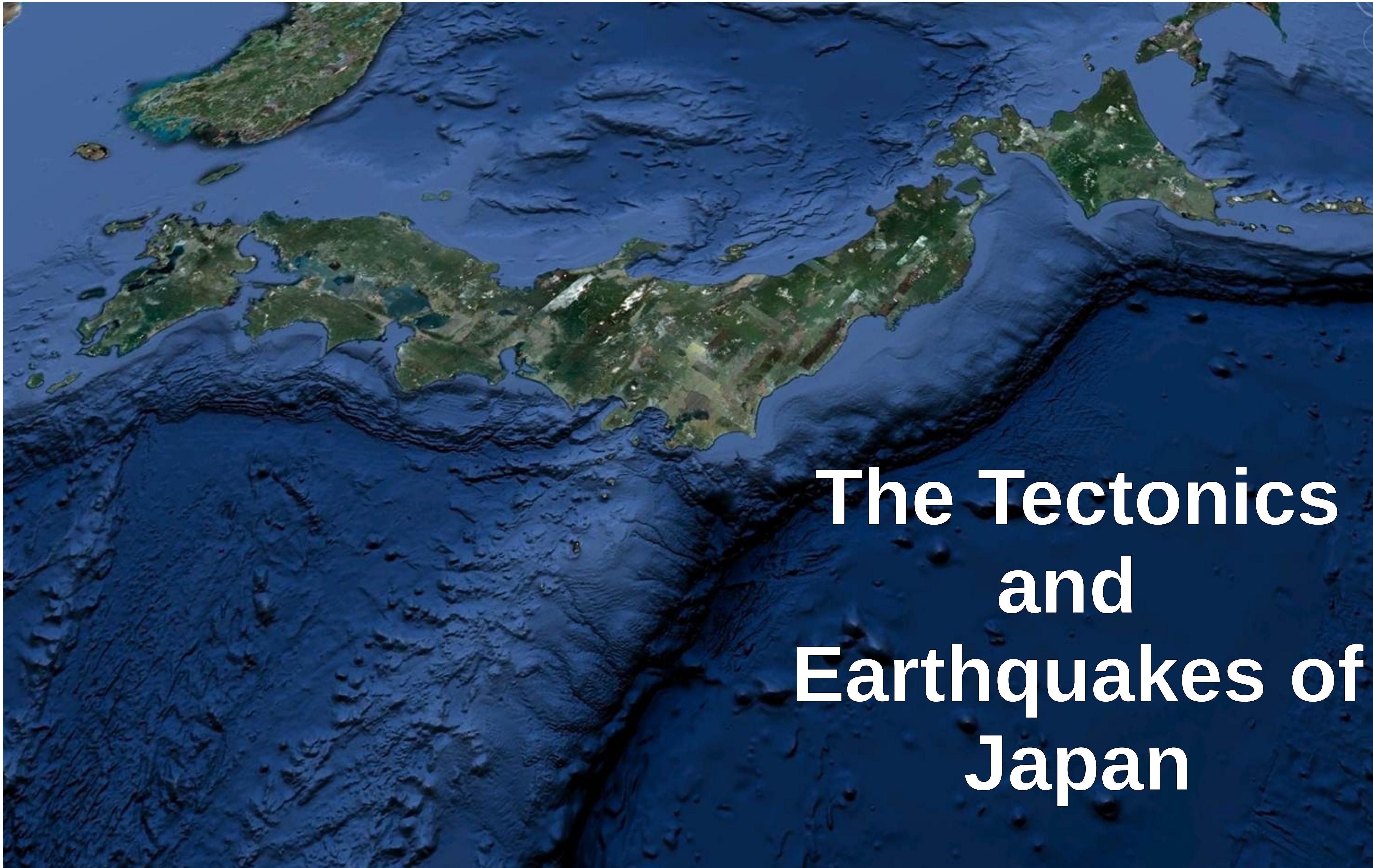


The Tectonics and Earthquakes of Japan

November 4, 1952
Kamchatka, Russia
1952 Kamchatka earthquake
9.0

May 22, 1960
Valdivia, Chile
1960 Valdivia earthquake
9.5

March 27, 1964
Prince William Sound, Alaska
1964 Alaska earthquake
9.2

December 26, 2004
Indian Ocean, Sumatra, Indonesia
2004 Indian Ocean earthquake
9.1–9.3

March 11, 2011
Pacific Ocean, Tōhoku region, Japan
2011 Tōhoku earthquake
9.0

Overview

- Geological faults and how they generate earthquakes
- Seismology: the study of earthquakes and the propagation of elastic waves through the Earth
- Plate tectonics and subduction zones
- The Japan Trench and the 2011 Tōhoku Earthquake

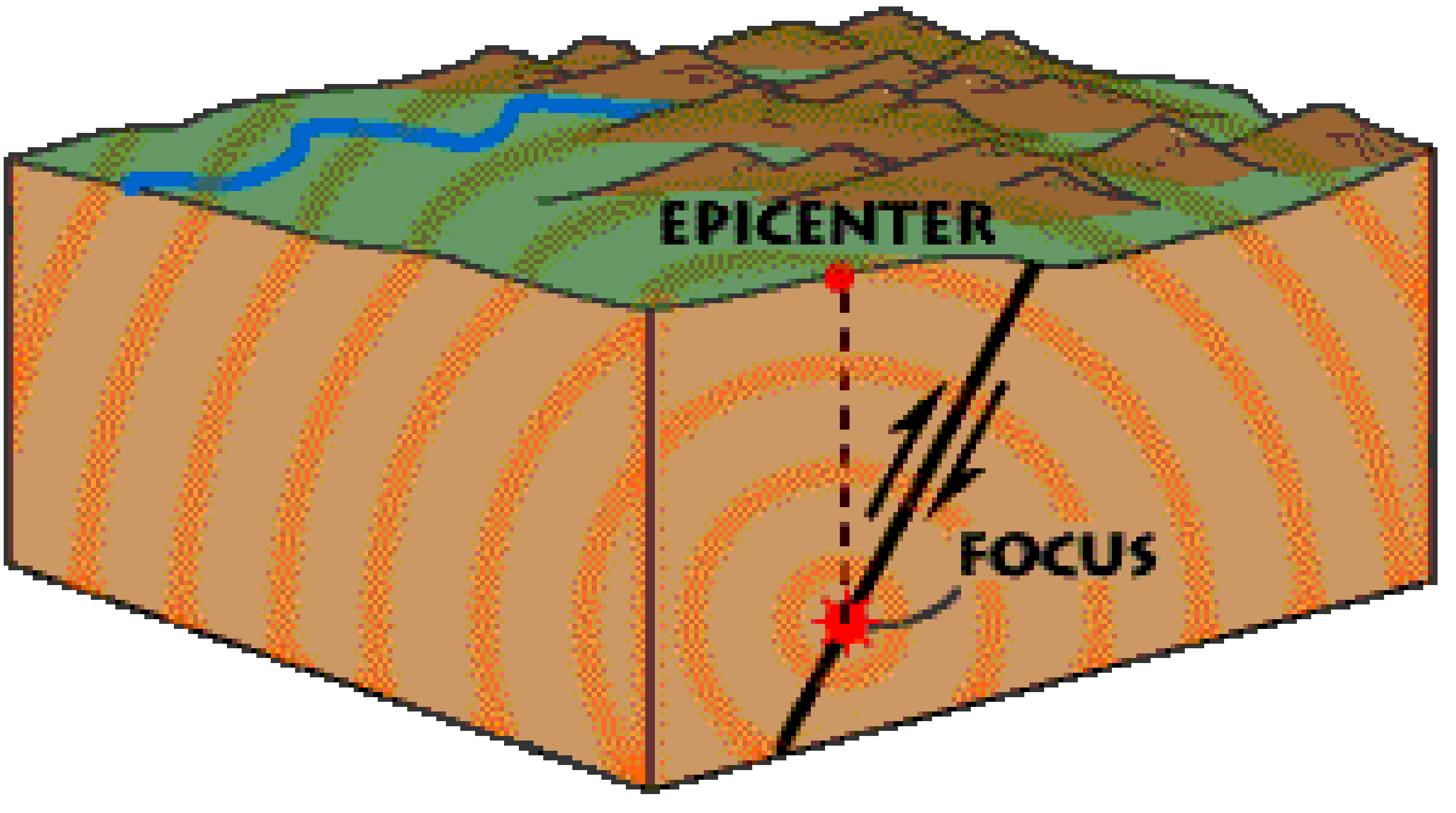
~5 mi W of Oskhosh, WI

San Andreas Fault, CA

Split Mountain Gorge, CA

Energy released as:

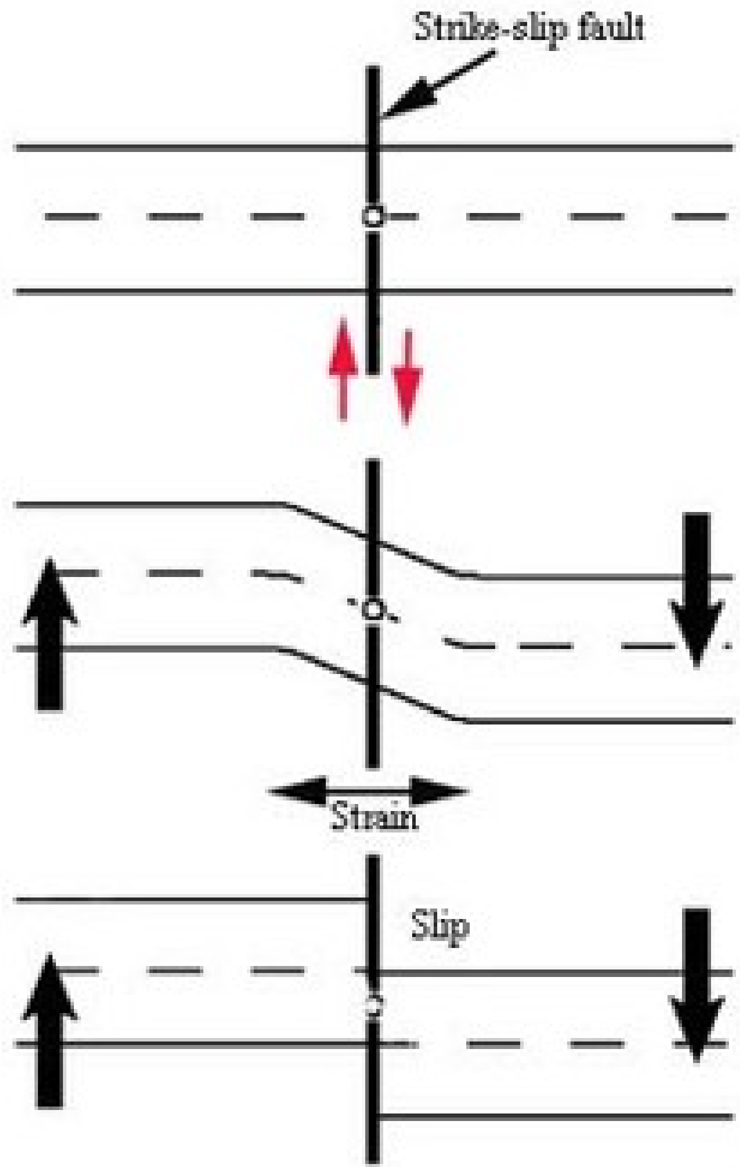
- heat (friction)
- seismic waves (orange circles)



Focus (hypocenter) = where the rupture begins

Image credit: www.windows2universe.org/earth/geology/quake1.html

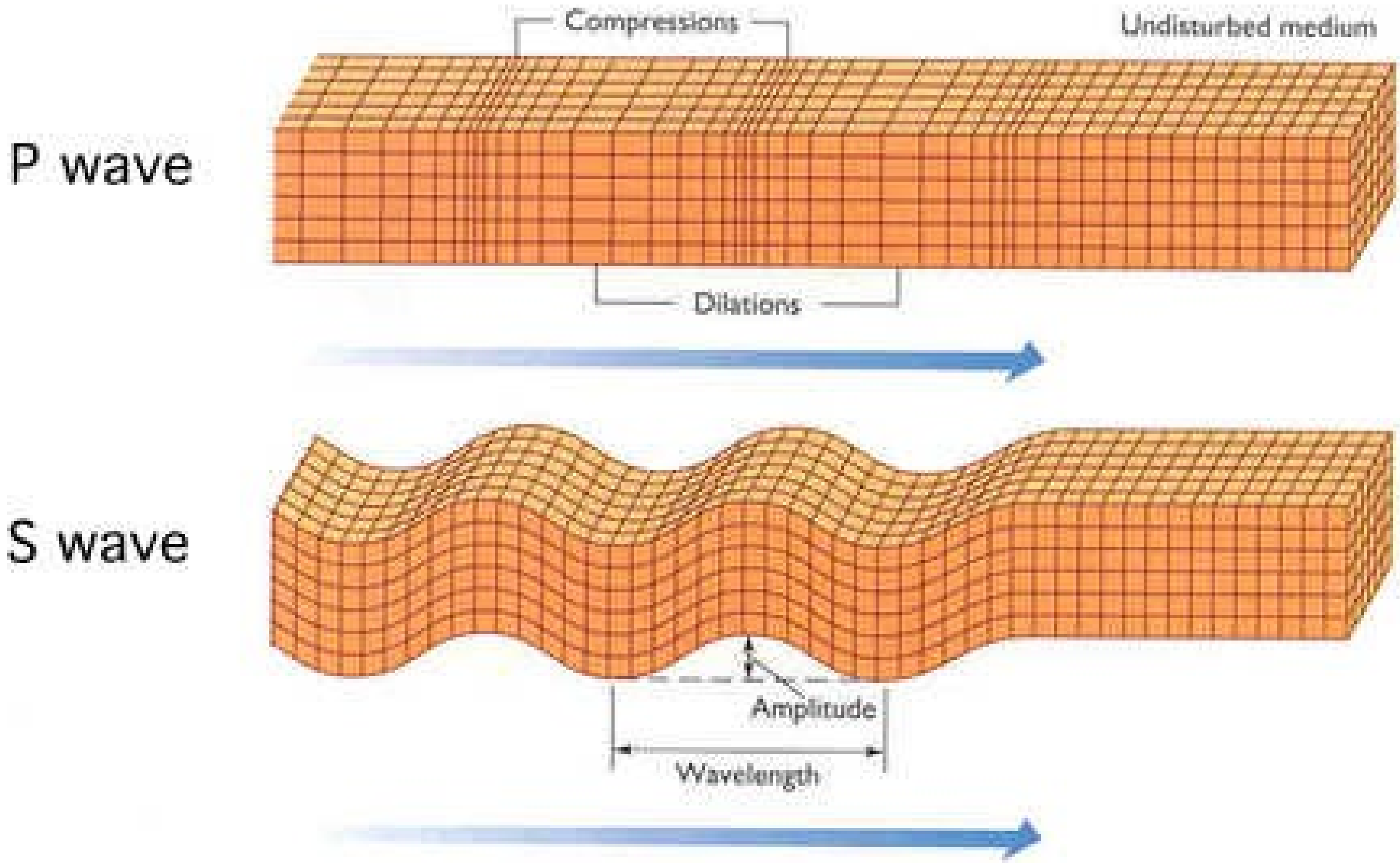
- Faults lock or get "stuck"
- Stress build up
- Fault ruptures or slips
- Cycle of "stick-slip"
- *Why does stress build up in the rocks?*



www.nature.com

Seismic waves – waves of energy which travel through the Earth

2 types of **body waves**:



P-wave: primary or pressure
(fastest seismic waves)

S-wave: secondary or shear
(slower than P-waves)

