Natural Hazards and Disaster

Class 4: Geohazards; Earthquakes

- Types of Geohazards
- Plate Tectonics
- Other Causes of Geohazards
- Earthquakes

Types of Geohazards

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Many, but by far not all, of the geohazards are related to plate tectonics. Increasingly, geohazards are also caused be humans.

Types of Geohazards

Tectonics:
- Stress and strain (tectonic movements)
- Earthquakes
- Tsunamis
- Volcanic activity
- Salt Tectonics

Ground instabilities and movements:
- Landslide
- Soil Creep
- Ground Dissolution
- Collapsible Ground
- Running Sand/ Liquefaction
- Shrink-swell clays
- Compressible Ground

Anthropogenic ground instabilities:
- Induced seismicity (reservoirs)
- Ground water management
- Oil and gas extraction
- Mining
- Underground construction
- Engineered ground
- Fracking

Other geohazards:
- health hazards of geologic materials:
  - radioactivity (non-human and human caused)
  - atmospheric aerosols
  - chemical elements (e.g. mercury, heavy metals)
  - water quality
  - anthropogenic pollution
- floods, droughts
- sediments
- meteorite impacts

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Plate tectonics

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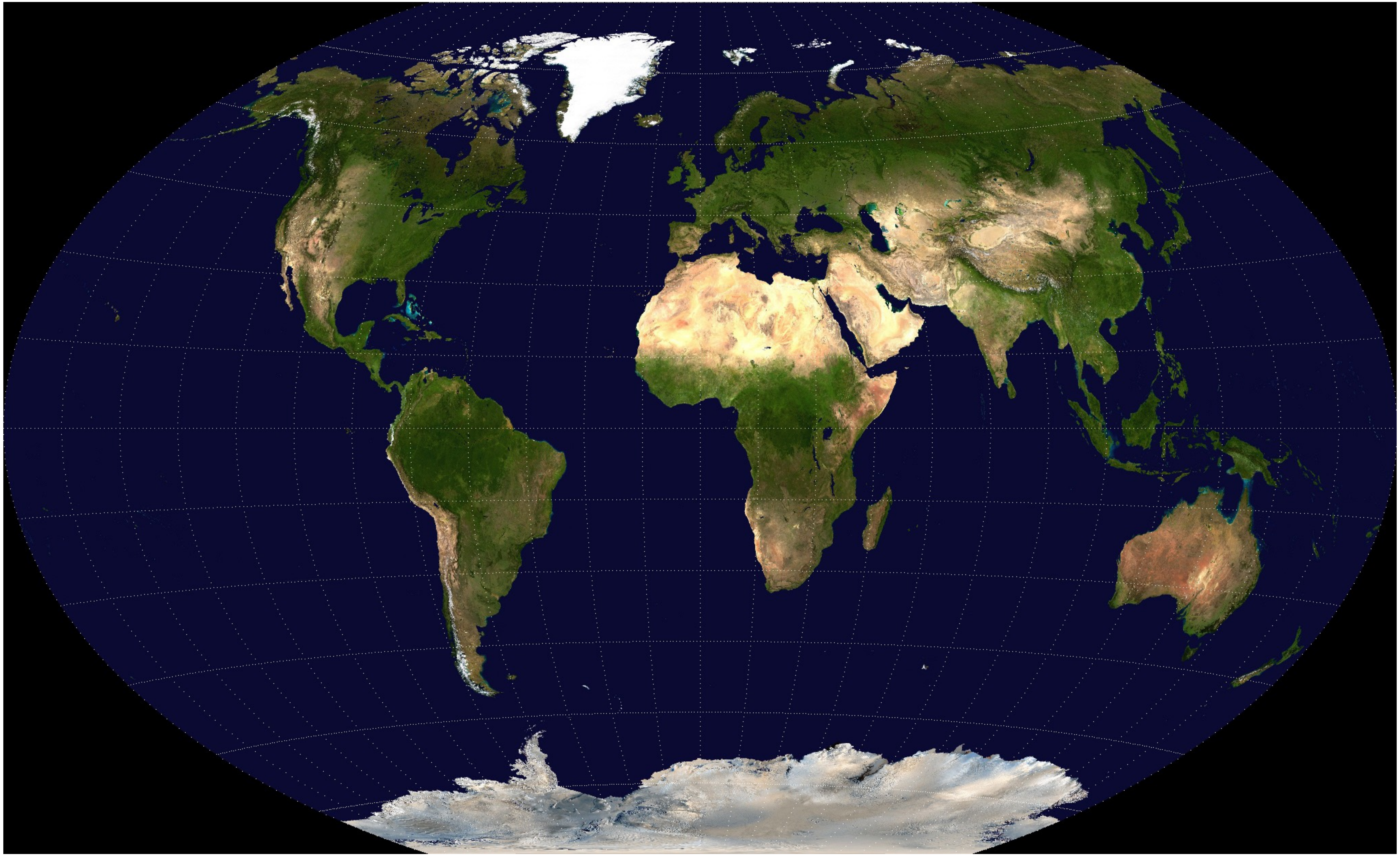
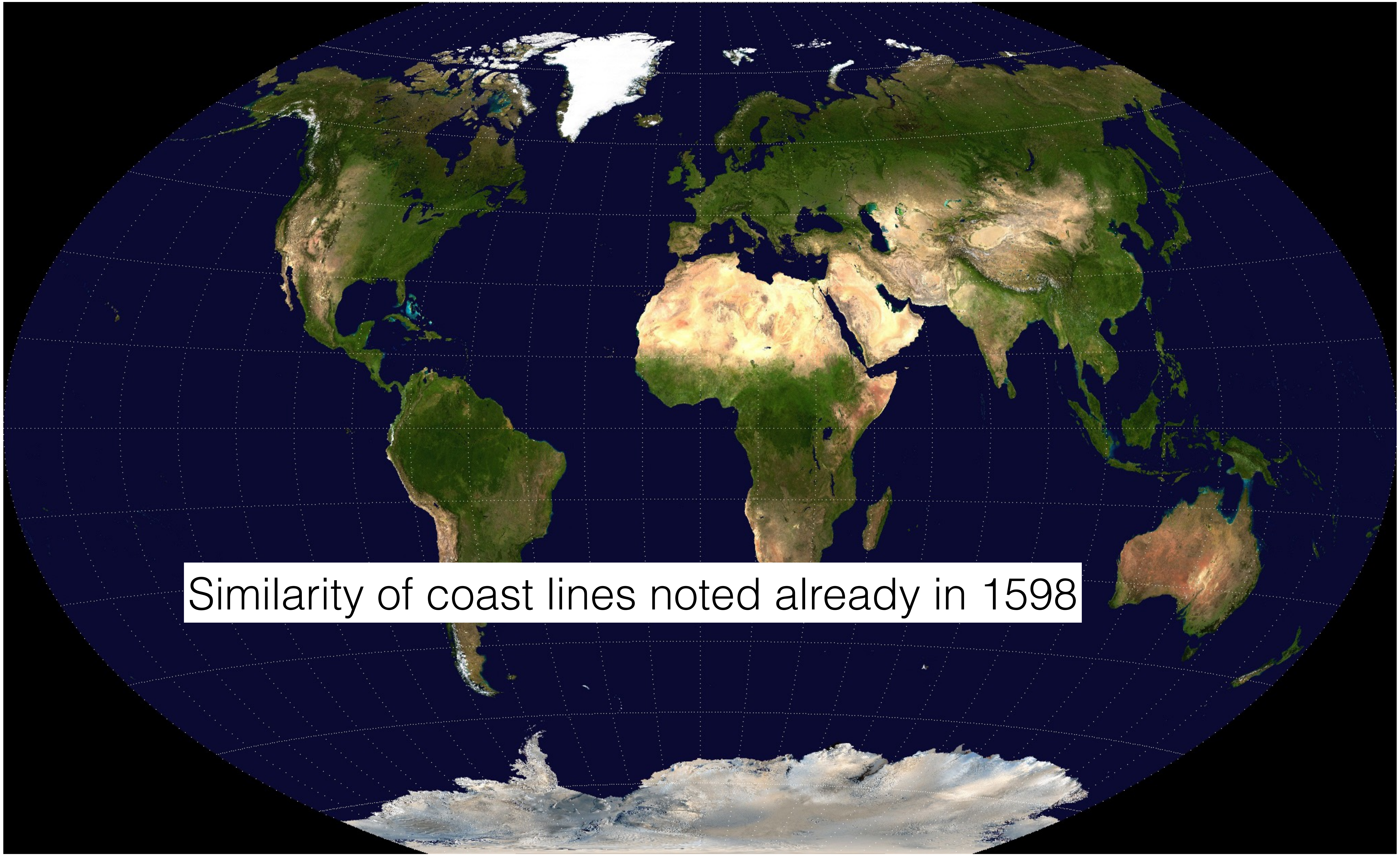


Plate tectonics



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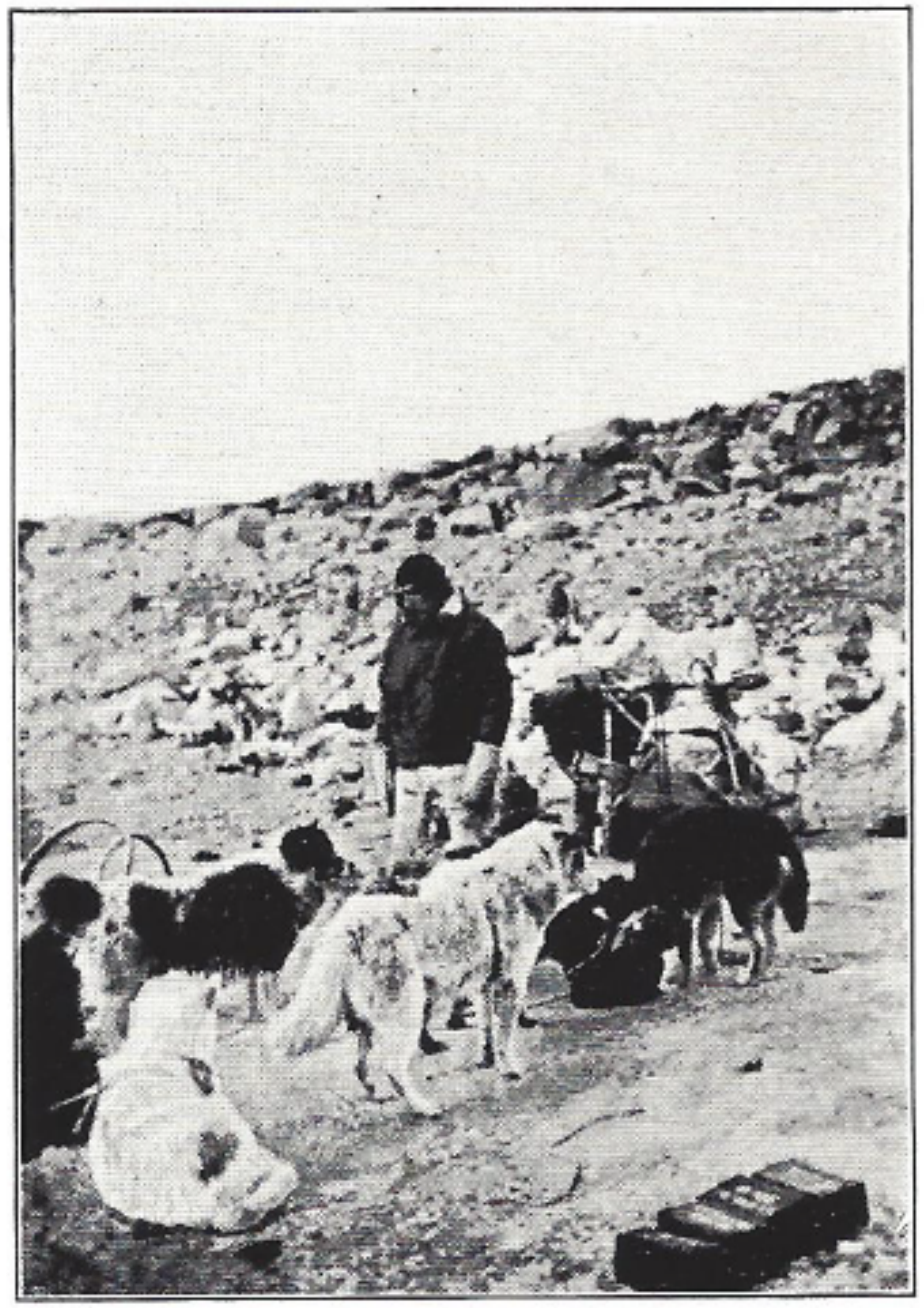

Aufnahme Holzapfel

Wegener mit seinen Hunden vor der Abfahrt nach „Eismitte". Seite 103.

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Alfred Wegener,
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Published the idea of "continental drift" in 1912

Supportive evidence:

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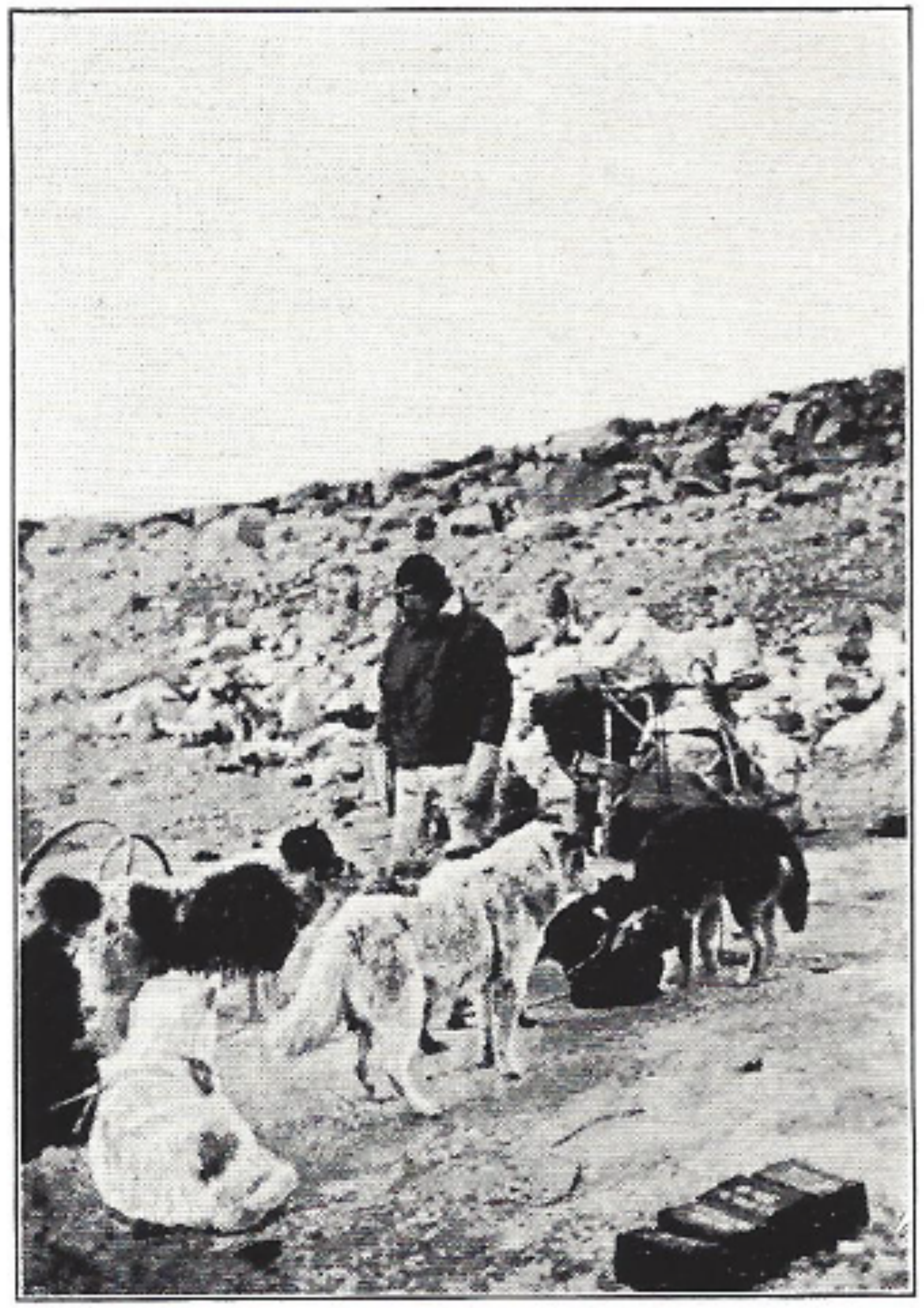
- Similarity of rocks on both sides of Atlantic

