Magnitude 9.1 SUMATRA
Sunday, December 26, 2004 at 00:58:53 UTC

Teacher Guide

Welcome to Teachable Moments! Our goal is to provide timely and accurate information to develop knowledge about a newsworthy earthquake for audiences from middle school through college. Please use the slides to get a concise, but thorough overview of this historical earthquake and then use them as is or customize it for your students and curriculum.

New for the 2024-25 school year:

1. **Color-coding for grade levels.** ALL middle school + HS high school + C college

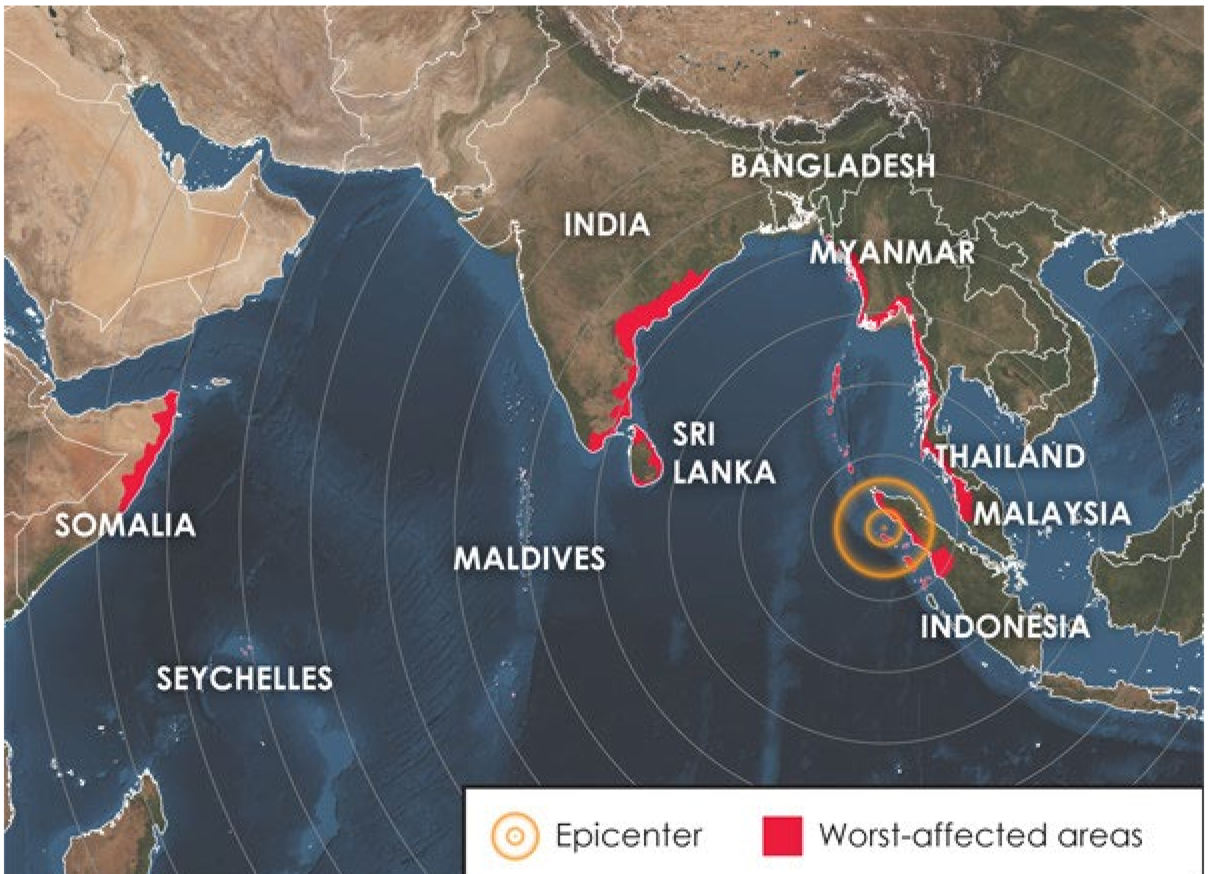
1. **Check out the new Slide Guide: Slides or pdf that will guide your students through the slide deck:** middle school pdf high school pdf college pdf
2. **New Geography slide(s): An additional slide about the city or area that gives you cross-curricular connections:** geography, physics, chemistry, biology, environmental science or even history.
3. **NGSS Connections for questions in the Slide Guide are located in the notes sections below each slide guide.**
4. **Fill in the blank sub-plans:** The first two pages can be completed and used all year (hint: sheet protector) The rest are for you to modify or fill-in to customize your sub-plans to fit what you're doing.

Magnitude 9.1 SUMATRA
Sunday, December 26, 2004 at 00:58:53 UTC

ALL

Latitude 3.295°N
Longitude 95.982°E
Depth 30.0 km

Twenty years ago, on December 26, 2004, a magnitude 9.1 earthquake struck off the west coast of northern Sumatra, Indonesia. It was one of the largest earthquakes ever recorded, caused by the sudden rupture of a 1,300 km section of the Sunda megathrust, where the Indian Plate is subducting beneath the Burma Plate. The rupture triggered a massive tsunami, with waves reaching heights of 30 meters (98 feet) in some areas. These waves spread across the Indian Ocean, impacting 14 countries. The tsunami caused widespread devastation, displacing millions of people and claiming over 230,000 lives, making it one of the deadliest natural disasters in history.



The Dec. 26, 2004, earthquake ruptured 250 kilometers offshore of Sumatra, Indonesia; tsunami waves traveled thousands of kilometers with enough power to kill hundreds of people and destroy villages as far away as the east coast of Africa.

Credit: Kathleen Cantner, AGI

Magnitude 9.1 SUMATRA
Sunday, December 26, 2004 at 00:58:53 UTC

ALL

Bulldozers clear the rubble at the market area in the center of Banda Aceh, Sumatra island, Indonesia, Wednesday Jan. 5, 2005. Cleanup and relief operations are gathering pace after the Dec.26, 2004 devastating quake-triggered tsunami claimed the lives of at least 94,000 people in Indonesia alone. (AP Photo/Peter Dejong)

Magnitude 9.1 SUMATRA
Sunday, December 26, 2004 at 00:58:53 UTC

Video overview of the Sumatra earthquake and the impact on indigenous populations

(possible trigger warning – please watch first to assess if this is a good fit for your classroom)

Magnitude 9.1 SUMATRA
Sunday, December 26, 2004 at 00:58:53 UTC

The Modified-Mercalli Intensity (MMI) scale is a ten-stage scale, from I to X, that indicates the severity of ground shaking.

Intensity is based on observed effects and is variable over the area affected by the earthquake and is dependent on earthquake size, depth, distance, and local conditions.

The black star indicates the epicenter of the earthquake, and the outline defines the full rupture zone of the earthquake.

MMI	Perceived Shaking
X	**Extreme**
IX	**Violent**
VIII	**Severe**
VII	**Very Strong**
VI	**Strong**
V	Moderate
IV	Light
II-III	Weak
I	Not Felt

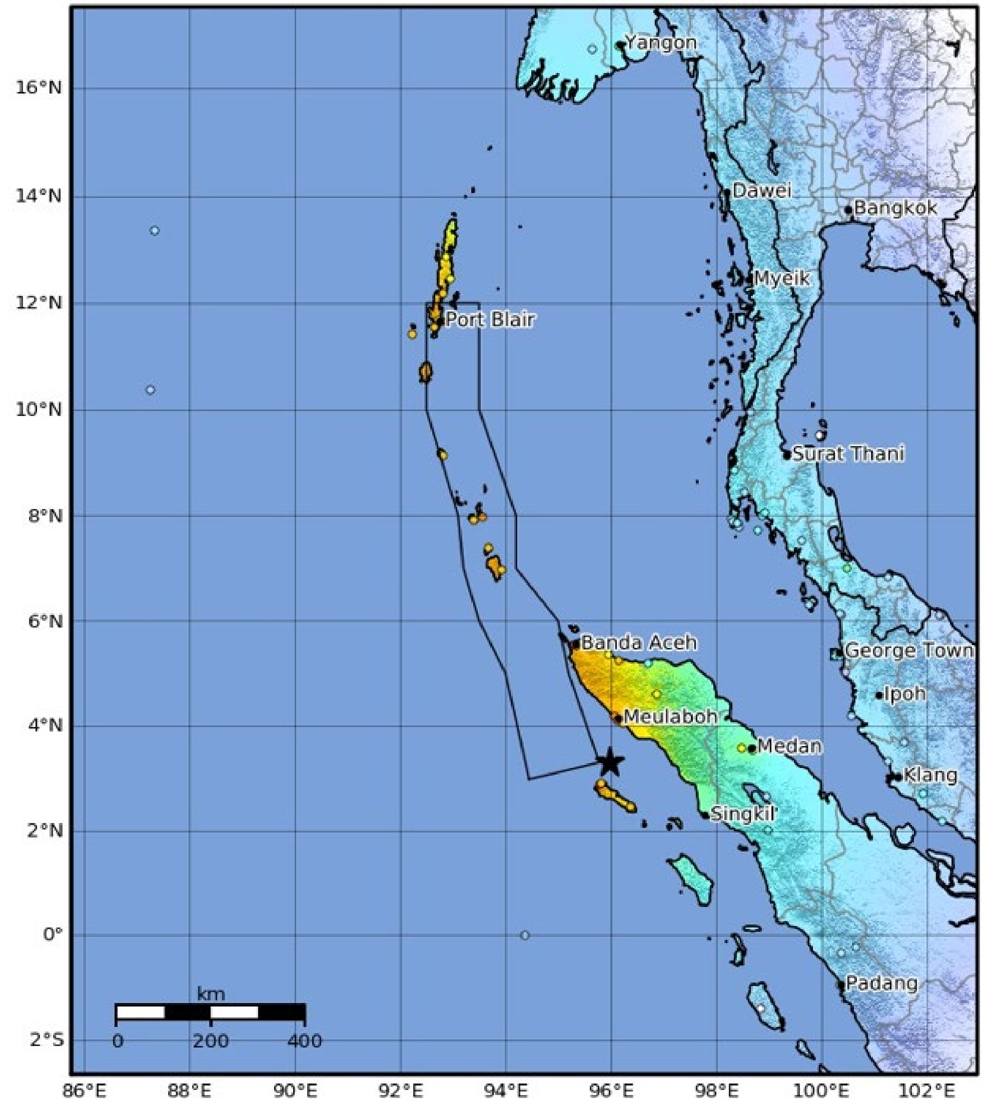


Image courtesy US Geological Survey

Magnitude 9.1 SUMATRA

Sunday, December 26, 2004 at 00:58:53 UTC

ALL

Sumatra is the largest island in the Indonesian territory and is the closest to the Asian continent. The Bukit Barisan Selatan National Park is a UNESCO World Heritage site. It is also home to the largest volcanic lake in the world called Lake Toba.

The rich volcanic soil supports a highly biodiverse rainforest ecosystem. This fertile soil has also helped Sumatra's agricultural industry: coffee, rice, coconuts, rubber and tea. Other industries include: cement, mining - mostly of coal, banking, fishing, and tourism. Tourists go to Sumatra for snorkeling, surfing, and the beautiful scenery.