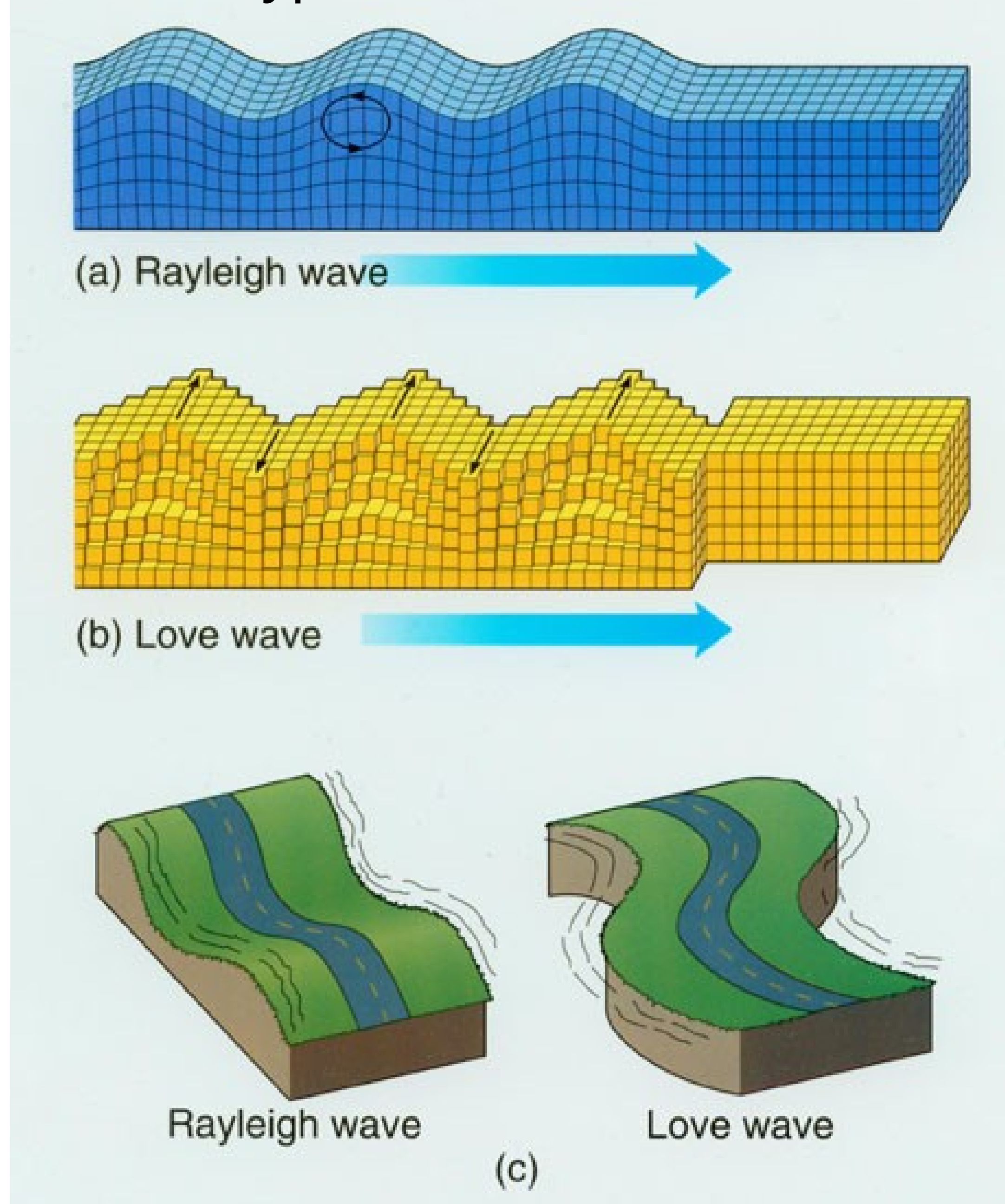
Image credit: USGS

Seismic waves – waves of energy which travel through the Earth

2 types of surface **waves**

- Form when body waves reach an interface (e.g. ground-air)
- Lower velocity -

  90% of the S-waves
- Lower frequency
- Higher amplitude
- Most damaging



www.zmescience.com/science/geology

Modified Mercalli scale (MMI) = effects of earthquake

MMI = roman numbers ~ R = Richter scale ~ J = energy measured in Joule

I. Instrumental R < 3.5 J < 1.6 E+7	Not felt by many people unless in favourable conditions.
II. Feeble R 3.5 J 1.6 E+7	Felt only by a few people at best, especially on the upper floors of buildings. Delicately suspended objects may swing.
III. Slight R 4.2 J 7.5 E+8	Felt quite noticeably by people indoors, especially on the upper floors of buildings. Many do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration similar to the passing of a truck. Duration estimated.
IV. Moderate R 4.5 J 4 E+9	Felt indoors by many people, outdoors by few people during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rock noticeably. Dishes and windows rattle alarmingly.
V. Rather Strong R 4.8 J 2.1 E+13	Felt outside by most, may not be felt by some outside in non-favourable conditions. Dishes and windows may break and large bells will ring. Vibrations like large train passing close to house.
VI. Strong R 5.4 J 5.7 E+11	Felt by all; many frightened and run outdoors, walk unsteadily. Windows, dishes, glassware broken; books fall off shelves; some heavy furniture moved or overturned; a few instances of fallen plaster. Damage slight.
VII. Very Strong R 6.1 J2.8 E+13	Difficult to stand; furniture broken; damage negligible in building of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken. Noticed by people driving motor cars.
VIII. Destructive R 6.5 J 2.5 E+14	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture moved.
IX. Ruinous R 6.9 J 2.3 E+15	General panic; damage considerable in specially designed structures, well designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X. Disastrous R 7.3 J 2.1 E+16	Some well built wooden structures destroyed; most masonry and frame structures destroyed with foundation. Rails bent.
XI. Very Disastrous R >8.1 J >1.7 E+18	Few, if any masonry structures remain standing. Bridges destroyed. Rails bent greatly.
XII. Catastrophic R > 8.1	Total damage - Everything is destroyed. Total destruction. Lines of sight and level distorted. Objects thrown into the air. The ground moves in waves or ripples. Large amounts of rock move position.

Intensity 0	Imperceptible to people.
Intensity 1	Some people in the building feel it.
Intensity 2	Many people in the building feel it. Some people awaken, if the quake strikes at night.
Intensity 3	Felt by most people in the building. Some people are frightened.
Intensity 4	Many people are frightened. Some people try to escape from danger. Most people awaken, if the quake strikes at night.
Intensity 5 lower	Most people try to escape from danger. Some people find it difficult to move.
Intensity 5 upper	Many people are very fright-ened and find it difficult to move.
Intensity 6 lower	Difficult to keep standing.
Intensity 6 upper	Impossible to keep standing and to move without crawling.
Intensity 7	Thrown around by the shaking. Impossible to move at will.

Earthquake Magnitude – Seismic moment

- A method was needed to measure larger earthquakes at various distances
- New magnitude scale based on physical properties of the earthquake fault
- **Seismic Moment** (energy)

  M = *shear strength x area x displacement*
- Calibrated to agree with the Richter scale

Magnitude and Energy

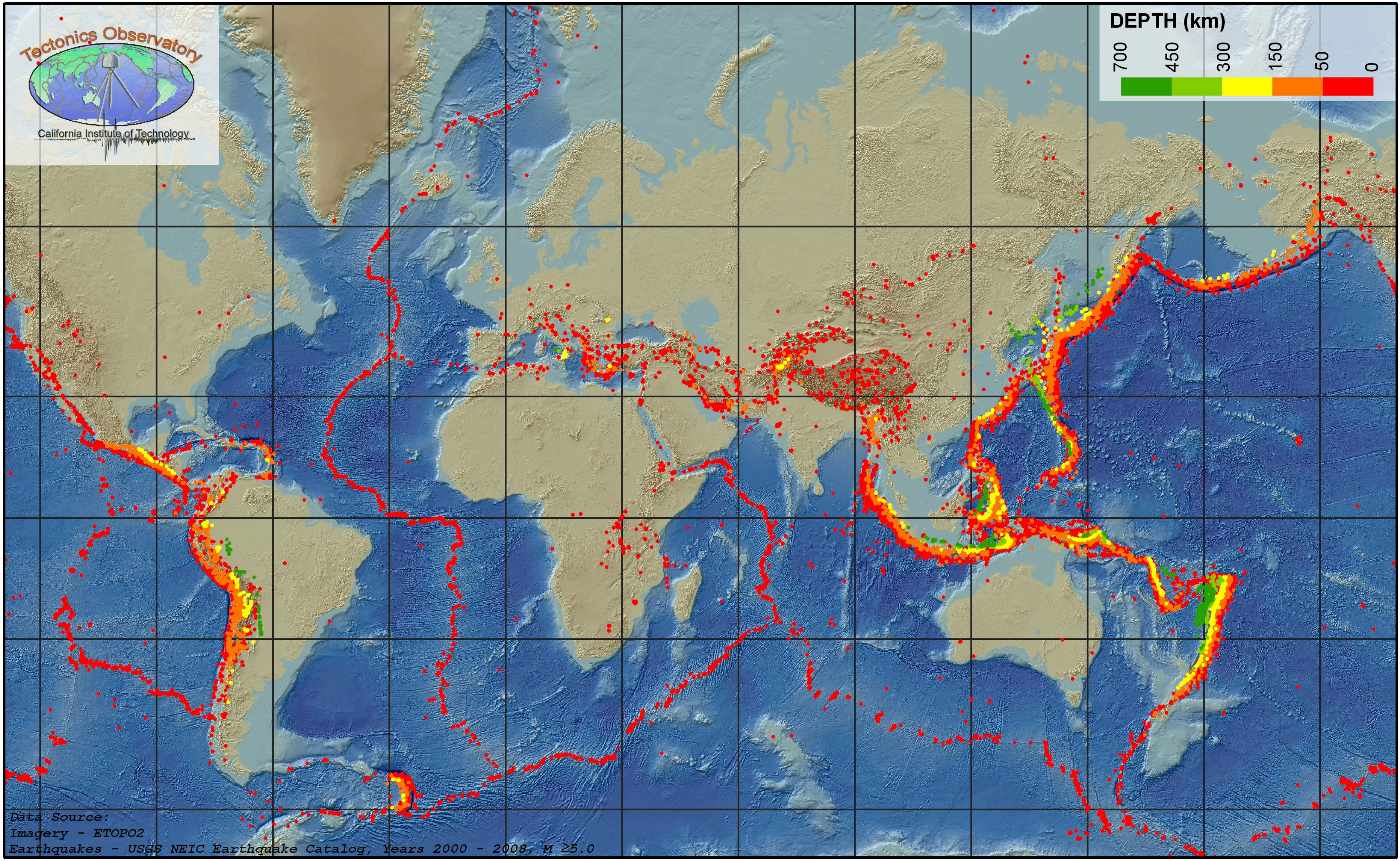
- All magnitude scales are logarithmic
- Energy difference between each magnitude is ~32 times
- Difference in energy release between a M 7 foreshock and a M 9 earthquake

  32x32 ~ 1024 times

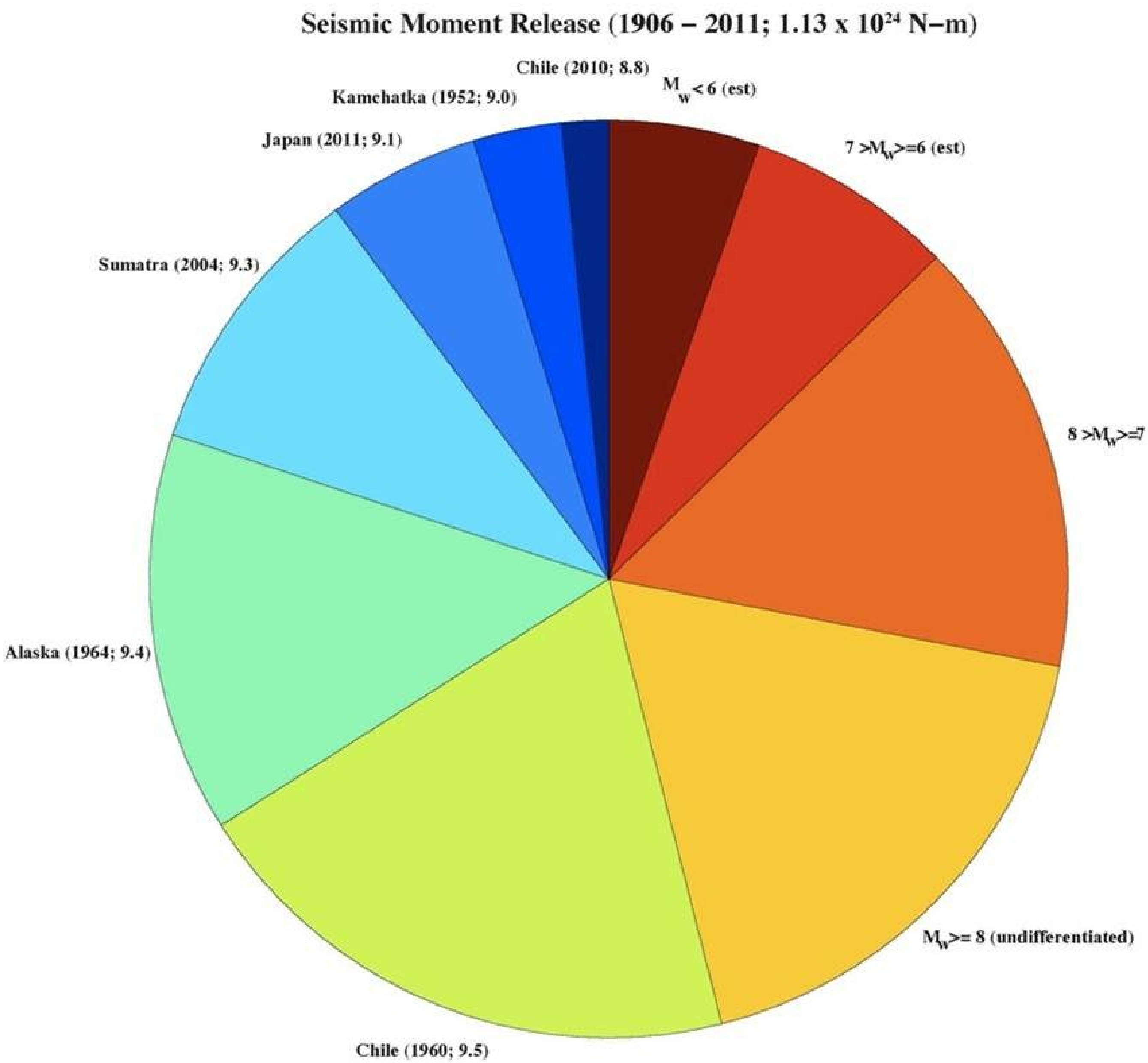
- Largest event in NH (Ossipee Lake) - M 5.5

  178,000 times less energy than M 9

Global Seismicity 2000-2005 (earthquakes > M 5)