Plate tectonics



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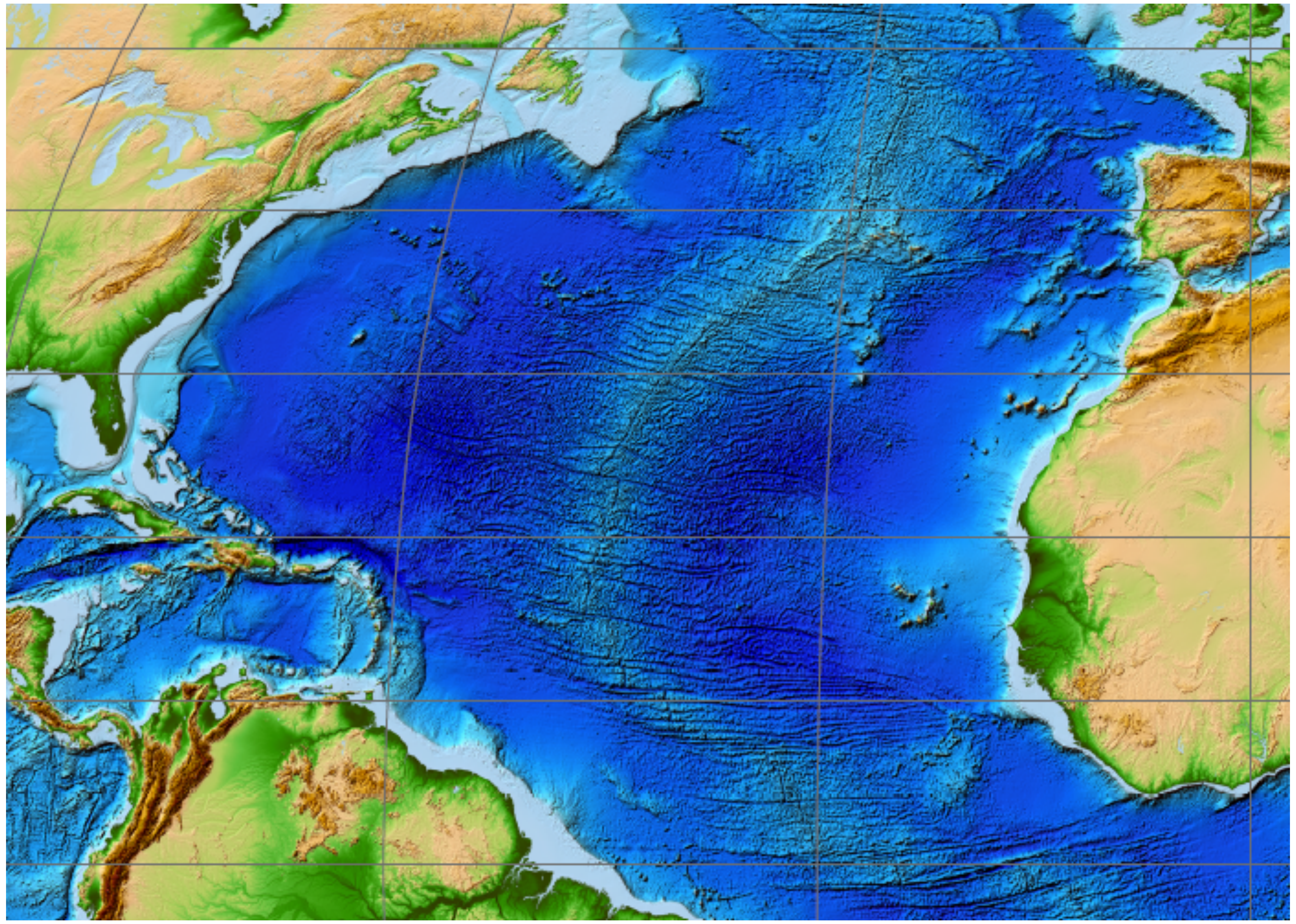
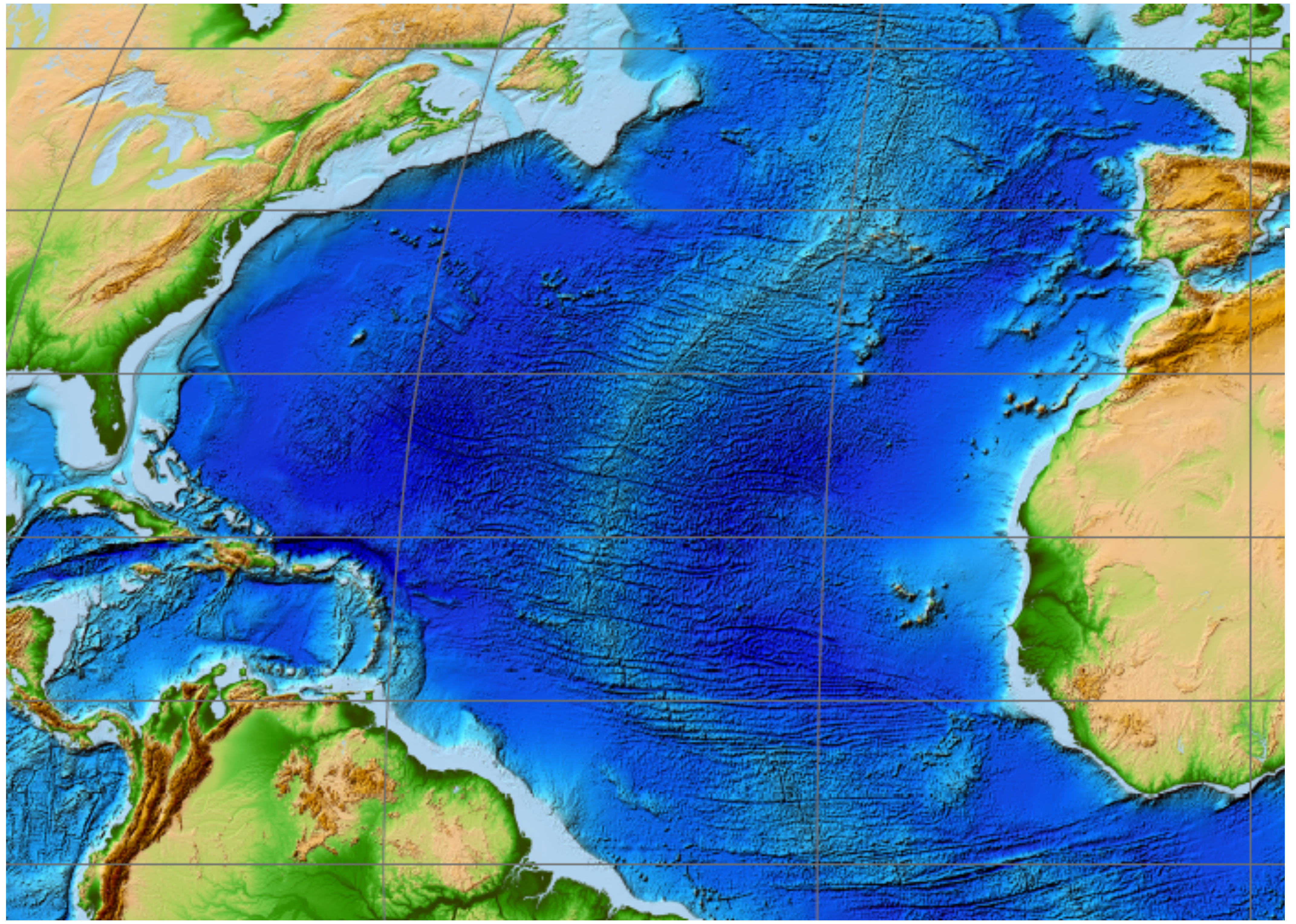
Theory not accepted because no explanation of the forcing processes



Magnetic patterns on ocean floor



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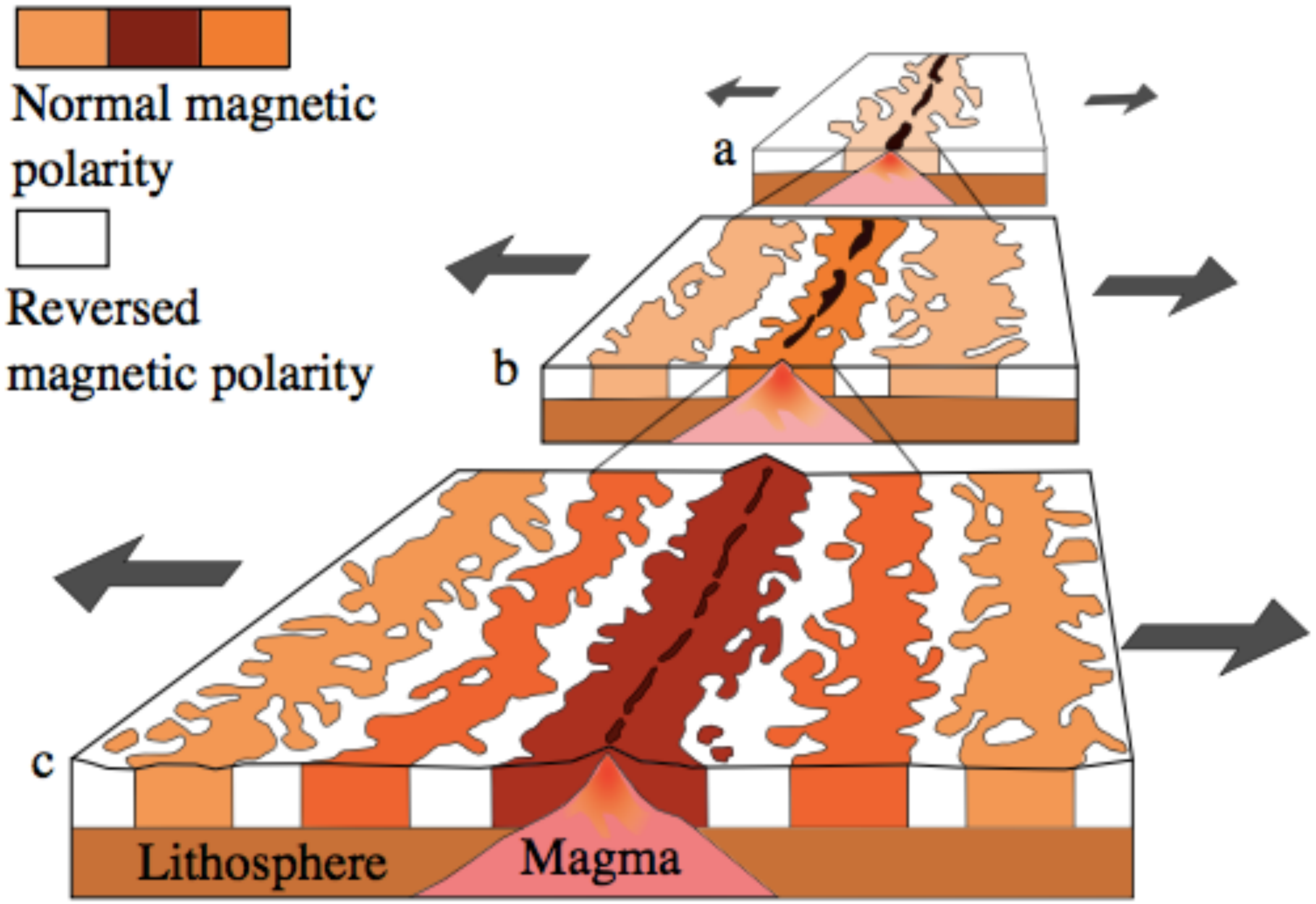
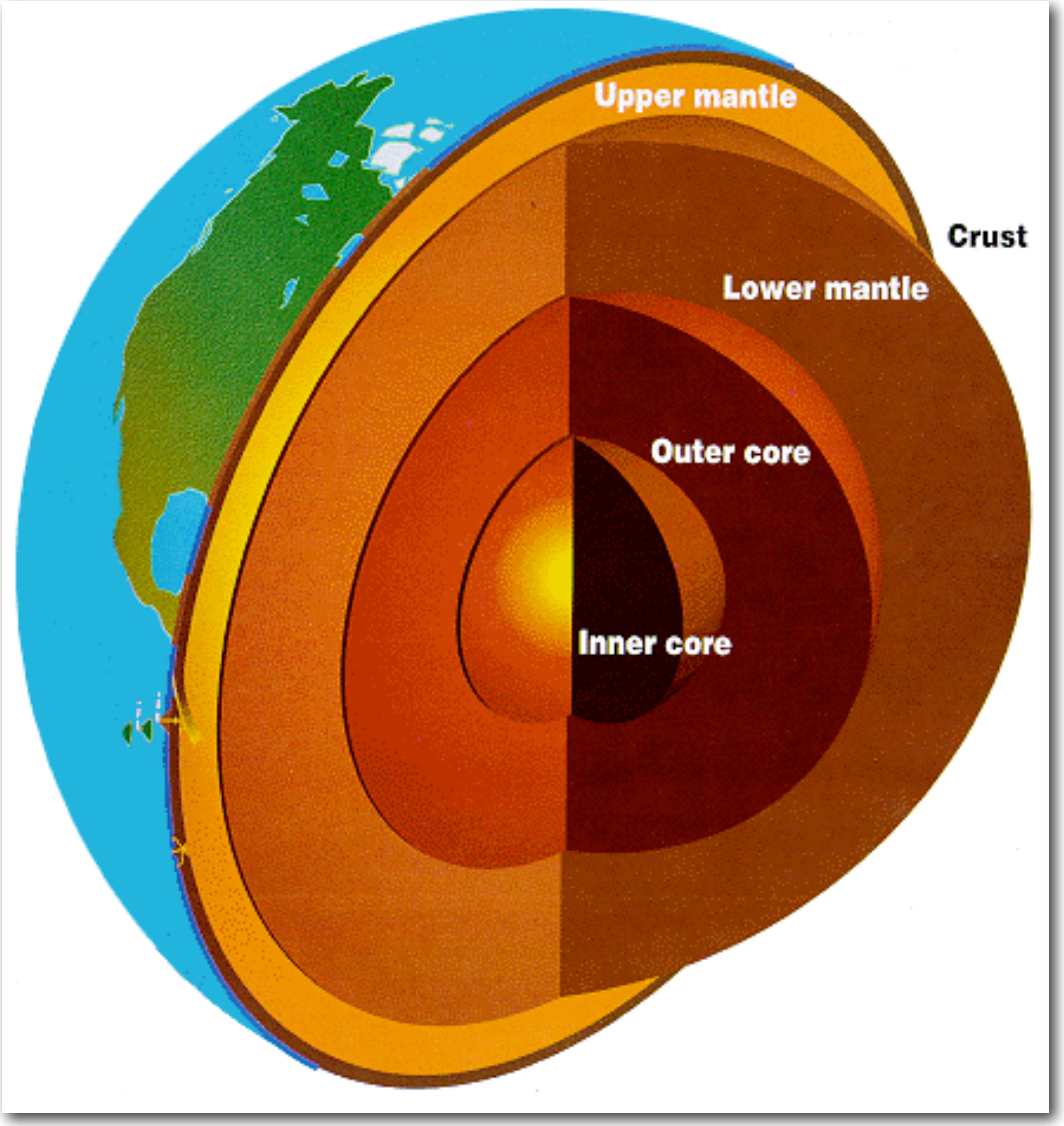
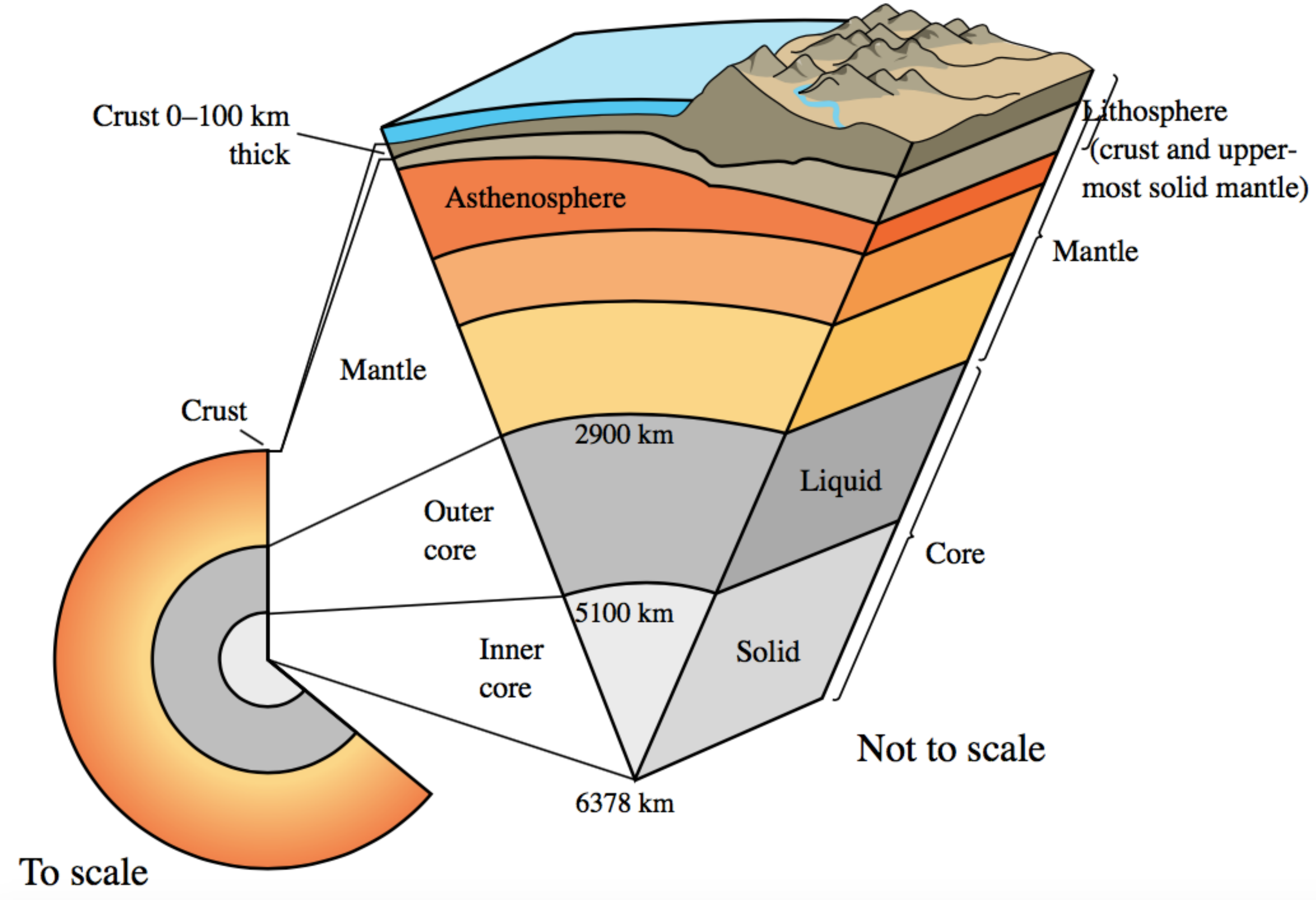


