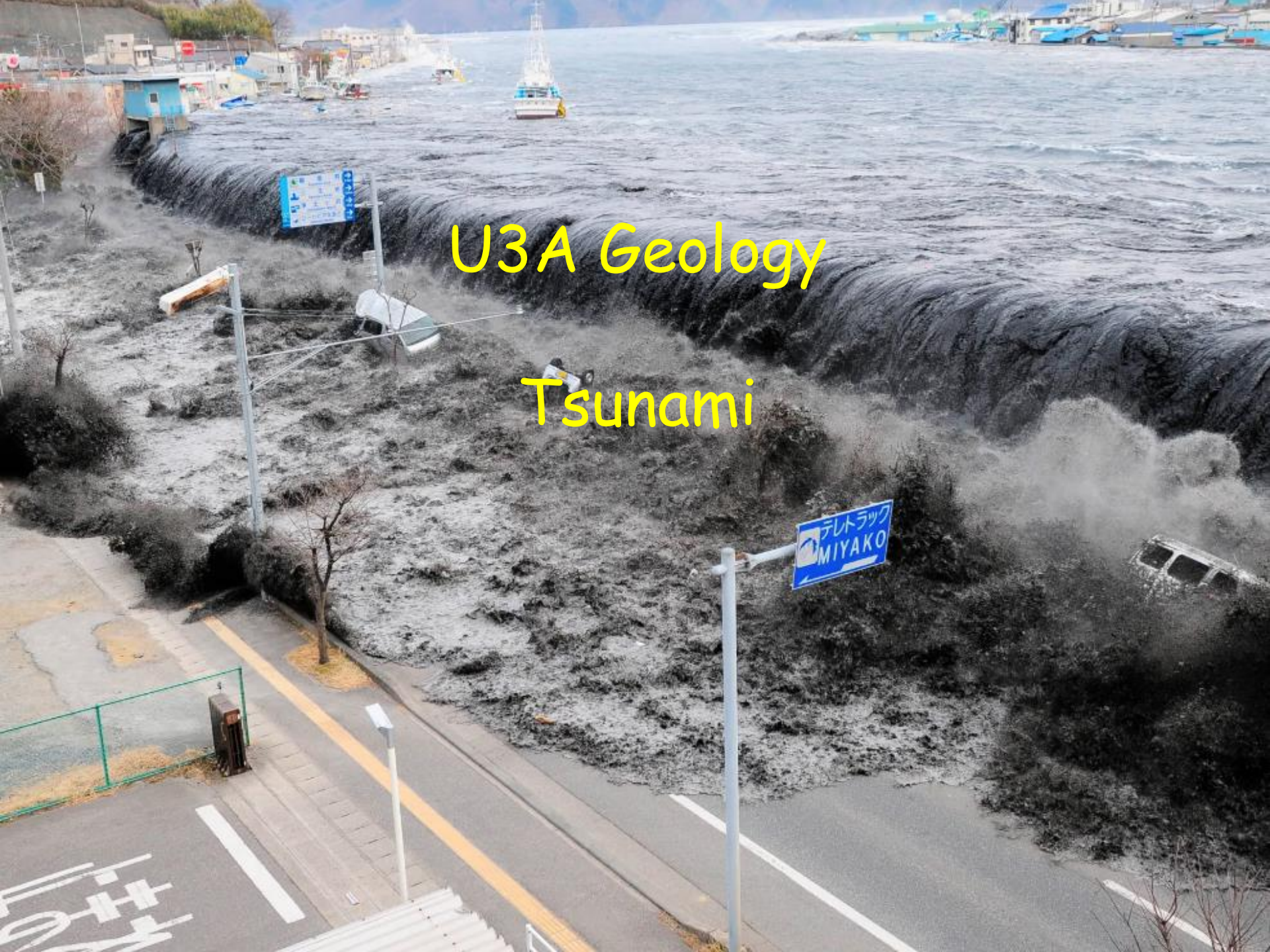

U3A Geology
Tsunami
テレトラック
MIYAKO

Introduction

- Tsunami are giant waves initiated by displacement of a large volume of water due to a sudden geological disturbance
- can be caused by submarine earthquakes or volcanic eruptions, landslides slumping in or into the ocean or, meteorite impacts
- tsunami generally consist of a series of waves with periods ranging from minutes to hours arriving in a so-called wave train
- formerly referred to as tidal waves but are unrelated to tides
- speed of waves depend on water depth → high speed over deep water → slowing down as water depth shallows

Tsunami characteristics

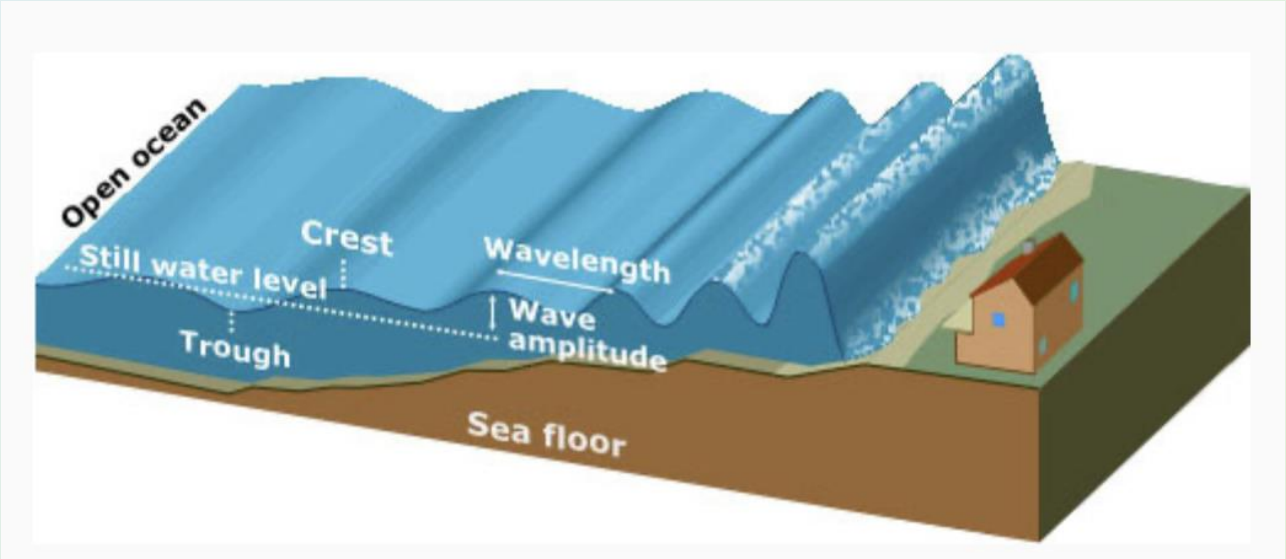
- A tsunami is different from wind generated waves in deep water
- everyday waves have a wavelength of about 100m and a height of roughly 2m
- tsunami wave behaviour is much different in deep water
- a tsunami in deep water has a much larger wavelength (up to 200m) and an amplitude of about 1m
- in deep water tsunami waves form a low broad hump, barely noticeable that generally travel at high speed 500-1000km/hr)

Tsunami shoaling

- Shoaling → changes that water waves experience as they move from deep water to shallow water
- a tsunami slows as it approaches increasingly shallow water
- causes the distance between successive wave peaks to decrease as well
- the total energy of the wave does not change, the energy is transferred to increasing wave height
- as a tsunami approaches the coast, wave shoaling compresses the wave and its speed decreases below 80km/hr
- its wavelength diminishes and its amplitude grows enormously

Tsunami shoaling

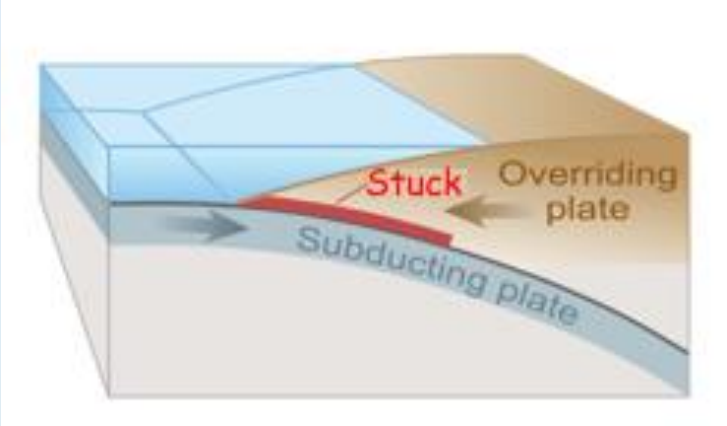
- A tsunami is often a series of waves with the first not necessarily the one with the greatest amplitude
- in open ocean, tsunami wave heights are typically 10s cm or less
- shoaling effect can increase open ocean wave heights to more than 10m above sea level



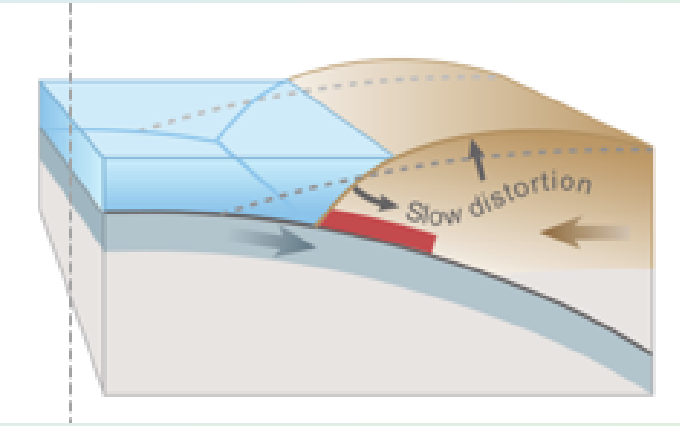
Megathrust earthquakes

- Megathrust earthquakes occur at convergent plate boundaries where one plate is forced under another
- the earthquakes are caused by a sudden slip along the thrust fault that forms the contact between the two plates
- friction along the megathrust fault can lock plates together with subduction forces building up stress in the two plates
- a megathrust earthquake occurs when fault ruptures allowing plates to move past each other releasing accumulated strain energy