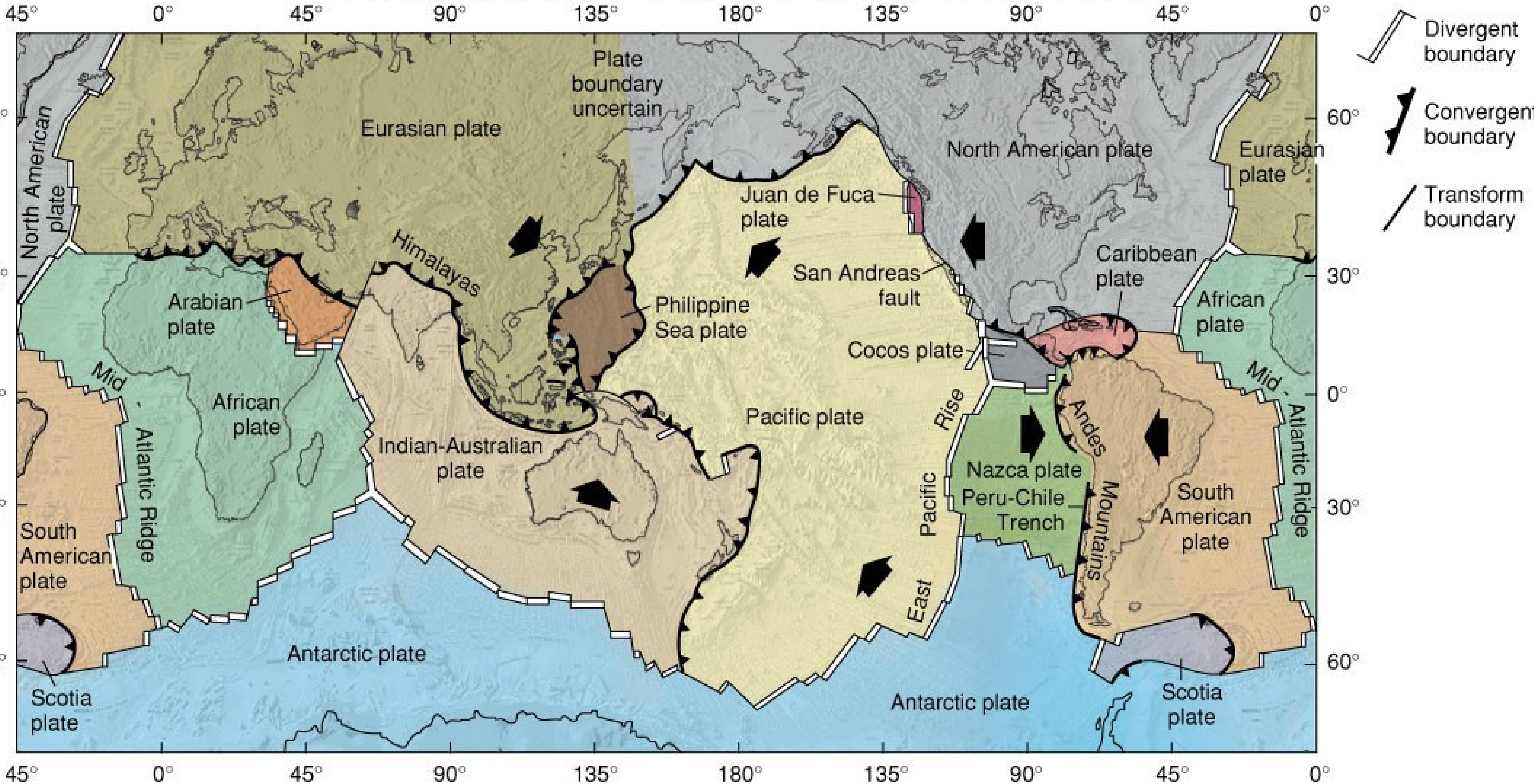


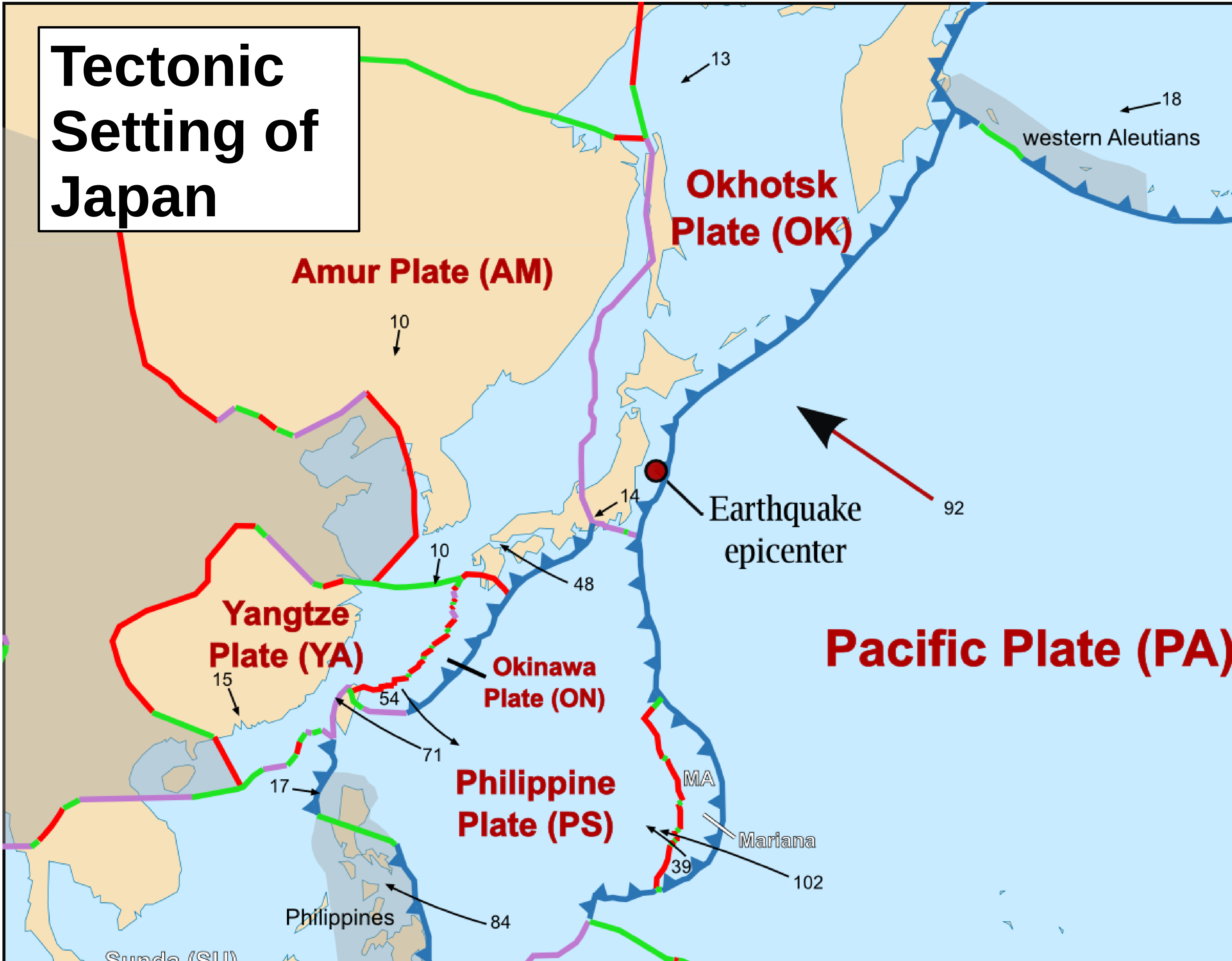
From USGS data – U. Alberta



Earthquake Magnitude	earthquakes per year
8 and higher	1
7 - 7.9	15
6 - 6.9	143
5 - 5.9	1319
4 - 4.9	13,000
3 - 3.9	130,000
2 - 2.9	1,300,000

Tectonic Plates





Tectonic Setting of Japan
Okhotsk Plate (OK)
Amur Plate (AM)
Yangtze Plate (YA)
Okinawa Plate (ON)
Philippine Plate (PS)
Pacific Plate (PA)
Earthquake epicenter
western Aleutians
Philippines
MA
Mariana
13
18
10
14
92
10
48
15
54
71
17
39
102
84

Subduction Zones

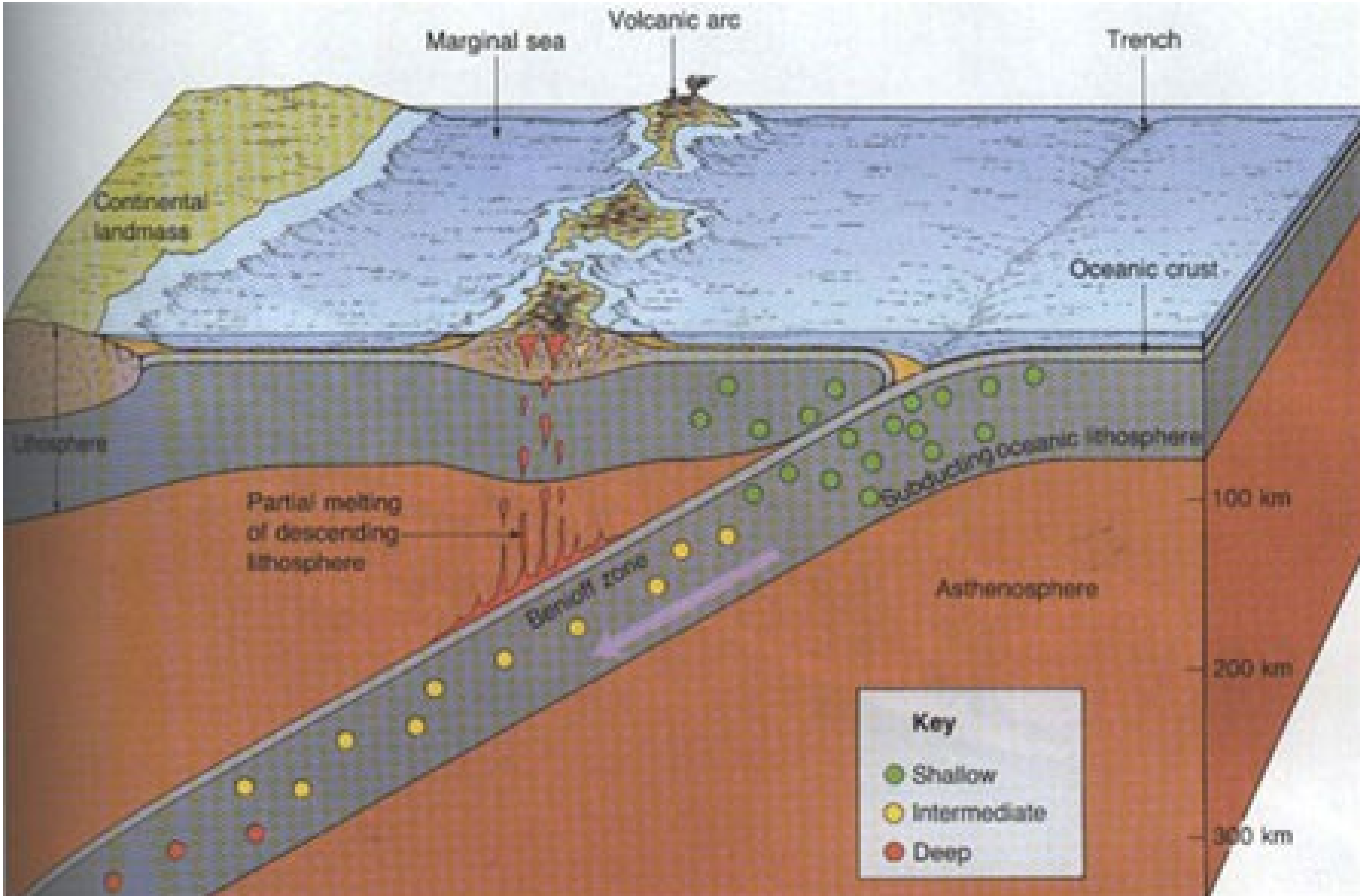


Figure If the earthquake foci are plotted in a cross-section view, we see that they follow the subducting plate.

Megathrust Faults

- Thrust fault = compressional stress
- Megathrust – very big thrust fault, found at subduction zones

Why are megathrust earthquakes so big?

Moment = strength x area x displacement

- Strong rocks
- Large area
- Large displacement

Subduction zones

Japan – Historical Seismicity

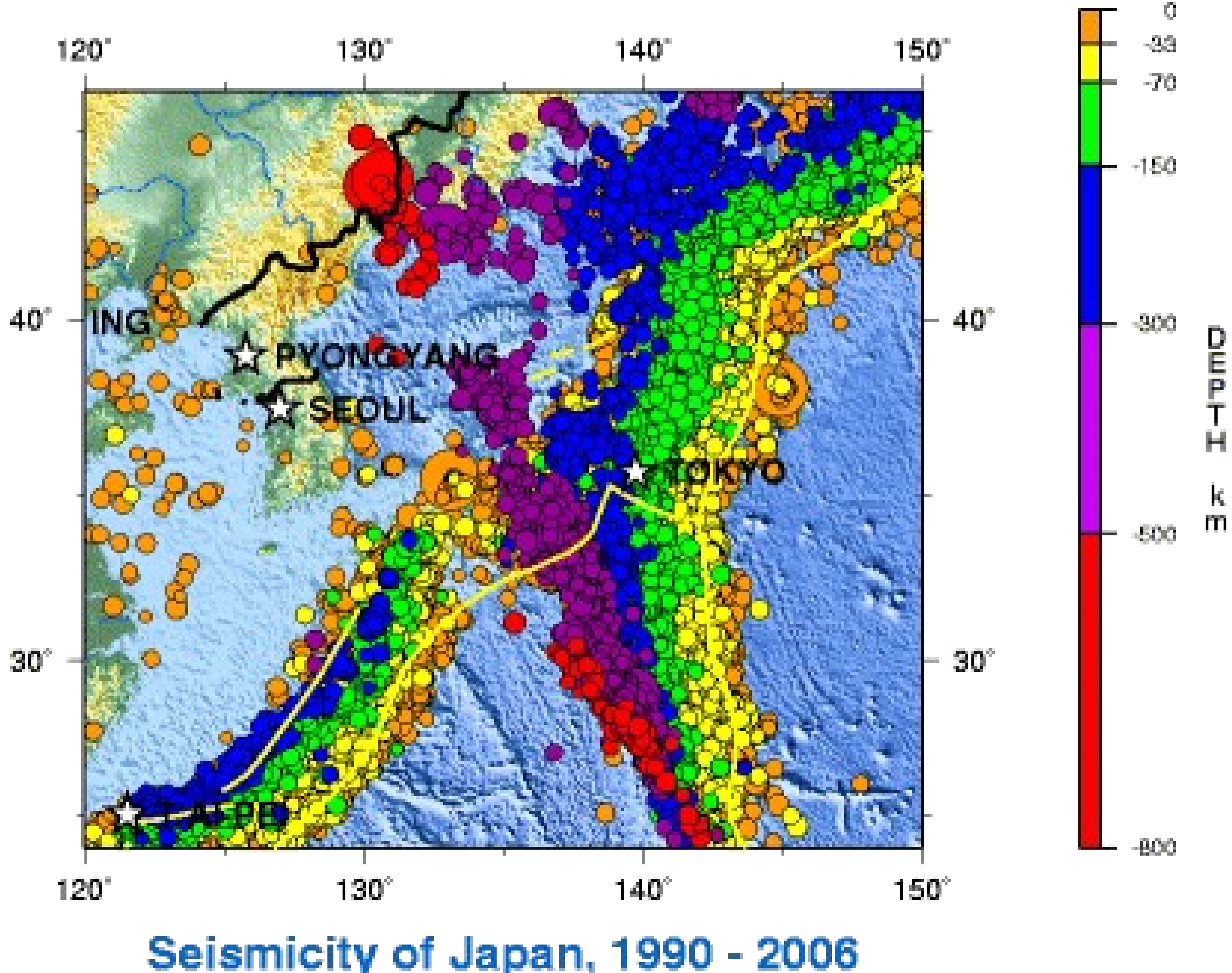
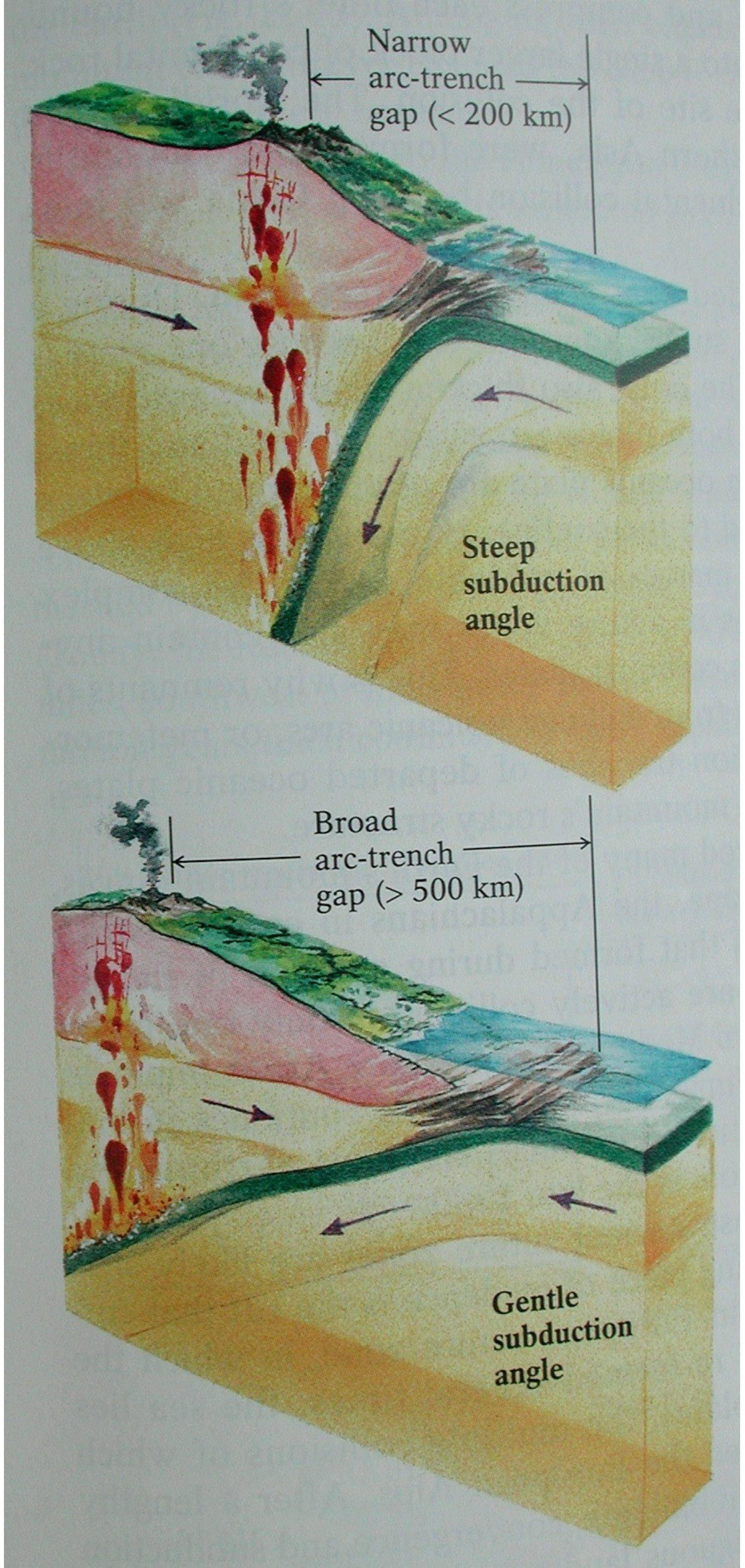


Image credit: USGS

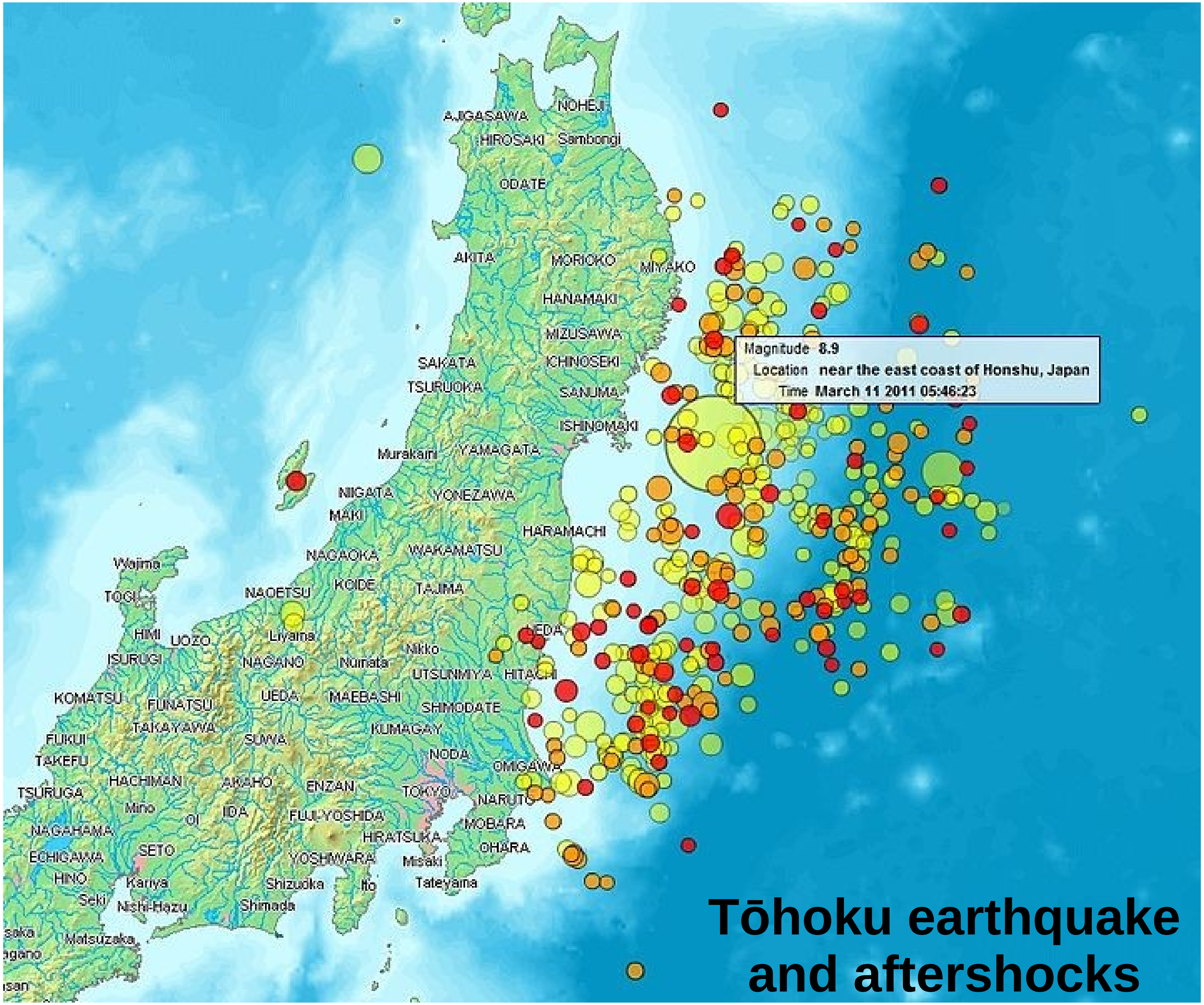
Japan Trench

- Subduction of the *Pacific* Plate under the *Okhotsk* plate
- Oldest oceanic crust in the world (130 Ma)
- Little sediment accretion
- Steeply "dipping", weakly coupled (not stuck together) than other margins
- Earthquakes no bigger than ~M 8.5 in the past