Magnitude 9.1 SUMATRA
Sunday, December 26, 2004 at 00:58:53 UTC

ALL

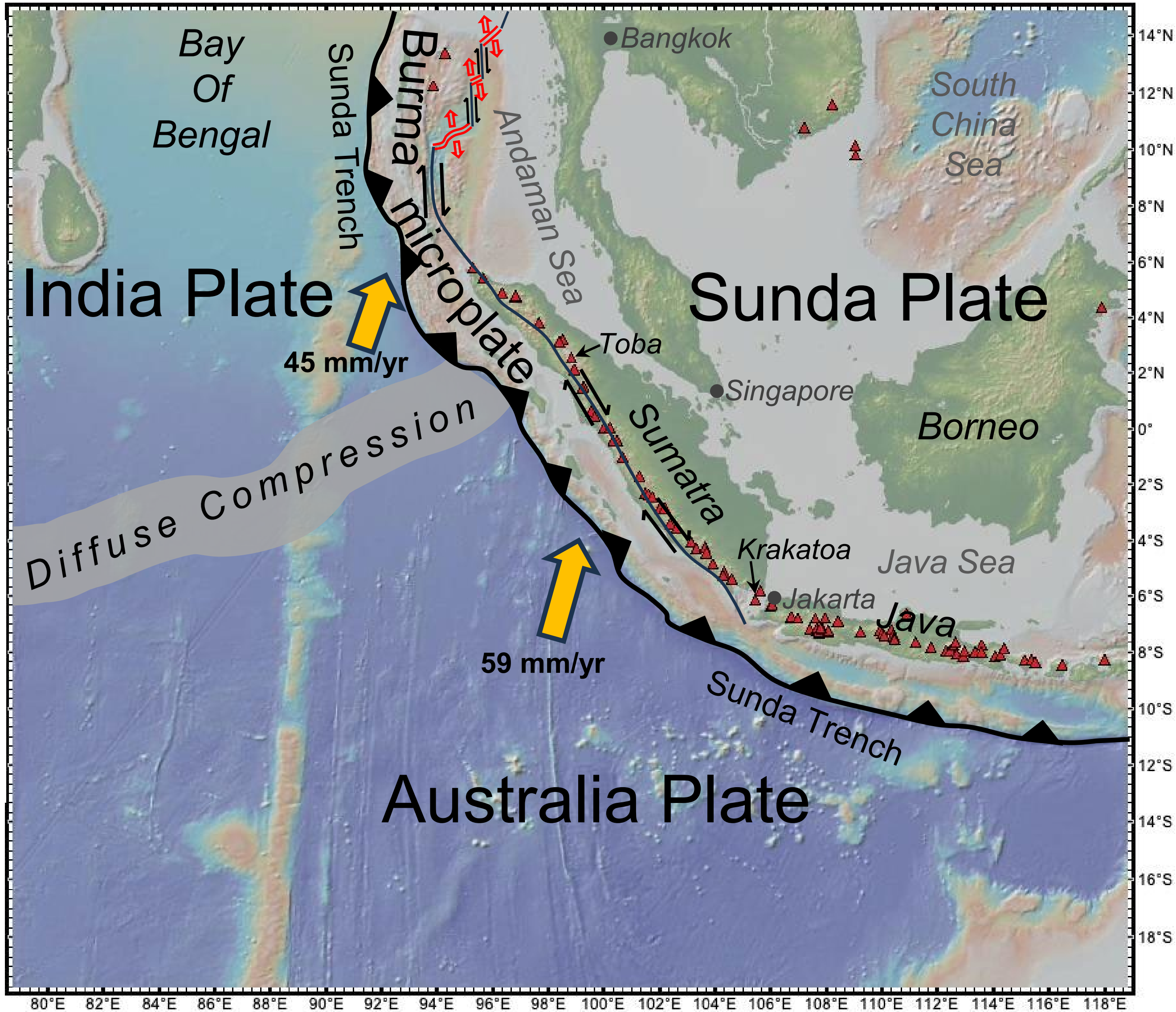
The map shows the major islands of Sumatra, Java, and Borneo on the Sunda Plate.

On the south side, the Australia Plate moves under the Sunda Plate at 59 mm/yr, creating the Sunda Trench.

On the northwest side, the India Plate moves under the Burma microplate at 45 mm/yr.

A compression zone separates the Australia and India plates.

Red triangles show volcanoes in the Sunda subduction zone, including Krakatoa and Toba.



Basemap from GeoMapApp

Magnitude 9.1 SUMATRA
Sunday, December 26, 2004 at 00:58:53 UTC

ALL

Before the Earthquake:

The India and Australia Plates subduct under the Burma and Sunda Plates but sometimes get stuck.

- Pressure builds causing ground to lift and push northeast.

During the Earthquake:

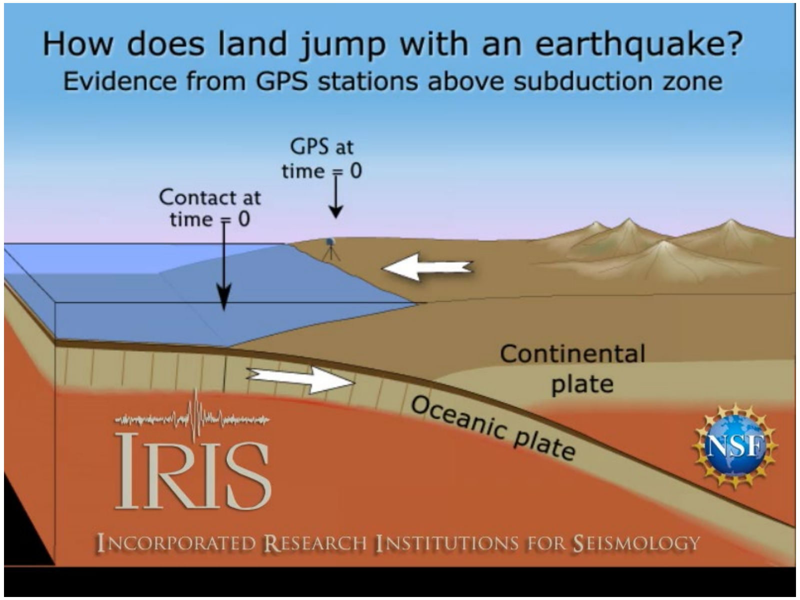
Plates suddenly slipped, causing an earthquake and releasing the pressure.

- Burma Microplate shifted west-southwest.
- Parts of the ocean floor rose while others sank, **triggering a massive tsunami.**

After the Earthquake:

The earthquake shifted landmasses.

- Islands near Sumatra moved southwest about 20 centimeters because of something called rebound.
- Some coastal areas sank, submerging parts of the land and changing the region's geography.



Magnitude 9.1 SUMATRA

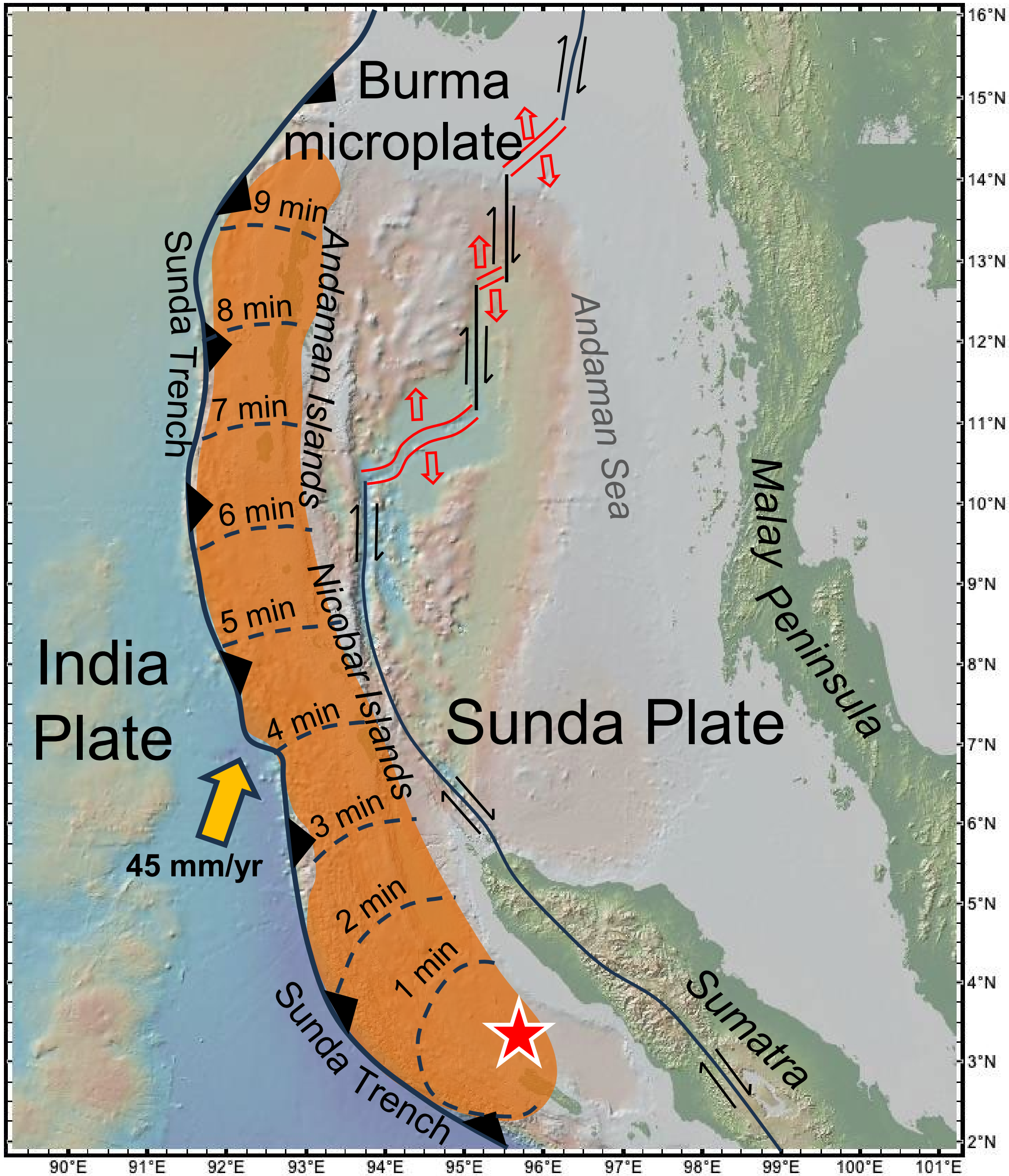
Sunday, December 26, 2004 at 00:58:53 UTC

The red star marks the epicenter of the 2004 Magnitude 9.1 Sumatra-Andaman earthquake, and the rupture zone is shown in orange.

The earthquake moved at 2.5 km/second along the boundary where the India Plate subducts beneath the Burma microplate.

A remarkable feature of this earthquake was the length of the rupture zone, stretching almost 1300 km—about the length of California.

Dashed lines on the map show how the rupture front moved: it passed the Nicobar Islands in 3–6 minutes and the Andaman Islands in 6–9 minutes after the initial rupture near Sumatra.



Magnitude 9.1 SUMATRA

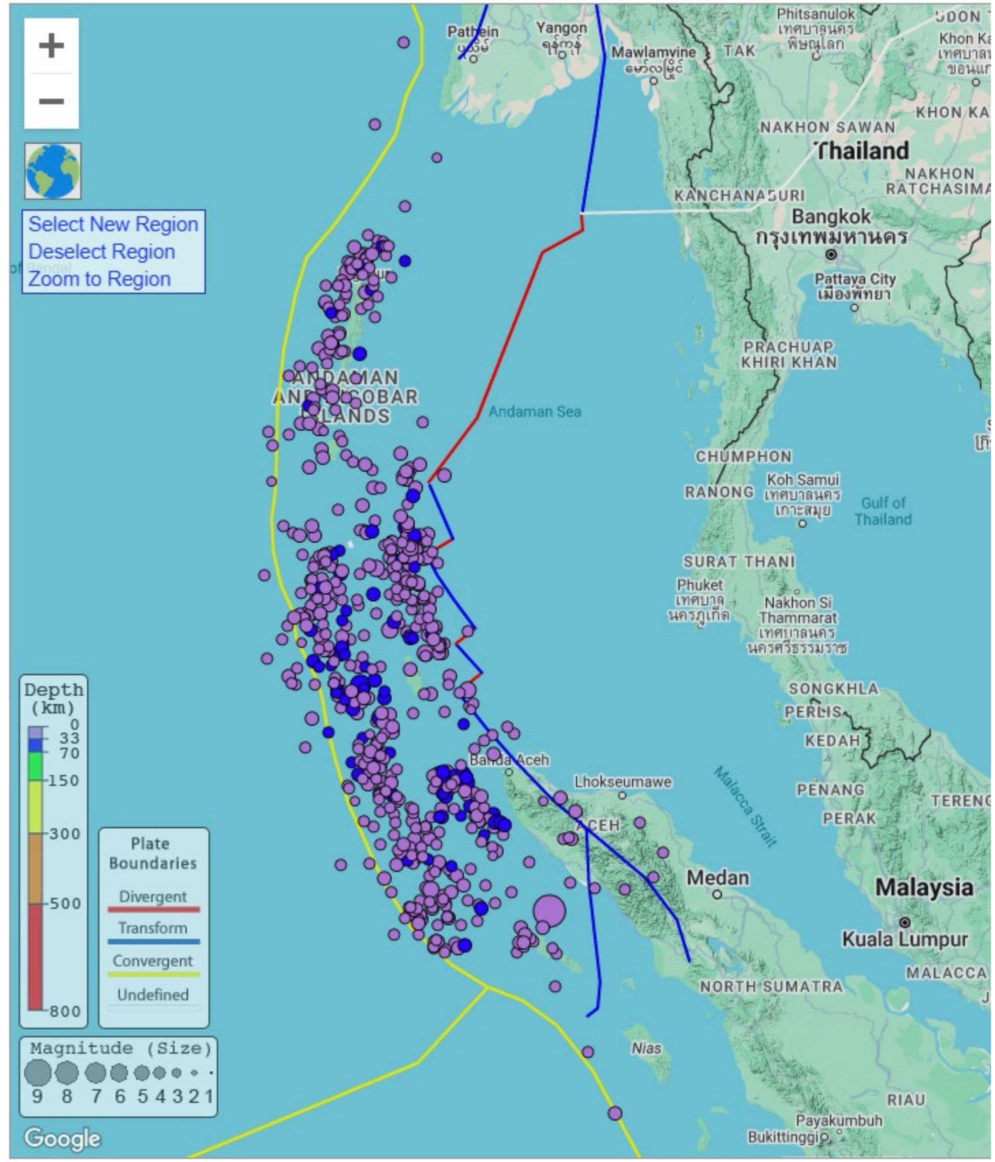
Sunday, December 26, 2004 at 00:58:53 UTC

While commonly plotted as points on maps, earthquakes of this size are more appropriately described as slip over a large fault area.