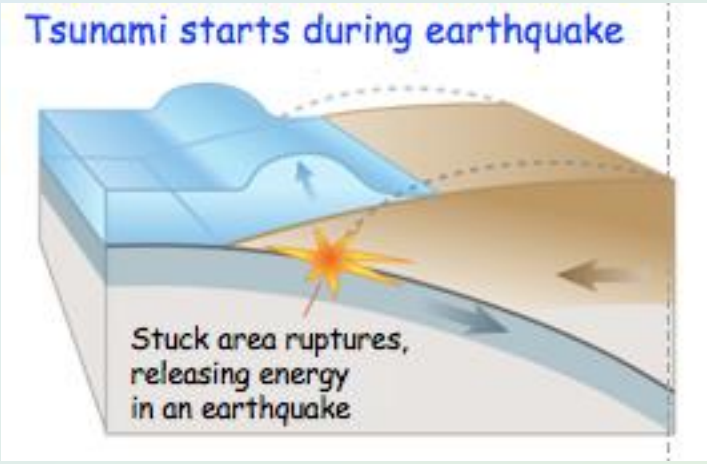
Megathrust earthquake



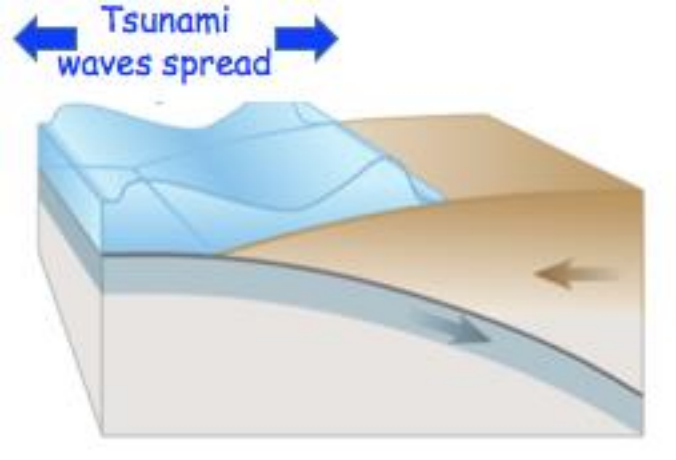
1. Drawing of tectonic plate boundary before earthquake



2. Over-riding plate bulges under stress causing tectonic uplift



3. Plate slips, causing subsidence and releasing energy into water



4. The energy released produces tsunami waves

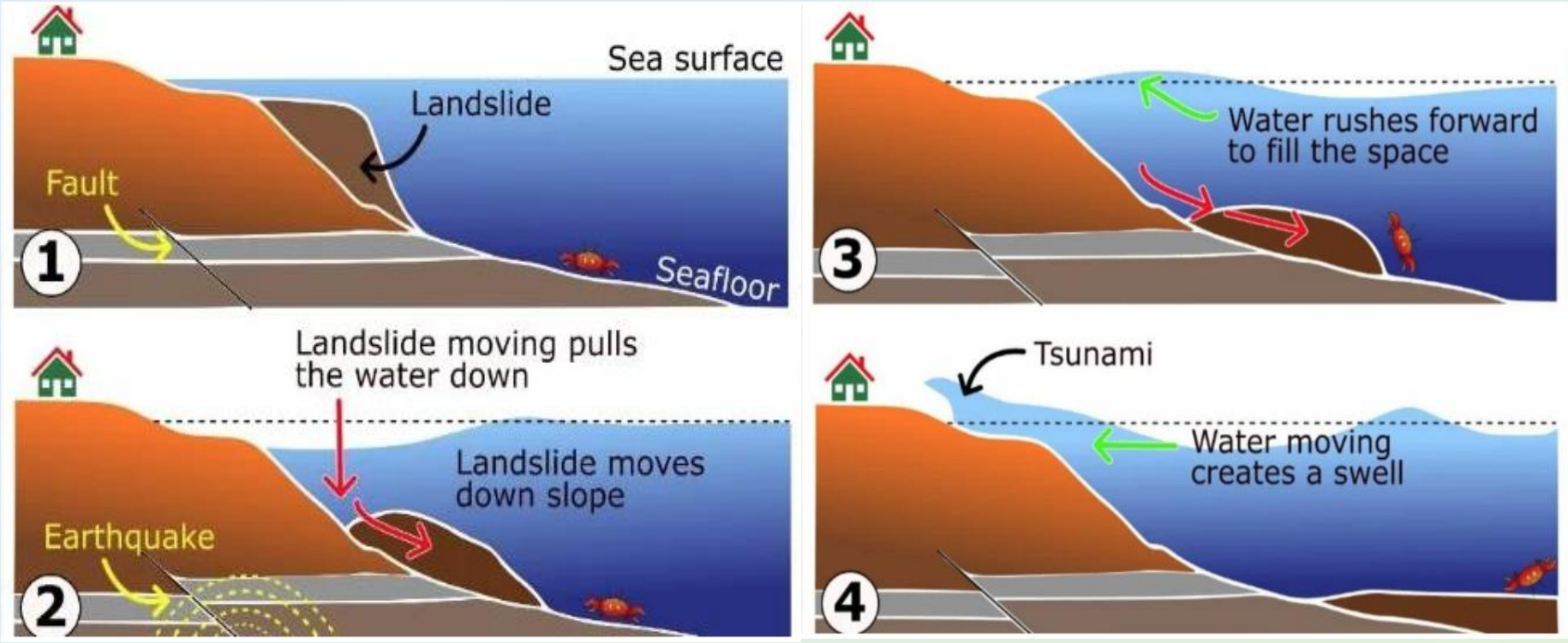
Tsunami caused by seismicity

- 75% of tsunami have been caused by large earthquakes on the sea floor
- tsunami can be generated when thrust faults associated with convergent plate boundaries move abruptly resulting in water displacement
- resultant waves move away from earthquake epicentre
- movement on extensional faults can also cause displacement of the sea bed without producing tsunami
- not every submarine earthquake produces a large tsunami

Tsunami caused by submarine landslides

- Landslides can happen on the seafloor just like on land
- areas of seafloor steep and loaded with sediment such as the continental shelf, are prone to submarine landslides
- a large amount of sediment can move down a slope (commonly triggered by an earthquake)
- downslope movement will draw water down and may cause a tsunami
- a giant submarine landslide in Alaska in 1958 caused the largest tsunami wave ever recorded with a height of 524m

Submarine landslide forming tsunami



Tsunami caused by volcanic eruptions

- Tsunami initiated by volcanic eruptions are less common, they occur in several ways:
  - destructive collapse of coastal, island and submarine volcanoes resulting in massive landslides
  - pyroclastic flows plunging down slopes into the ocean and pushing water outwards
  - a caldera volcano collapsing after an eruption causing overlying water to drop suddenly

- tsunami have been triggered by a number of volcanic eruptions including Krakatoa in 1883 and the 2022 Hunga-Tonga Hunga-H'apai eruption

Hunga-Tonga Hunga H'apai volcano and tsunami

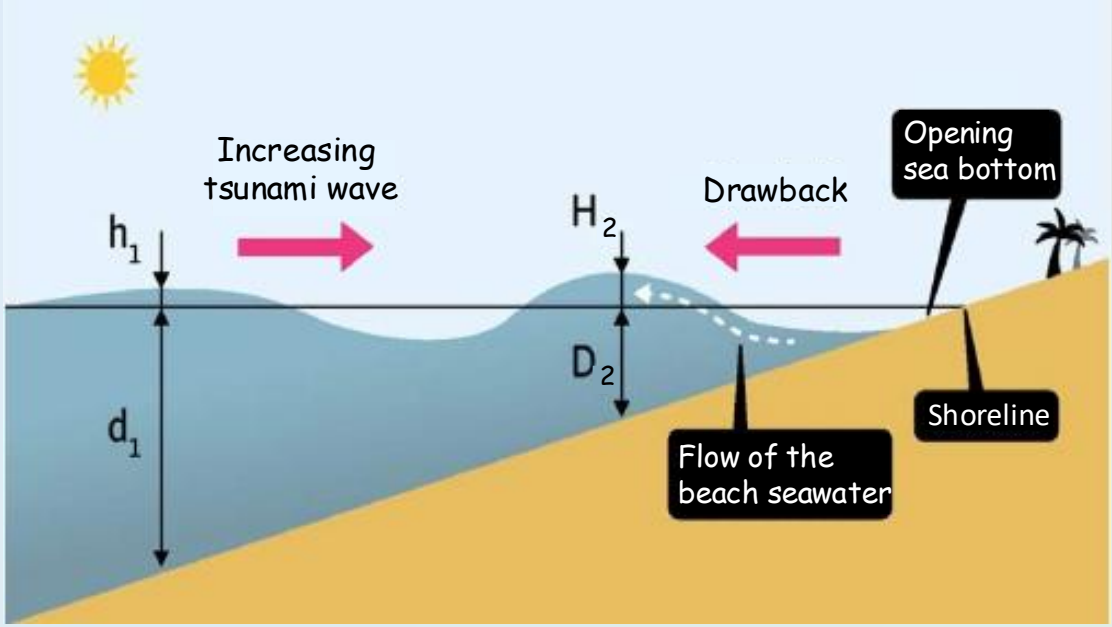
Hunga-Tonga Hunga H'apai eruption

Hunga-Tonga Hunga H'apai tsunami

Drawback

- In the minutes preceding a tsunami impact, the sea sometimes recedes temporarily from the coast this is called drawback
- all waves have a crest and trough; in the case of a propagating wave or a tsunami, either may be first to arrive
- if the first to arrive is the crest, a massive breaking wave or sudden flooding will be the first effect
- if the trough is the first to arrive drawback will occur → shoreline recedes dramatically exposing normally submerged areas
- drawback can exceed hundreds of metres