2011 Tōhoku Earthquake

- Magnitude 9.0 – strongest earthquake in Japan
  - 14:46 JST (05:46 UTC)
  - Depth of 32 km (19.9 miles)
  - lasted 2 minutes, surface ground shaking lasted longer
- next closest earthquakes in size
  - 1933 Sanriku 8.3M – Tōhoku region
  - 1854 Ansei-Tōkai, Ansei-Nankai (both 8.4 M_L)
  - 1707 Hōei 8.6ML (Nankaidō and Tokai regions)



March 11 – green March 12 – yellow March 13 – orange March 14 - red

- Sendai -

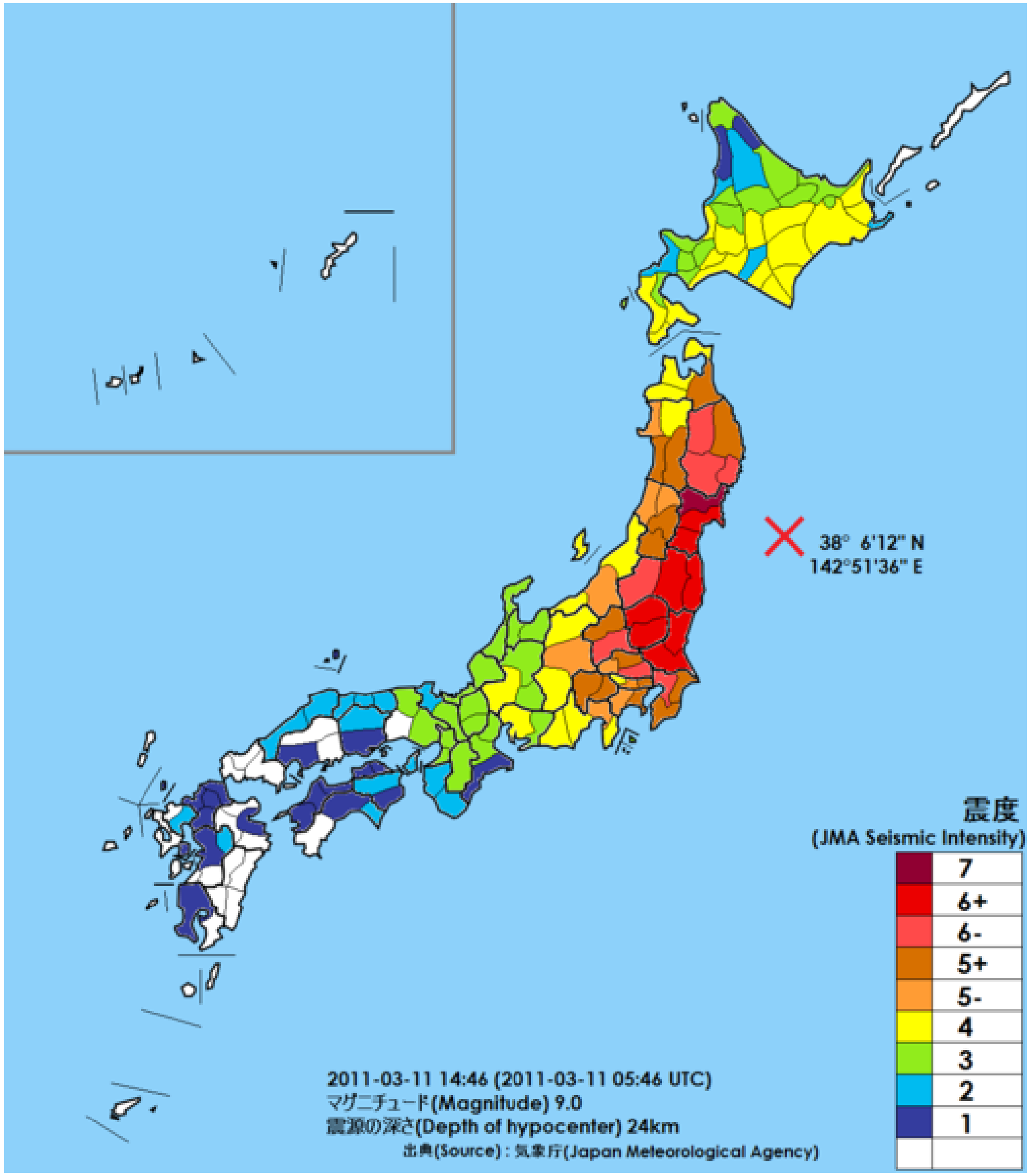
  130 km (81 mi)

- Oshika Peninsula -

  72 km (45 mi)

- Tokyo -

  373 km (232 mi)



Intensity scale from JMA

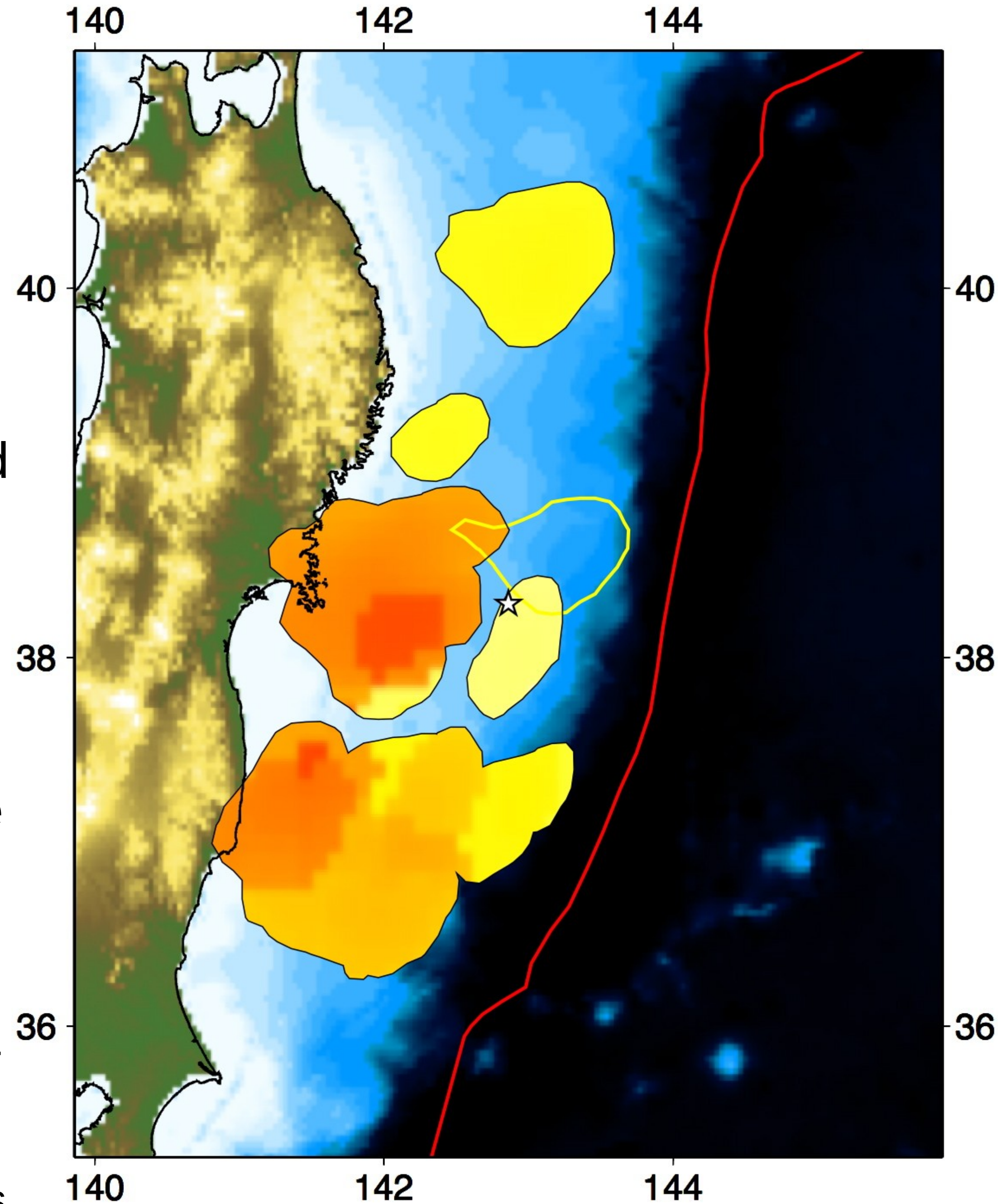
Early Warning System:

- P-waves detected first, early warning system message was broadcast
- S-waves arrive next
  - Travel time to Tokyo of 90s
- Surface waves arrive last (most damaging)
- Time for people to move to safety, shut down trains, shut down nuclear reactors

What actually happened on the fault during the earthquake (rupture)?

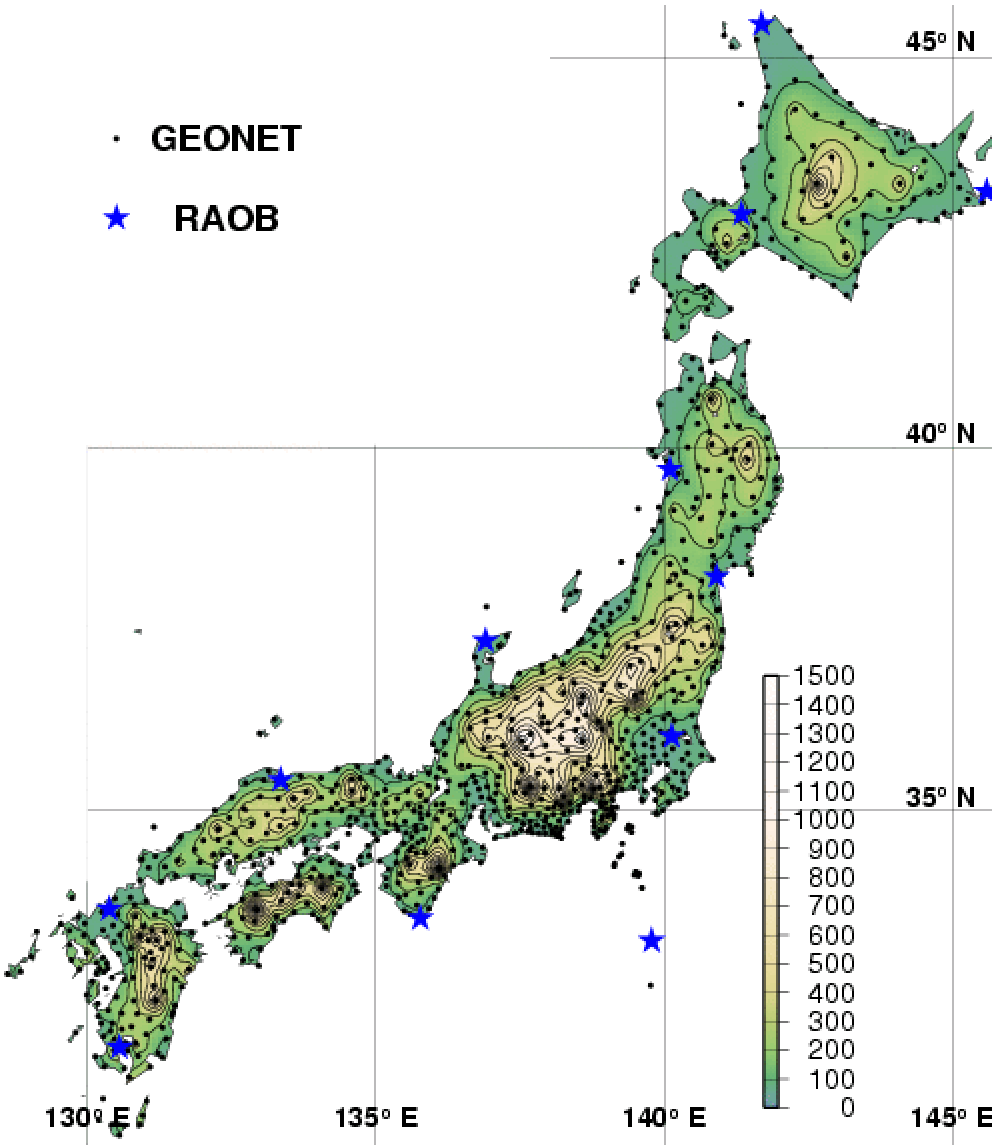
Mainshock

- Largest seismic event in a series of earthquakes
- 3 separate events on different parts of the subduction zone
- broke almost the entire coupled region of the plate interface between 36 degrees N and 40.5 degrees N
- 300 km x 150 km
- If all segments had failed at the same time – magnitude 9.4



Rupture Extent and Time Dependence of the Super Mainshock -
Relative Energy Release during the first 25 minutes

Harvard Seismology

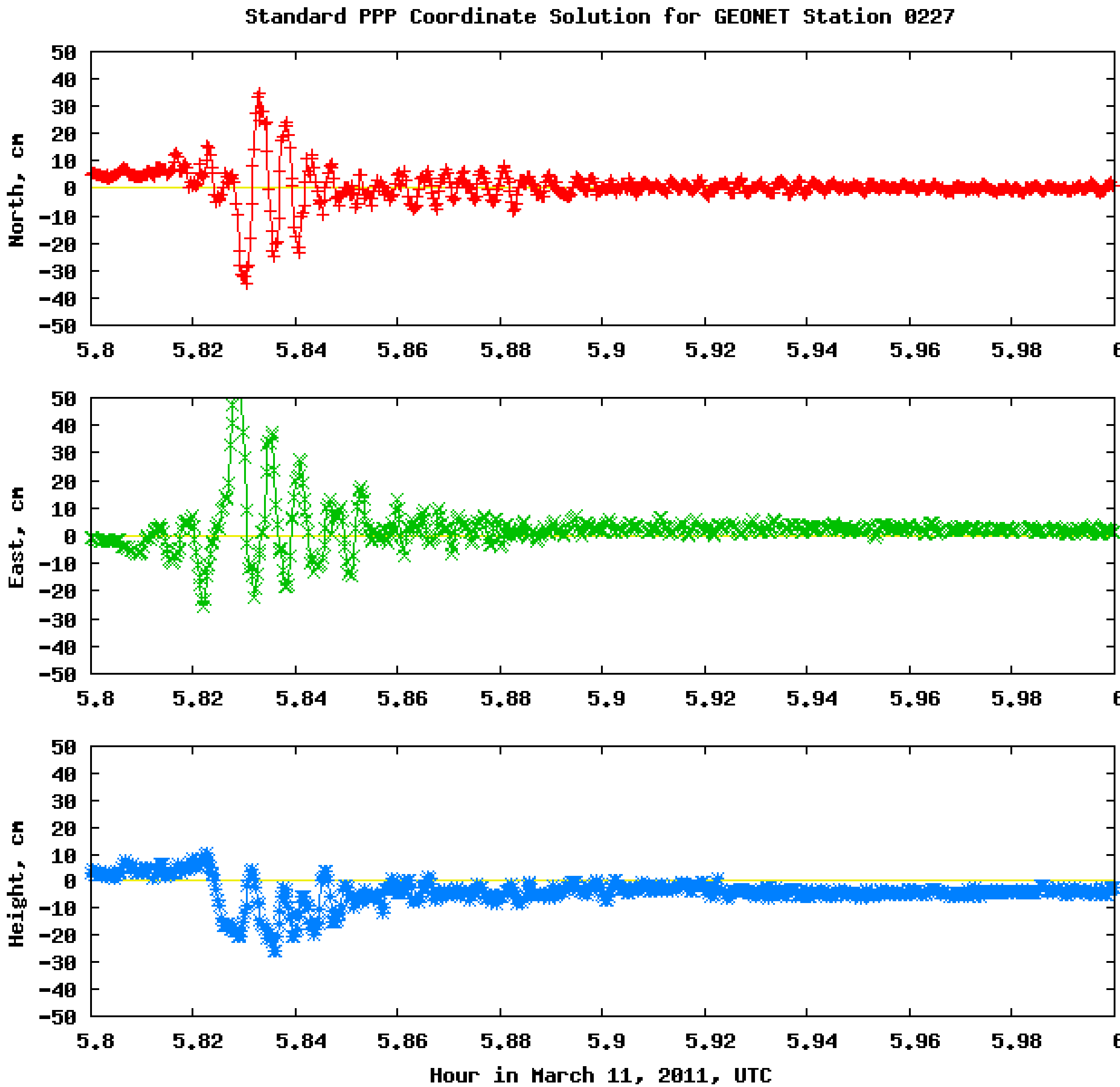


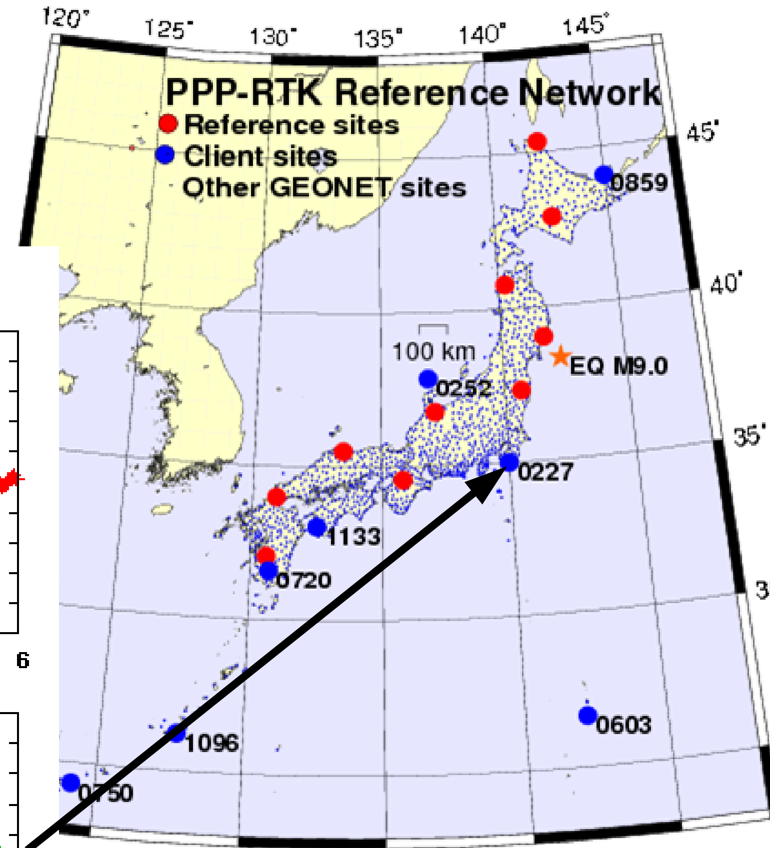
1,200 GPS permanent stations - largest GPS network in the world