One week of aftershocks are plotted, sized by magnitude and colored by depth.

The slip wasn't uniform across the fault. After an earthquake, the stress on the fault changes. Aftershocks occur due to these stress changes.

Since aftershocks occur on or near the main fault, their distribution allows visualization of the size of the rupture from this earthquake.



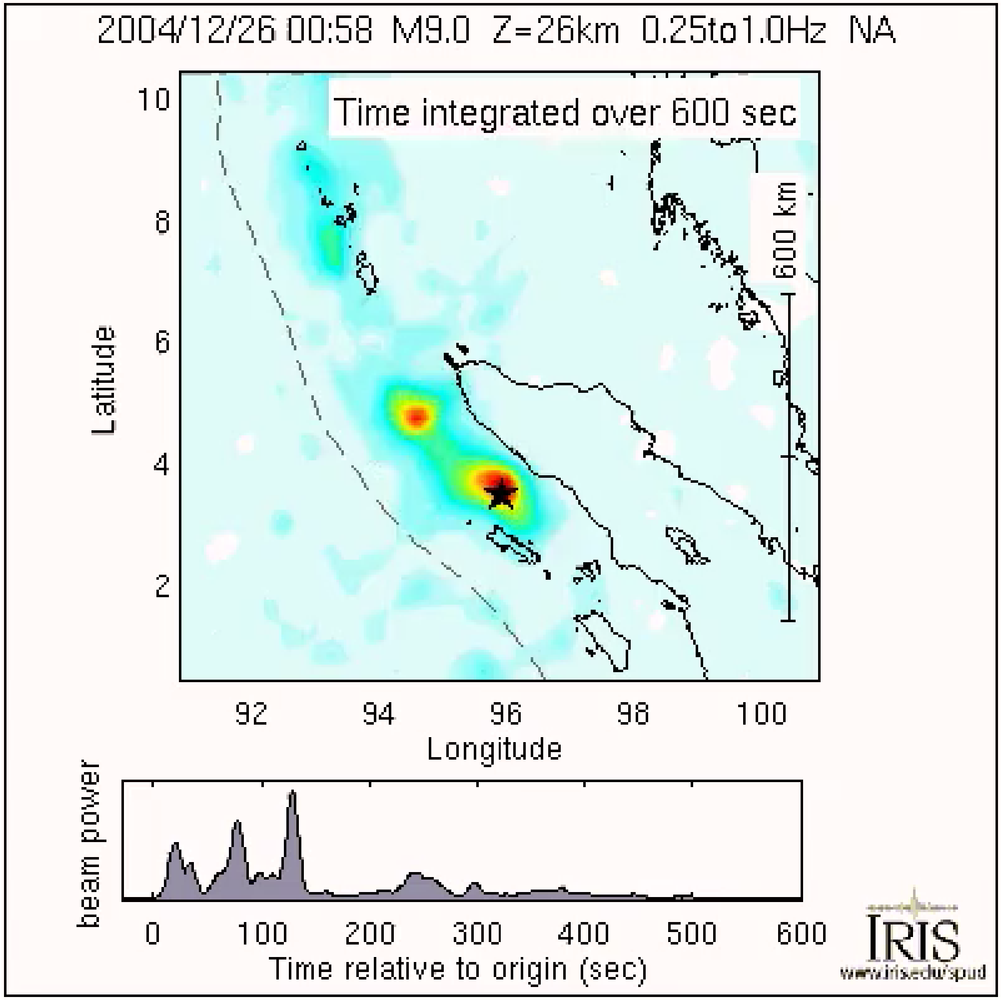
Magnitude 9.1 SUMATRA
Sunday, December 26, 2004 at 00:58:53 UTC

C

Back Projections are movies created from an automated data processing sequence that stacks up P wave energy recorded on many seismometers on a flat grid around the source region. This grid is meant to be a fault surface and creates a time and space history of the earthquake.

Warmer colors indicate greater beam power.

This event has an extremely complex source. The source-time function is about 600 seconds in duration.



Magnitude 9.1 SUMATRA
Sunday, December 26, 2004 at 00:58:53 UTC

One of the ways we measure ground motion is with GPS instruments. GPS stations receive signals from satellites and use the time offset between when the signal leaves the satellite and when it arrives at the station to determine distance. If a station receives signals from 4 or more stations, it can determine its location (6 or more satellites is much better).

This is the same way GPS works in phones and other devices, but the high-precision stations can determine location within millimeters (<¼ inch) rather than 5-10 meters (15-30 feet).

The purple arrows on the map show horizontal GPS displacements.

The 2004 magnitude 9.1 Sumatra-Andaman earthquake was the first magnitude 9 event recorded by modern broadband seismometers and GPS networks.

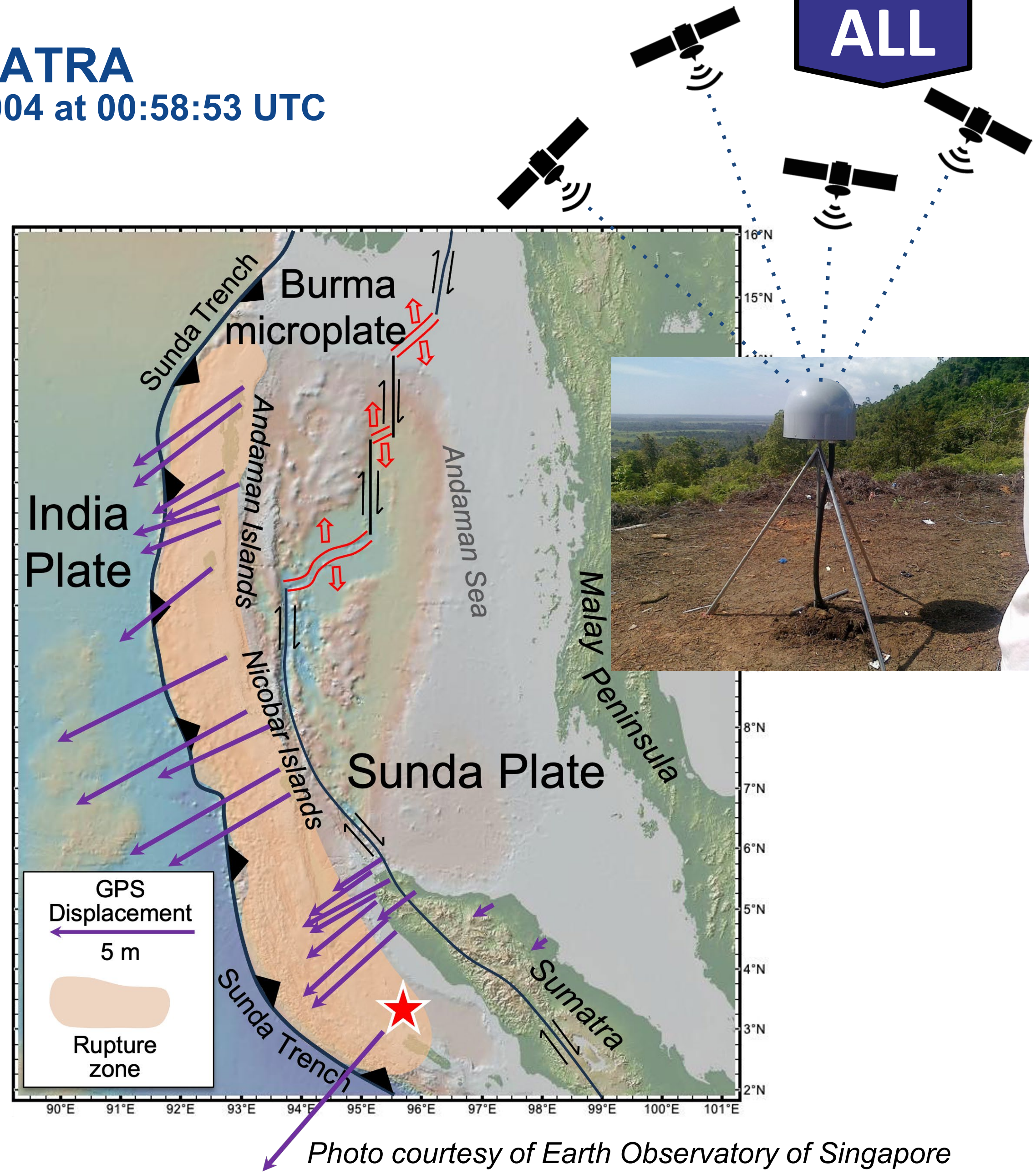


Photo courtesy of Earth Observatory of Singapore

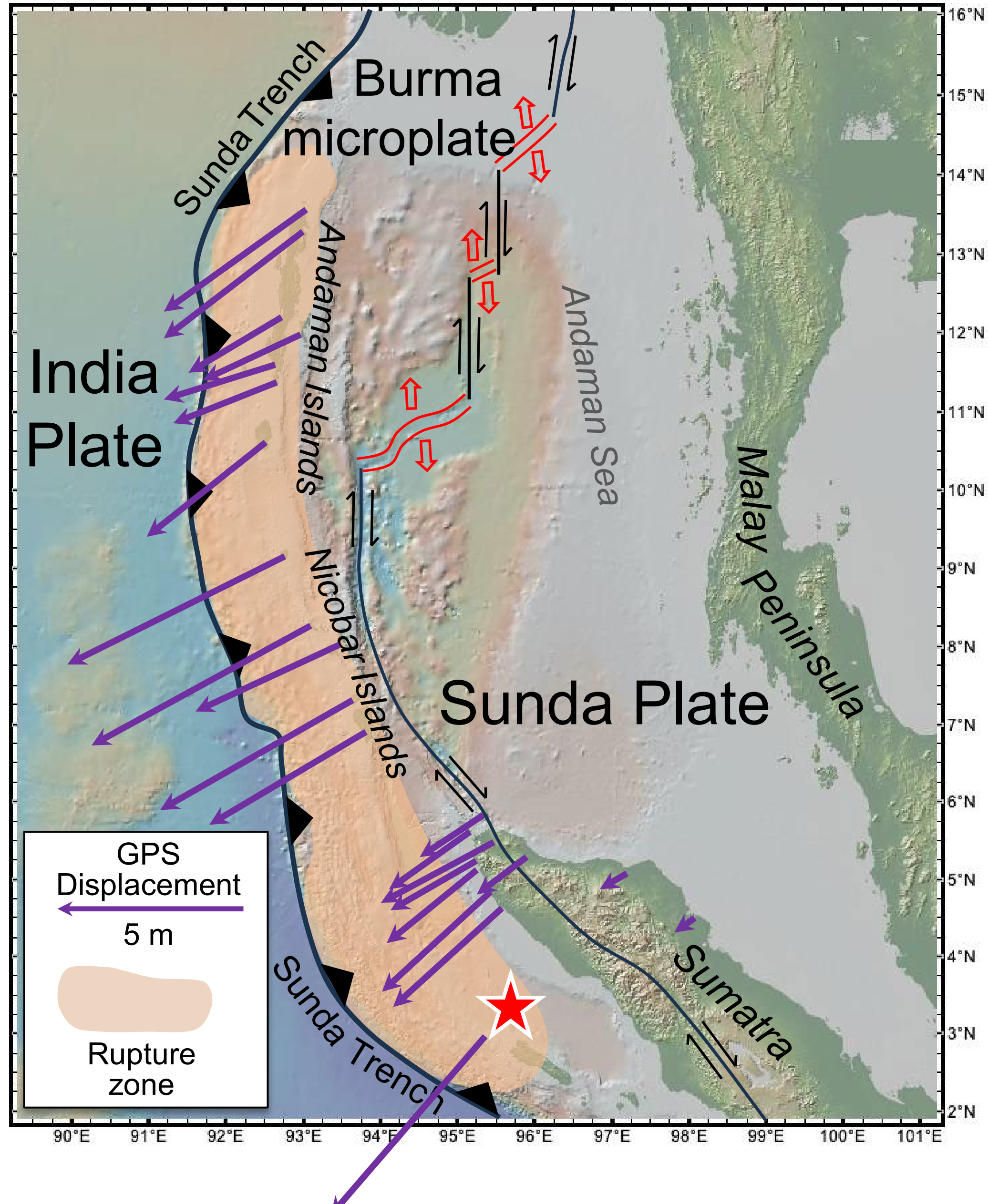
Magnitude 9.1 SUMATRA
Sunday, December 26, 2004 at 00:58:53 UTC

During the Magnitude 9.1 Sumatra-Andaman, the closest permanent GPS stations were on the Malay Peninsula and only moved 30 cm (~1 ft).