Drawback



Drawback Thai beach

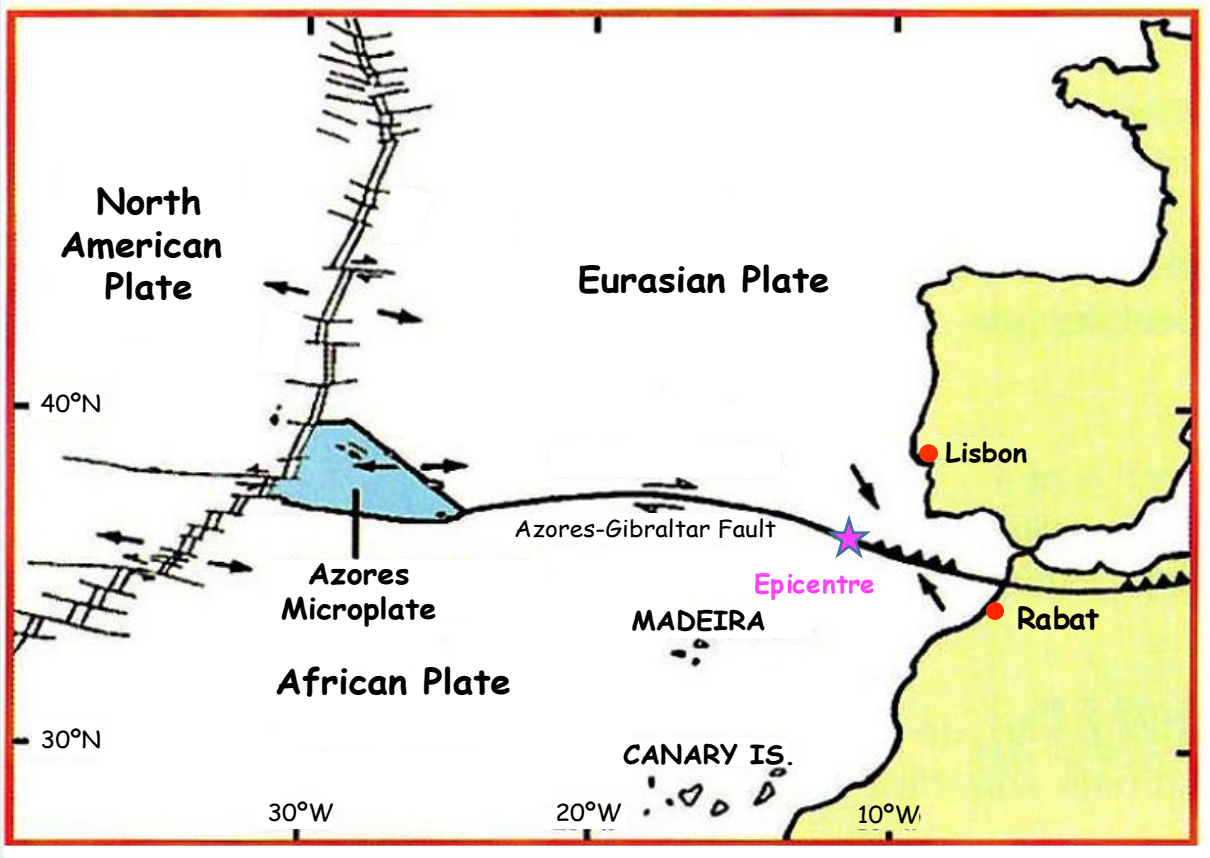
2004 Indian Ocean tsunami

Lisbon earthquake and tsunami, 1755

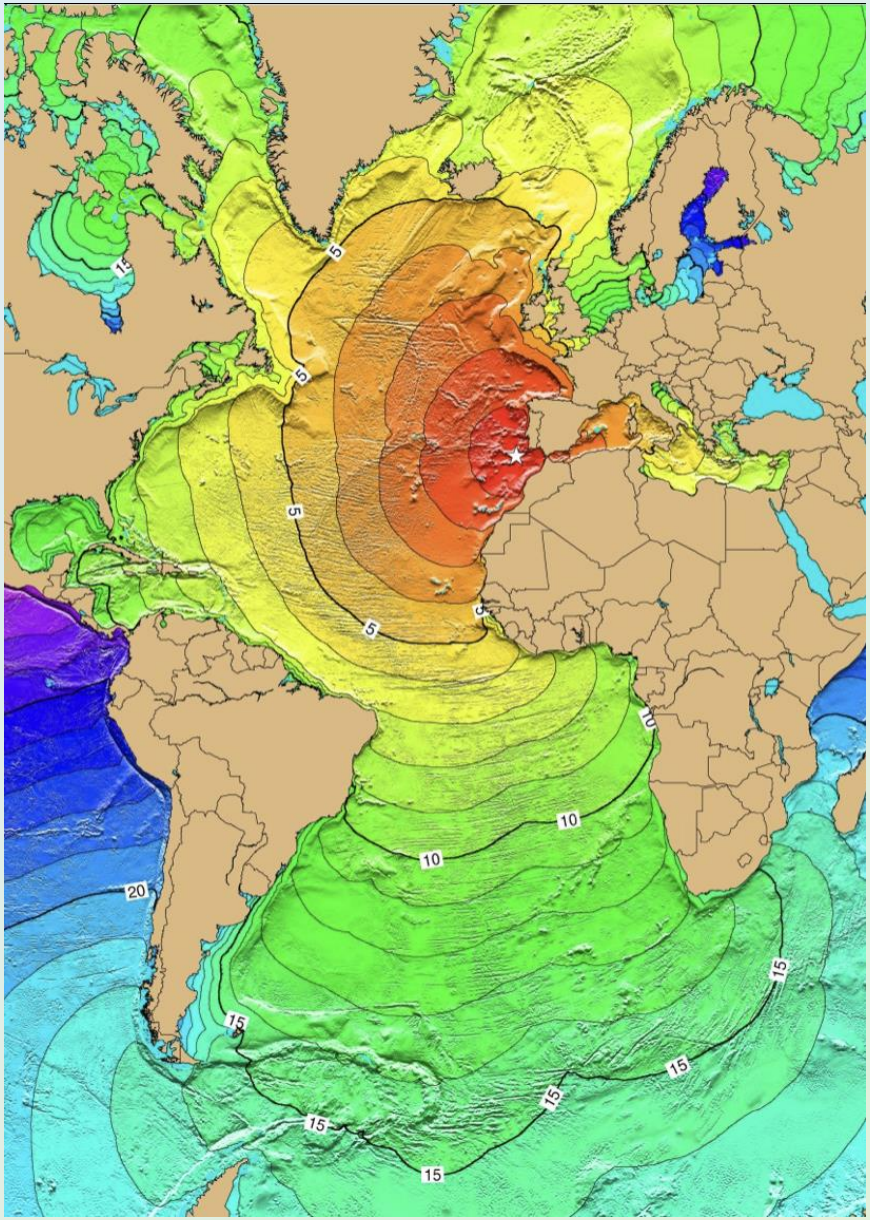
- Lisbon earthquake and tsunami struck on morning of November 1, 1755
- after the quake, survivors rushed to dock to escape fire and watched as the sea receded revealing a muddy plain littered with lost cargo
- approximately 40mins after the earthquake, a tsunami engulfed the harbour and downtown area rushing up the Targus River
- two more tsunami waves later struck the shore, each dragging people and debris out to sea and exposing the river bed
- waves as high as 20m swept along coast of north Africa and struck Barbados and Martinique across the Atlantic Ocean
- the earthquake and tsunami killed an estimated 50,000 people in Lisbon alone

Simplified tectonic setting

- Earthquake epicentre → 200km WSW of Cape Vincent → along Azores-Gibraltar transform fault
- combination of strike-slip and compression components → clockwise twisting of plate boundary



Tsunami travel time Lisbon earthquake



Lituya Bay, Alaska, megatsunami 1958

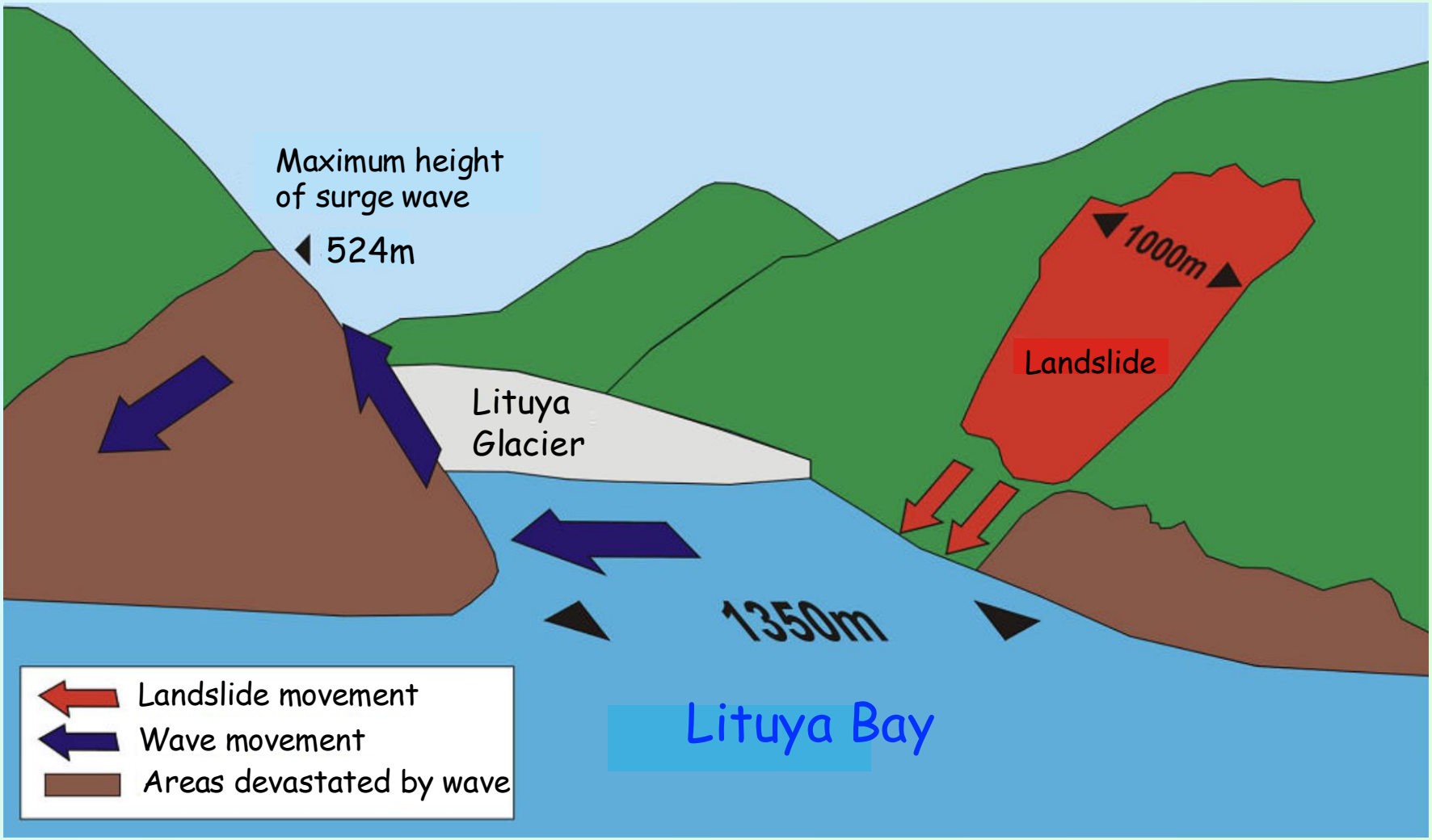
- On July 10 1958, a magnitude 7.8 earthquake occurred along the Fairweather Fault in SE Alaska
- the quake caused areas of uplift and subsidence and caused a rock slide of ~90million tonnes into the narrow inlet of Lituya Bay
- the sudden displacement of water generated a megatsunami that caused damage at higher elevations than any other tsunami
- the megatsunami pushed water up tree covered slopes to a height of 524metres
- it flooded the entire bay stripping vegetation and soil up to 213m around outline of bay