GEONET: Nationwide GPS array of Japan

Ground movement

Real-time 1Hz measurements



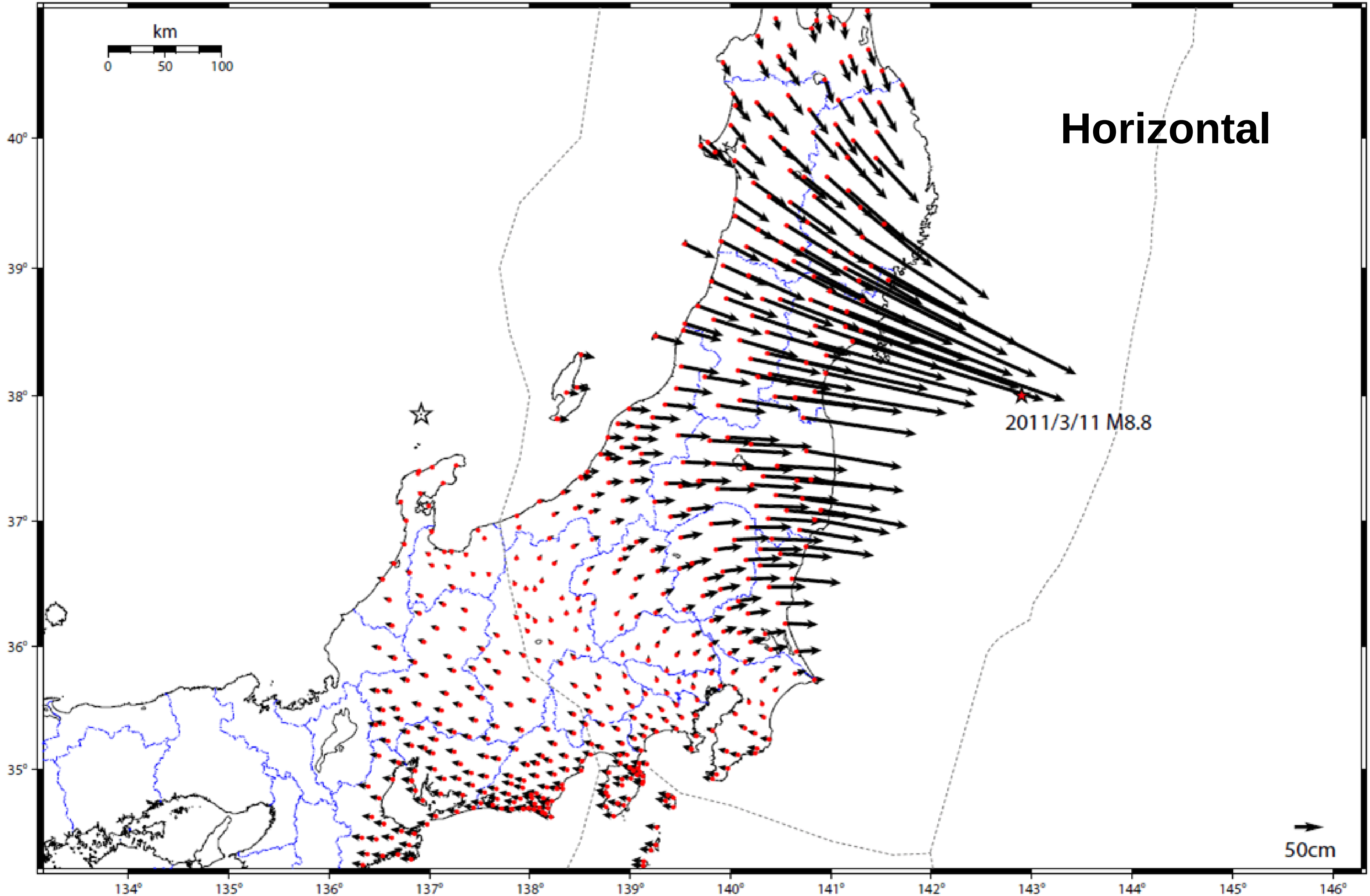


Station displacement was ~1m

5 “jerks” in ~1 minute!

変動ベクトル図（水平）

基準期間：2011/03/01 21:00 - 2011/03/08 21:00
比較期間：2011/03/11 16:30 - 2011/03/11 16:30



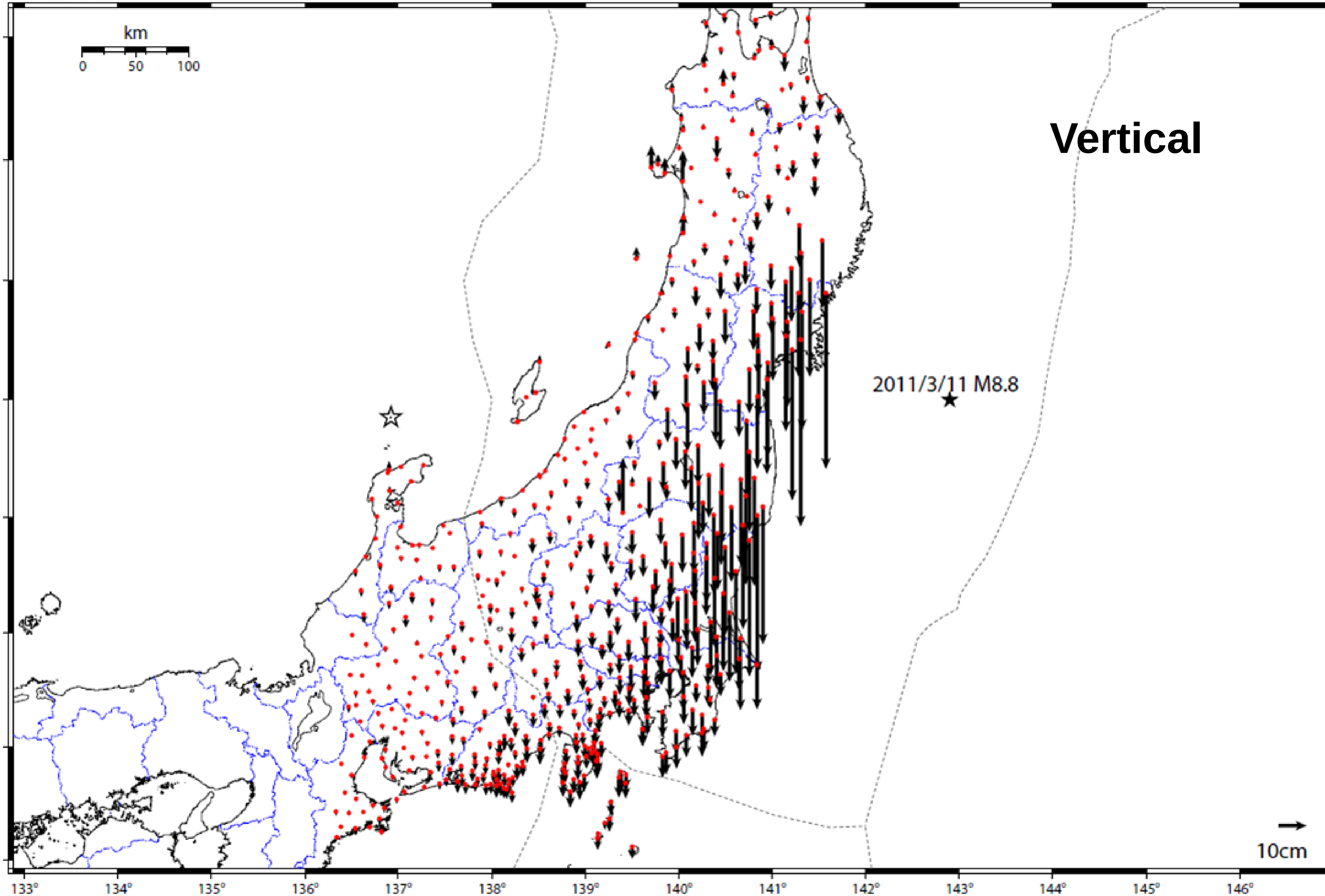
［基準：Ｒ３速報解　比較：Ｓ３迅速解］

☆固定局：舳倉島（９５０２５２）

国土地理院

変動ベクトル図（上下）

基準期間：2011/03/01 21:00 - 2011/03/08 21:00
比較期間：2011/03/11 16:30 - 2011/03/11 16:30



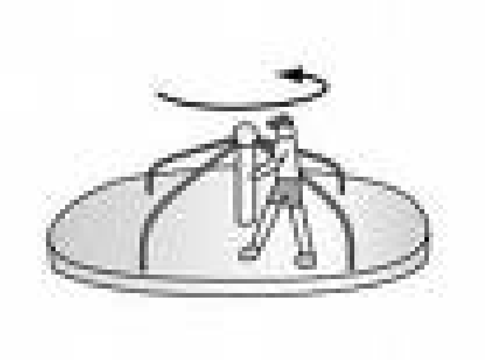
［基準：Ｒ３速報解　比較：Ｓ３迅速解］

☆固定局：舳倉島（９５０２５２）

国土地理院

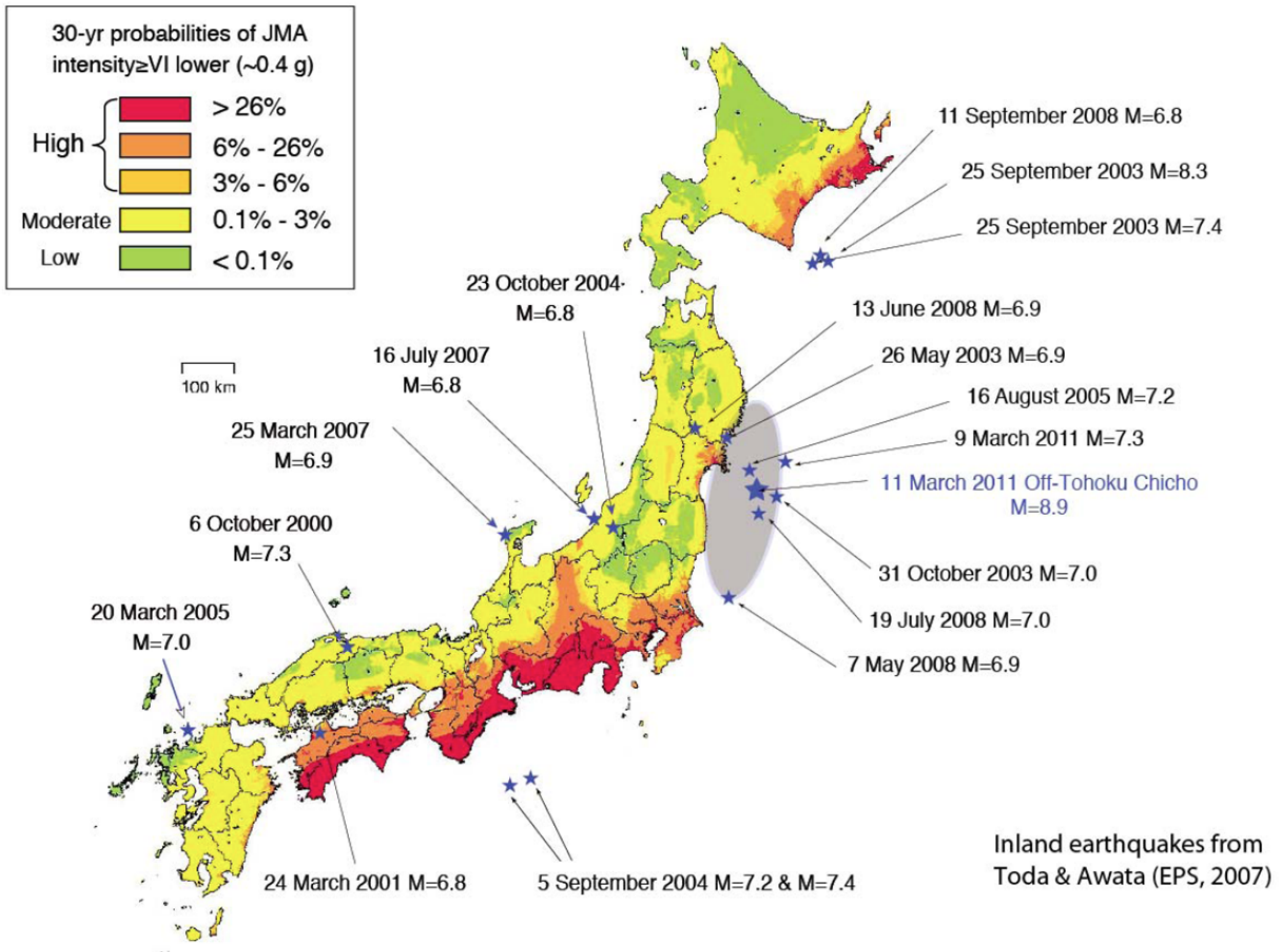
Geophysical impact

- Changes in Earth's rotation rate and length of day
  - Earth's rotation speed increased
  - shortened the day by 1.8 microseconds
  - Mass closer to the center of the Earth



- Position of Earth's figure axis
  - Axis about which the mass is distributed
  - Changed by 25 centimeters (9.8 in)
- Expected changes for a M 9 earthquake

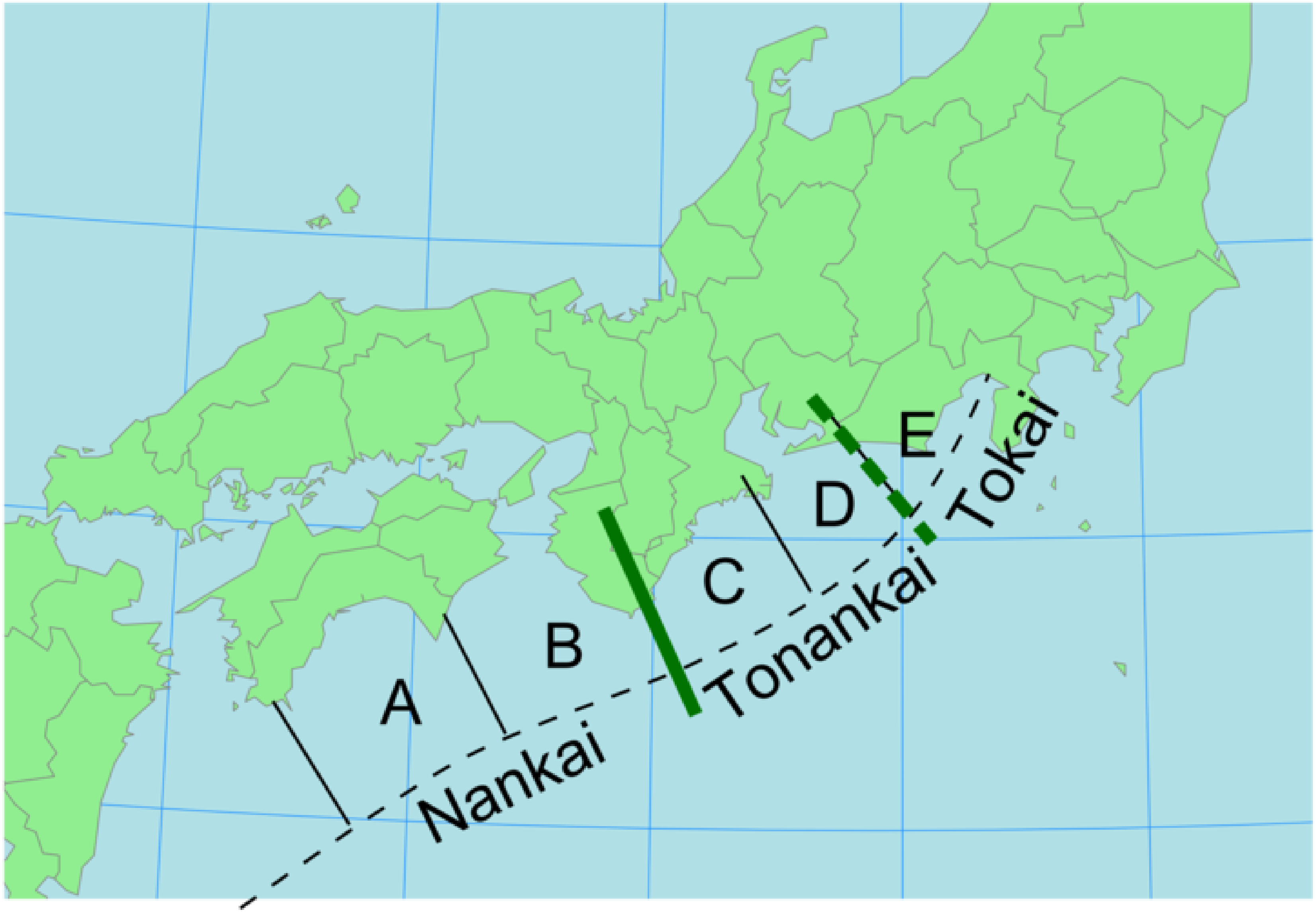
How well has the 2005 Japanese National Seismic Hazard Map forecast the last decade of earthquakes?