But after the earthquake, scientists remeasured benchmarks on in northern Sumatra, the Nicobar Islands, and the Andaman Islands and learned that the land had moved up to 6 meters to the southwest.

Campaign GPS on a tripod

Permanent GPS station drilled into the ground.



Magnitude 9.1 SUMATRA

Sunday, December 26, 2004 at 00:58:53 UTC

C

The map shows a fault-displacement model for the 2004 magnitude 9.1 Sumatra-Andaman earthquake.

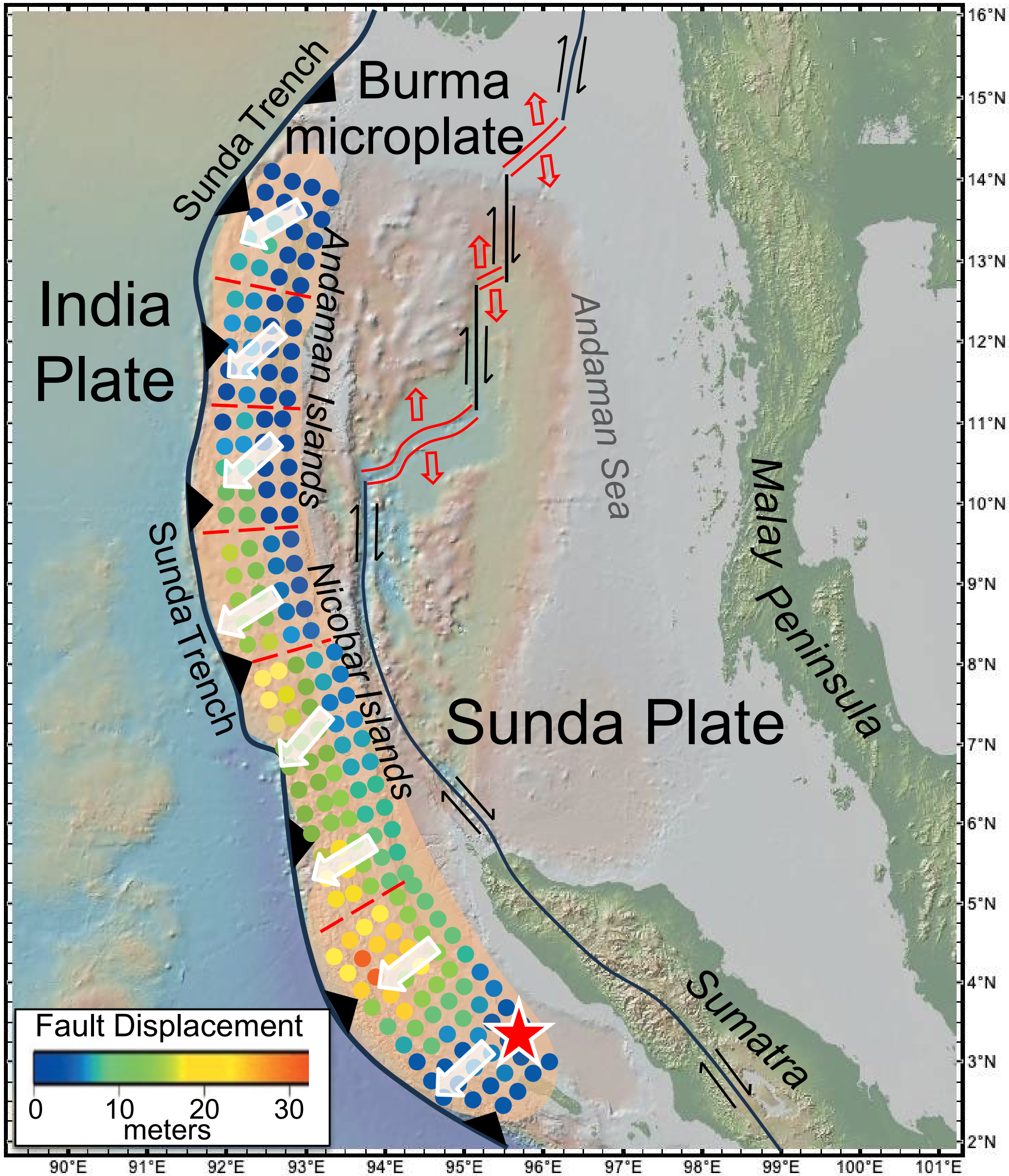
The red star marks the epicenter, and the rupture zone is shown in salmon.

Seismic data from 10 stations around the earthquake and GPS data from 38 stations near the rupture zone were analyzed.

The megathrust rupture zone between the India and Burma plates was divided into six segments, with red dashed lines showing the boundaries.

Colored circles represent the displacement of each 30 km by 30 km patch of the rupture zone, while white arrows show the direction of the Burma microplate's movement relative to the India Plate.

Fault displacement was over 30 meters near 4° N, 94° E, and over 20 meters near 8° N, 93° E.



Magnitude 9.1 SUMATRA

Sunday, December 26, 2004 at 00:58:53 UTC

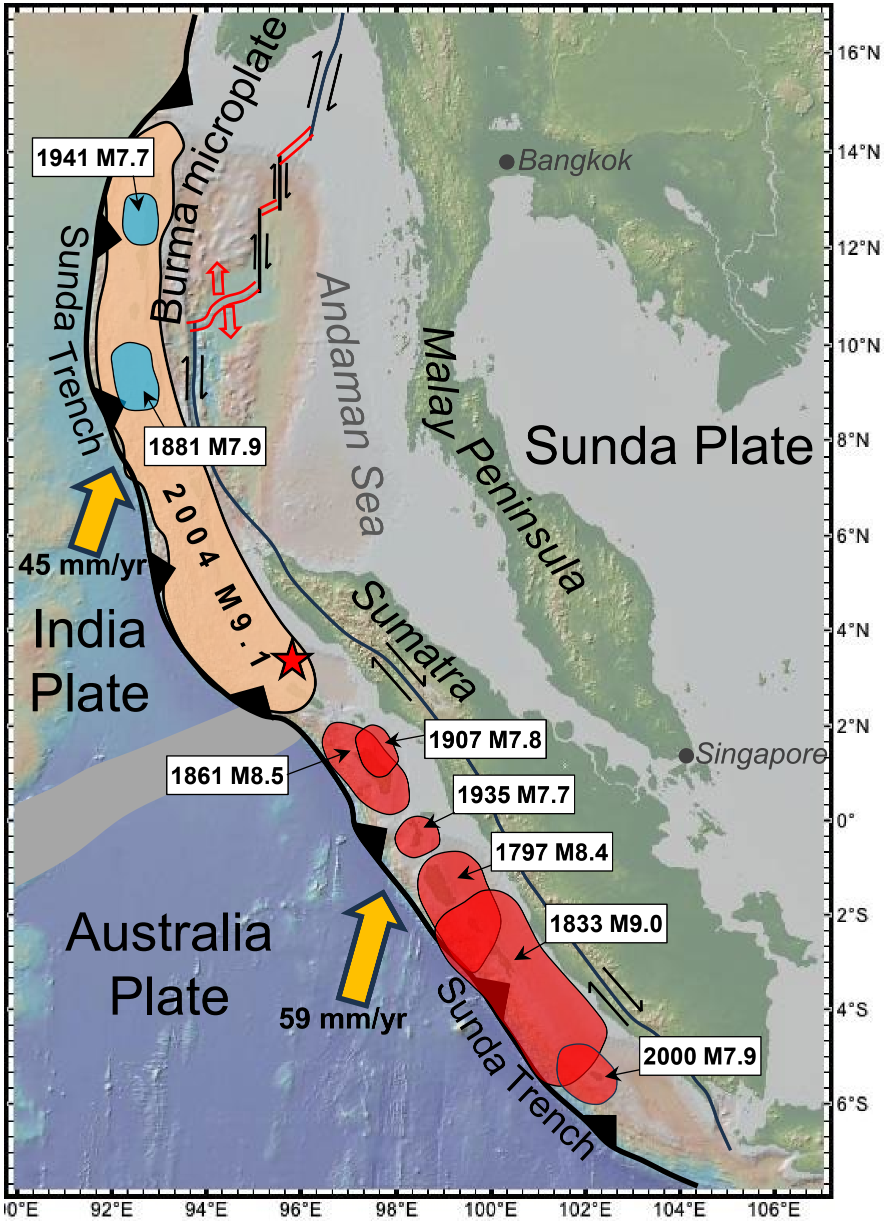
This map summarizes earthquake history from 1797 to 2004.

The red star marks the epicenter, and the salmon color shows the rupture zone of the 2004 magnitude 9.1 earthquake.

Red areas show rupture zones of six magnitude 7.7-9.0 earthquakes from 1797 to 2000 that occurred south of the 2004 rupture zone.

In contrast, before the 2004 earthquake, only two strong earthquakes larger than magnitude 7.7 and no great megathrust earthquakes had been recorded along the Sunda subduction zone between the India and Burma plates (shown in blue).

This history shows that a few centuries of data is not enough to fully understand the maximum size of earthquakes that can occur along a megathrust boundary.



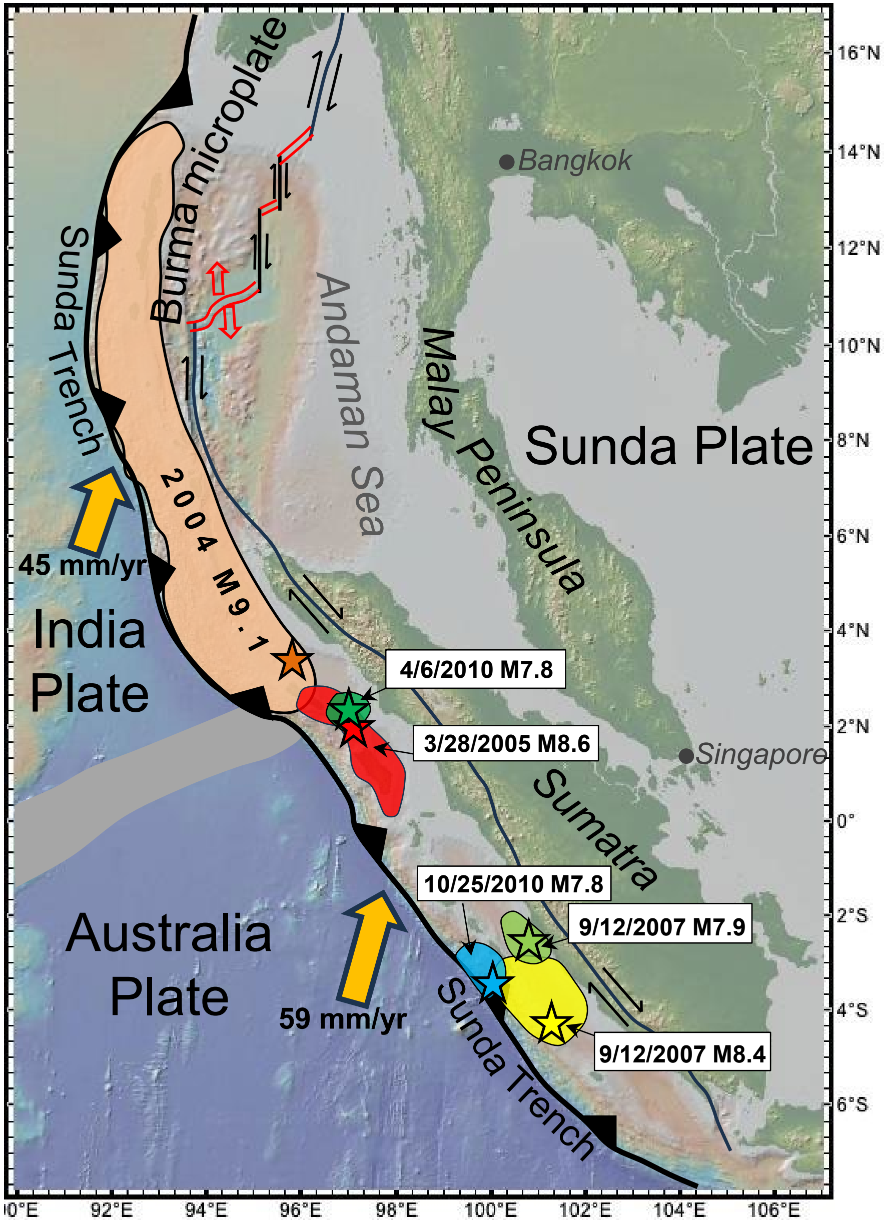
Magnitude 9.1 SUMATRA

Sunday, December 26, 2004 at 00:58:53 UTC

C

Since the 2004 earthquake, the Australia-Sunda megathrust boundary west of Sumatra has experienced a significant increase in major and great earthquakes.