Plate tectonics





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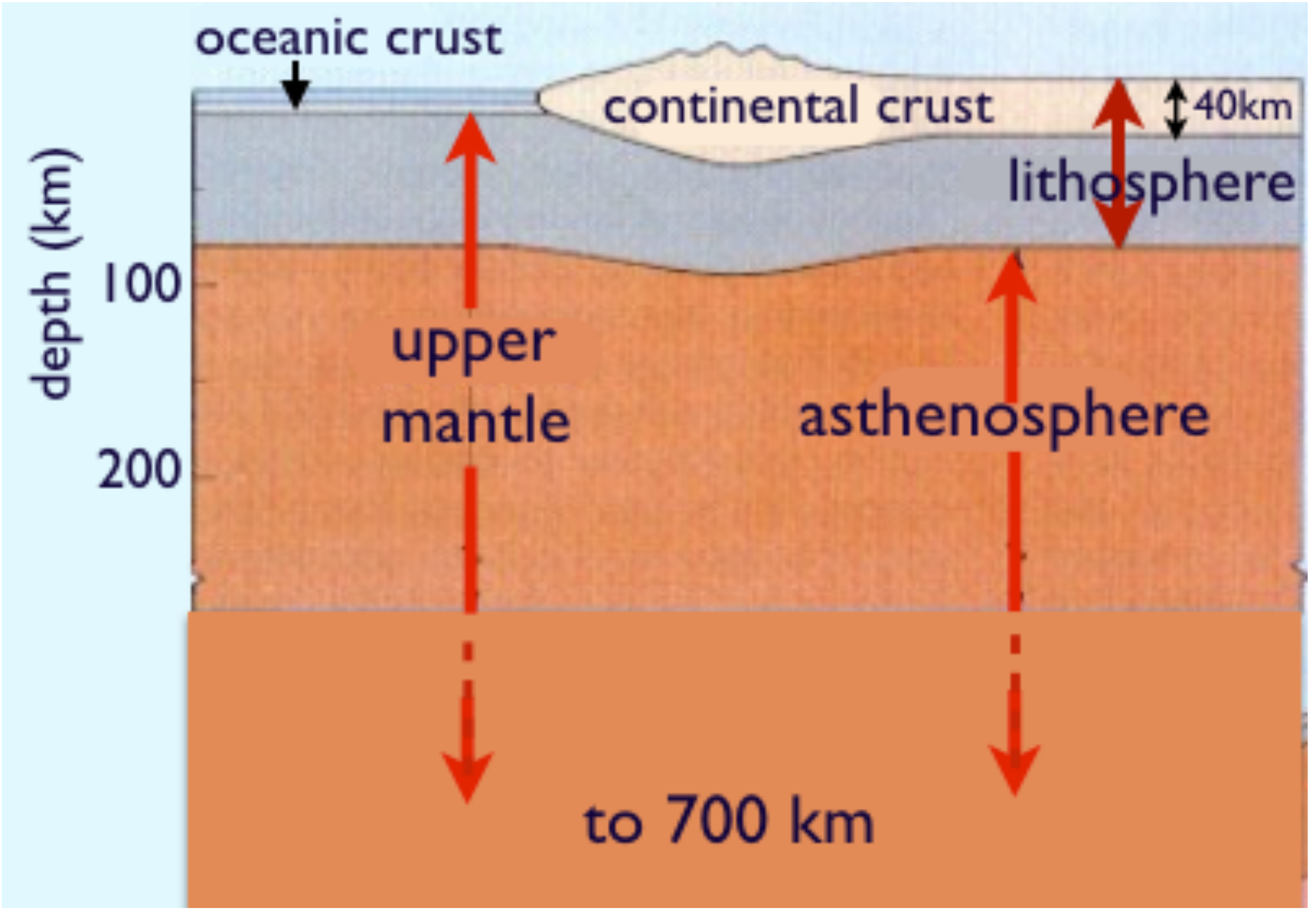
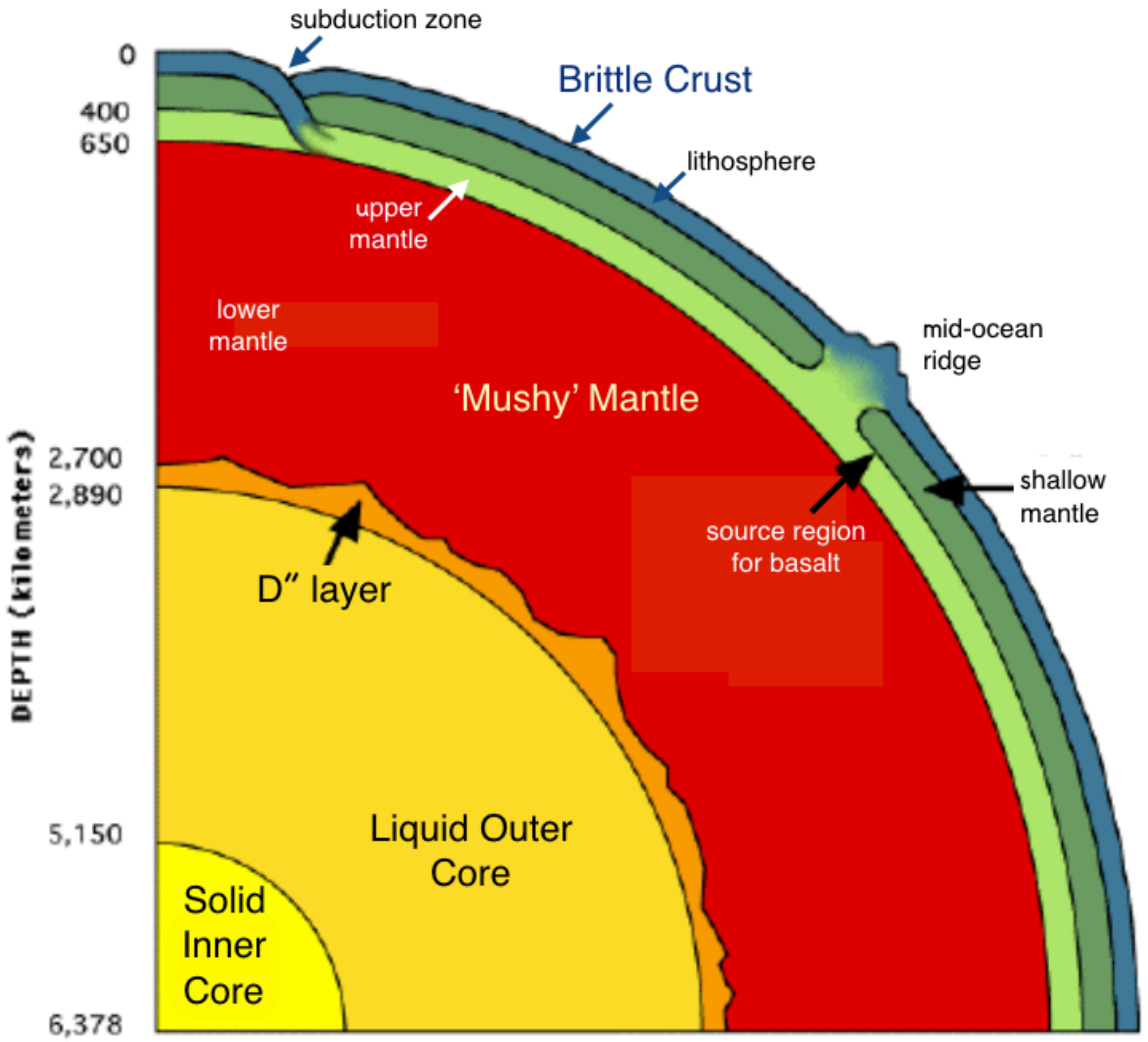
Earth's Internal Structure

- Earth's Crust: continental and ocean crusts are the thinnest, outermost layers of the planet.
- Lithosphere: is chemically and mineralogically part of the upper mantle.
- Tectonic Plates: The continental and oceanic crustal rocks and their underlying lithosphere, which together comprise the tectonic plates, are on average 100 km thick and for the most part they are rigid and brittle.
- Asthenosphere: beneath the lithosphere is the asthenosphere, which although solid, is capable of flowing slowly due to its high temperature (1300°C).
- Mantle: Layer between the asthenosphere and the outer core, which makes up about 84% of Earth's volume. It is a viscous solid.
- D": Transition zone between base of lower mantle and liquid outer core.
- Outer core: Liquid layer below the D" zone most likely composed of iron mixed with nickel and trace amounts of lighter elements.
- Inner Core: Solid core most likely composed of an iron-nickel alloy and some other elements.



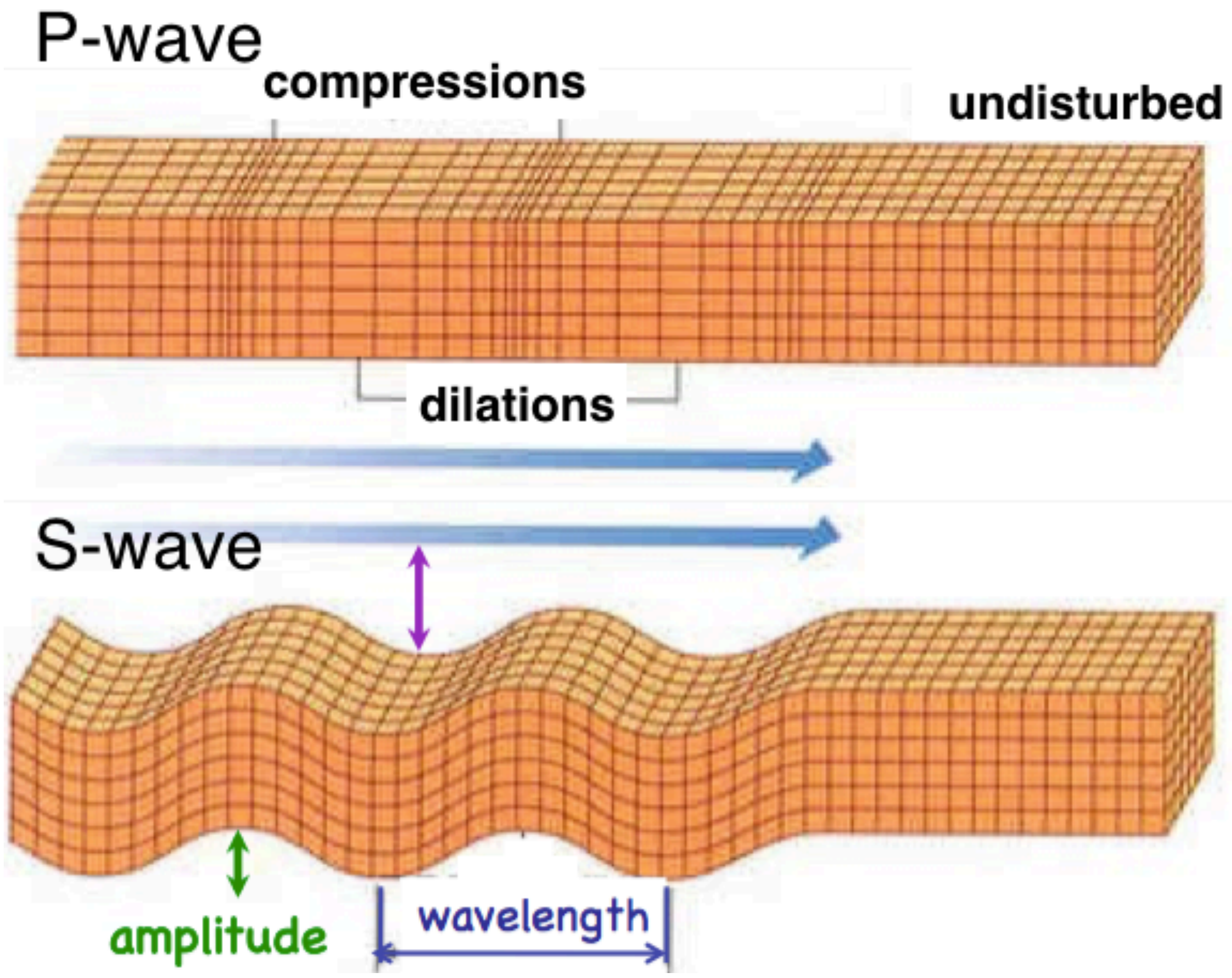
Earth's tectonic plates, sometimes referred to as lithospheric plates, are made of the lithosphere and the overlying oceanic and/or continental crust.



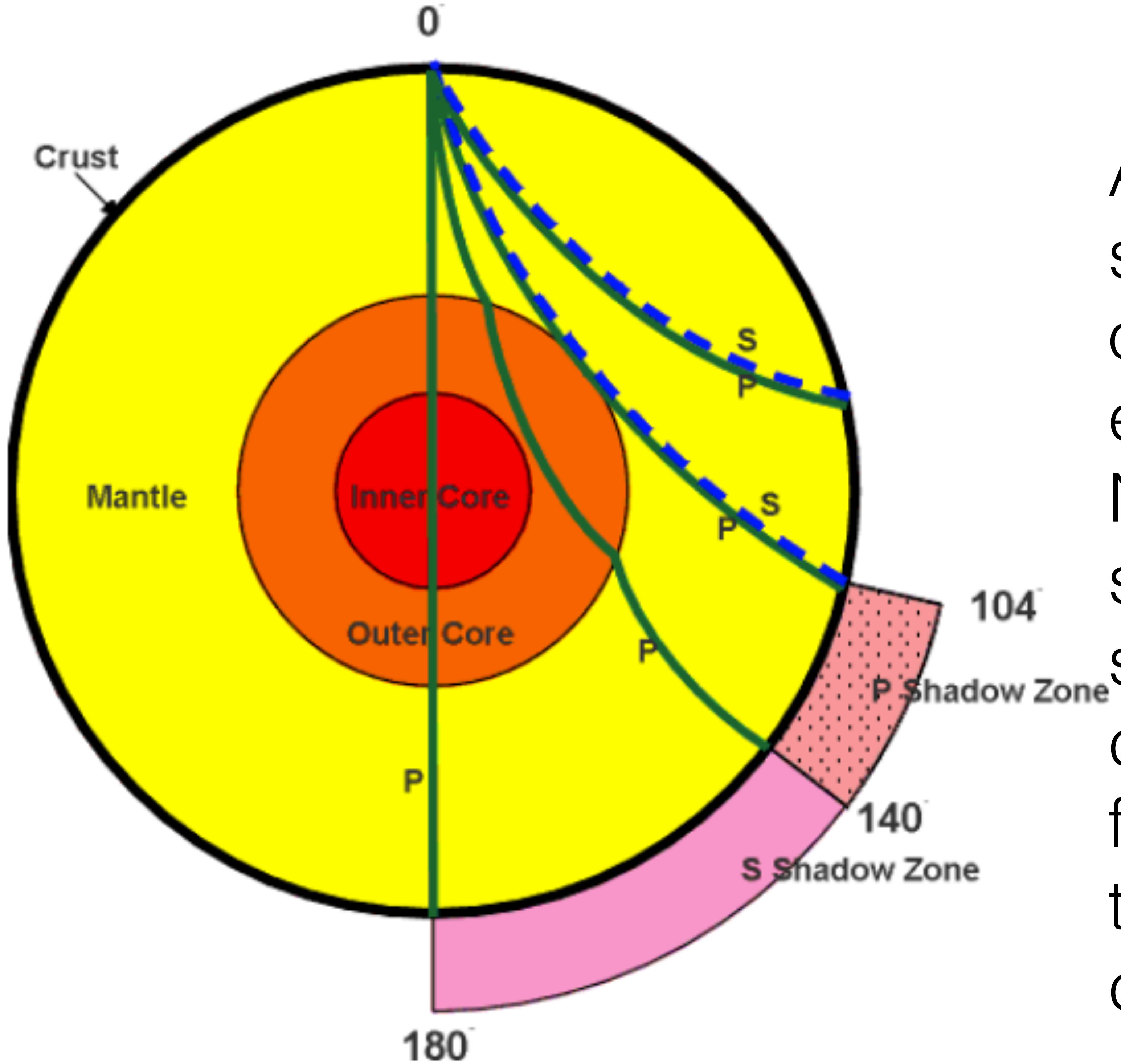
The internal structure of Earth. Layer D" is the transition zone between the liquid outer core and the base of the lower mantle.

Using Earthquakes To Map Earth’s Internal Structure

- Seismic waves generated by earthquakes are useful for mapping Earth’s internal structure.
- Earthquakes and very large explosions release energy in the form of seismic waves that travel in all directions through the Earth.
- The different physical properties of compressional (P) and shear (S) seismic body waves are useful for mapping Earth’s internal structure.
- Unlike P-waves, the S-waves cannot travel through fluids; there is always a ‘shadow zone’ without S-waves.
- The recognition of this shadow zone allowed scientists to infer the existence of Earth’s fluid outer core.