Will we do any better in the U.S? *We need to re-think how we assess maximum magnitudes and earthquake frequency-magnitude distributions*

H. Tobin - U-Wisconsin

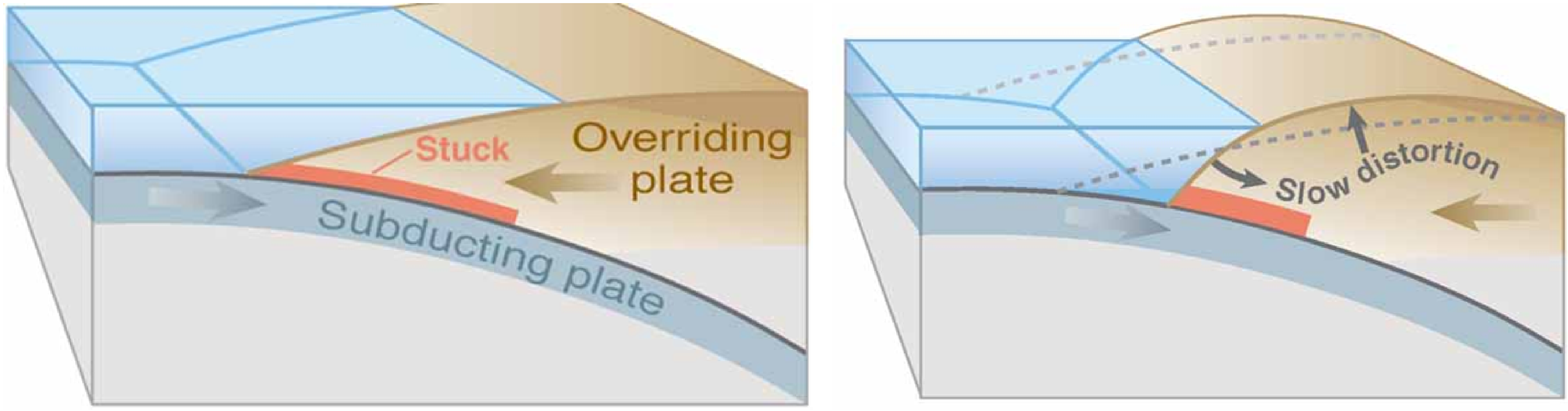
The next big earthquake?



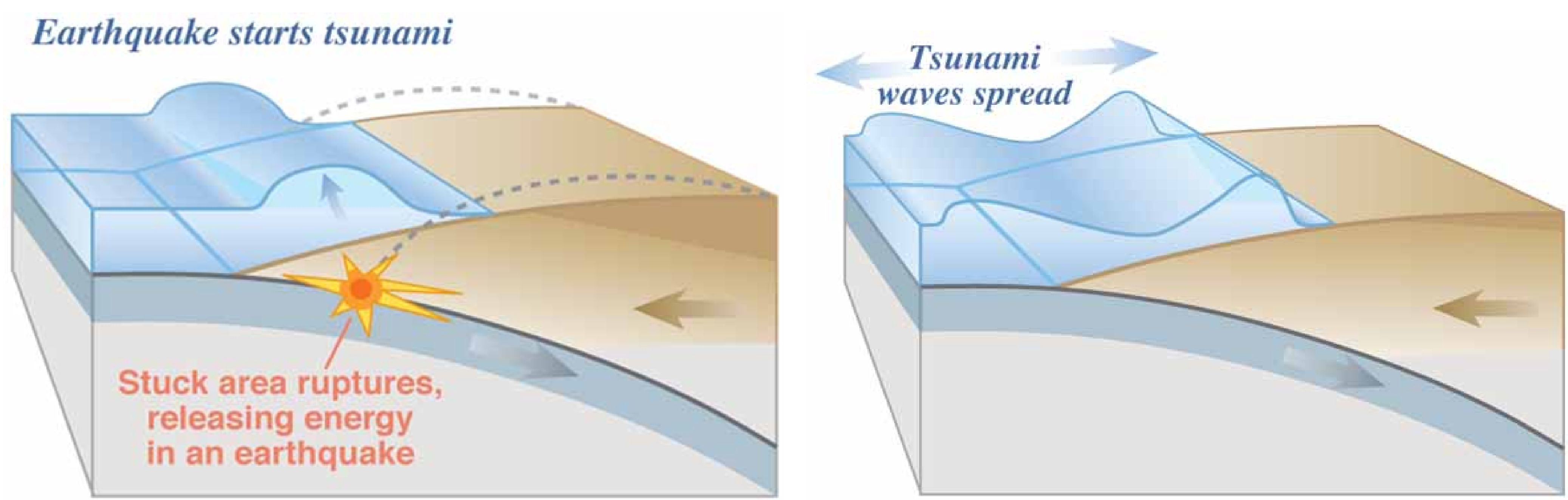
Rupture areas of the Nankai Trough

Tsunami

How a tsunami forms

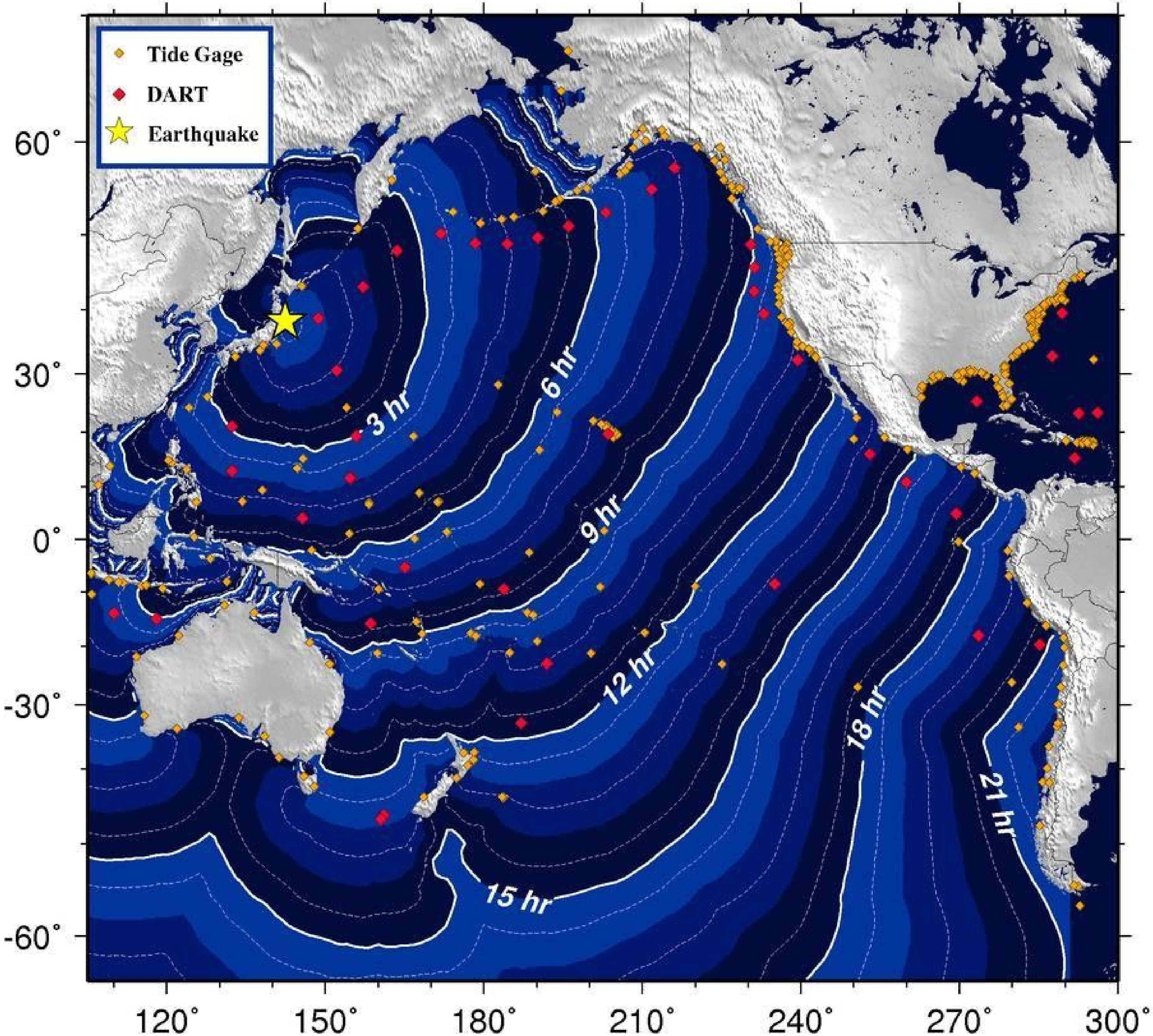


Before earthquake



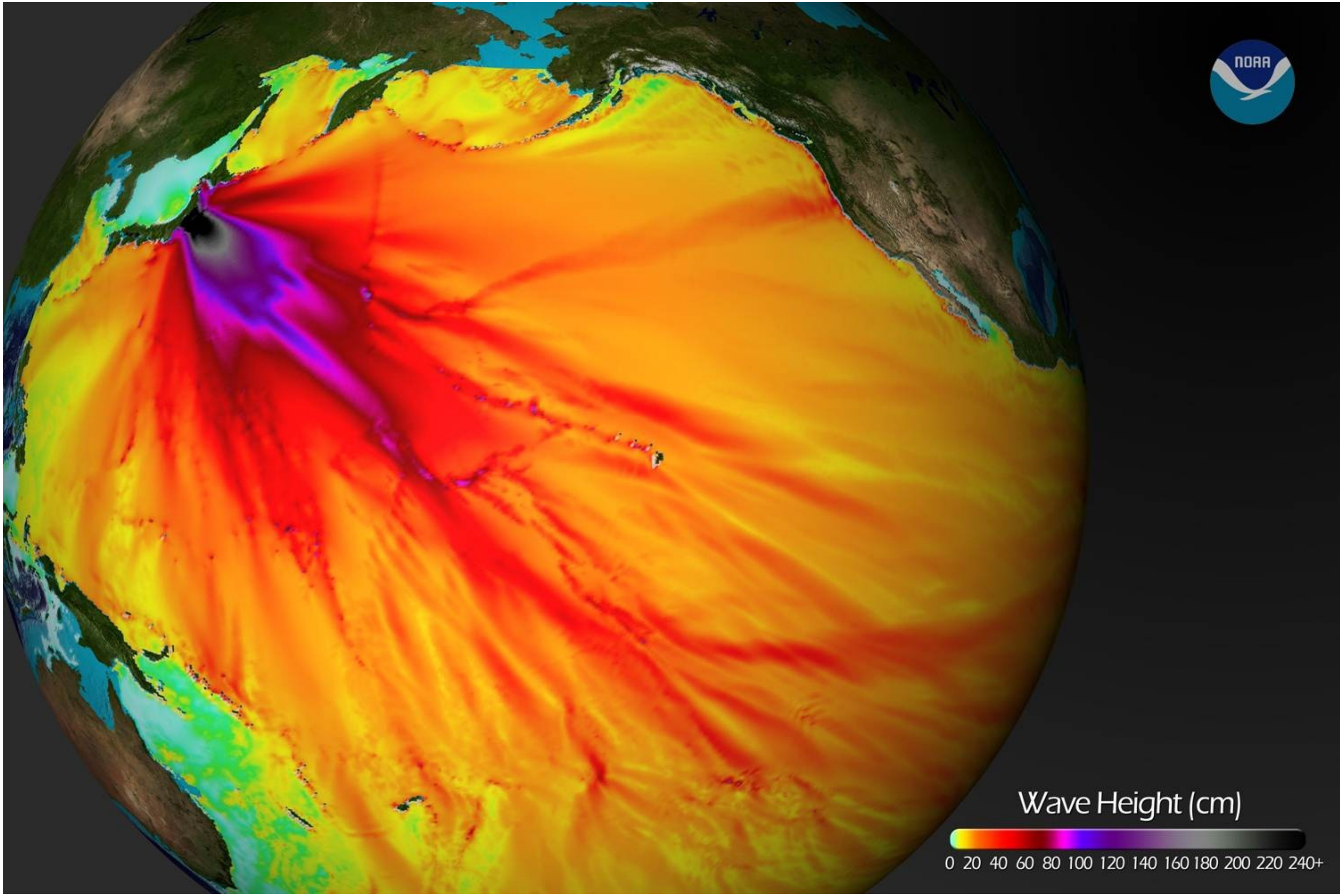
After earthquake

Tsunami Travel Times



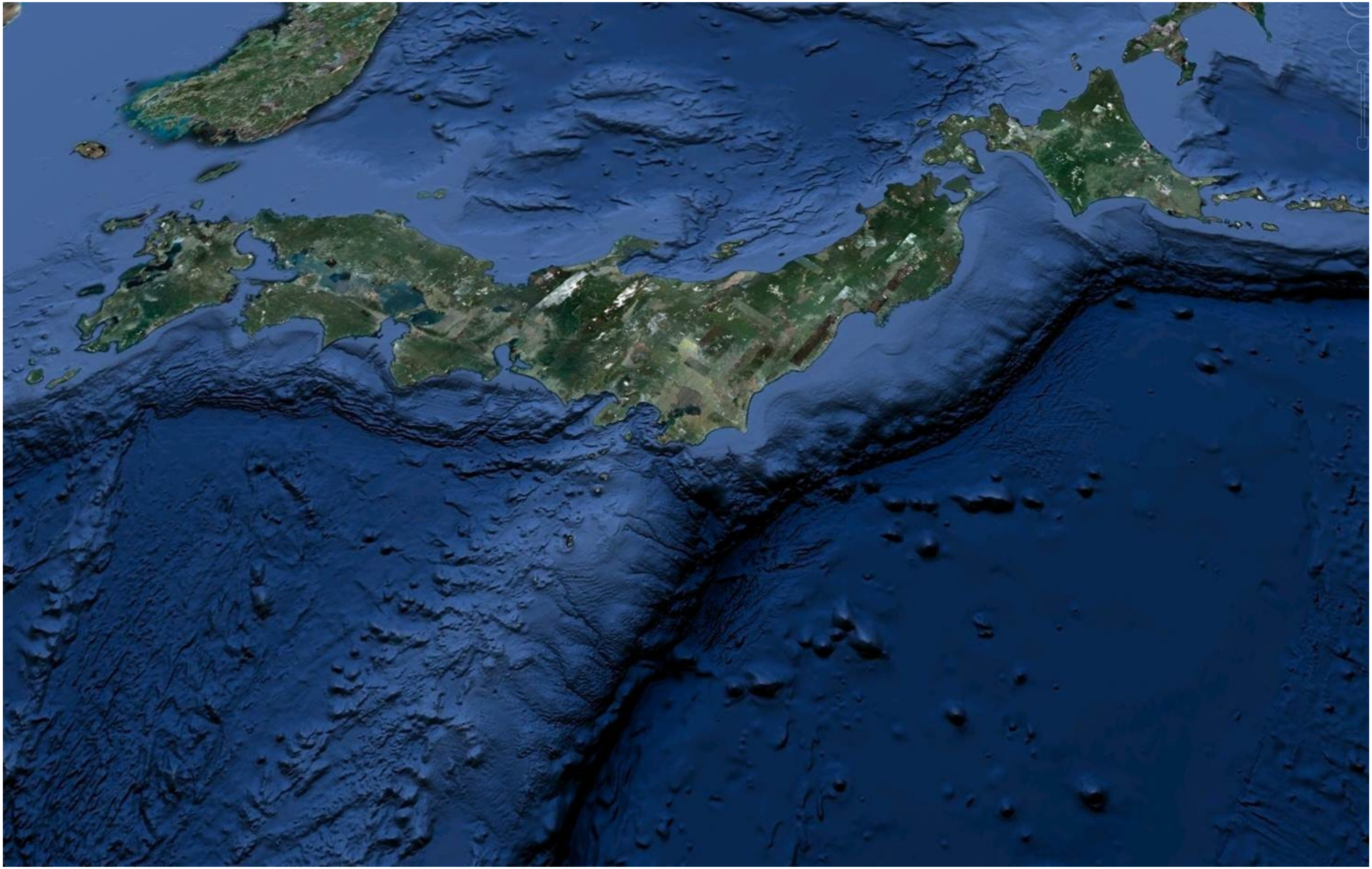
West Coast/Alaska Tsunami Warning Centre (WC/ATWC)