- From 2005 to 2010, there were:
  - Two earthquakes magnitude ≥8
  - Three earthquakes magnitude ≥ 7.8
- The 2004 magnitude 9.1 Sumatra-Andaman earthquake likely triggered the 2005 magnitude 8.6 Nias-Simeulue earthquake, resulting in:
  - Over 1,000 fatalities
  - A tsunami with waves up to 3 meters high
- On September 12, 2007:
  - A magnitude 8.4 earthquake struck just north of the June 4, 2000 rupture zone, leading to 25 fatalities.
  - A magnitude 7.9 earthquake occurred at the northern edge of the aftershock zone from the earlier quake.



Magnitude 9.1 SUMATRA

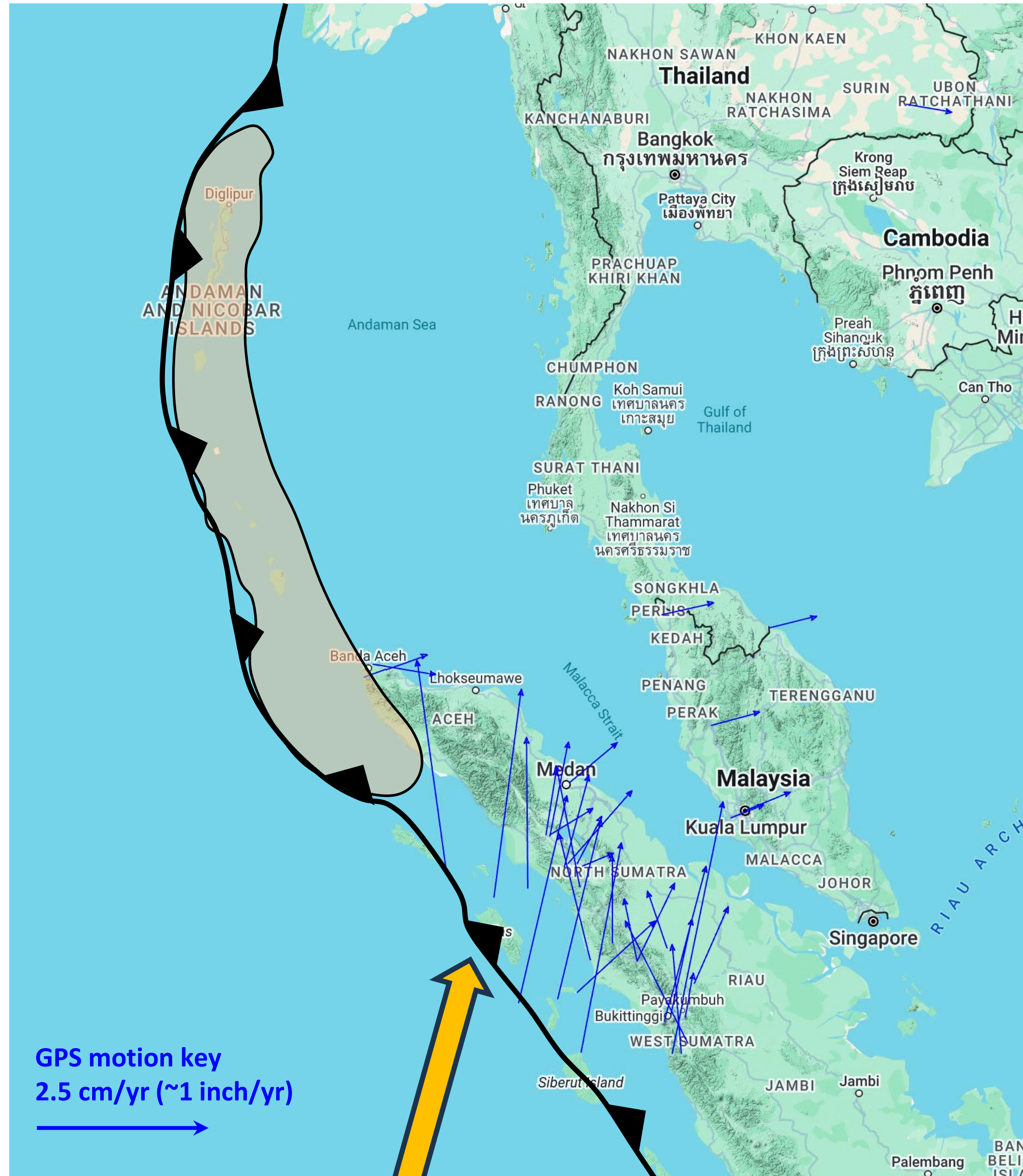
Sunday, December 26, 2004 at 00:58:53 UTC

In the time since the 2004 M 9.1 Sumatra-Andaman earthquake, permanent GPS have been installed around Sumatra.

The stations closest to the plate boundary are moving to the north-northwest at ~3 cm/yr (~1.2 inch/yr), compared to more stable northern Asia.

They are being pushed by the Indian Plate as it subducts below Sumatra.

Over decades and centuries this compression accumulates until it is released in earthquakes like the 2004 Sumatra-Andaman earthquake.

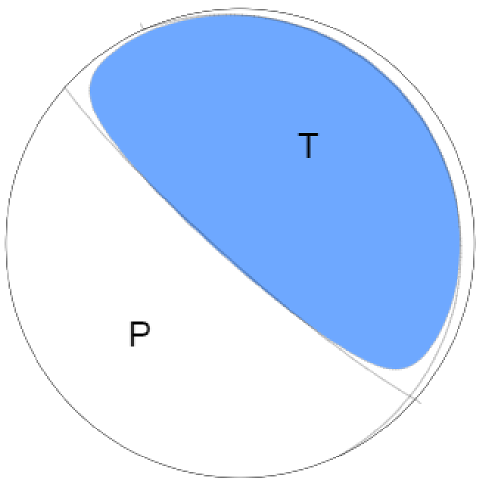


C

Magnitude 9.1 SUMATRA

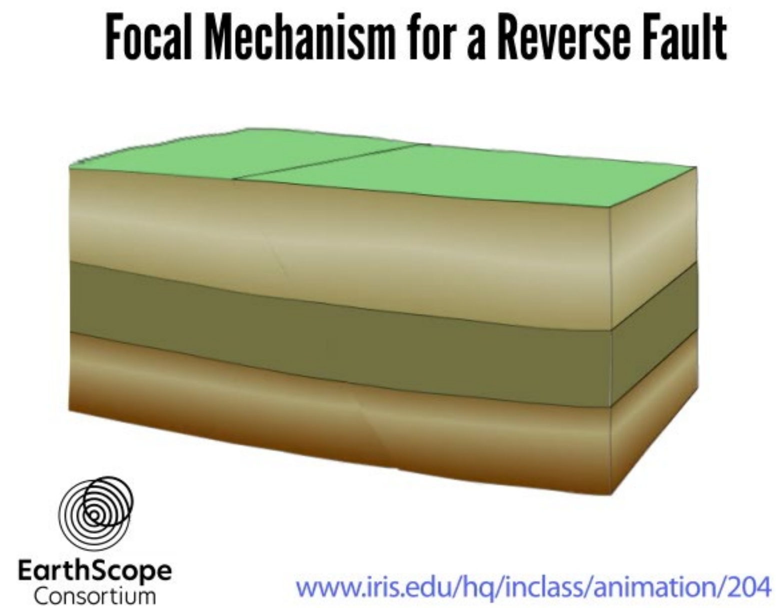
Sunday, December 26, 2004 at 00:58:53 UTC

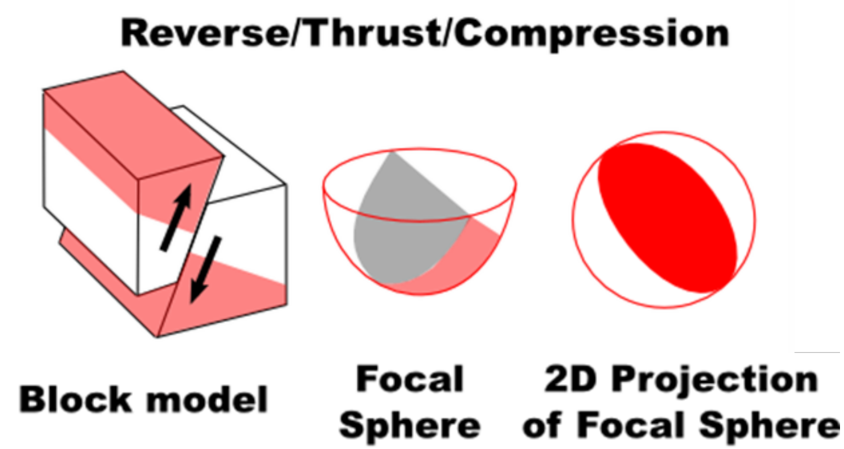
The focal mechanism is how seismologists plot the 3-D stress orientations of an earthquake. Because an earthquake occurs as slip on a fault, it generates primary (P) waves in quadrants where the first pulse is compressional (shaded) and quadrants where the first pulse is extensional (white). The orientation of these quadrants determined from recorded seismic waves determines the type of fault that produced the earthquake.



USGS W-phase Moment Tensor Solution

The tension axis (T) reflects the minimum compressive stress direction. The Pressure axis (P) reflects the maximum compressive stress direction.