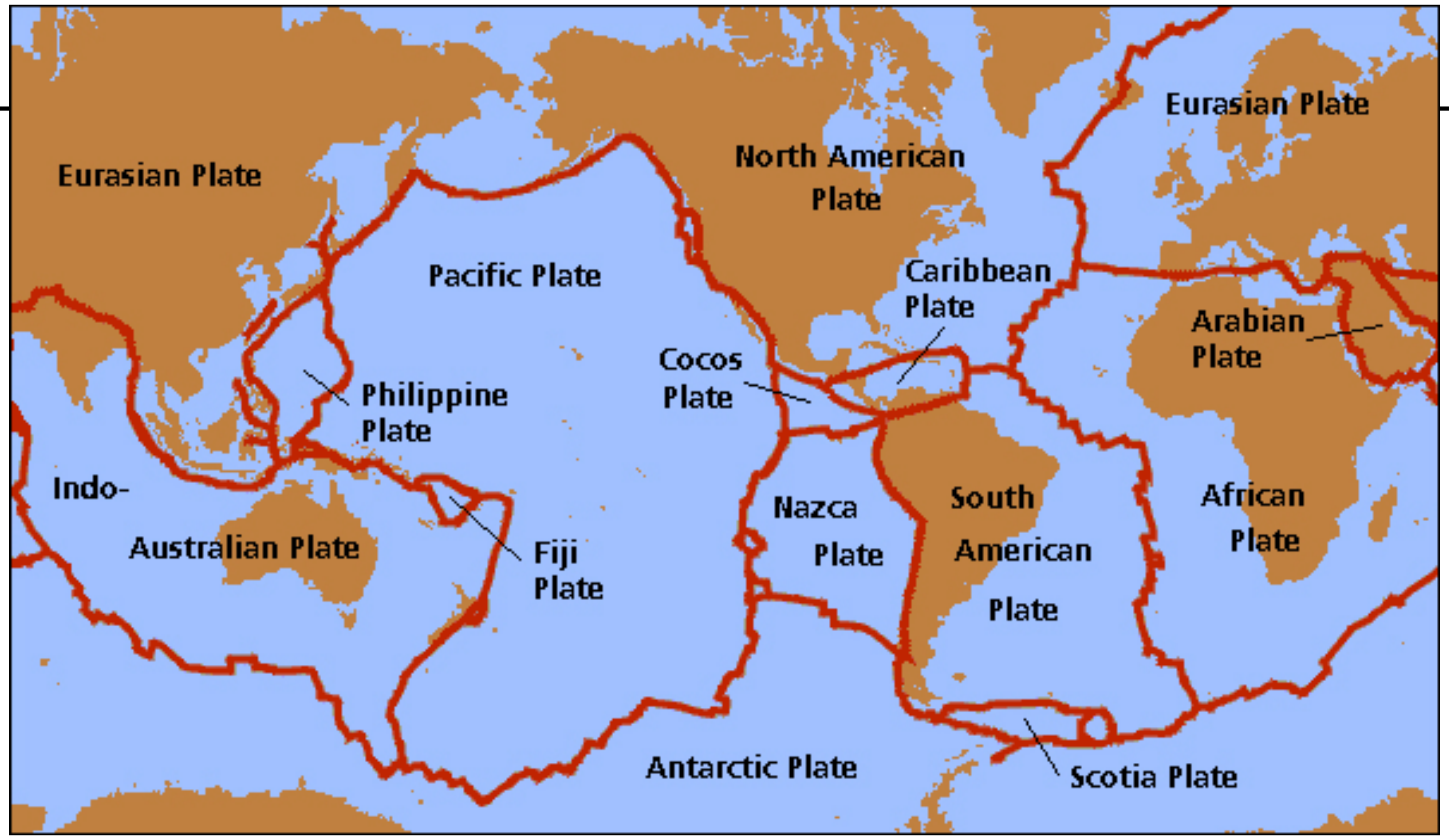
Compressional (P) and shear (S) seismic body waves. S-waves cannot be transmitted through a liquid.



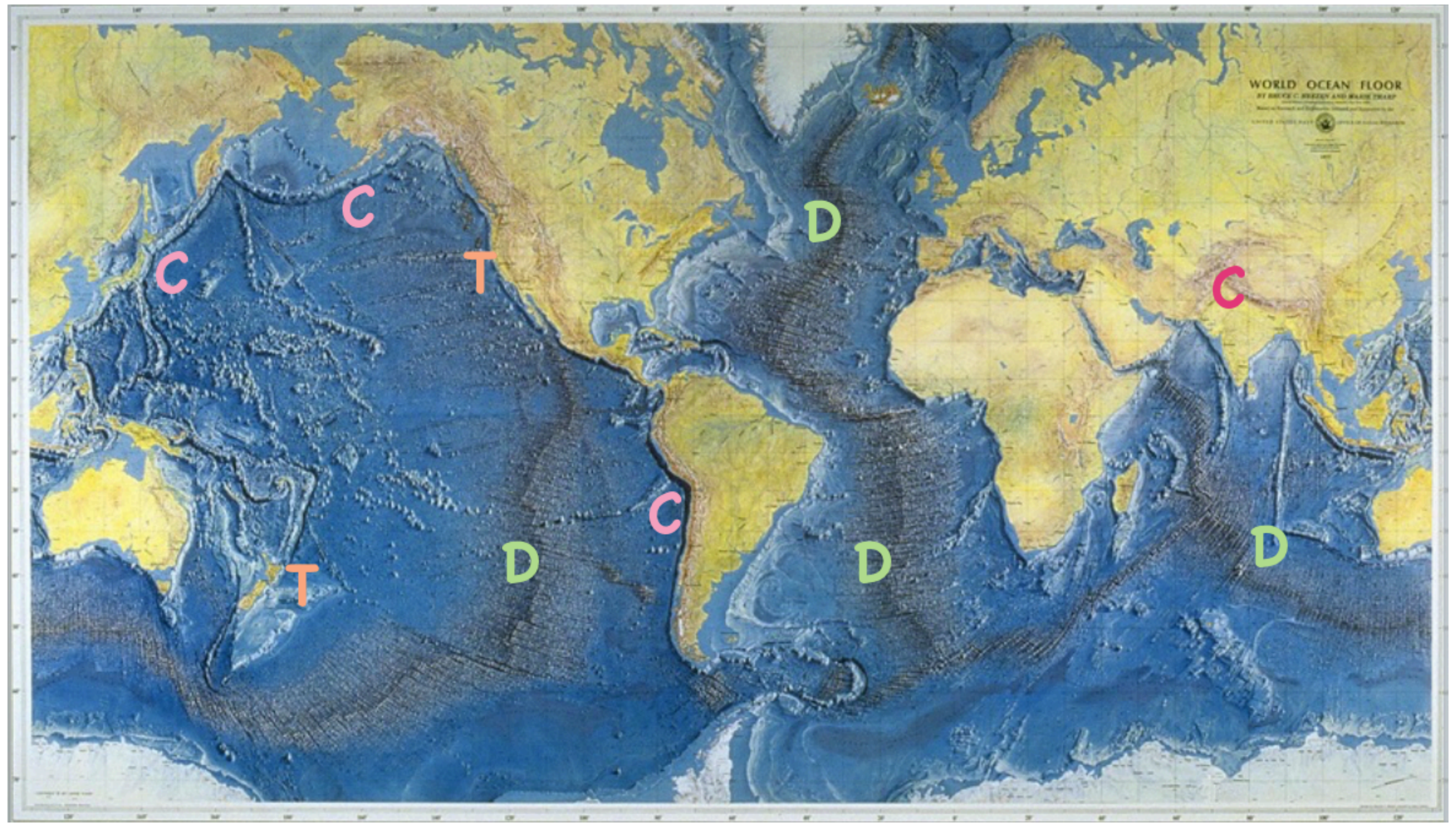
An S-wave ‘shadow zone,’ shown in pink, occurs on the opposite side of Earth to an earthquake at position ‘0’. No S-waves are received by seismograph stations in the shadow zone; only P-waves can travel through Earth’s fluid outer core, although they are refracted at the core-mantle boundary.

Tectonic Plates

- The three main types of plate boundary are:
  1. divergent, where plates move apart along mid-ocean spreading ridges;
  2. convergent, where one plate moves over the top of another;
  3. transform, where plates slide past one another.
- More complex boundaries combine different types.
- Relative to an Earth-fixed reference frame, they move with few exceptions with velocities of less than 10 cm/year.
- Relative velocities between neighboring plates can reach up to 25 cm/year.
- Over thousands to millions of years, the plates can accomplish a great deal of motion.
- The boundaries and relative movement vectors of the larger plates are well-defined.
- There are also dozens of micro-plates whose boundaries and relative motions are still the subject of research activity.
- Earthquakes and volcanic eruptions occur mainly because Earth's lithospheric plates are constantly in motion.

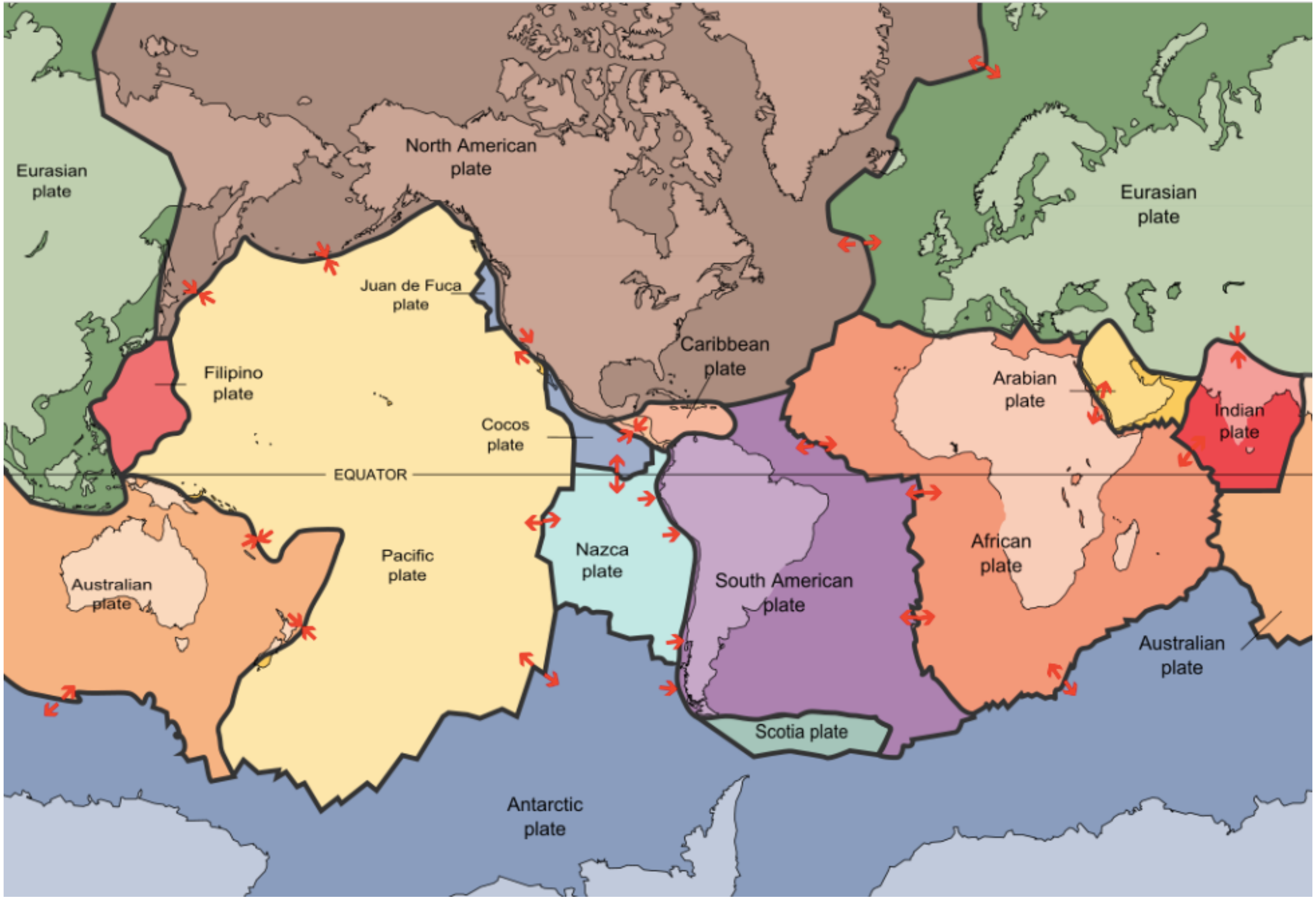


Earth's major tectonic plates and some of the smaller plates (boundaries outlined in red).



Earth's divergent (D), convergent (C), and transform (T) plate boundaries have a distinct appearance on an ocean floor elevation map. Not all plate boundaries are simple; a few have more complex D+T or C+T movement and some plate boundary regions, such as in the western Pacific, contain numerous micro-plates.

Plate tectonics



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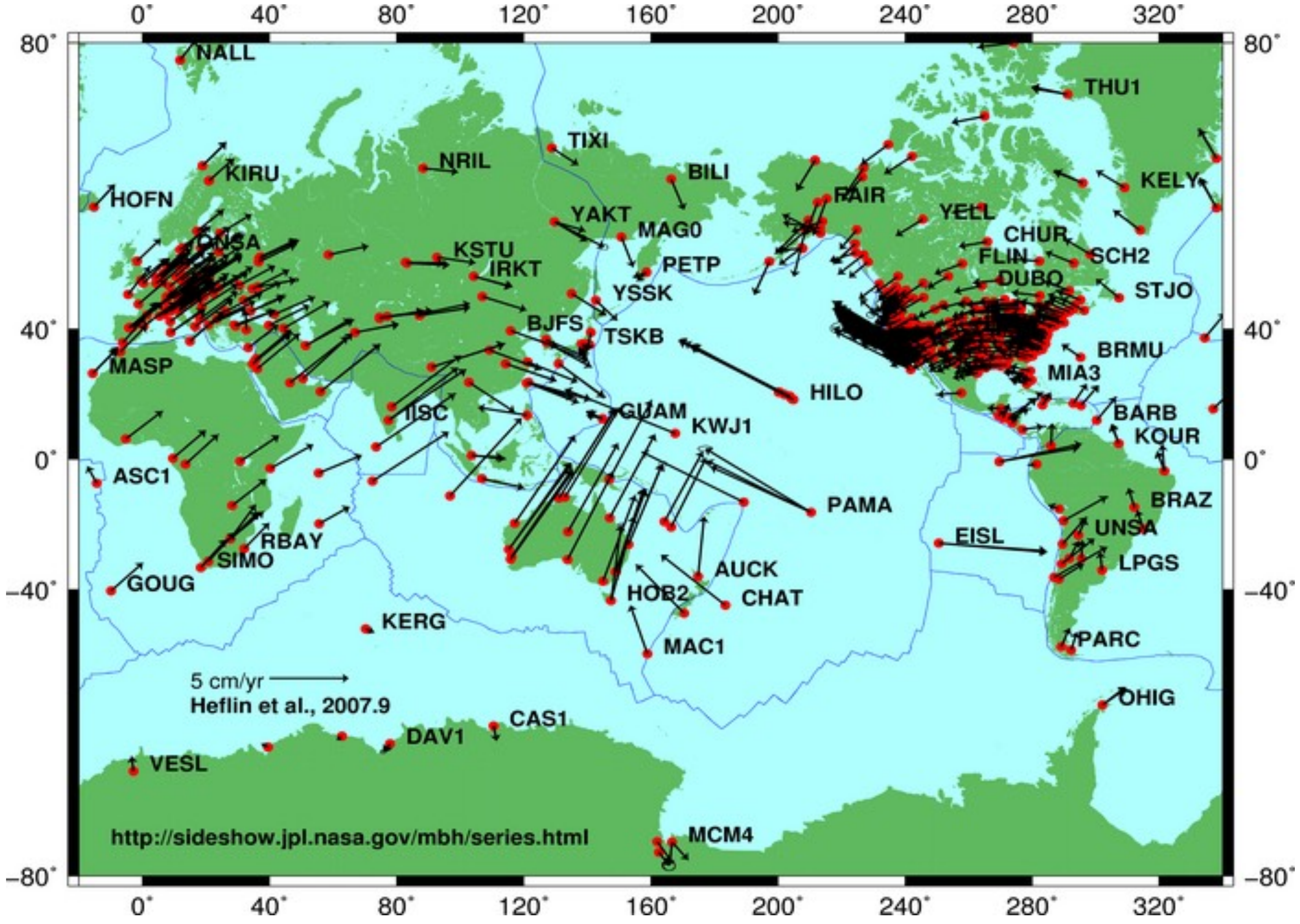

