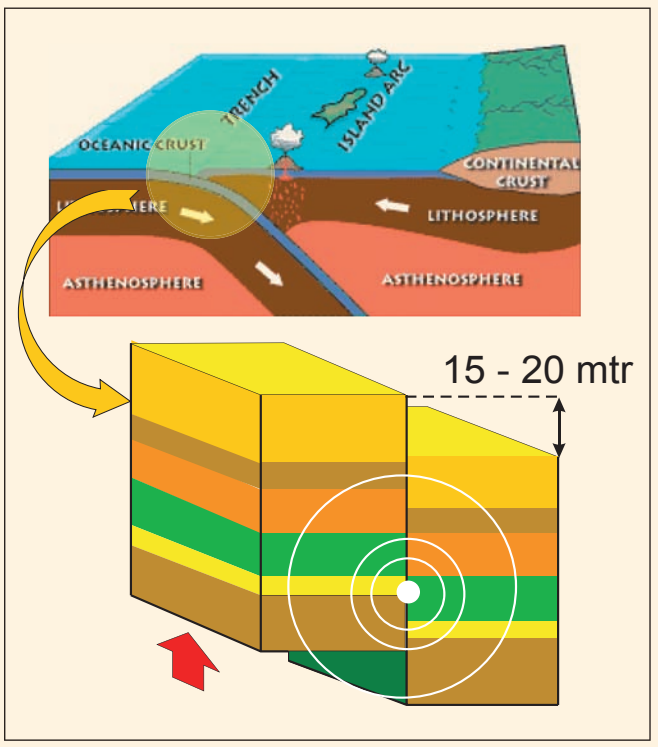

Figure 4: Earthquakes that can trigger tsunamis occur at convergent plate boundaries. In the area of highest friction (as indicated by the circle) large movements can suddenly occur when plates start moving abrupt. Big parts of the Earth in this area will instantaneously shift up- or downward causing a disturbance in the sea that might grow to a tsunami if the displacement is large enough.

For more information:

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