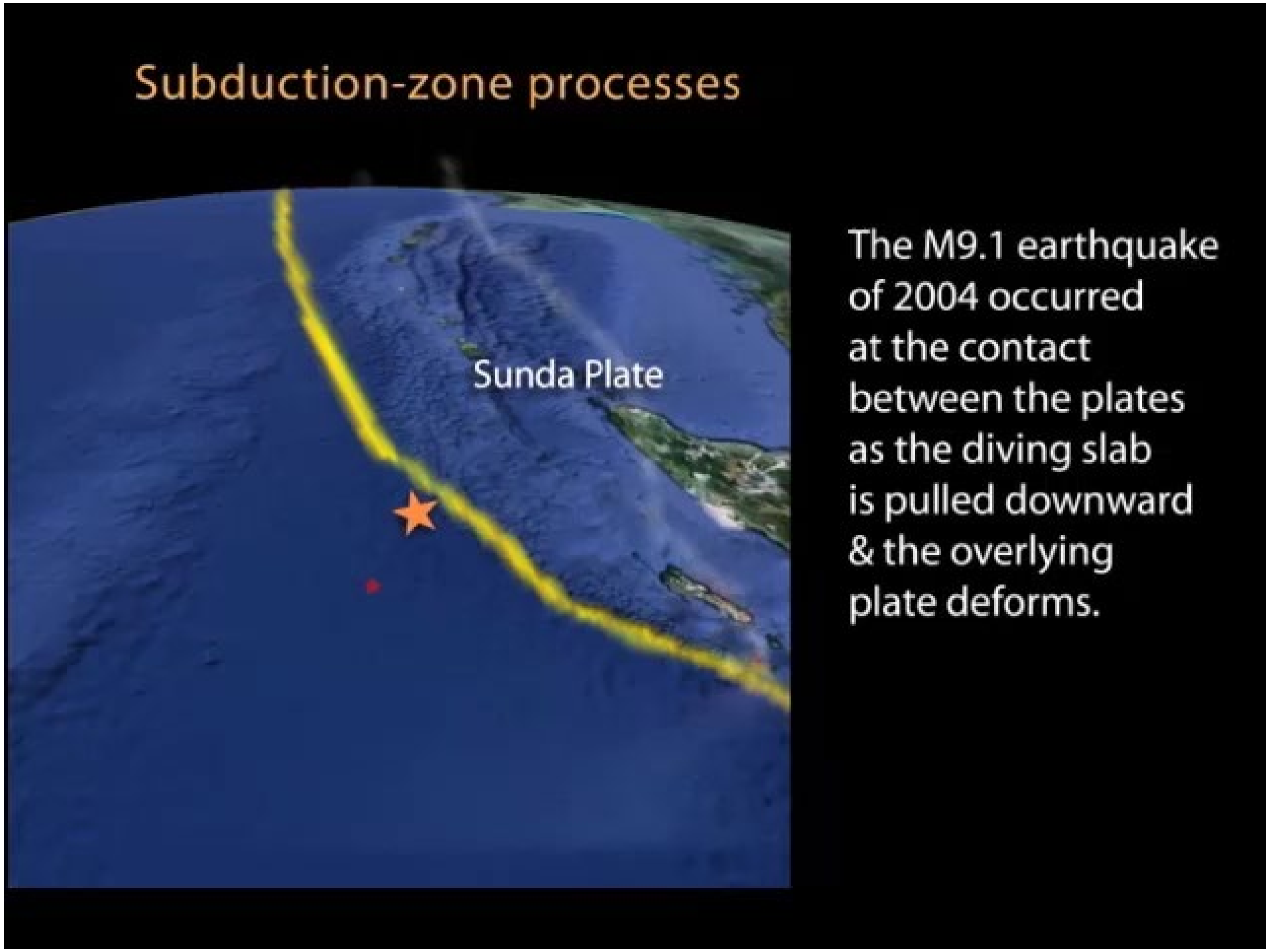
Magnitude 9.1 SUMATRA

Sunday, December 26, 2004 at 00:58:53 UTC

Slip along the megathrust boundary between the between the subducting India Plate and the overriding Sunda Plate caused vertical displacement of the seafloor, generating a large tsunami that radiated outward in all directions.

The tsunami produced by the 2004 Sumatra earthquake was the largest and deadliest in recorded history.

The tsunami waves traveled as fast as a jet plane away from the fault in all directions.



Video excerpt from *Sumatra: A Tale of Two Earthquakes*

Magnitude 9.1 SUMATRA
Sunday, December 26, 2004 at 00:58:53 UTC

C

Within minutes after the earthquake occurred, the tsunami arrived and devastated the coastal villages of Sumatra Island. Around two hours after the earthquake, the tsunami arrived at the coasts of Thailand, Sri Lanka, and India, causing mass fatalities. Seven hours after the earthquake, the tsunami stuck the east coast of Africa, resulting in fatalities in Somalia.

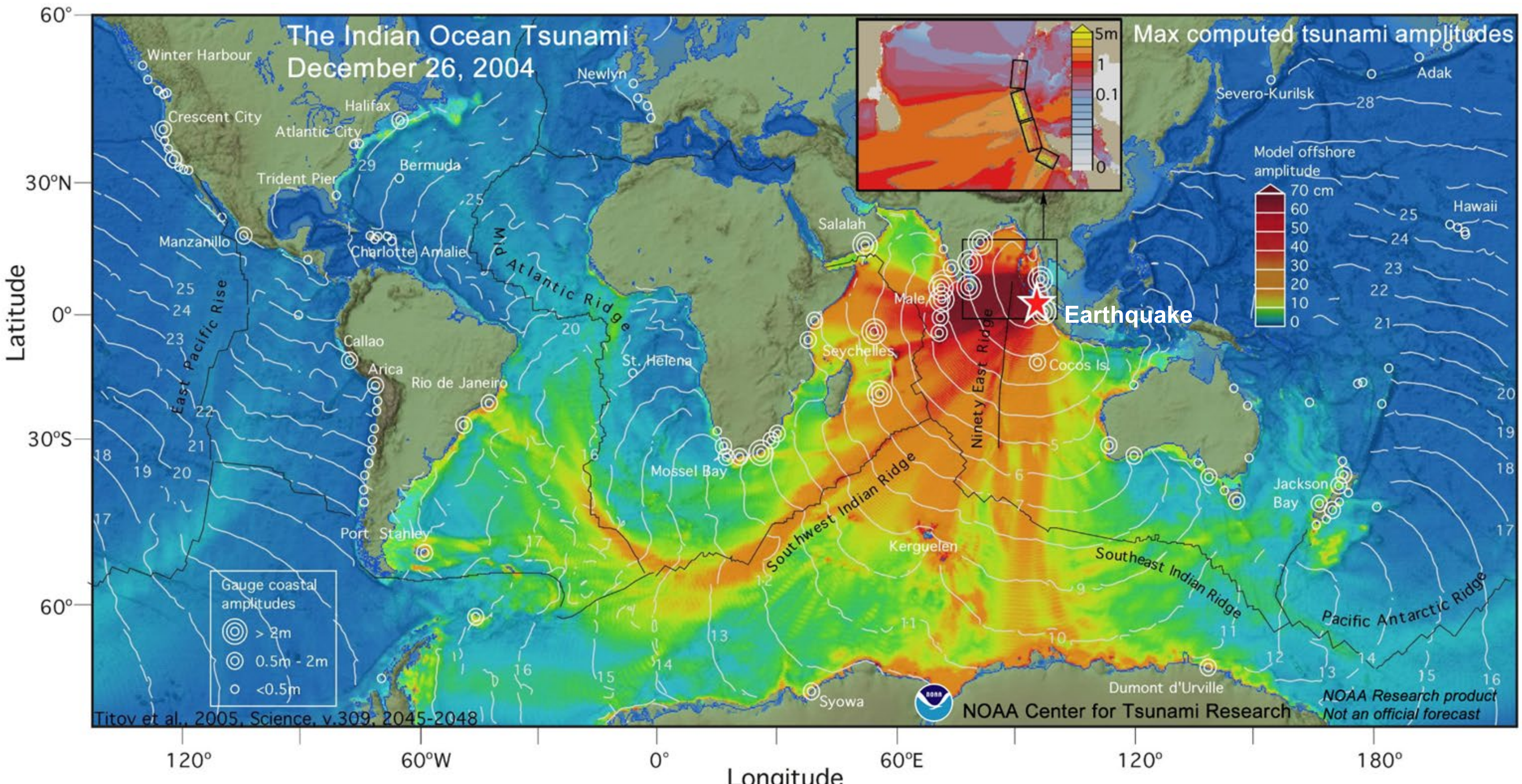


Image courtesy of NOAA

Magnitude 9.1 SUMATRA
Sunday, December 26, 2004 at 00:58:53 UTC

C

The tsunami produced wave heights above 32 feet (10 m) along parts of Thailand and Sri Lanka and wave heights up to 100 feet (30 m) along parts of Indonesia.

The 167 foot (51 m) waves recorded in Northern Sumatra caused flooding 3 miles (5 km) inland.

The figure on the right highlights elevations within 33 ft (10 m) of Sea Level acquired from the Shuttle Radar Topography Mission (SRTM) flown aboard the space shuttle Endeavour in February 2000. The project acquired radar data which were used to create the first near-global set of land elevations.

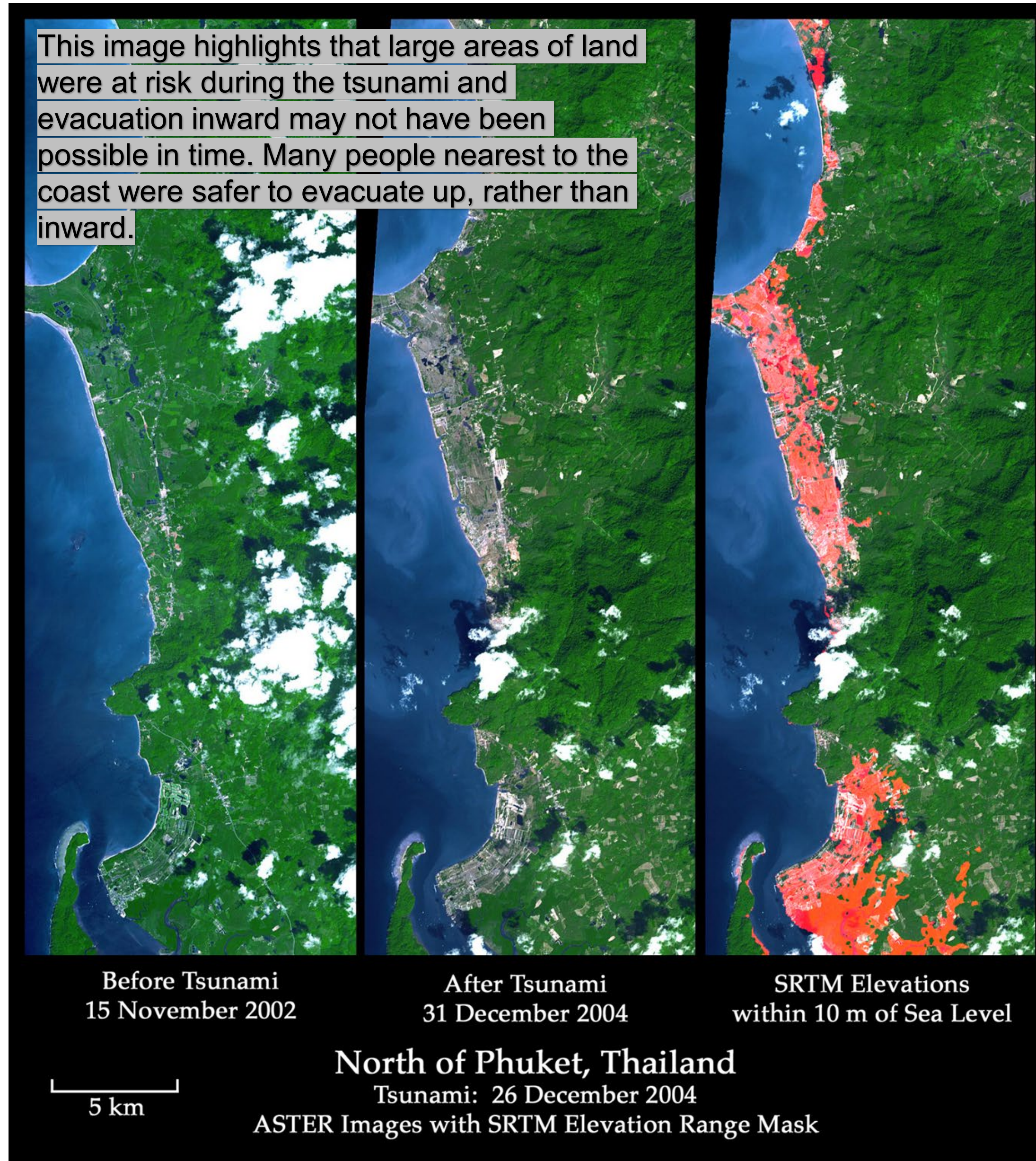


Image courtesy of NASA/JPL

Magnitude 9.1 SUMATRA
Sunday, December 26, 2004 at 00:58:53 UTC

HS

The magnitude of a submarine earthquake is the most important factor in determining the size of a tsunami produced.

The size of the 2004 Sumatra tsunami was similar in size to the tsunami produced by the magnitude 9.2 1964 Great Alaska earthquake.