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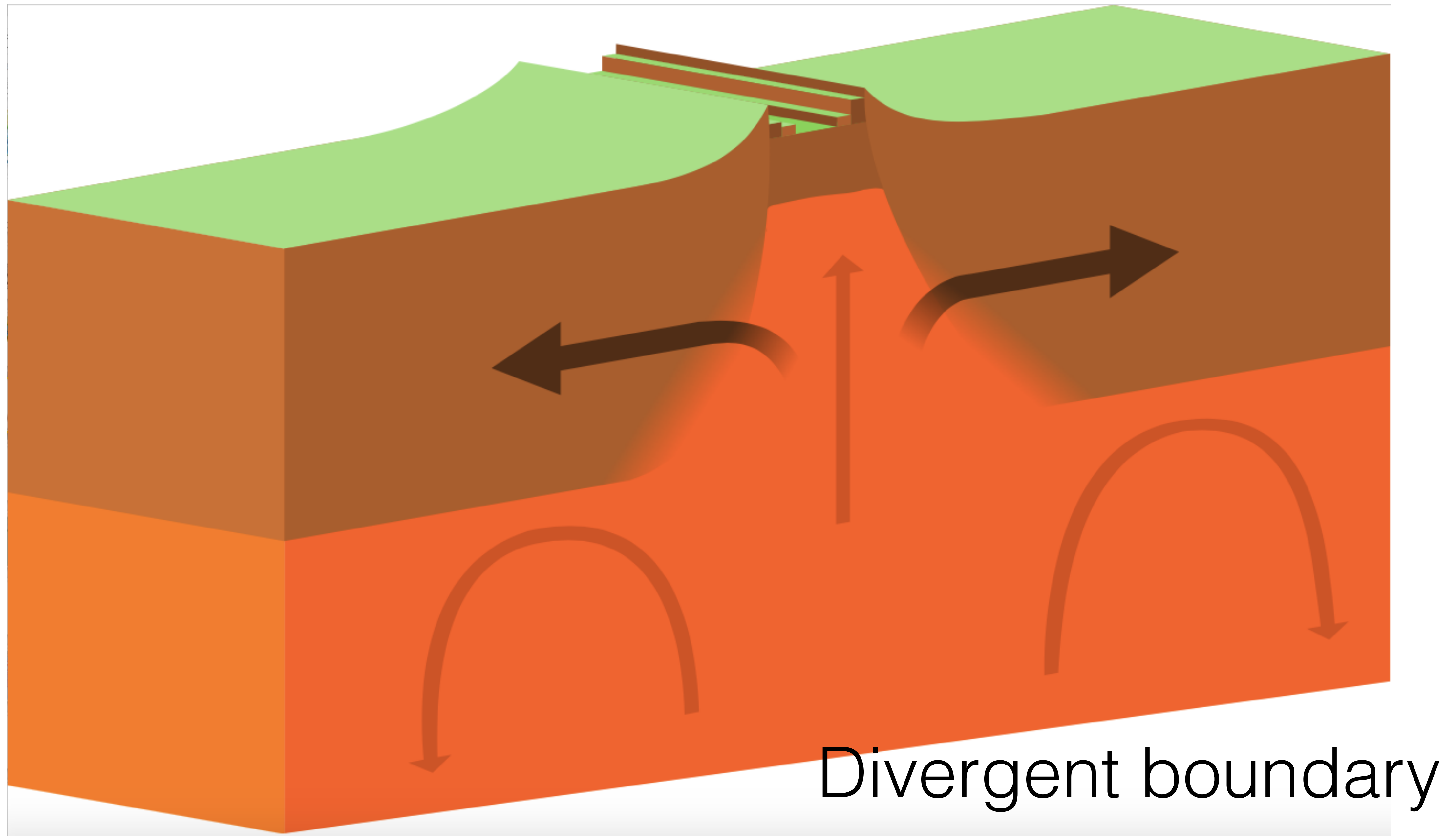
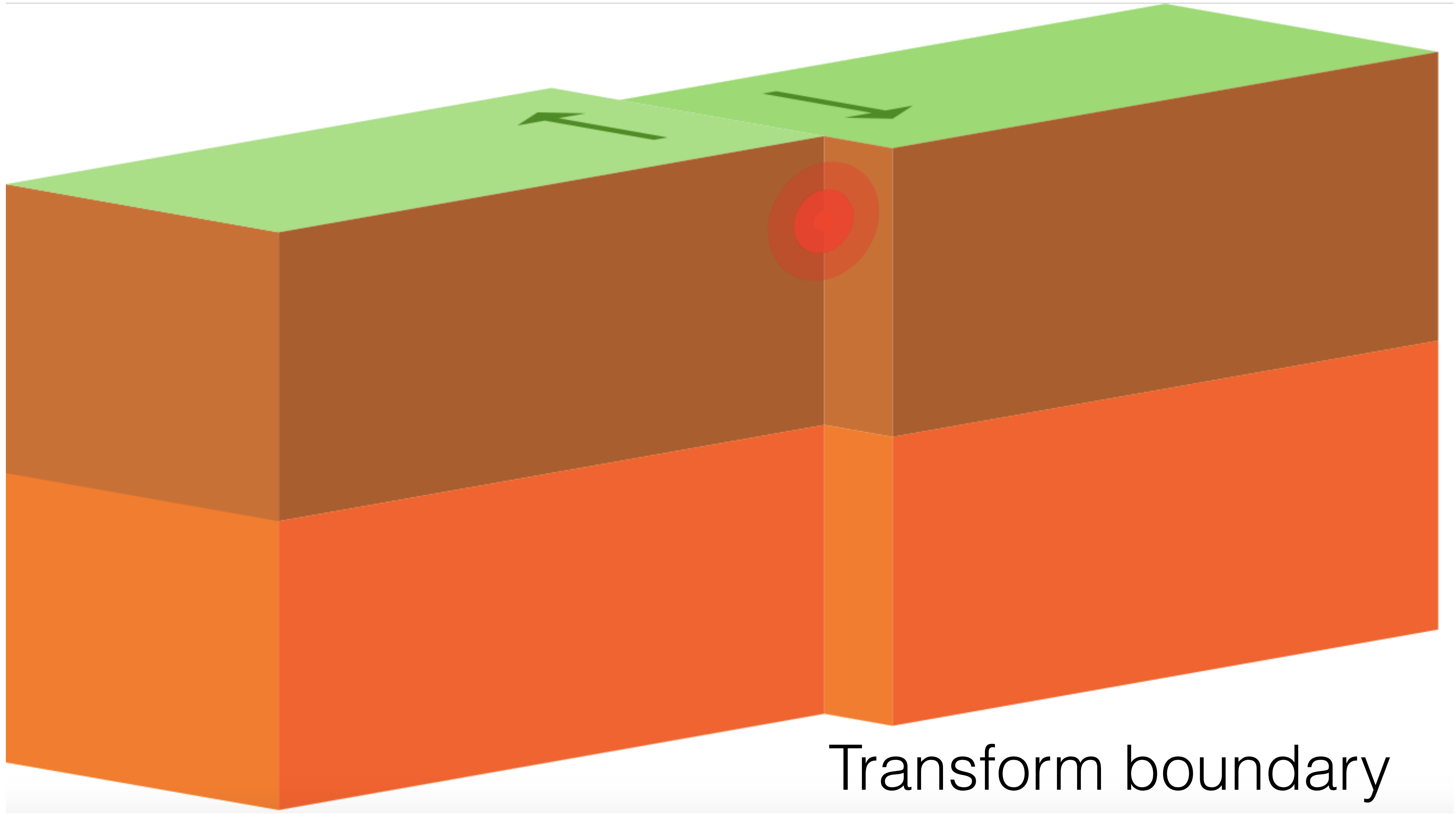
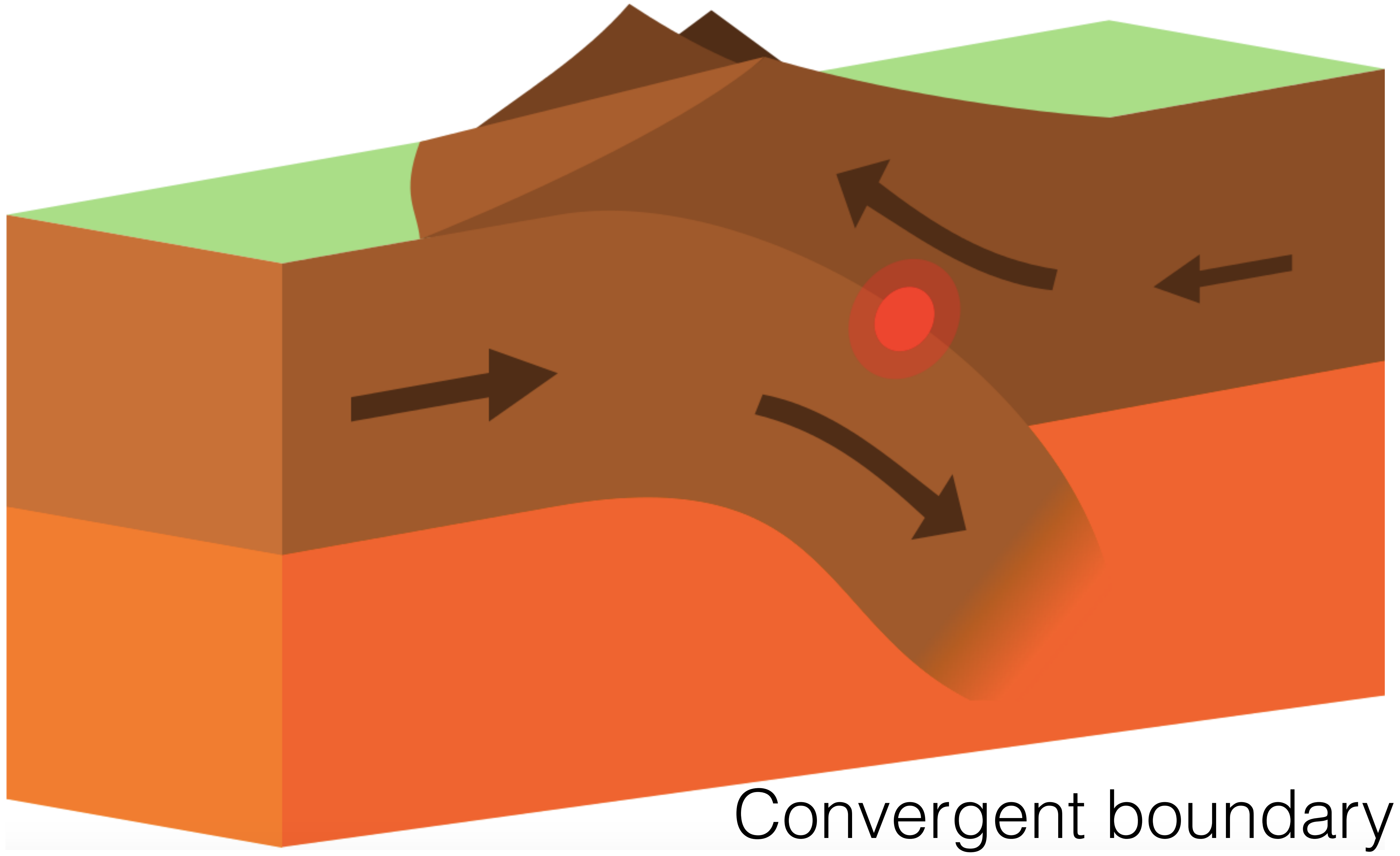
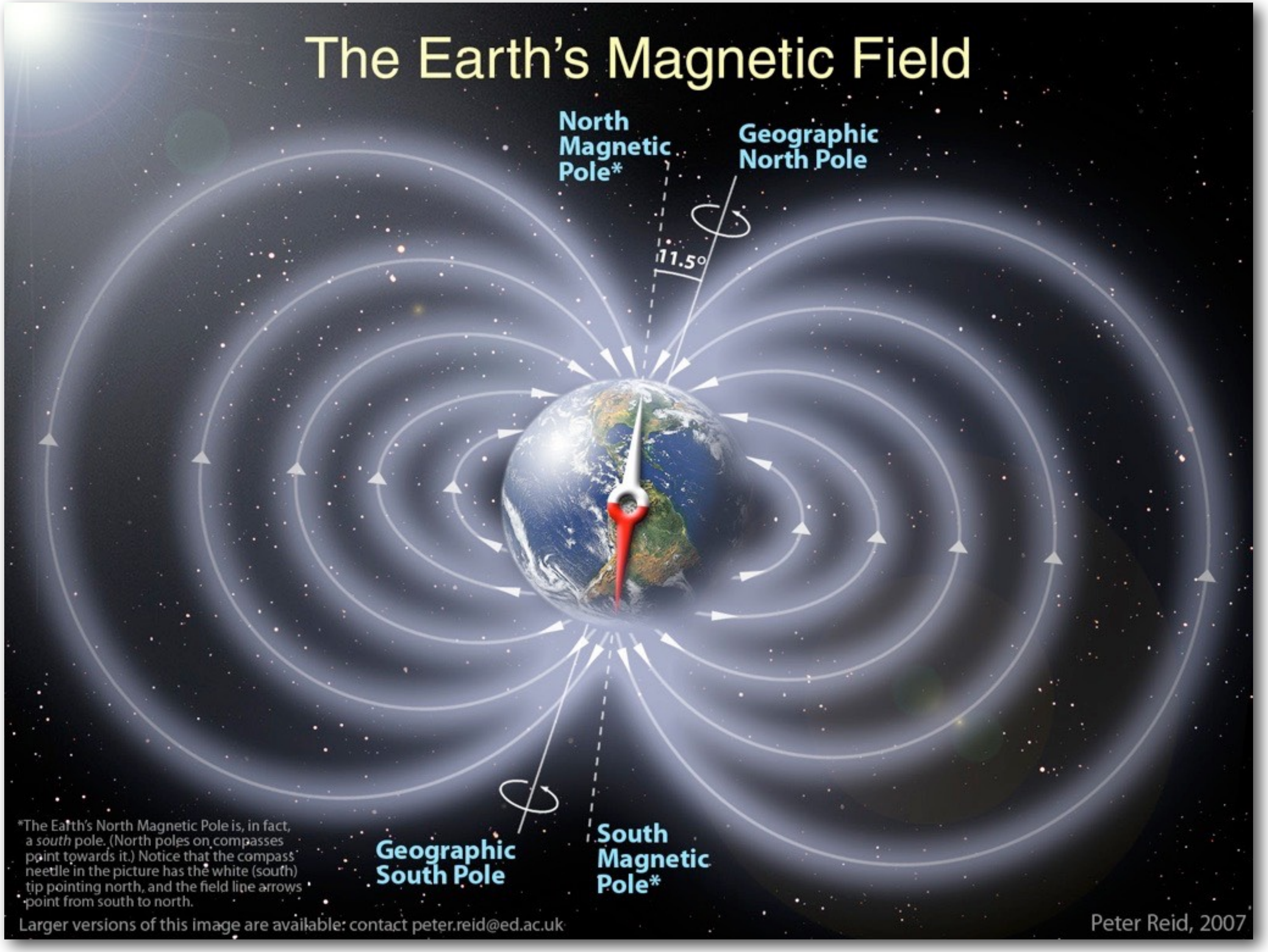