Lituya Bay and surrounds

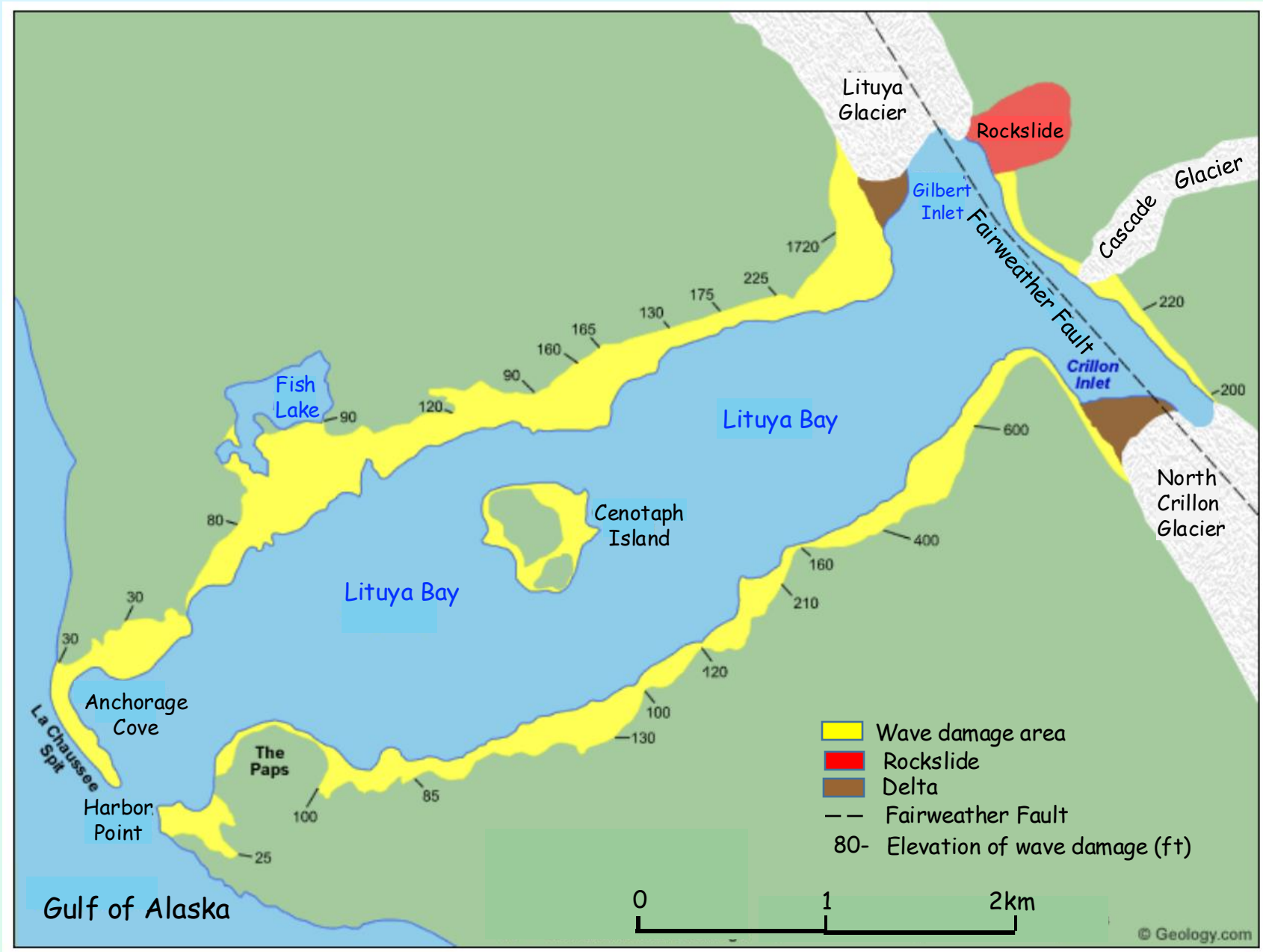
Lituya Bay megatsunami

- Scientists were puzzled for some time by the sheer size of wave
  → could not identify a mechanism to create such a massive reaction
- ultimately discovered that a piece of rock 750m x 900m and 90m thick had dislodged from face of northern wall of inlet
- large slab fell 600m into the bay
- the slide sent 90 million tonnes of rock plunging into bay, amount equivalent to 8 million dump truck loads
- five people were killed, many injured and many homes destroyed