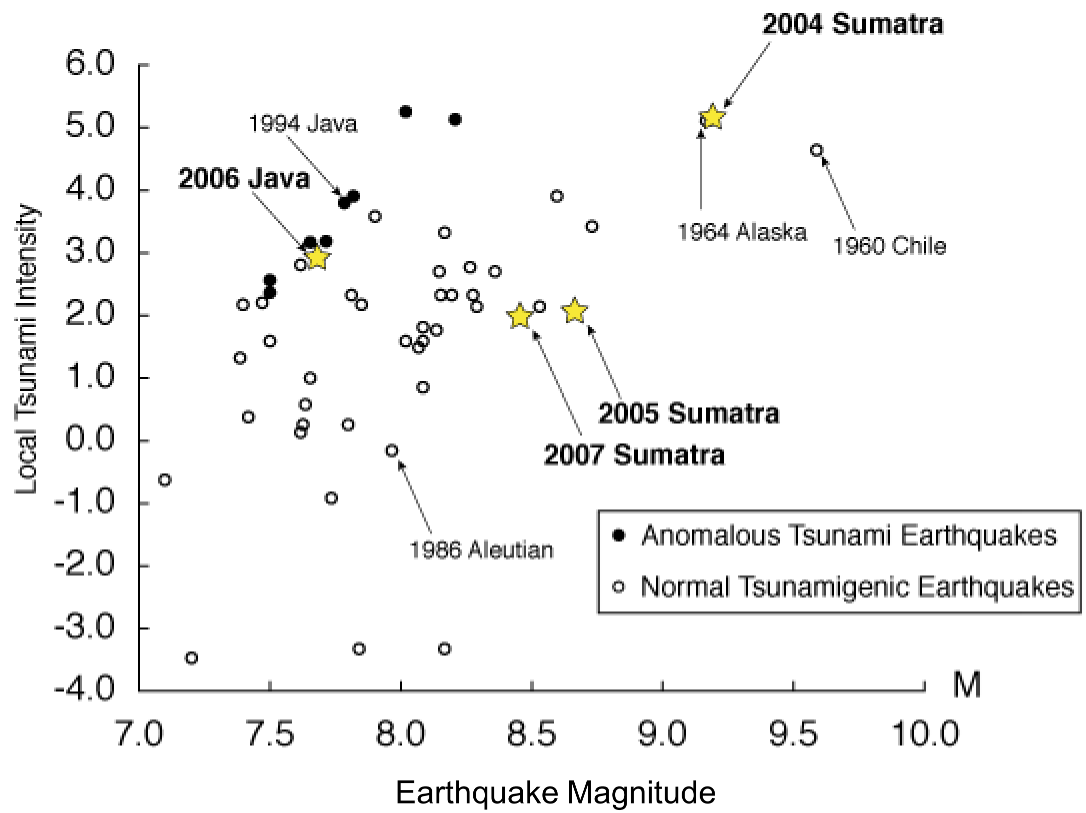


Image courtesy of the USGS

Magnitude 9.1 SUMATRA

Sunday, December 26, 2004 at 00:58:53 UTC

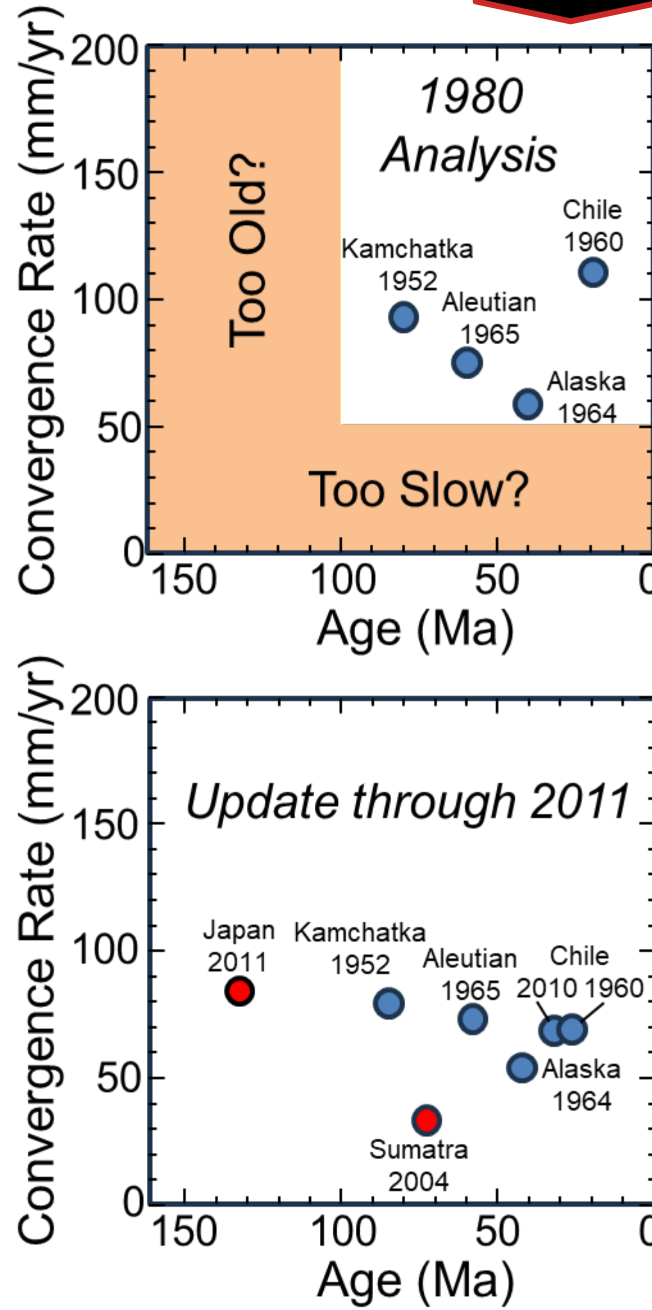
C

Shallow subduction zone megathrust earthquakes pose hazards of intense shaking and large tsunamis, potentially impacting entire ocean basins.

A 1980 study of M>8.7 earthquakes (1952-1965) suggested that such massive events might only occur where young, fast-moving oceanic plates subduct. These young, warm plates increase friction at the boundary, storing elastic energy released in rare, large quakes. In contrast, old, dense plates were thought less likely to cause such events due to weaker coupling.

However, the 2004 Sumatra earthquake (M9.1) and the 2011 Japan earthquake (M9.1) disproved these assumptions, showing that even slow-moving or old subducting plates can produce immense quakes.

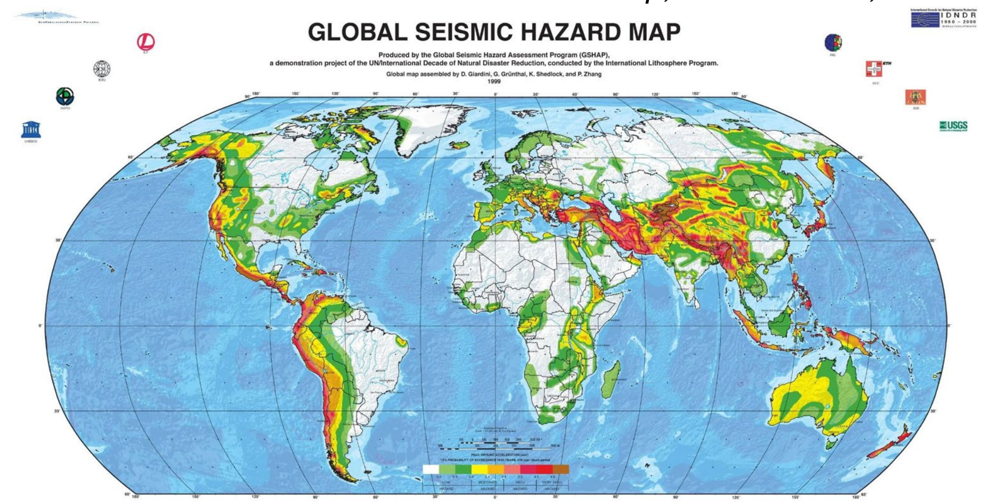
Now, it's clear that many more subduction zones have the potential to generate extremely large megathrust earthquakes.



ALL

Magnitude 9.1 SUMATRA
Sunday, December 26, 2004 at 00:58:53 UTC

Global Seismic Hazard Map, Giardini et al., 2003



Natural hazards are caused by many events, including avalanches, droughts, earthquakes, floods, volcanoes, wildfires, etc. While most of these hazards are unavoidable, the impact they have on people and societies can be reduced through preparedness.

One way to prepare for earthquake hazards is by preparing hazard maps, like the ones for seismic and tsunami hazards seen here. These maps use scientific and historical knowledge to identify where future hazards are likely to occur so that people in those areas can take steps to prevent damages, injuries, and deaths.

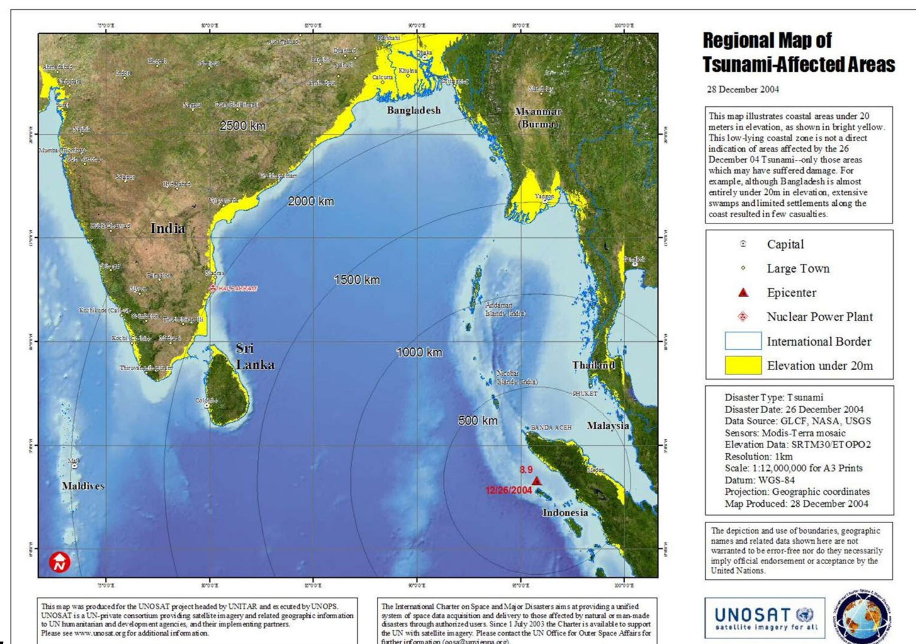


Image courtesy of UNOSAT

Magnitude 9.1 SUMATRA
Sunday, December 26, 2004 at 00:58:53 UTC

ALL

The deadliest hazard produced by the M9.1 Sumatra earthquake was the massive tsunami it generated which spread across the Indian Ocean.

In some places people vacationing ventured into the ocean to explore the exposed seafloor and pick seashells as the water withdrew ahead of the approaching tsunami waves. They did not recognize the ocean withdrawing as a sign of the tsunami.

Hazard education, like the installation of tsunami evacuation signs below, is one step that states and governments have taken to warn people about the dangers of tsunamis and how to avoid them.

Hat Rai Lay Beach, near Krabi in southern Thailand. Waders escaping from the first wave of the 26 December 2004 tsunami.

Tsunami hazard zone warning sign at Rockaway Beach, Oregon

At the time of this earthquake, there was no tsunami warning system in place in the Indian Ocean, and proper education on local tsunami hazards was lacking.

The 2004 tsunami prompted the creation of an Indian Ocean Tsunami Warning System and lead to the completion of NOAA's Deep-ocean Assessment and Reporting of Tsunami (DART) buoy array, helping to forecast when a tsunami may hit the coast.

A NOAA DART buoy can measure tsunami waves as small as 1 cm in the open ocean.

Image courtesy of NOAA

ALL

Magnitude 9.1 SUMATRA
Sunday, December 26, 2004 at 00:58:53 UTC

The effectiveness of hazard education was made clear by the story of Tilly Smith, a 10-year-old girl who was vacationing in Thailand with her family when the tsunami struck.

She had recently learned about tsunamis in her UK geography class, including the warning signs and how to respond. She alerted her family and the hotel staff of the danger, and nearly 100 beachgoers were evacuated as a result.

The evacuees made it to the second floor of the hotel just as the first waves arrived, and their beach was one of only a few in the area that reported no casualties.

Tsunamis are not as likely in the UK, where Tilly is from, but she still learned about them in class and was able to apply her knowledge in an emergency.