- wave of 1.08m amplitude was recorded by a DART buoy
- 25-35 minutes after earthquake for the biggest waves to arrive at the coast
- Red diamonds- DART stations

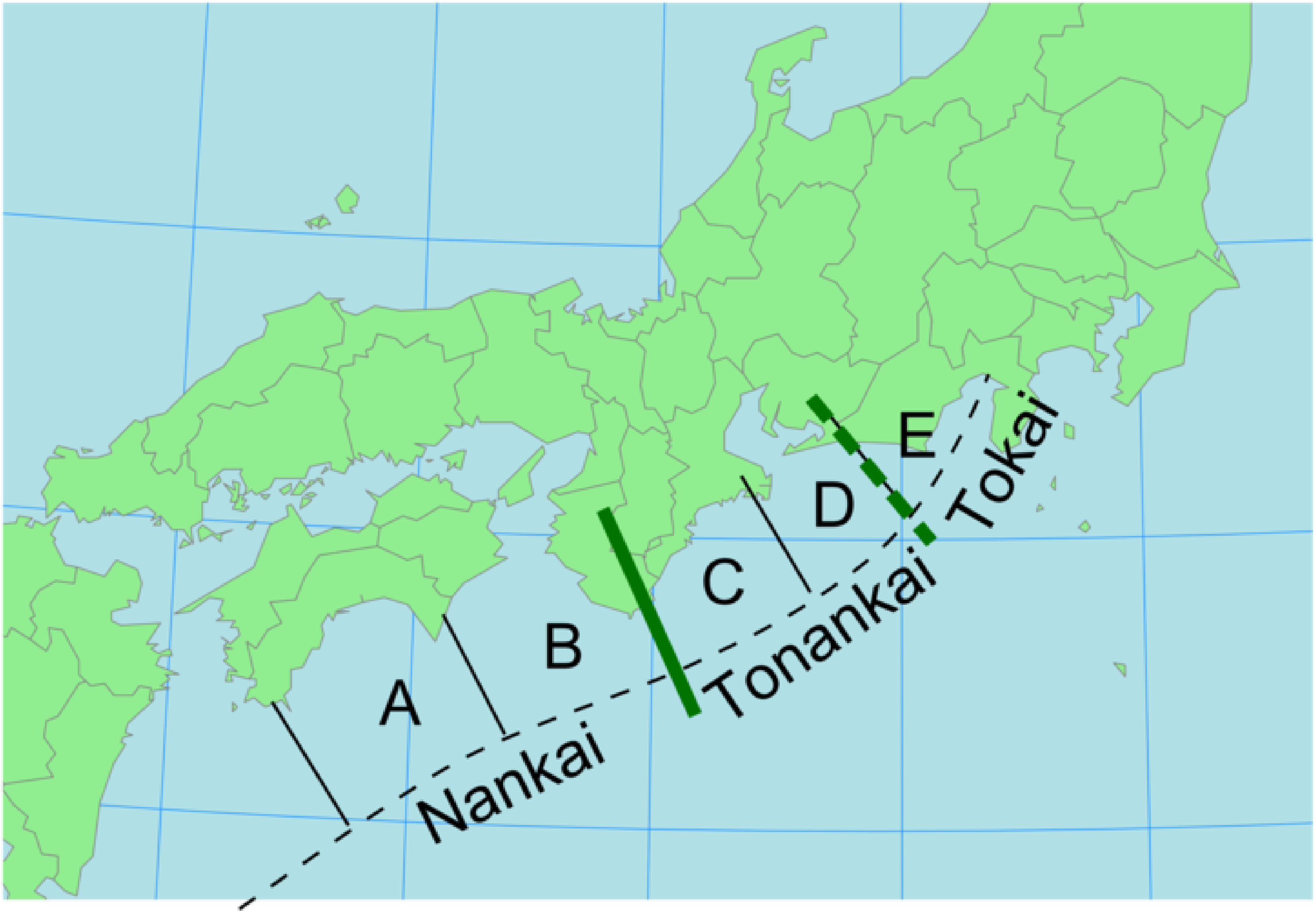

NOAA
Wave Height (cm)
0 20 40 60 80 100 120 140 160 180 200 220 240+

Conclusions

- Much we do not know about megathrust earthquakes
- Unprecedented amount of information from the Tōkohu earthquake
- Continuing research in the Nankai Trough
- New projects in the Japan Trench?
- Many opportunities for research in geophysics, marine geology, drilling technology



The next big earthquake?



Rupture areas of the Nankai Trough

ODP/IODP Current Research- Nankai Trough

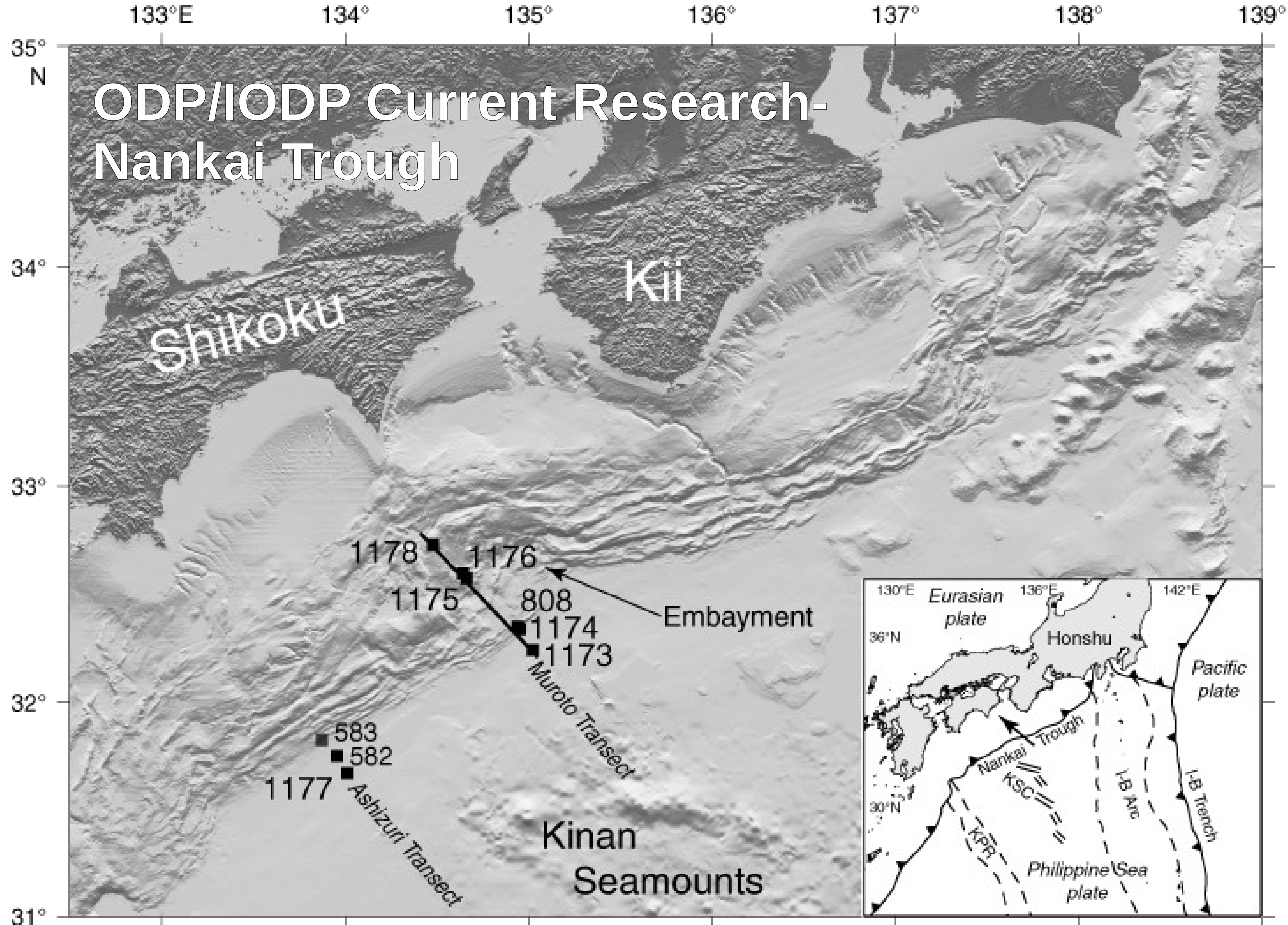
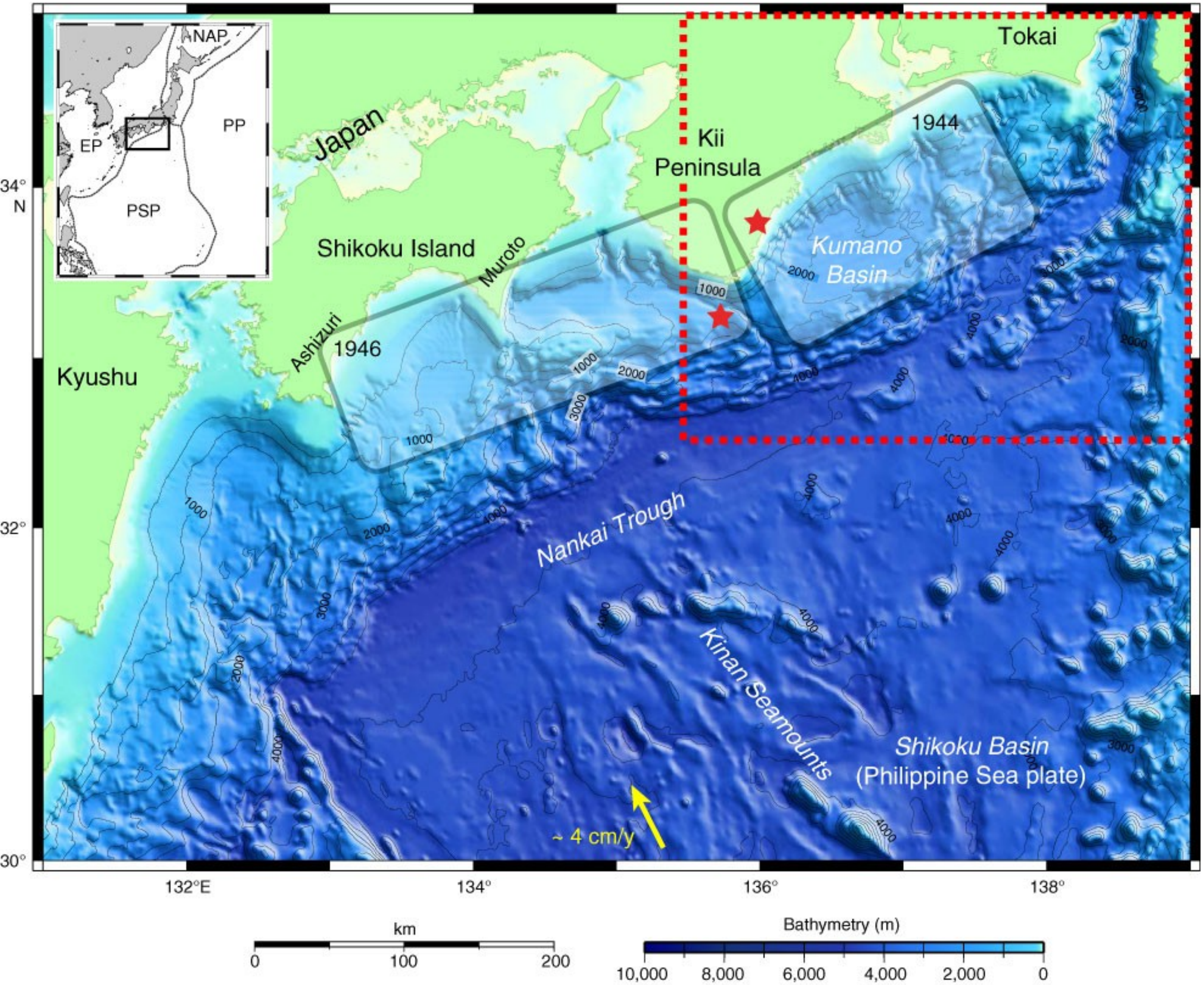


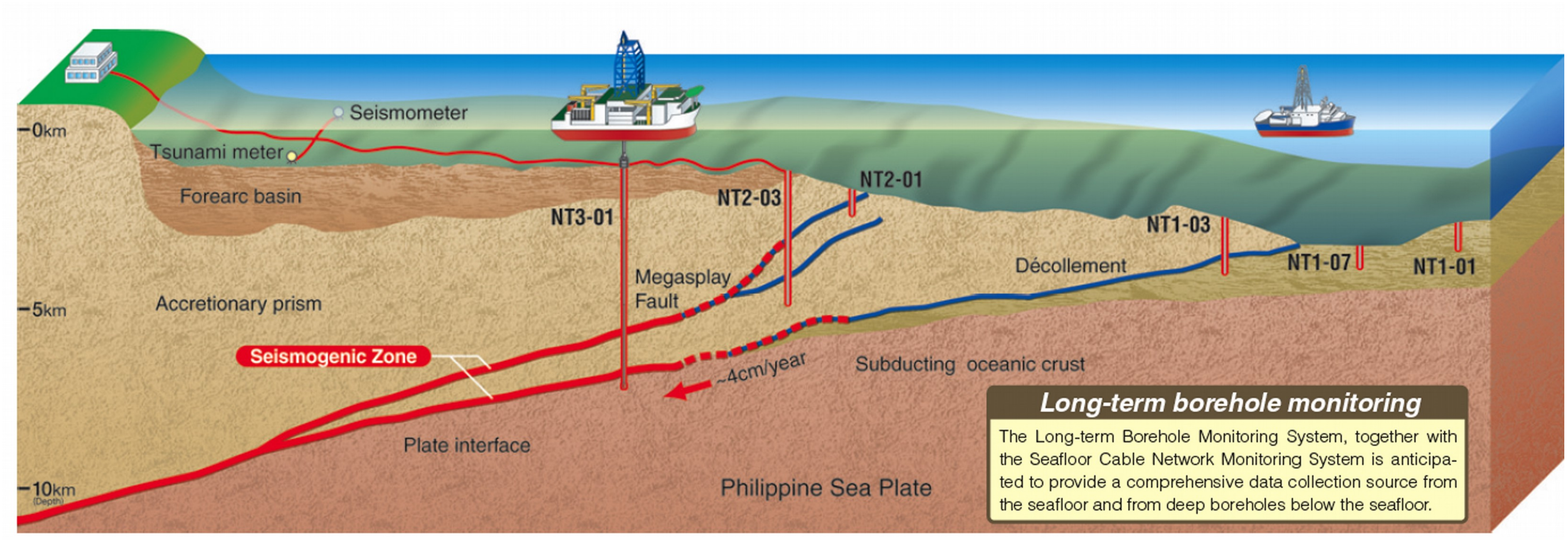
Image credit: Ocean drilling program



Why study the Nankai Trough?