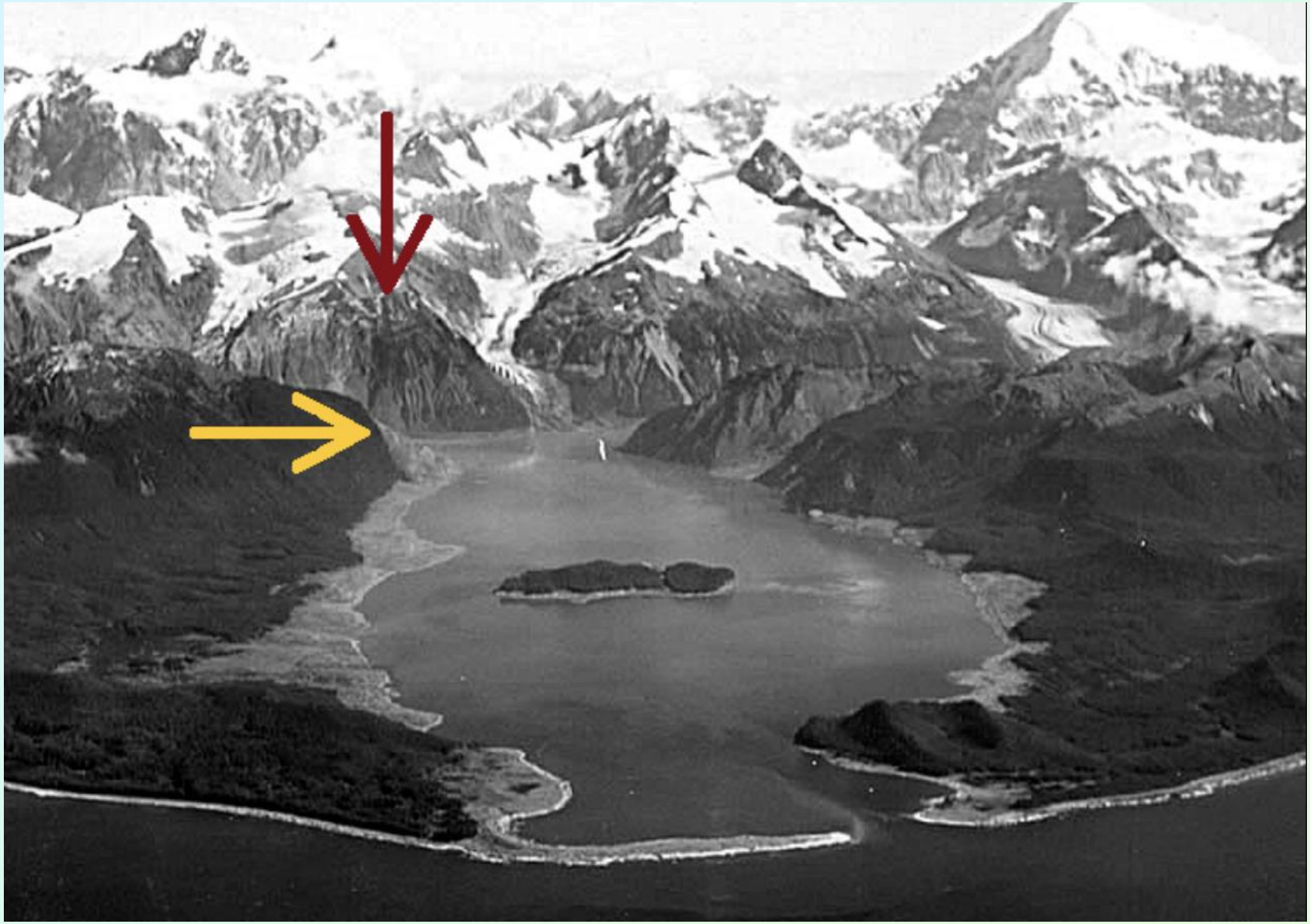
Lituya Bay megatsunami



Lituya megatsunami damage area



Lituya Bay damage, shoreline stripping



Valdivia earthquake, 1960

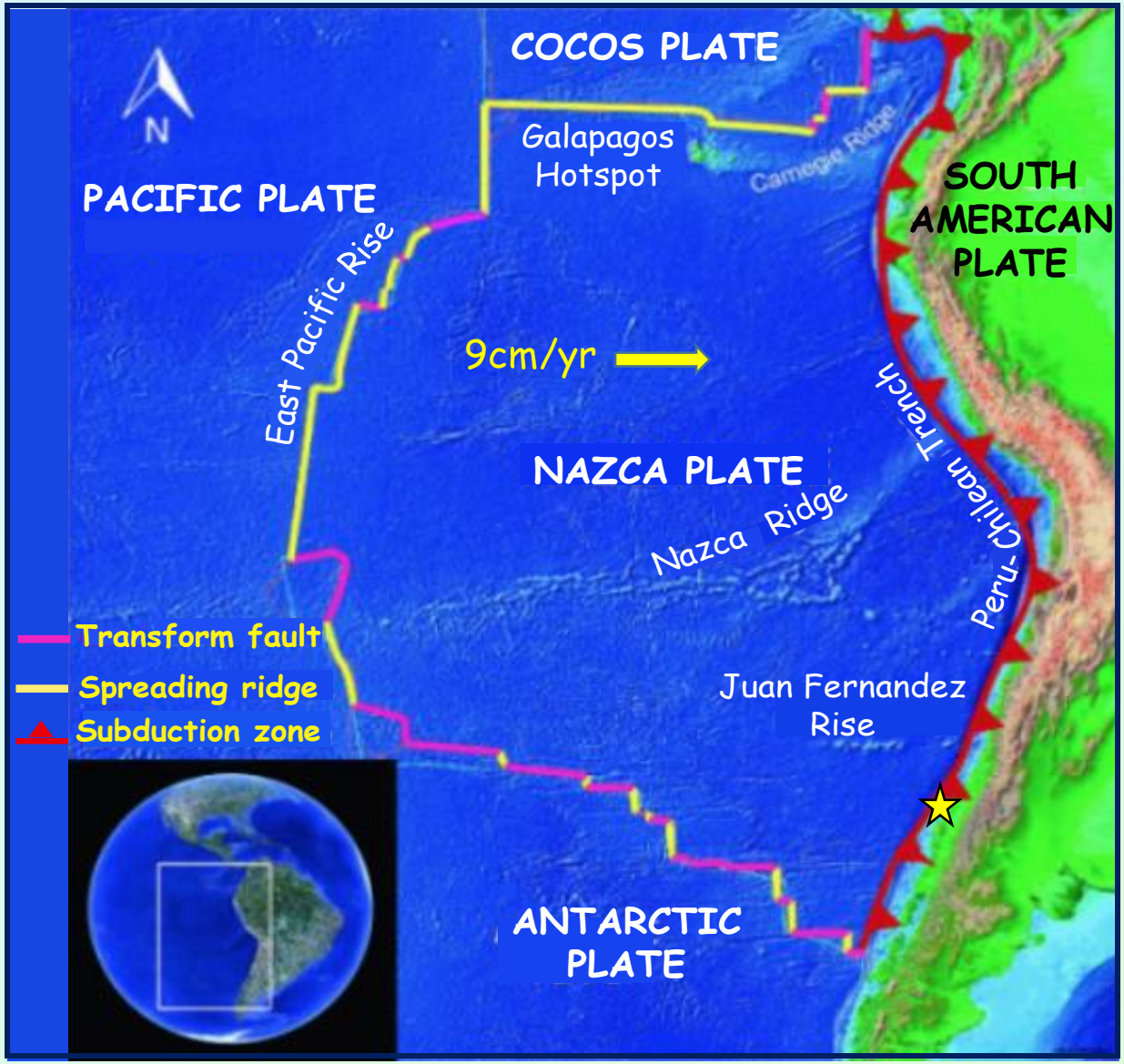
- The 9.4 magnitude Valdivia earthquake occurred on May 22 1960
- most powerful earthquake ever recorded
- the earthquake was a submarine megathrust earthquake resulting from release of mechanical stress between the subducting Nazca and South American plates along the Peru-Chile trench
- epicentre was located ~570km south of Santiago
- focus of earthquake was relatively shallow at 33km
- affected all of Chile between Talca and Chiloe Island
- hundreds of people were dead before the tsunami struck

Valdivia earthquake epicentre

Valdivia Tsunami

- An earthquake induced tsunami battered the Chile coast with waves up to 25m high
- resultant tsunami severely affected southern Chile, Hawaii, Japan, Philippines, eastern NZ, SE Australia and the Aleutian Islands
- it travelled across the Pacific at speeds of several hundred Km/hr
- the tsunami devastated Hilo on the Island of Hawaii with 11m high waves, killing 61 people
- total death toll from tsunami in Chile was estimated at 1,655
- the massive earthquake triggered a number of natural disasters in addition to the tsunami (landslides, floods, volcanic eruption)

Tectonic setting

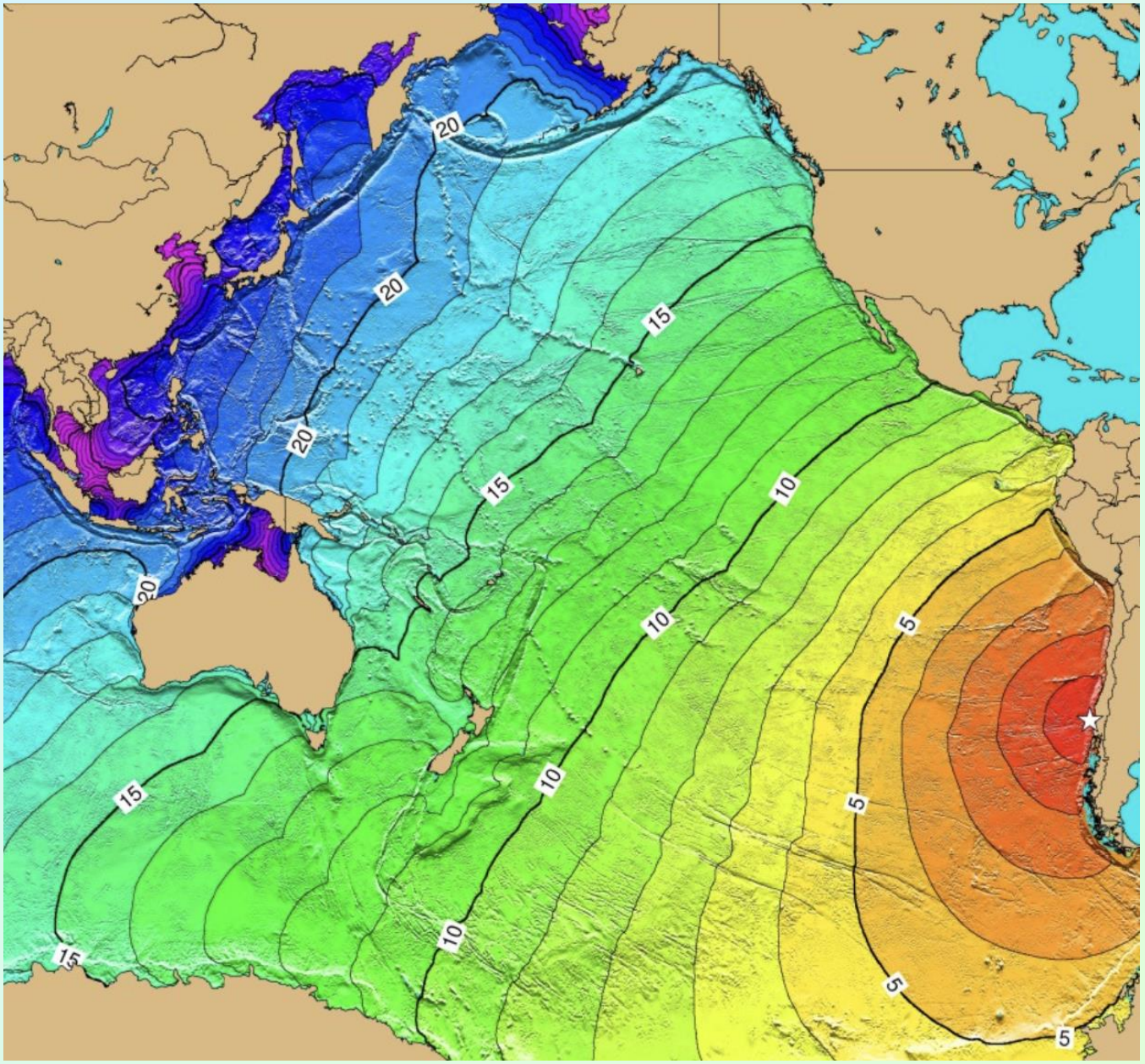


Tsunami damage Hawaii

Tsunami damage Hilo, Hawaii

Tsunami damage Waiakea, Hawaii

Tsunami travel time Valdivia earthquake



Aitape (PNG) earthquake and tsunami, 1998

- An earthquake occurred on July 17 1998 off the north coast of PNG
- while most tsunami are triggered by megathrust quakes, the Aitape tsunami → generated by the earthquake induced submarine landslide
- three catastrophic tsunami waves followed entirely razing villages along a 45km stretch of the north coast of PNG killing >2,200 people
- the second of the three waves rose to height of 10-15m after it crossed the shoreline causing most damage
- maximum wave heights and greatest damage occurred along a 14km sector of coast west of Aitape
- in this zone 20-40% of the population were killed, villages wiped out

Tectonic setting

- The epicentre of the 7.0 magnitude earthquake was located 16km north of PNG
- it occurred on a thrust fault along the boundary of the convergent Australian and Pacific tectonic plates
- currently the Australian and Pacific tectonic plates are converging at a rate of 11.1m/yr