Video via United Nations,
https://www.youtube.com/watch?v=V0s2i7Cc7wA

Magnitude 9.1 SUMATRA

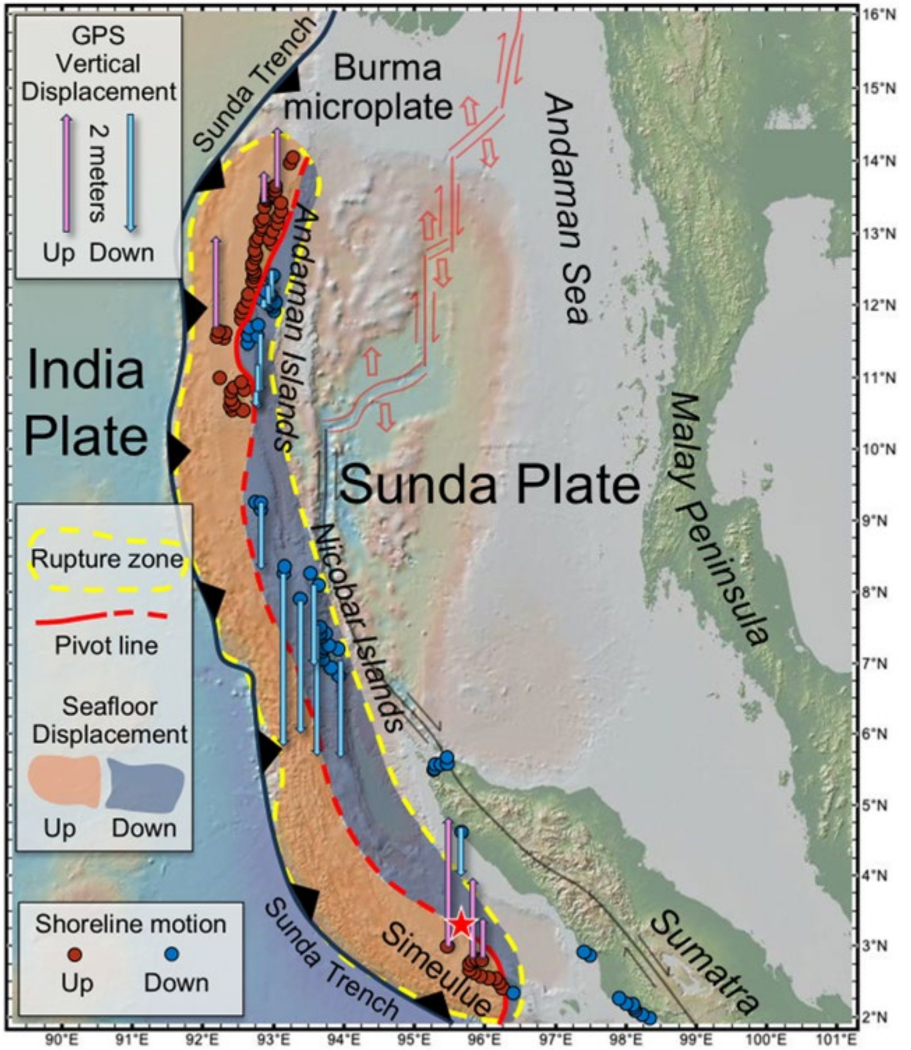
Sunday, December 26, 2004 at 00:58:53 UTC

The islands within the earthquake zone showed how the seafloor moved due to the quake. This movement helped cause the Tsunami and is visible after the event.

On the Andaman and Nicobar Islands, satellite images of coral reefs before and after the earthquake showed areas where shorelines rose or sank. In Simuelue and Sumatra, scientists measured changes in coral heads to estimate these shifts. Red circles mark areas of uplift (where the land rose), and blue circles mark subsidence (where it sank).

The Nicobar Islands sank nearly 3 meters, while parts of the Andaman Islands and Simuelue rose by about 2 meters.

These changes show that the seafloor sank on the eastern side of the rupture and rose on the western side.



Magnitude 9.1 SUMATRA
Sunday, December 26, 2004 at 00:58:53 UTC

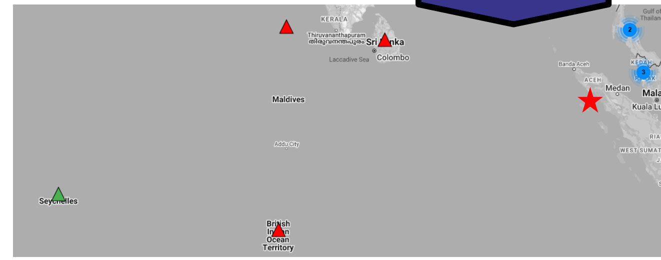
ALL

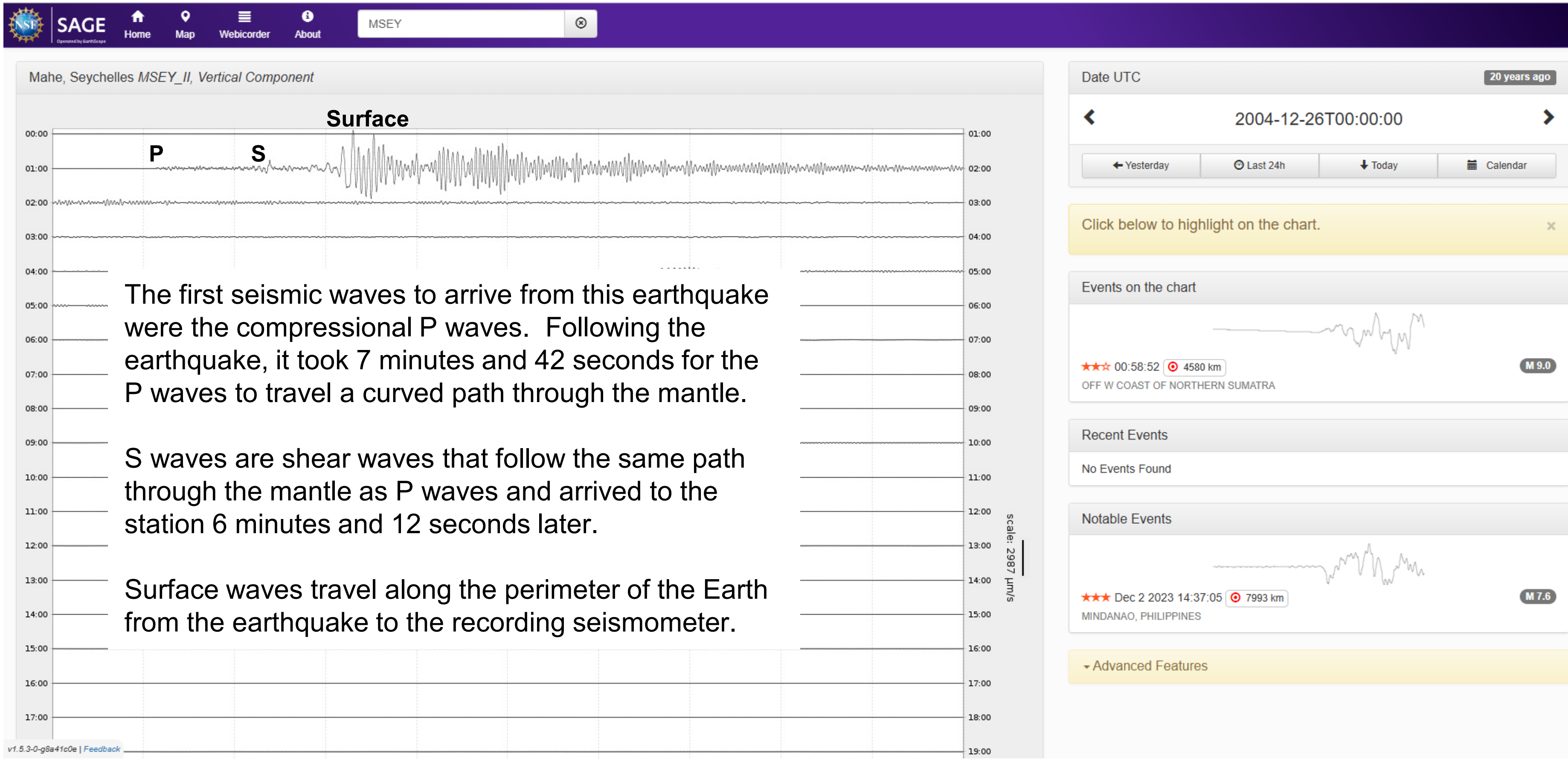
Ecosystems are impacted by natural hazards and humans:

- The tsunami's powerful waves damaged coastal regions and reefs.
- Ground deformation affected agriculture, coral reefs and mangroves.
- The tsunami caused saltwater contamination of wetlands, freshwater sources and agricultural land.
- Deforestation has caused 50% of the rainforests to disappear over the last 35 years.
- The Sumatran ground cuckoo, Sumatran tiger, rhinoceros, and orangutan are among critically endangered species.

ALL

Magnitude 9.1 SUMATRA
Sunday, December 26, 2004 at 00:58:53 UTC





The first seismic waves to arrive from this earthquake were the compressional P waves. Following the earthquake, it took 7 minutes and 42 seconds for the P waves to travel a curved path through the mantle.

S waves are shear waves that follow the same path through the mantle as P waves and arrived to the station 6 minutes and 12 seconds later.

Surface waves travel along the perimeter of the Earth from the earthquake to the recording seismometer.

Station Monitor provides web access to continuous, real-time ground motion from hundreds of locations around the globe. Above is the recording of this earthquake at Mahe, Seychelles about 4580 km (2850 miles from the epicenter). https://www.iris.edu/app/station_monitor

ALL

Slide Guide

1. Where was the epicenter of this earthquake? (What city/region was it closest to?) When did the earthquake happen? What was its magnitude?
2. How many people are estimated to have felt the earthquake?
3. Which type of boundary is this earthquake related to?
4. What impact did the earthquake have on the location in which it was felt the strongest? (buildings, streets, animals, people…)
5. What additional hazards occurred in addition to the ground shaking? (tsunamis, floods, sinkholes, landslides, fires, volcanoes…)
6. How long did it take the first P-wave to travel to the seismic station in this slide stack?
7. What are 2 more questions you have about earthquakes that can NOT be answered with this slide stack?

Extension Questions

1. Seismic waves travel through the earth. Why did you or did you not feel the earthquake?
2. If you were going to write a news story on this earthquake, what would the headline be? *HINT: Think about where this earthquake occurred, the impact it had on the people living in the area, any effects the earthquake had on the area itself.*

Slide Guide

1. Where was the epicenter of this earthquake? (What city/region was it closest to?) When did the earthquake happen? What was its magnitude?
2. How many people are estimated to have felt the earthquake?
3. What relationship is shown between the seismic hazard map and population density?
4. Which plates are involved and what type of boundary are they creating?
5. What impact did the earthquake have on the location in which it was felt the strongest? (buildings, streets, animals, people…)
6. What additional hazards occurred in addition to the ground shaking? (tsunamis, floods, sinkholes, landslides, fires, volcanoes…)
7. How long did it take the first P-wave to travel to the seismic station in this slide stack?
8. What are 2 more questions you have about earthquakes that can NOT be answered with this slide stack?

Extension Questions

1. Seismic waves travel through the earth. Why did you or did you not feel the earthquake?
2. If you were going to write a news story on this earthquake, what would the headline be? *HINT: Think about where this earthquake occurred, the impact it had on the people living in the area, any effects the earthquake had on the area itself.*

C

Slide Guide

1. Where was the epicenter and hypocenter of this earthquake? (What city/region was it closest to? Longitude/latitude/depth?) When did the earthquake happen? What was its magnitude?
2. What impact did the earthquake have on the location in which it was felt the strongest? *(buildings, streets, animals, people…)*
3. Draw the block model of the fault for this earthquake. Overlay a drawing of the focal mechanism to show how the 2D projection was created. Label it with the type of fault.
4. How are the related tectonic plates involved in creating the nearby boundary? *(Include the type of boundary, and the velocity and name of the plates.)*
5. What additional hazards occurred in addition to the ground shaking? *(tsunamis, floods, sinkholes, landslides, fires, volcanoes…)*
6. Relate the area's population density to its seismic hazard level and earthquake history.

Extension Question

1. What efforts have there been to mitigate impacts from earthquakes? What additional mitigation efforts should be implemented?

Teachable Moments are a service of

The EarthScope Consortium
and
The University of Portland

Please send feedback to tammy.bravo@earthscope.org

To receive automatic notifications of new Teachable Moments
send a blank email to earthquakes+subscribe@earthscope.org

These resources have been developed as part of the SAGE facility operated by the EarthScope Consortium via support from the National Science Foundation.