Note: rotation axis and magnetic field axis are not parallel



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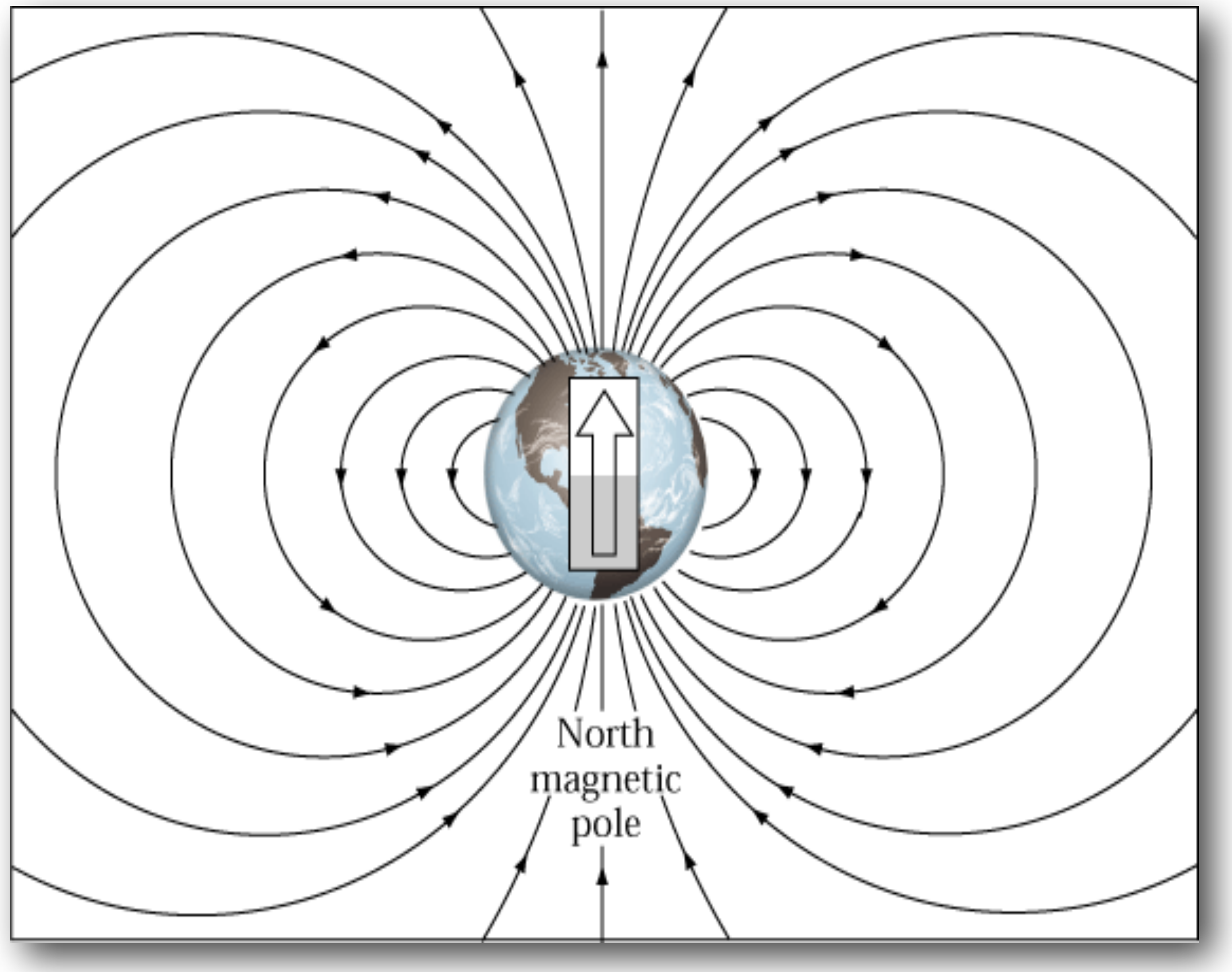
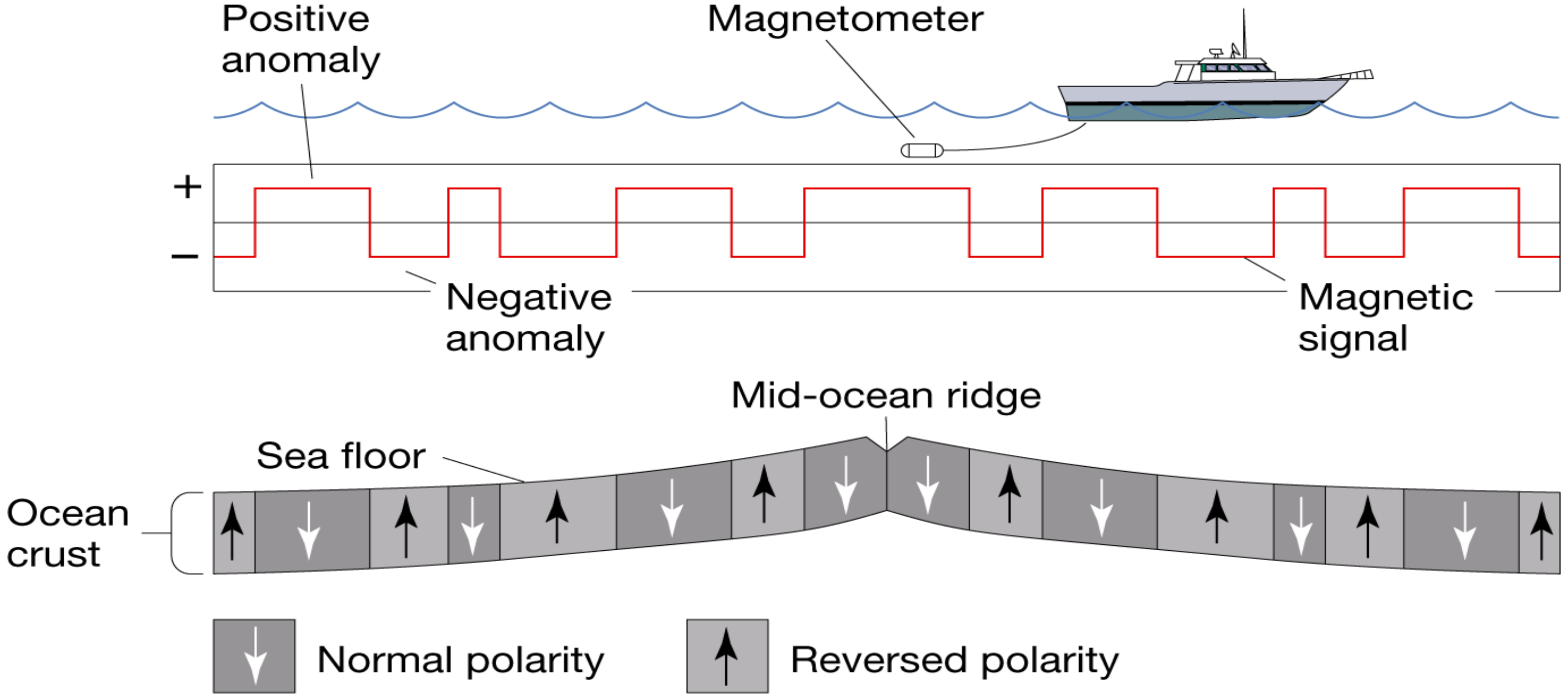
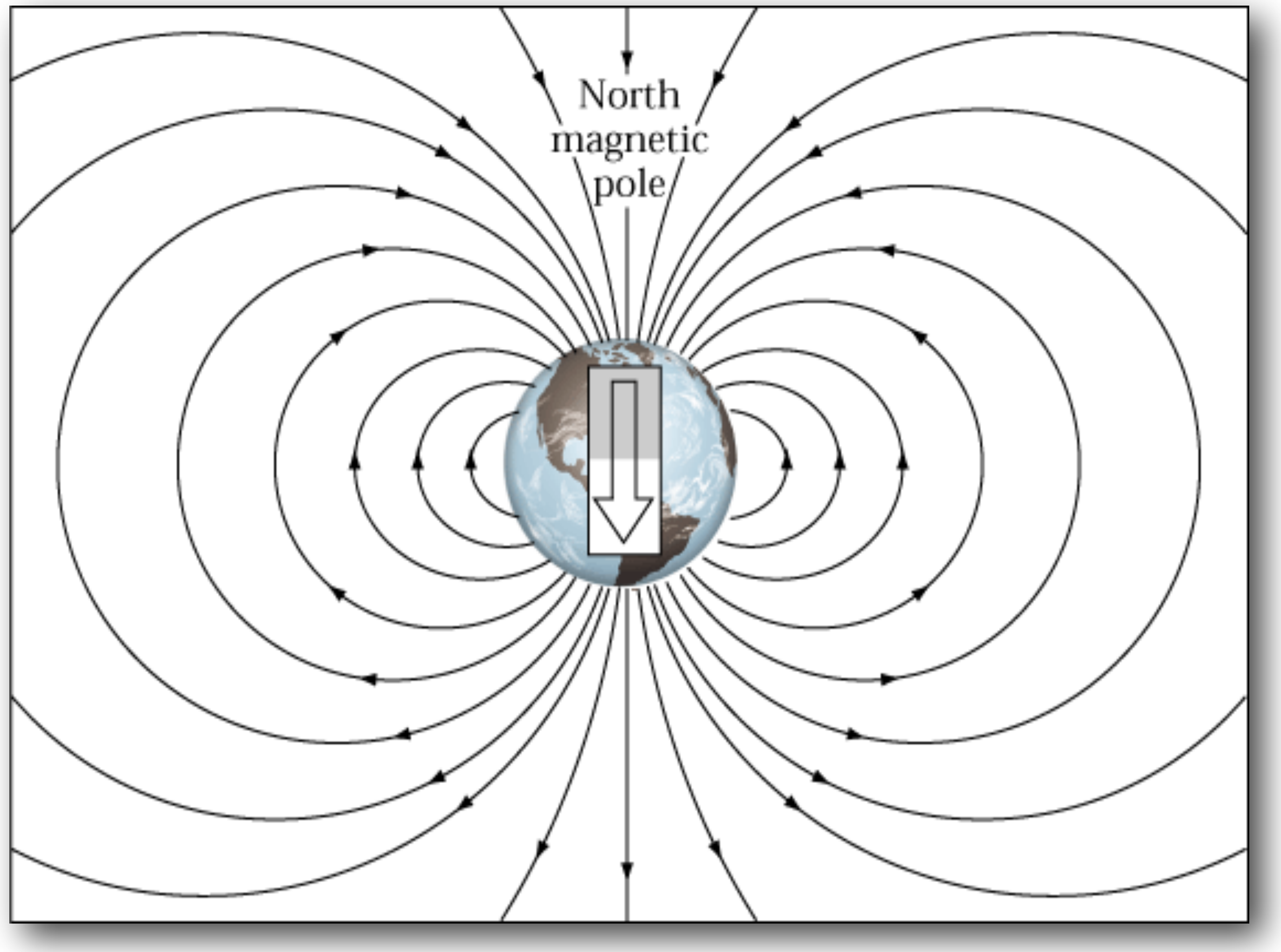






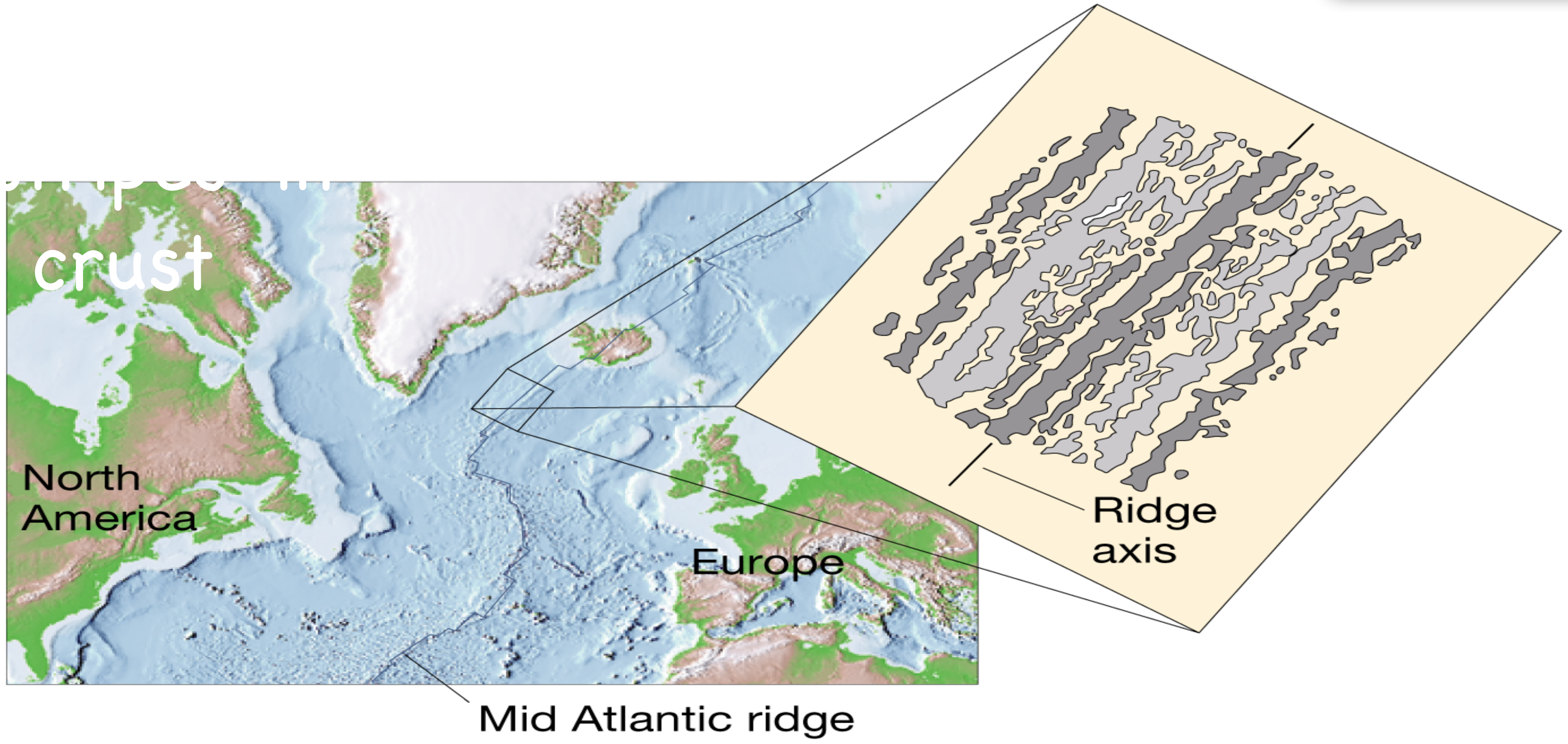
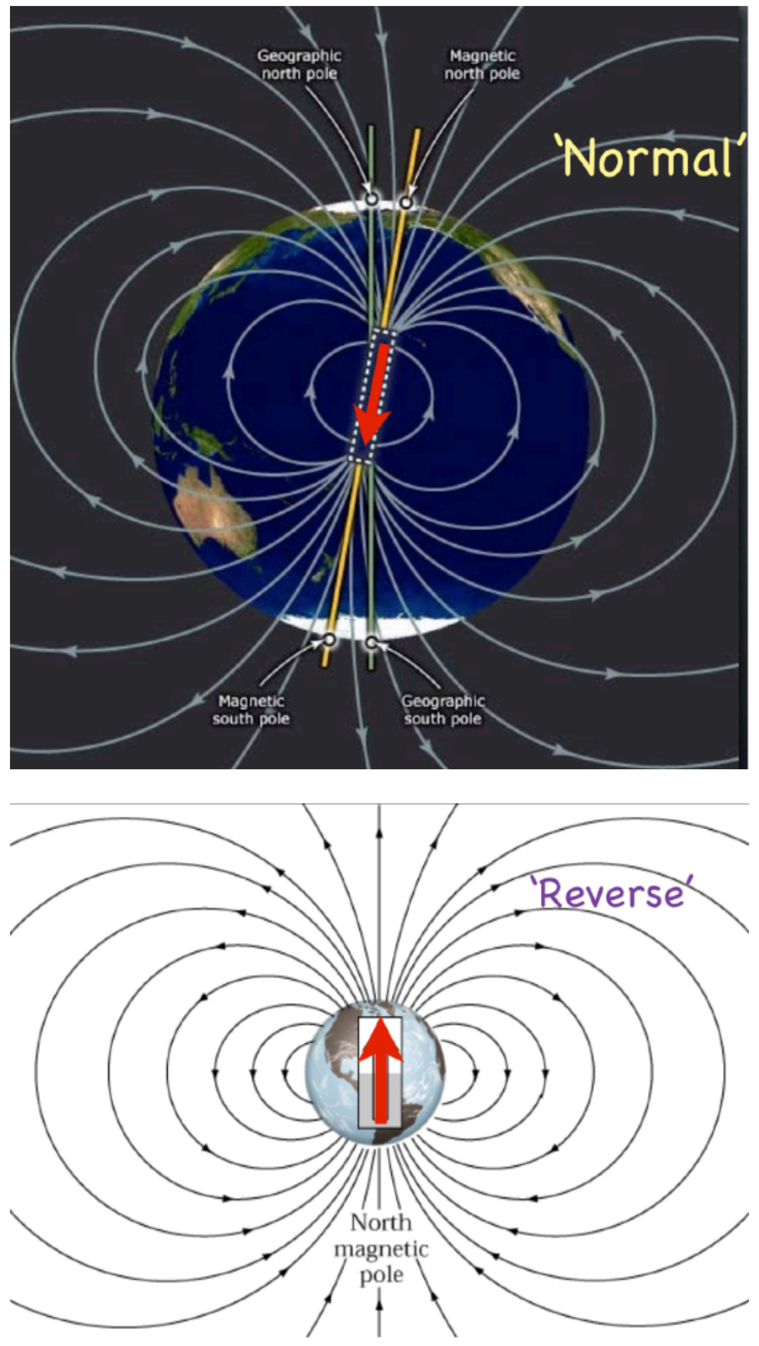