Aitape earthquake epicentre

Aitape tsunami damage

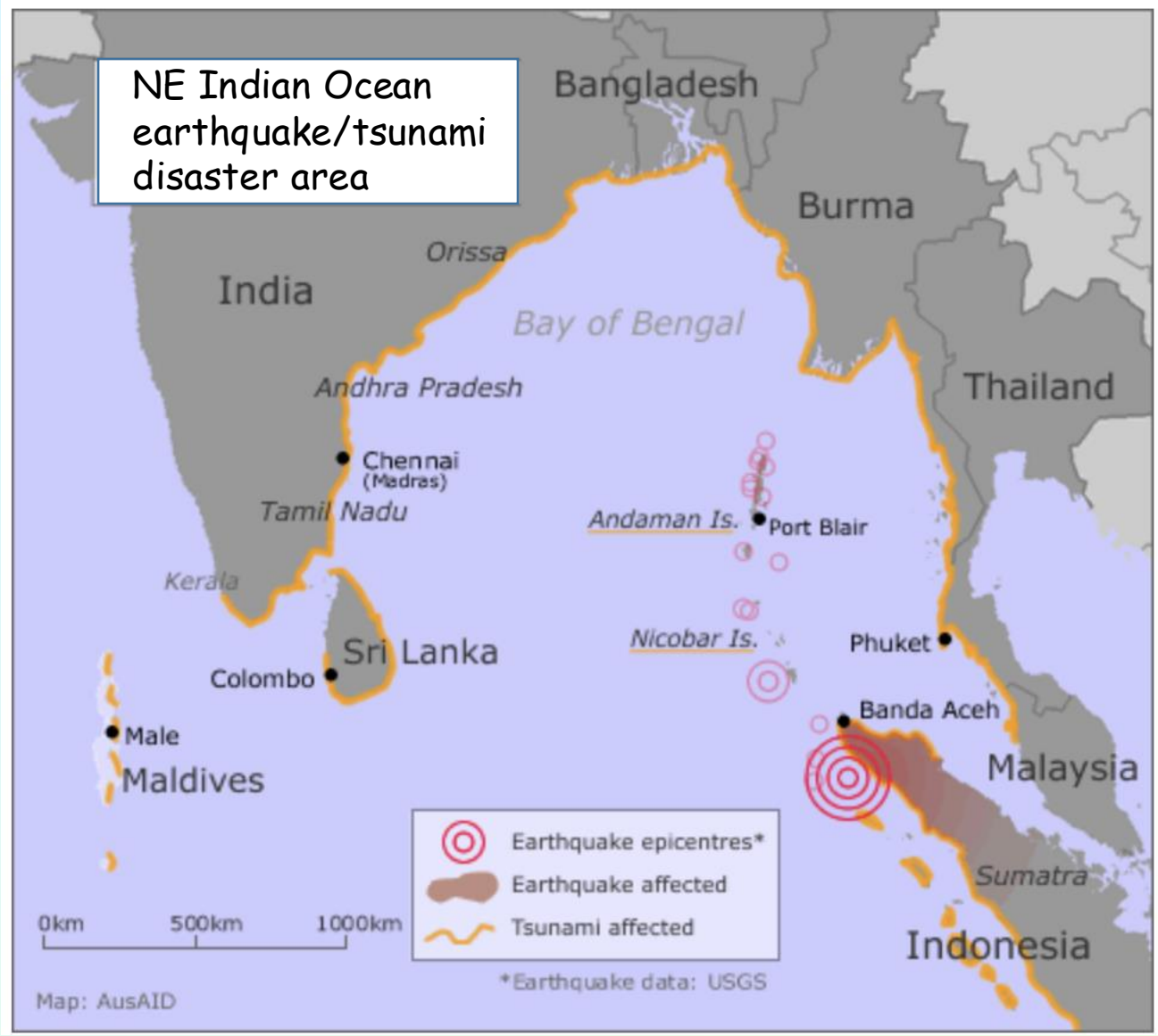
Three concrete slabs, remains of class rooms Warapu school

Sissano Mission school carried 65m away by tsunami waves

Indian Ocean tsunami, 2004

- The Indian Ocean tsunami occurred on Boxing Day 2004 resulting from a 9.2-9.3 earthquake with epicentre located off the west coast of northern Sumatra, Indonesia
- most powerful earthquake ever recorded in Asia, 3rd most in history
- cause of tsunami was a submarine megathrust earthquake resulting from a rupture between the Burma and Indian plates
- sudden rise of the sea bed displaced massive volumes of water
- massive tsunami waves up to 30m high were generated by the earthquake

Earthquake epicentre and areas affected by tsunami



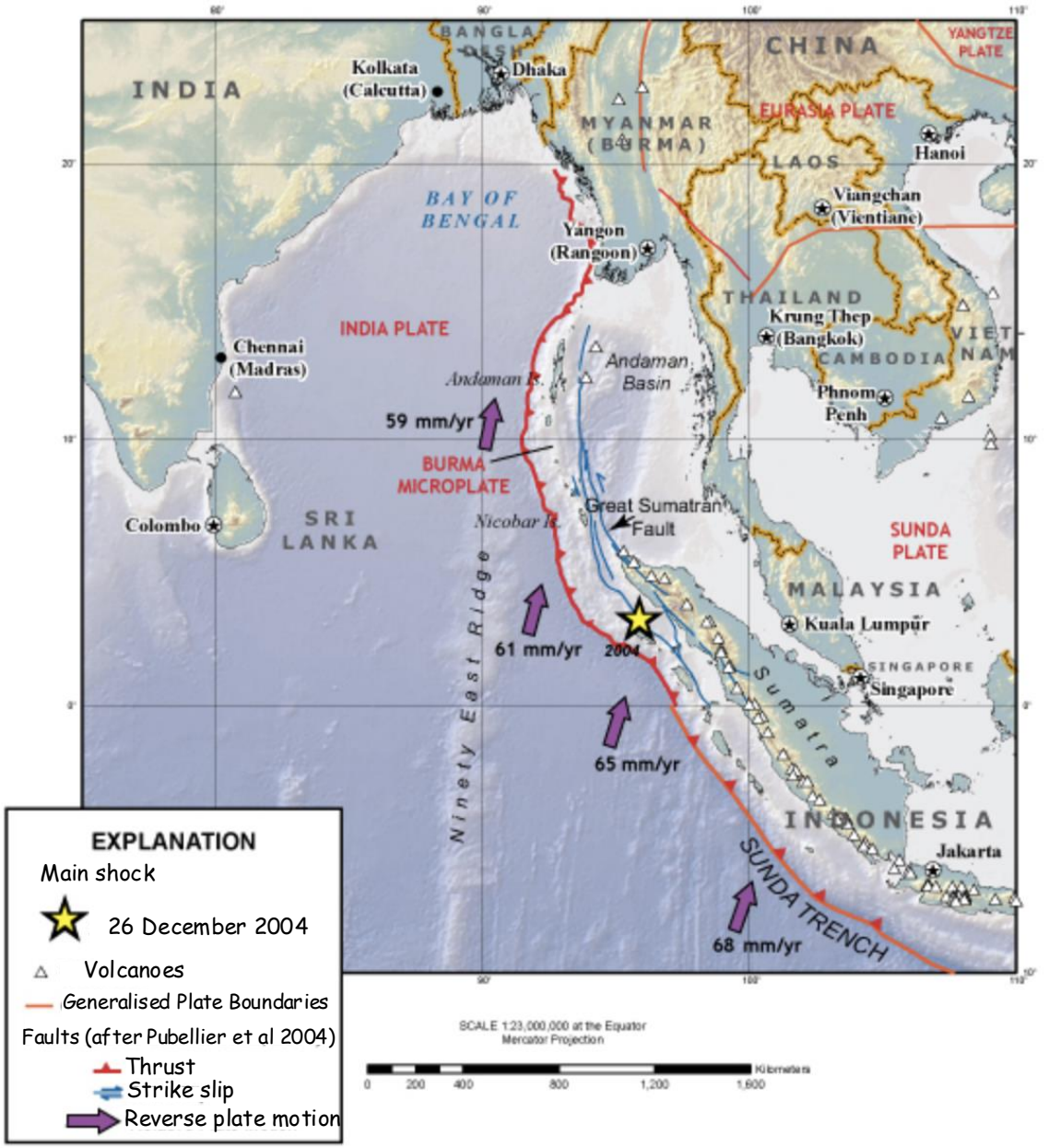
Tsunami effects

- Death toll from tsunami estimated to be 227,898 in 14 countries
- countries most affected → India, Malaysia, Maldives, Myanmar, Somalia, Sri Lanka and Thailand
- Indonesia → worst affected area with an estimated death toll of 167,590 and 37,063 missing
- the tsunami devastated the coastline of Aceh Province, Indonesia
- because the fault was in a nearly N-S orientation, the greatest strength of tsunami waves was in E-W direction