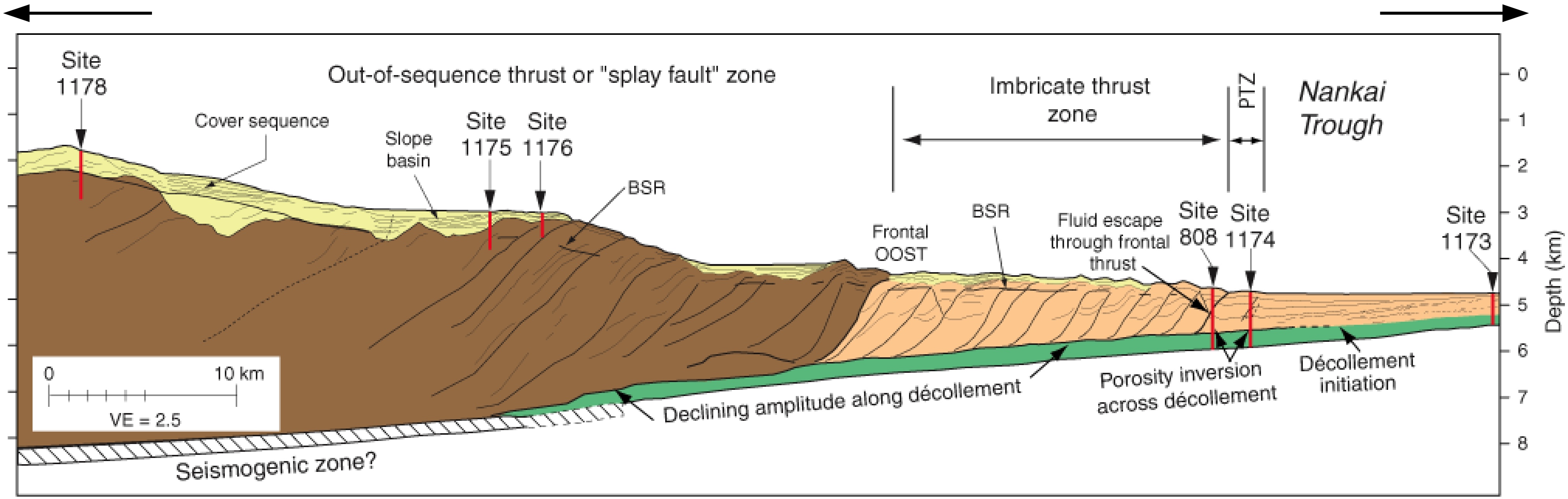
- 1300 year history of recurring great earthquakes with tsunami
- Relatively predictable rupture area for future events
- Well understood rupture area for the 1944 Tonankai (M=8.1)
- Plate boundary thrust is strongly locked (“stuck”)

Drilling into a subduction zone



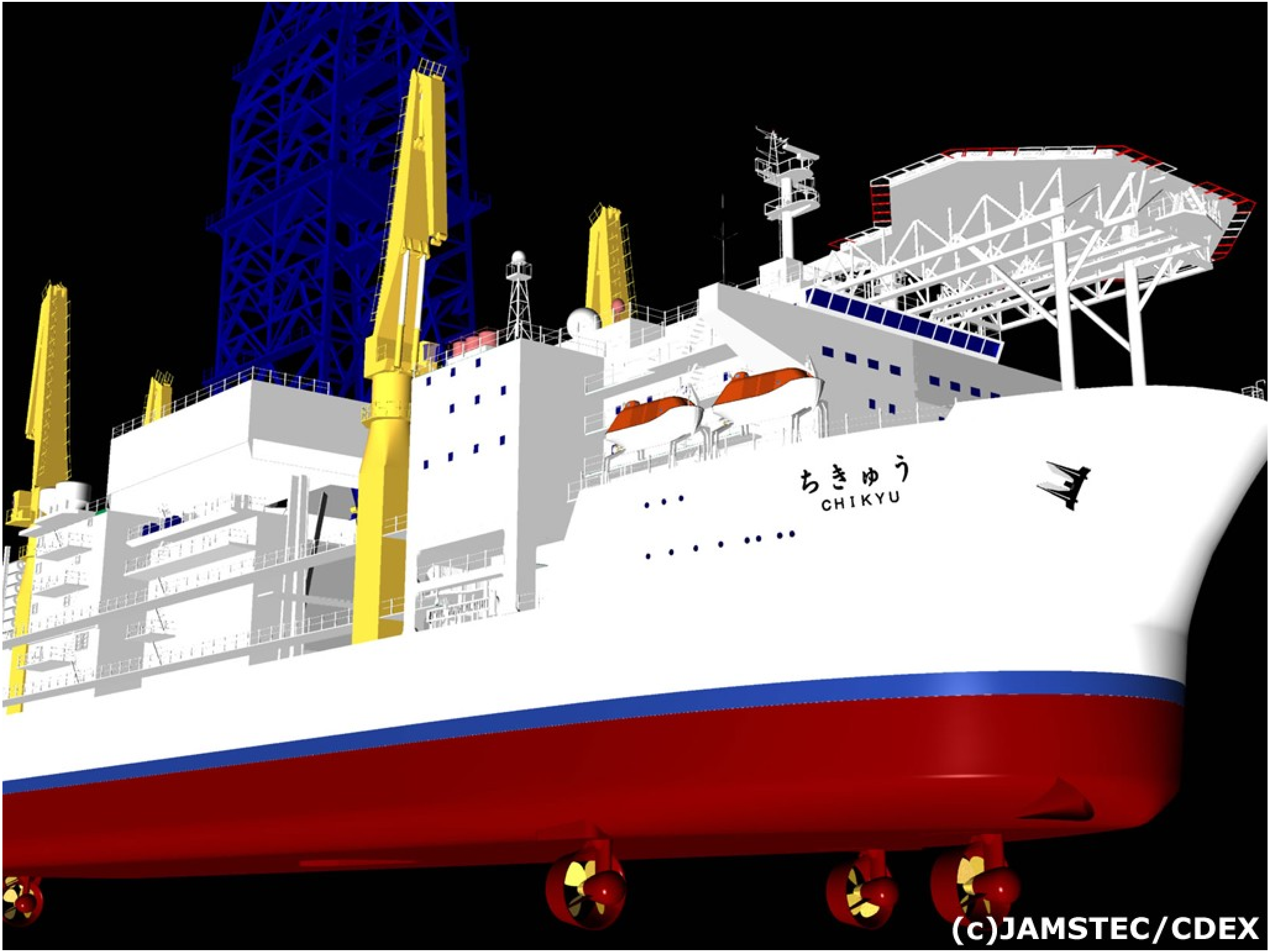
Drill into the part of the plate boundary fault where earthquakes occur (June 2012)

Cross section – Nankai Trough



- characterize properties of the sediments as subduction occurs
- Implications for how the earthquake zone behaves
  - What parts of the fault likely to rupture
  - How will the rupture propagate up to the seafloor

Chikyū Japanese for "Earth Discovery"

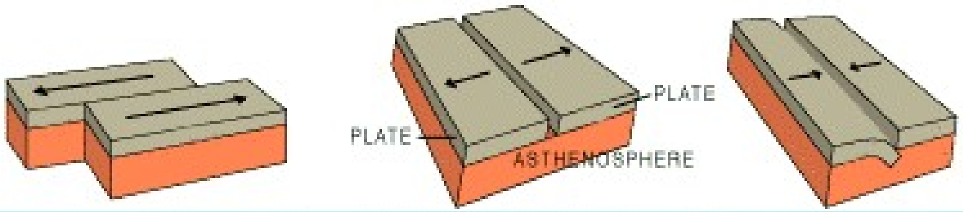

ちきゅう
CHIKYU
(c)JAMSTEC/CDEX

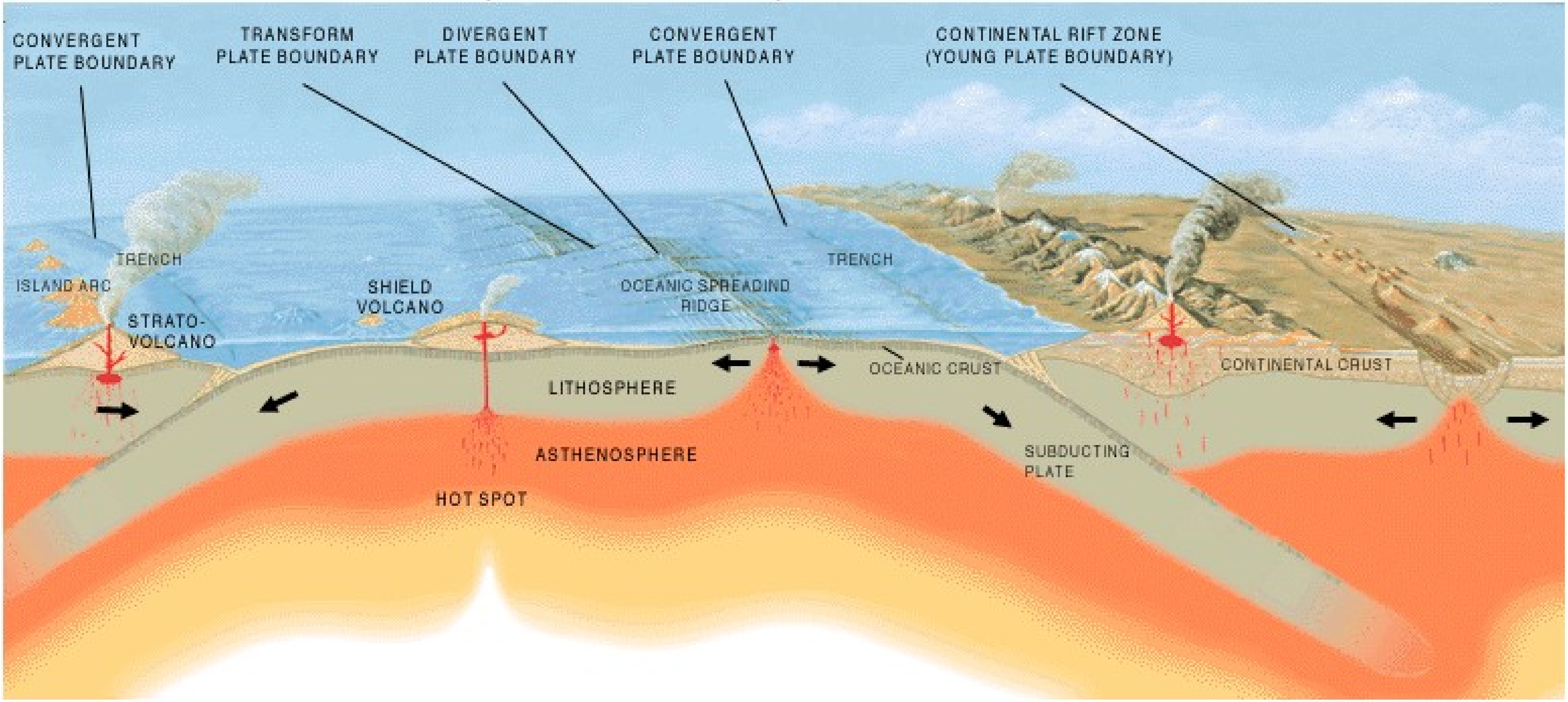
- 210 m long, 38 m in width, 16.2 m high
- Drill to 7000m beneath the seafloor
- Hachinohe port in preparation for IODP Expedition 337
- CHIKYU immediately evacuated port
- One of her six thrusters suffered damage.

Chikyū 1:100 scale model at the

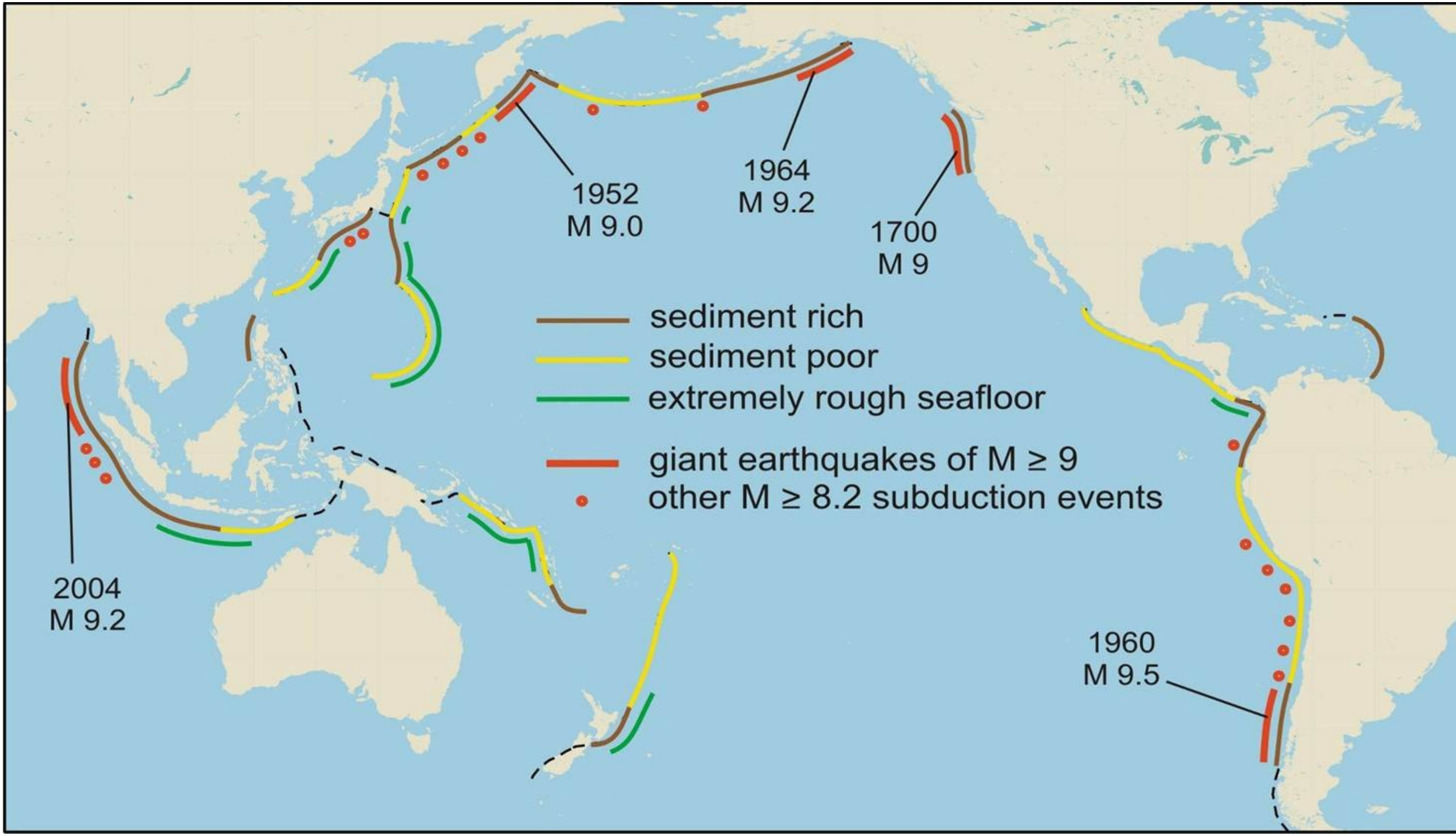
Smithsonian's National Museum of Natural History

Plate Boundaries



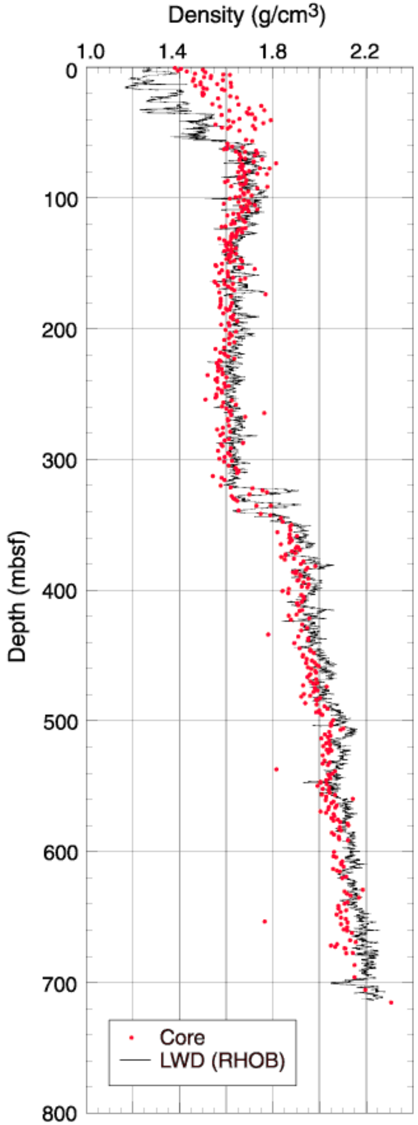


Subduction Earthquakes

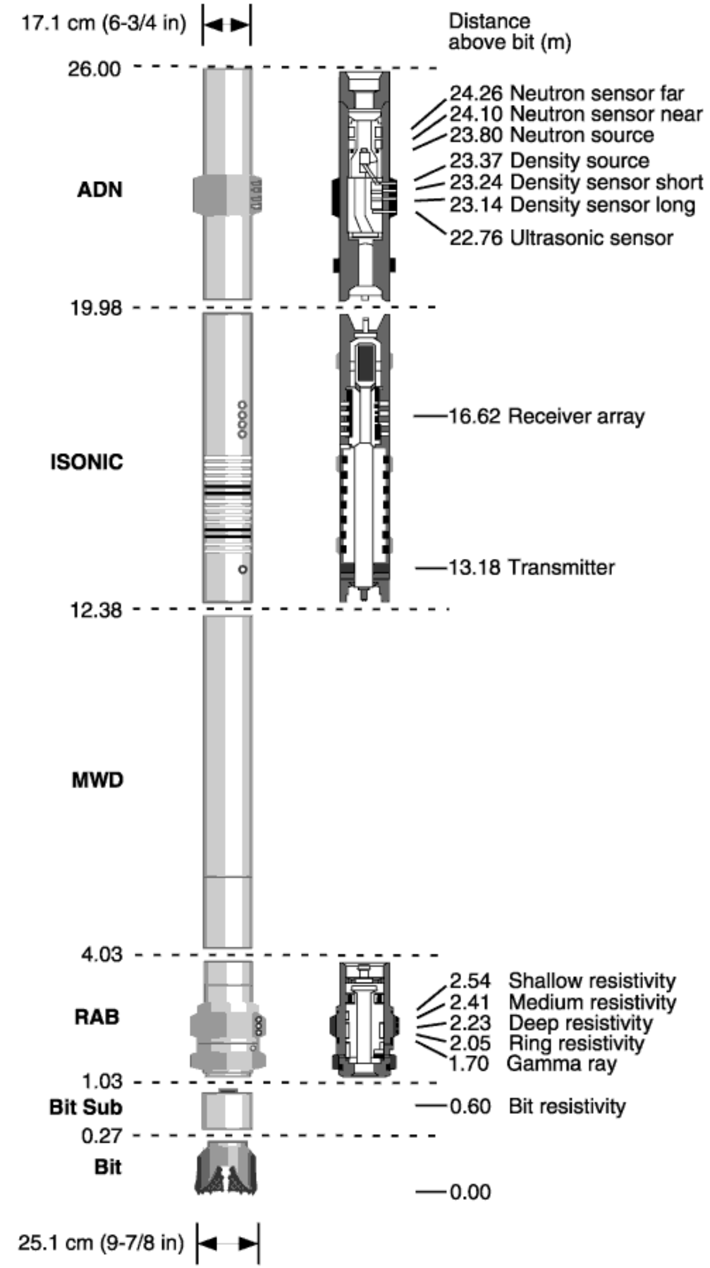


How are the sediments studied?

- Drilling
  - Wireline logs
  - Logging-while-drilling (LWD)
  - Core samples
- Seismic reflection surveys



Leg 196 – Site 1173



Drill String – Leg 196