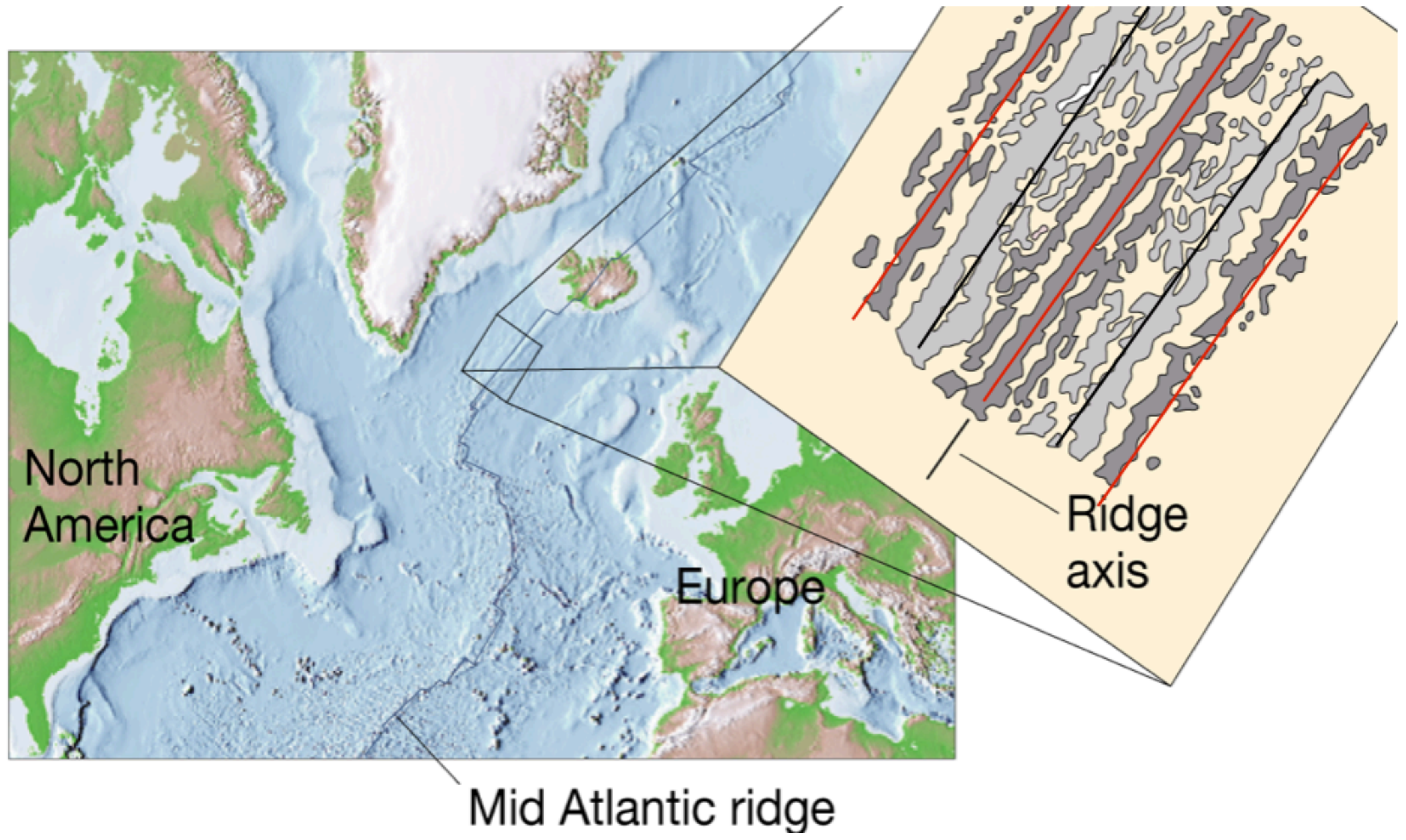
Plate tectonics

Divergent Plate Boundaries

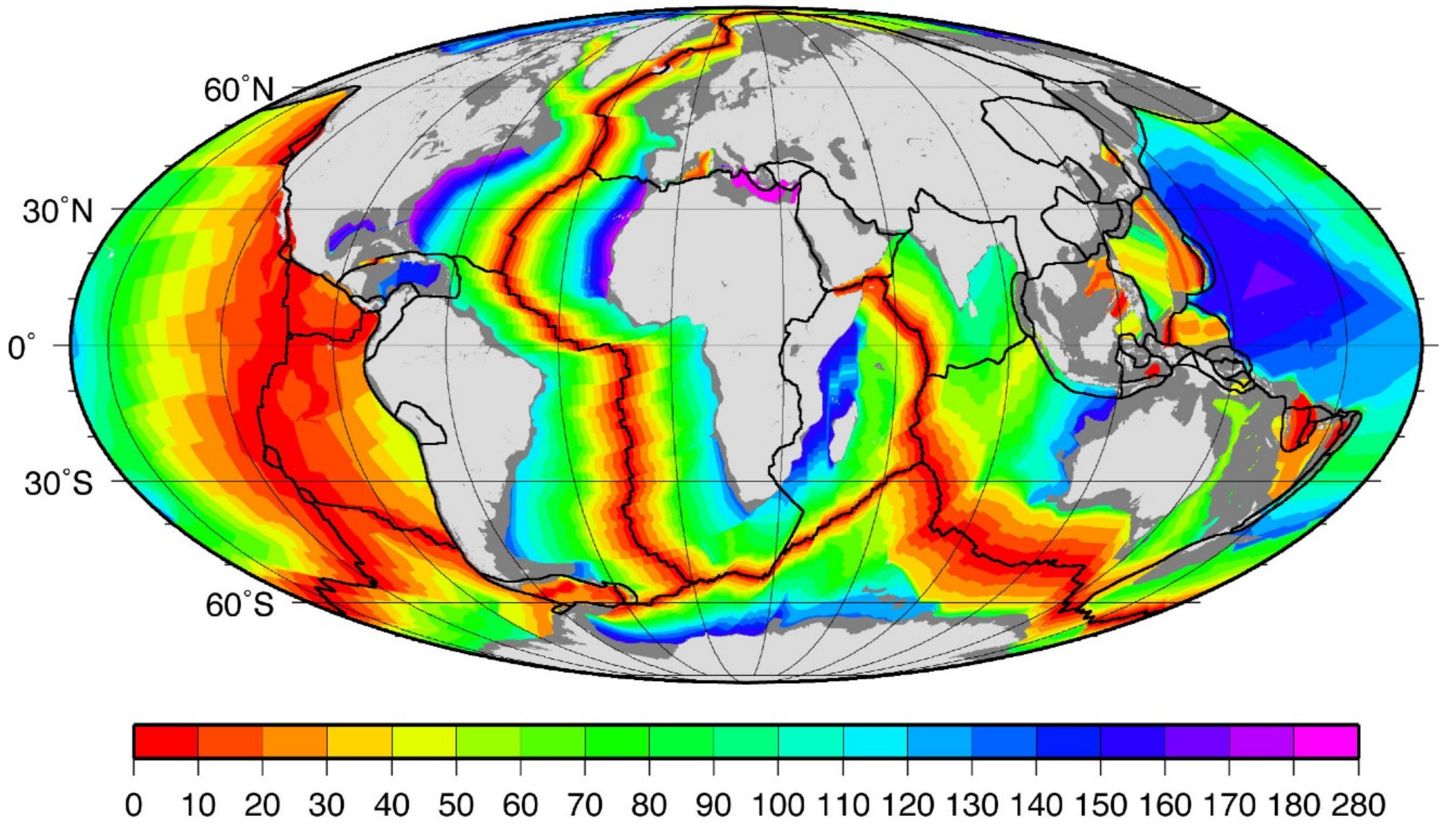
- Divergent plate boundaries are where new lithosphere is created, along mid-ocean ridges. Hence the term ‘sea floor spreading’.
- At mid-ocean ridges, hot, buoyant basaltic magma reaches the surface where it solidifies into basalt rock in undersea mountain ridges.
- As the magma cools, it reaches a temperature at which iron atoms in magnetic minerals such as magnetite lock their magnetic field into the same orientation as that of the Earth’s magnetic field.
- Earth’s magnetic field reverses direction about every 200,000 to 300,000 years.
- A ship-towed magnetometer that crosses a mid-ocean ridge receives a signal of alternating normal and reverse polarity in the ocean floor rocks.
- These alternating patterns are consistent with a symmetrically increasing age of the rocks on either side of the mid-ocean ridges.



Earth’s magnetic field polarity in normal (left) and reverse (right) orientation. Earth’s field is more complex than is illustrated and has reversed polarity without any observable ill-effects in the fossil record.



Magnetic ‘stripes’ of normal (red) and reversed (black) polarity in ocean floor basalts have a symmetrical pattern consistent with the rock ages on either side of the Mid Atlantic Ridge. Similar patterns are seen across most mid ocean ridges.

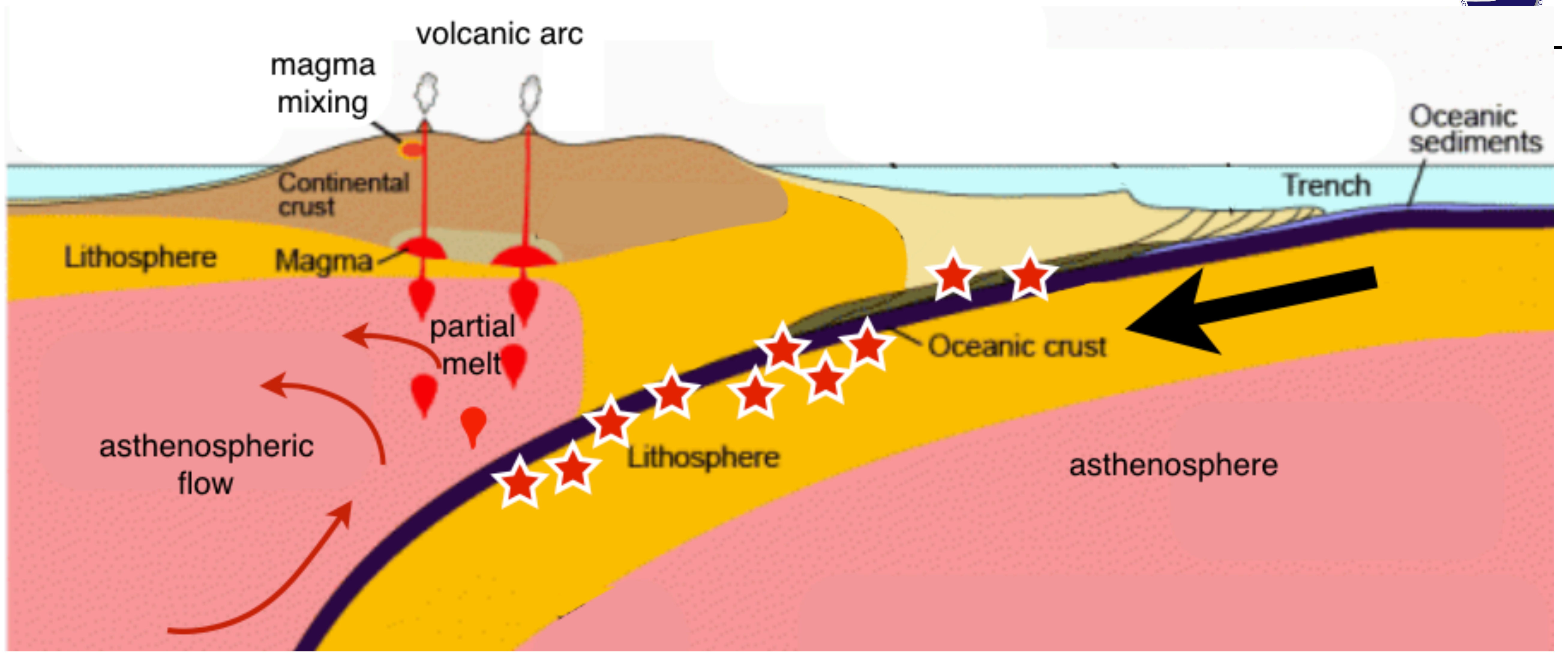


Age distribution of Earth’s oceanic lithosphere, created at divergent plate boundaries.

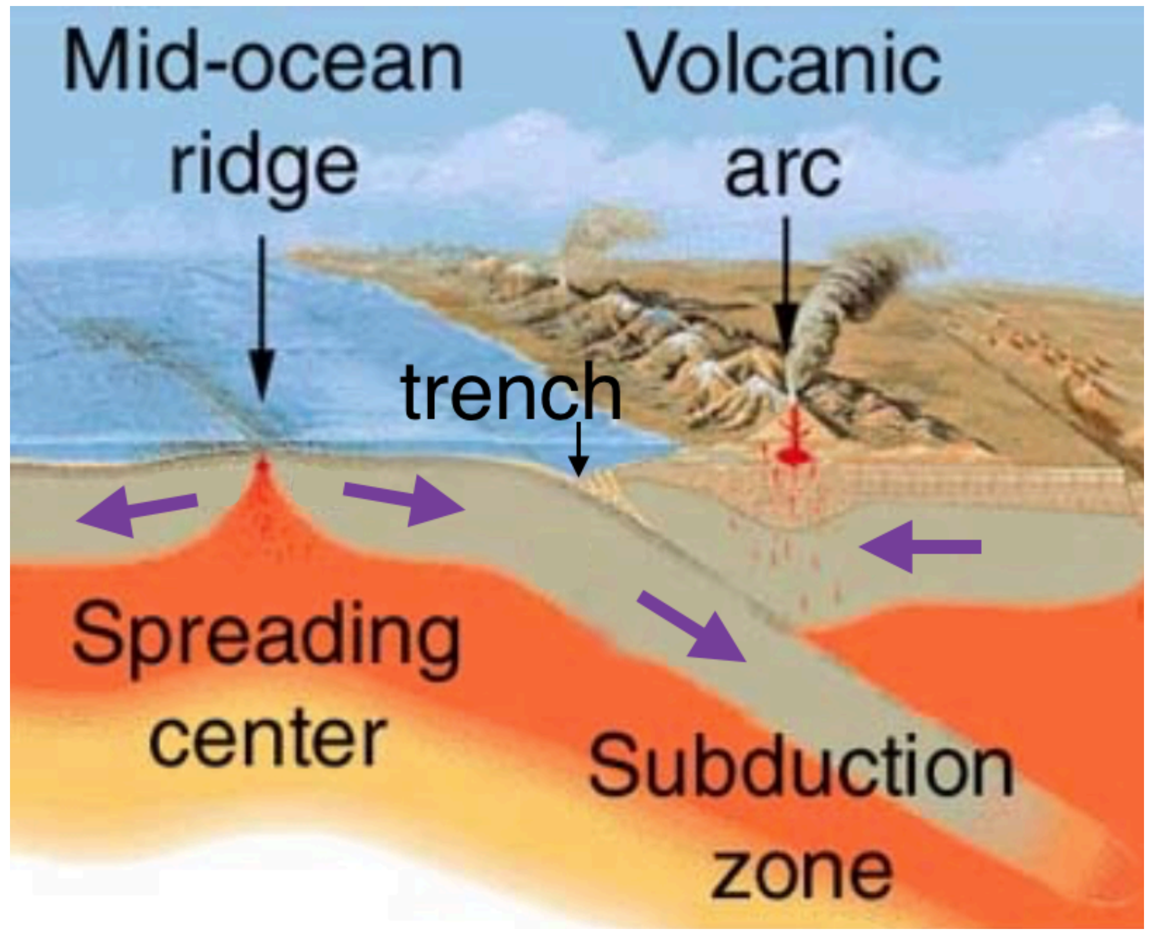
Plate tectonics

Convergent Plate Boundaries

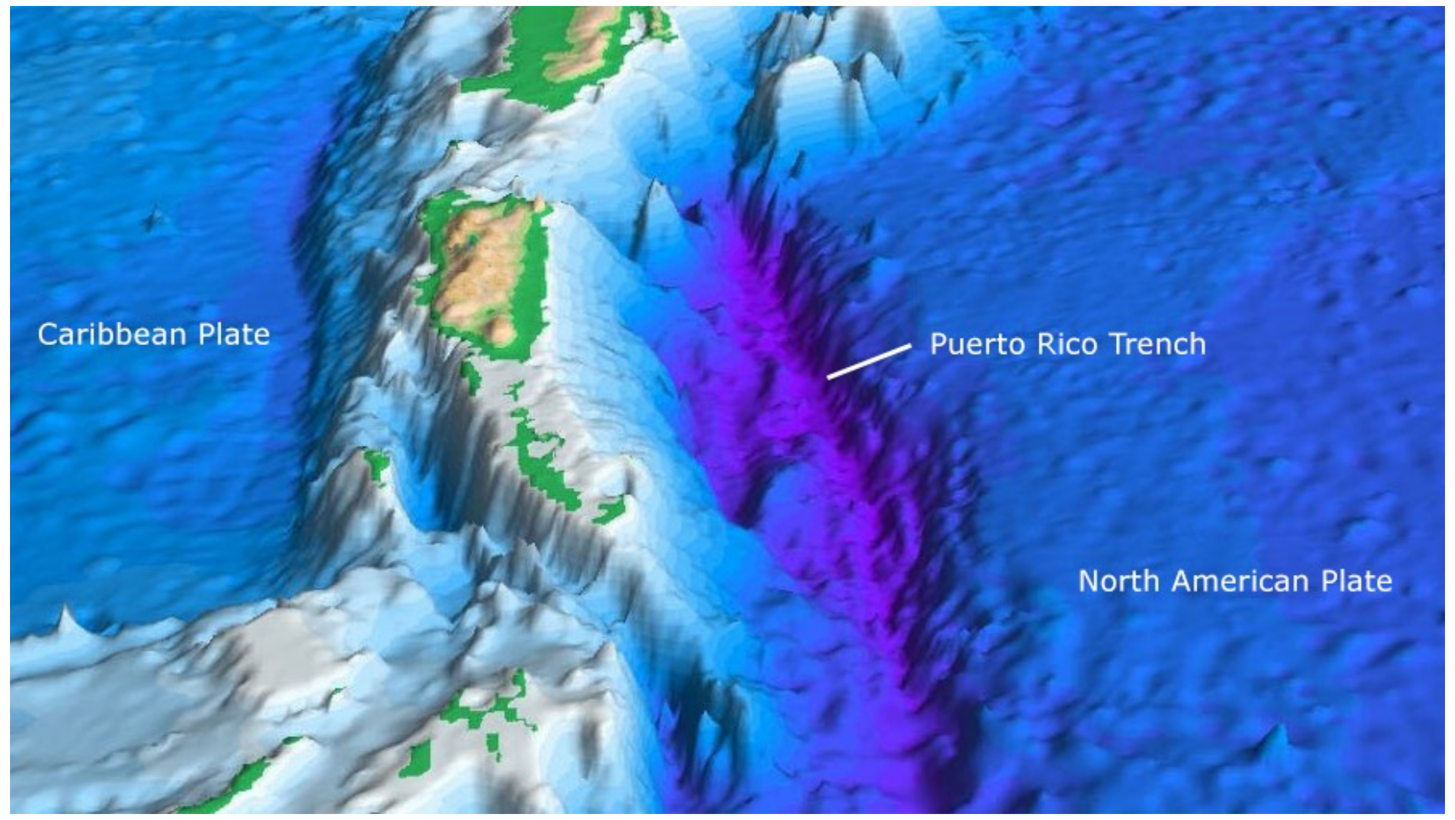
- Cold, dense lithosphere is subducted into the mantle at convergent plate boundaries, while the mantle above partially melts to form volcanic arcs.
- As the cold lithosphere thickens with distance from the spreading ridge, gravitational forces eventually cause it to sink back into the mantle along subduction zones.
- Flexure of the sinking slab creates deep ocean trenches at surface, but neither the bending nor the descent of lithosphere into the mantle is smooth.
- Some of the deepest and largest earthquakes occur in, and just above, the down-going slab.
- Above the sinking slab, the lithosphere and asthenosphere are heated and partially melted by an upward counter-flow of mantle.
- The resulting magma rises and incorporates more crustal rock as they ascend, and the resulting silica-enriched magma erupts in volcanoes to form a volcanic arc.



Lithospheric slabs sink into the mantle along subduction zones, creating a counter-flow of asthenosphere (red arrows) above the down-going slab. Stars represent earthquakes where the slab bends and slides under the more buoyant lithospheric plate.