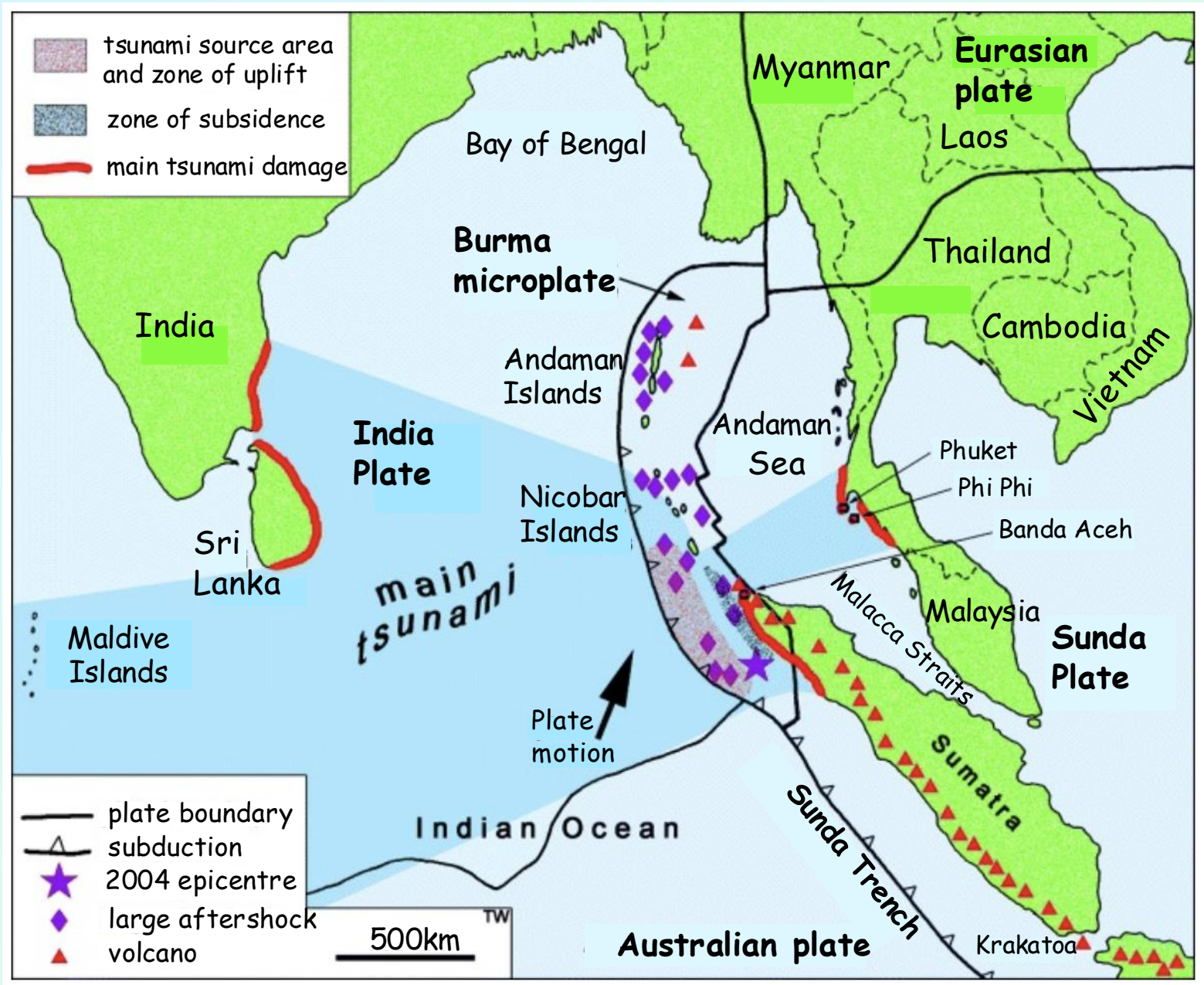
Tectonic setting

- Earthquake occurred along a tectonic subduction zone in which the Indian plate is being subducted beneath the Burma microplate
- the boundary between the descending and overriding plates is marked by the Sunda Trench
- Sumatra subduction zone is characterized by decoupled faulting. In this case, nearly pure thrust faulting occurs along the interplate thrust and strike-slip faulting occurs in the overriding plate
- during the 2004 earthquake, the seafloor of the overriding Burma plate deformed, vertically uplifting seawards towards the trench and subsiding landwards

Tectonic setting



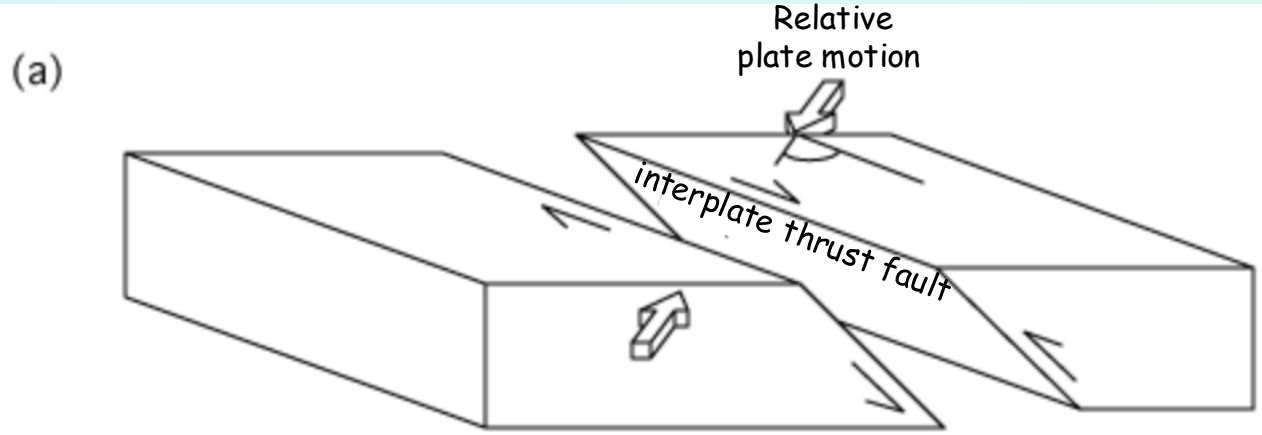
Earthquake and tsunami effects



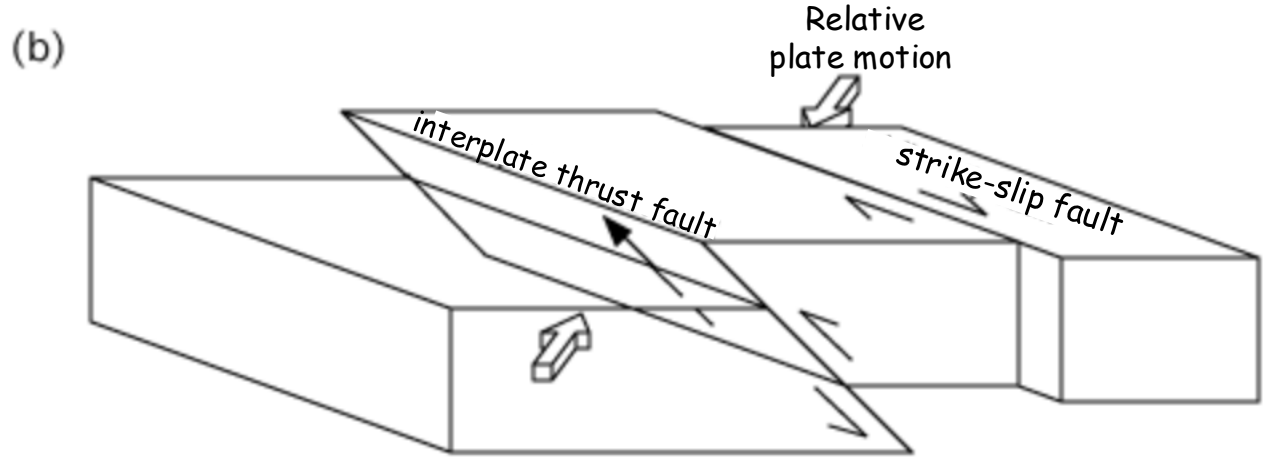
Decoupling faulting

- Direction of convergence of Indian Plate is orientated oblique to interplate thrust
- for this oblique subduction, movement between the two plates can be accommodated in one of two ways
  - (1) oblique thrusting
  - (2) decoupled faulting
- Sumatra subduction zone is characterised by decoupled faulting
- nearly pure thrust occurs along the intraplate thrust and strike -slip faulting occurs in the overriding plate, notably the Great Sumatra Fault

Decoupling faulting

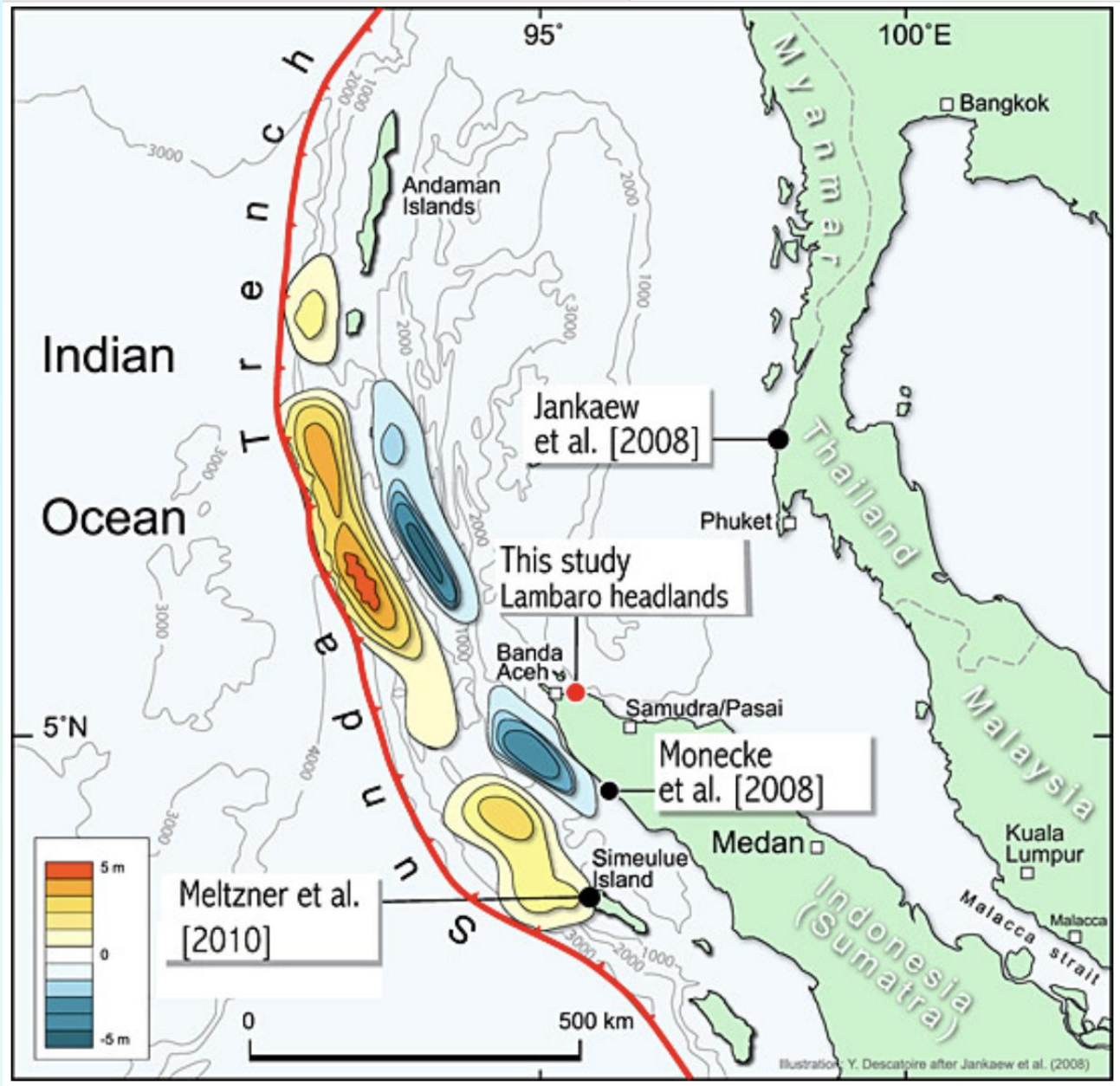


Oblique thrust faulting



Decoupled: Pure thrust and strike-slip faulting

Areas of uplift and subsidence associated with earthquake



Indian Ocean tsunami damage

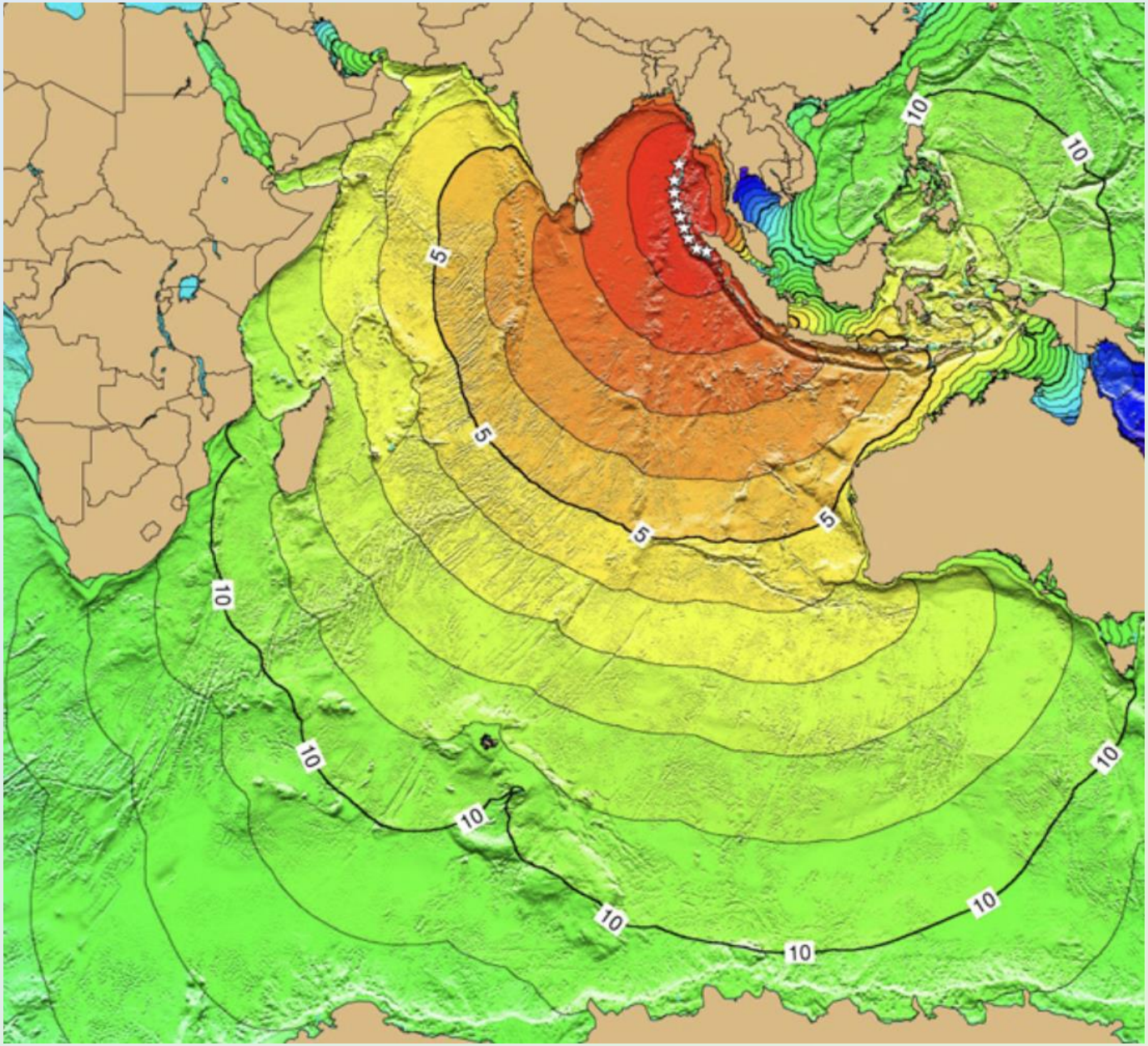
Tsunami damage, Patong, Thailand

Tsunami damage Banda Aceh, Indonesia

Environmental impact

- Despite delay of up to several hours between earthquake and impact of tsunami there were no warning systems on Indian Ocean
- tsunami caused enormous environmental damage that affected region for years
- severe damage inflicted on ecosystems e.g. mangroves, coral reefs, forests, coastal wetlands, vegetation, sand dunes, rock formations and groundwater

Travel time (hrs) Indian ocean tsunami



Tohoku tsunami 2011

- An earthquake and tsunami struck the Japanese island of Honshu on March 11, 2011
- event began with a powerful 9.0 magnitude earthquake that occurred off NE coast of the Tohoku Region, Honshu
- epicentre was located 130km E of city of Sendai with focus at a depth of 30km below the floor of W Pacific Ocean
- the earthquake initiated a series of large, destructive tsunami waves that devastated many coastal towns of eastern Honshu
- the tsunami also instigated a major accident at a power station along the coast

Earthquake epicentre

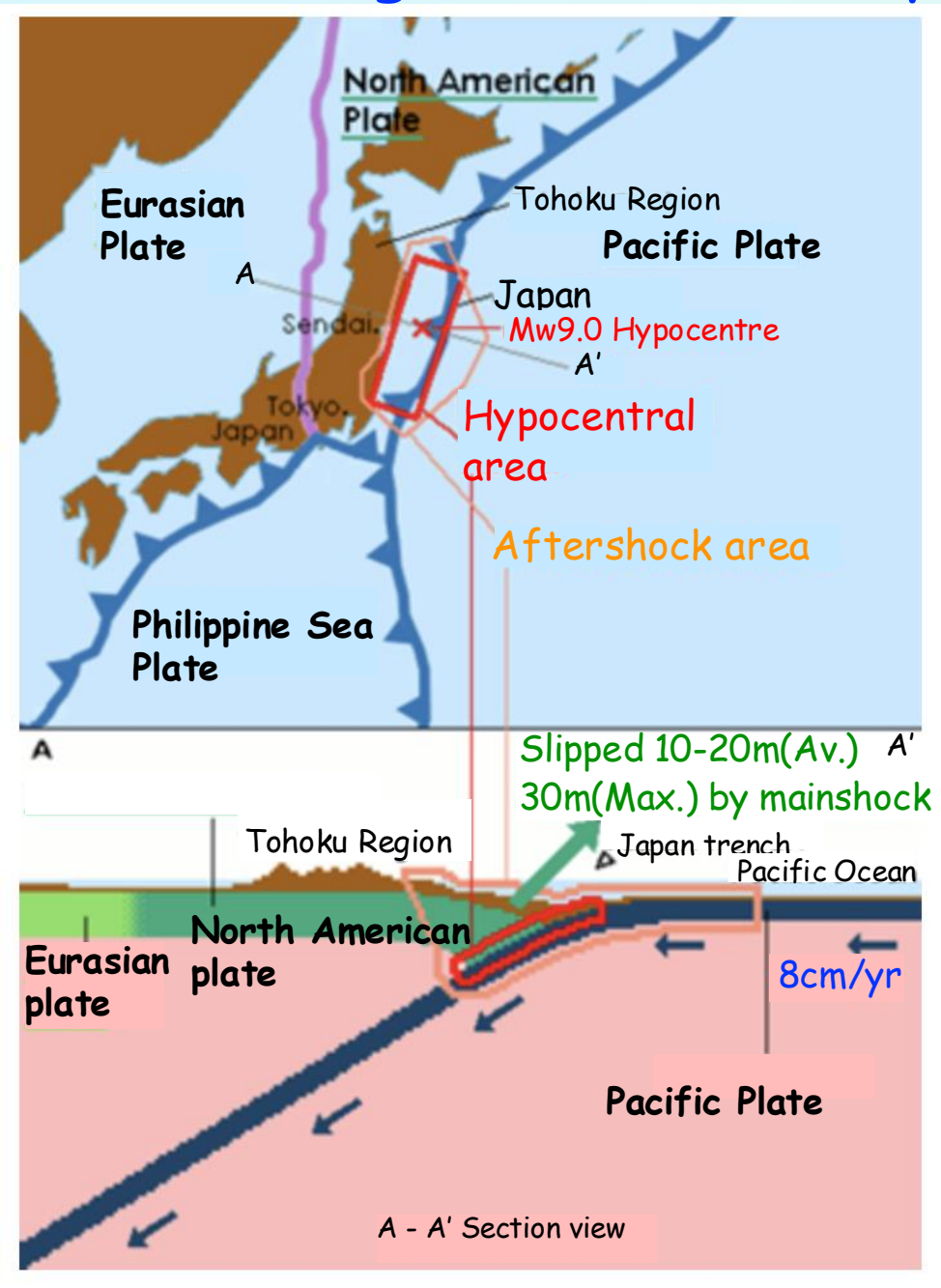
Tohoku tsunami 2011

- The earthquake was the strongest to hit the area since records began early in 19th century
- sudden oblique thrusting of the Pacific plate displaced water above initiating a series of highly destructive tsunami waves
- as floodwaters retreated they carried back with them enormous quantities of debris as well as thousands of victims
- the tsunami raced outwards from the epicentre at speeds approaching 800km/hr striking coasts of California and Oregon
- the confirmed number of those dead and missing is ~19,000

Tectonic setting

- Honshu, Japan's main island lies at the intersection of three tectonic plates → Eurasian, Philippine and North American plates
- oceanic crust of the Pacific plate is converging on Eurasian and Philippine plates and is subducting beneath Japanese continental crust
- as these plates converge, compression stress builds up along the moving plate boundaries → release of stress → earthquakes
- earthquake caused by rupture of the subduction zone associated with the Japan trench separating Eurasian tectonic plate from subducting Pacific plate
- part of subduction zone (300km long, 150km wide) lurched as much as 50m ESE and thrust upwards 10m

Tectonic setting Tohoku earthquake



Fukushima disaster

- As the tsunami swept inland to Fukushima prefecture, the Daiichi nuclear power plant was melted down
- more than 300,000 people living near the power plant were forced to temporarily evacuate
- since the disaster, the Tokyo Electric Power Company (TEMPCO) has been pumping hundreds of tonnes of water to cool the reactors and control the outflow of radiation

The Tohoku earthquake and tsunami

Structural damage Tohoku earthquake

Smoke pour from Fukushima-Daiichi nuclear power plant