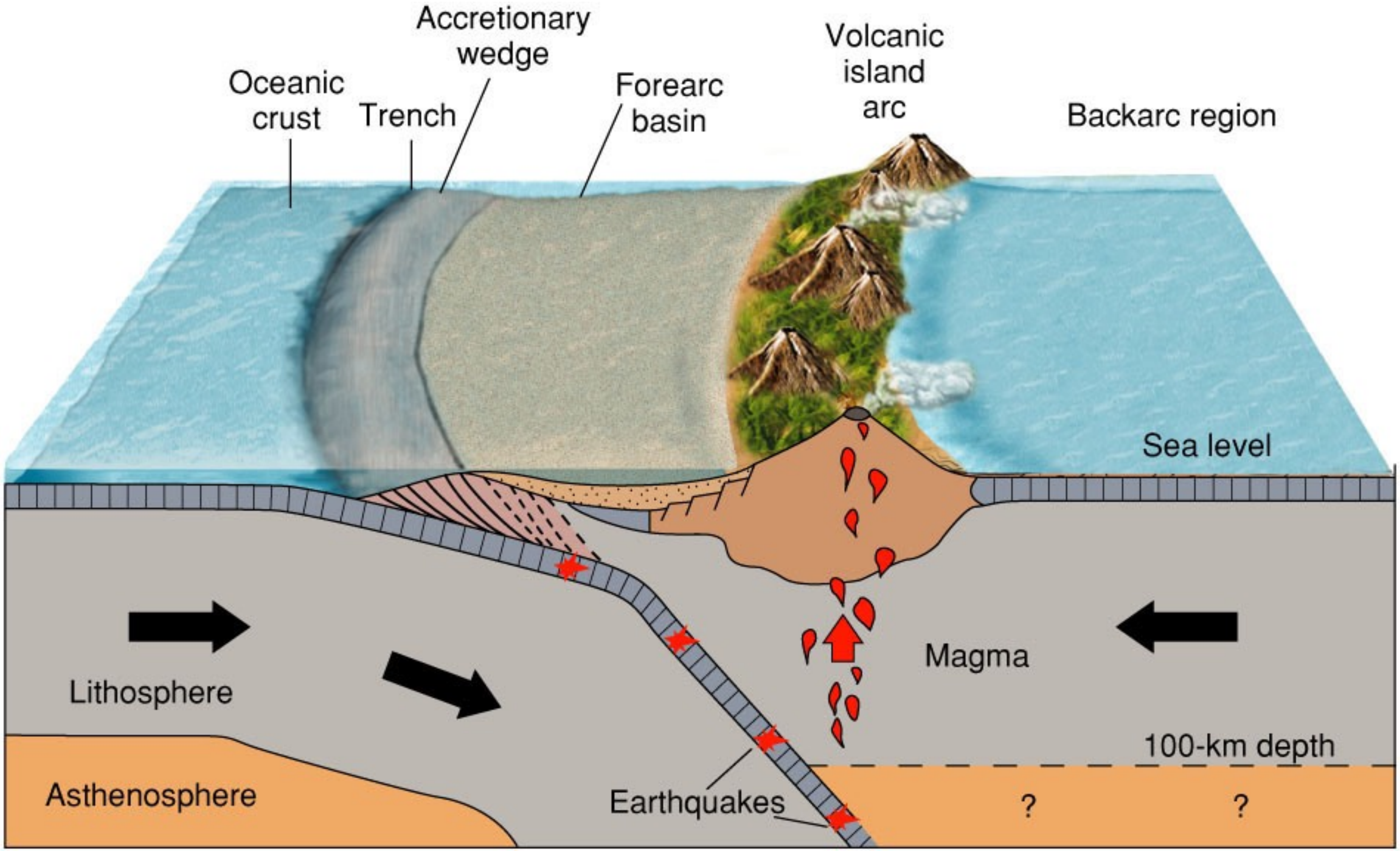


Volcanic arcs develop above subduction zones, where lithosphere descends back into the mantle. Graphic not to scale.



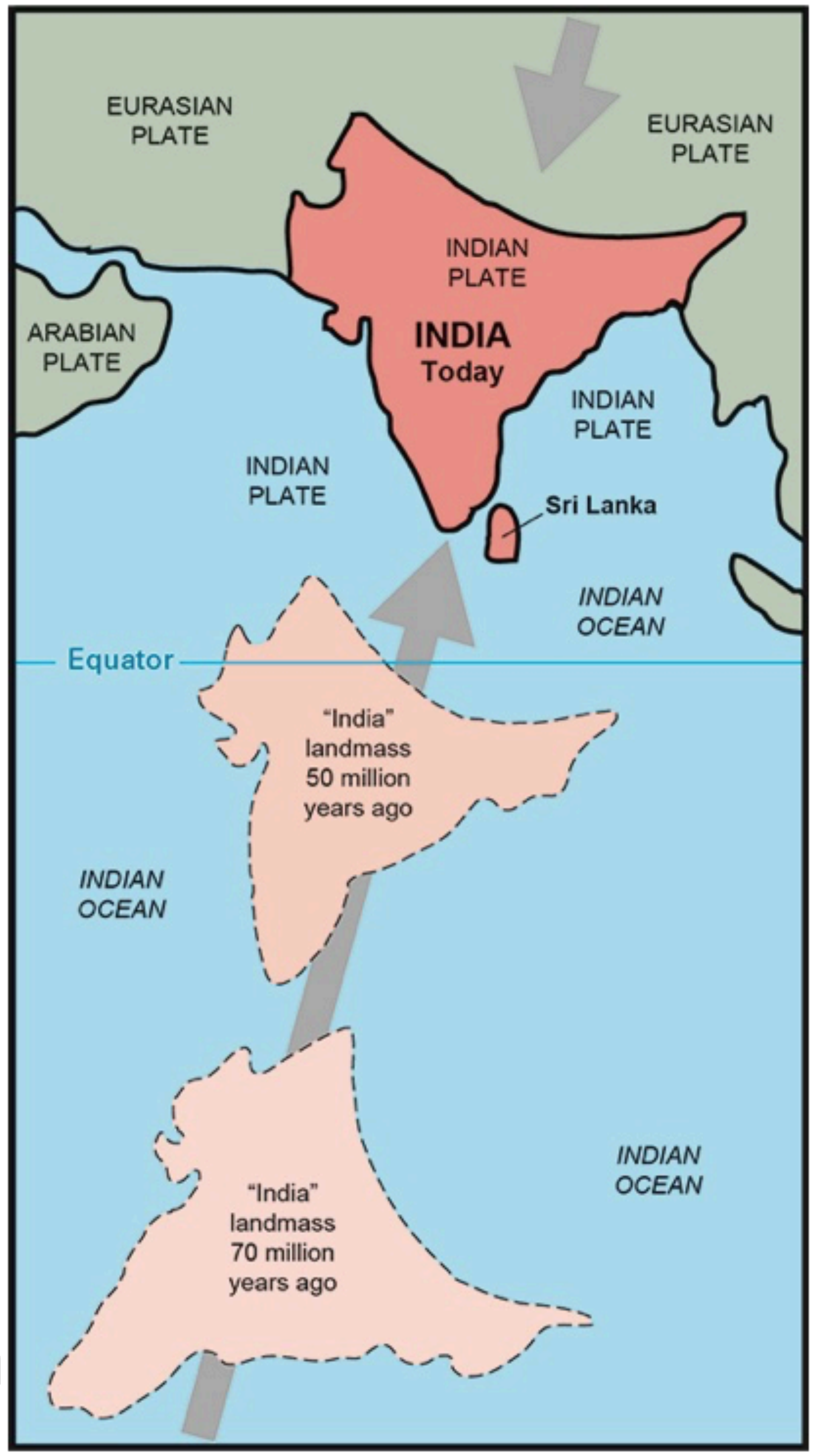
Topography of the Puerto Rico Trench (purple) and volcanic arc (brown) above the subduction zone where cold lithosphere of the North American Plate sinks beneath the Caribbean Plate. Ocean trenches often exceed depths of 6,000 m.

Plate tectonics



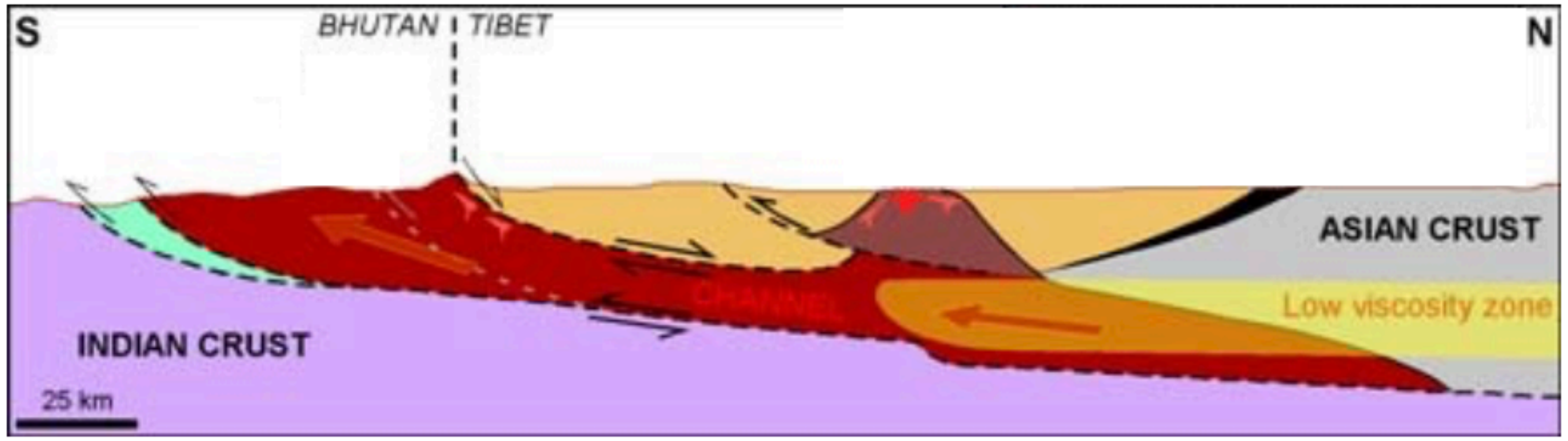
Continent-Continent Convergence

- When all of the oceanic lithosphere has been consumed in a subduction zone, the result is a convergence of continental lithosphere.
- The region of Tibet, north of the Himalayan Mountains, has an average elevation of 4,500 m above sea level.
- About 70 million years ago, oceanic lithosphere of an ocean called Tethys, on the northern margin of the Indian Plate, began to be subducted beneath the Eurasian Plate.
- By 40 million years ago, the convergence of the Indian and Eurasian plates had consumed all the Tethyian lithosphere, and the continental crust of India collided with that of Eurasia.
- The descending lithosphere continued to pull the Indian plate northward, under Eurasia, resulting in a doubling of the crust beneath Tibet.
- The many large earthquakes and landslides that occur in the Himalayas, Tibet, and far into China, are due to the continuing convergence along this continent-continent plate boundary.



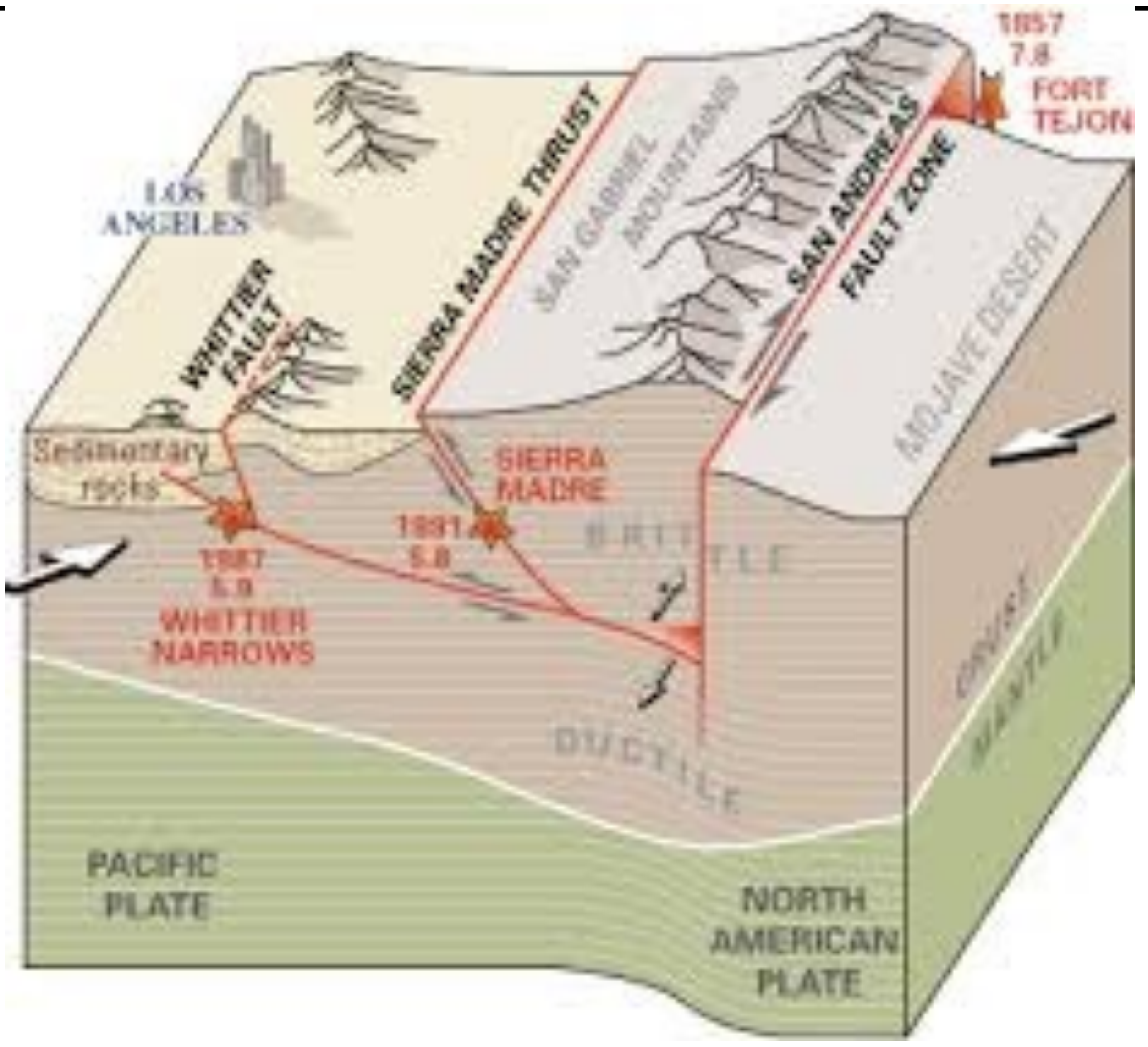
The northward migration of the Indian plate began at about 70 million years and ended in collision and suture with Eurasia about 40 million years ago.

Below: Profile across the suture between Indian (light purple) and Eurasian (gray) continental crust. Light orange = Tethys Ocean floor sediments; red = rocks squeezed from deep in the crust.

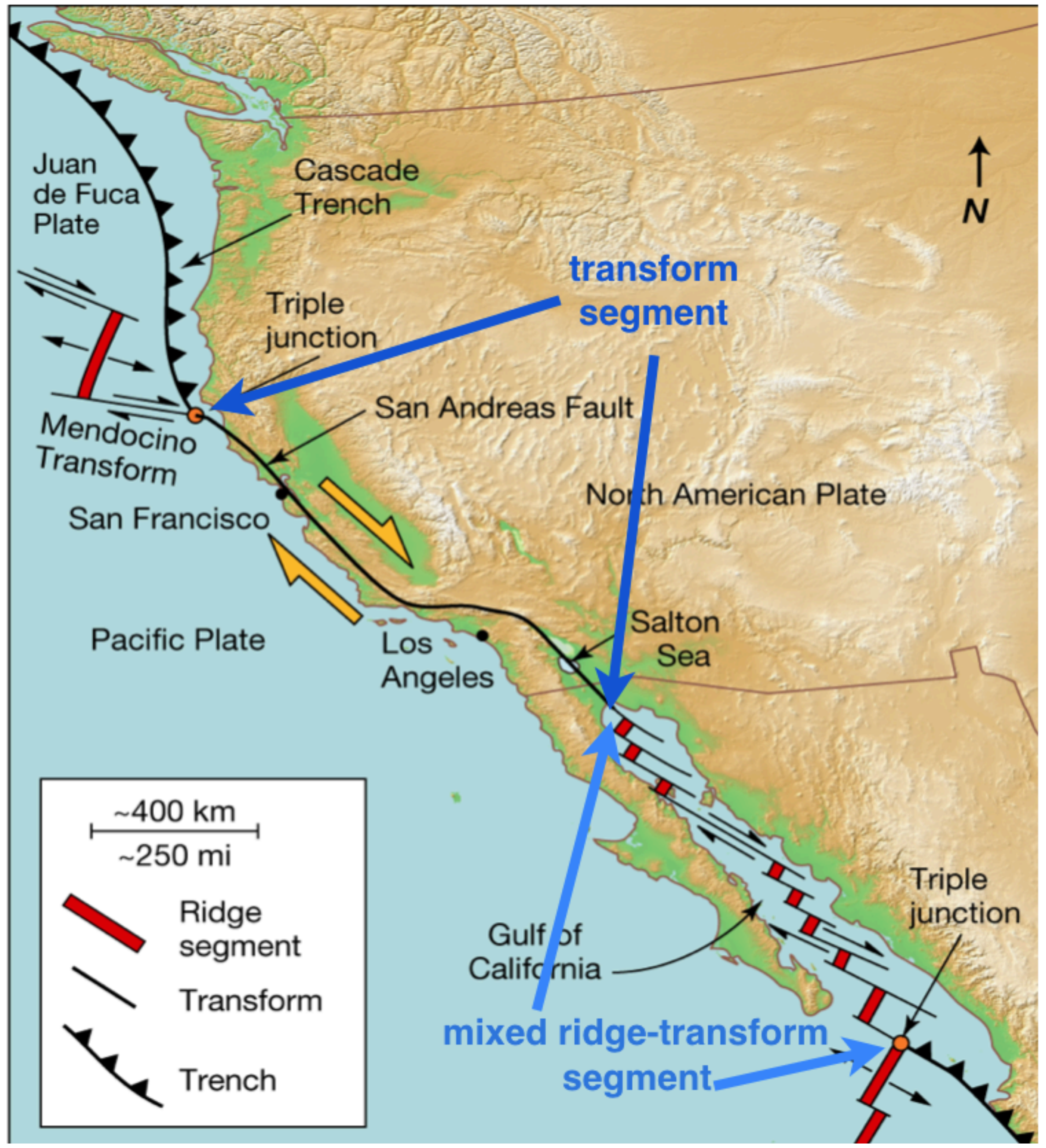


Transform Plate Boundaries

- At transform boundaries, the lithospheric plates slide jarringly past one another.
- Earth is spheroidal and therefore as its tectonic plates spread apart in some places and converge in others, some segments of their boundaries must slide past one another.
- This slip occurs on transform fault zones, such as along the San Andreas Fault zone in coastal California.
- Transform fault zones have a very steep to vertical orientation.
- The majority of large earthquakes on these faults occur in the most brittle, upper section of crust, at depths of 3 to 4 km.
- The many faults that comprise a transform fault zone are not perfectly planar and any one of them can get 'stuck' and be unable to slide – until stresses build to the point that the rocks rupture.
- When the fault finally slips, it releases its potential energy as an earthquake.

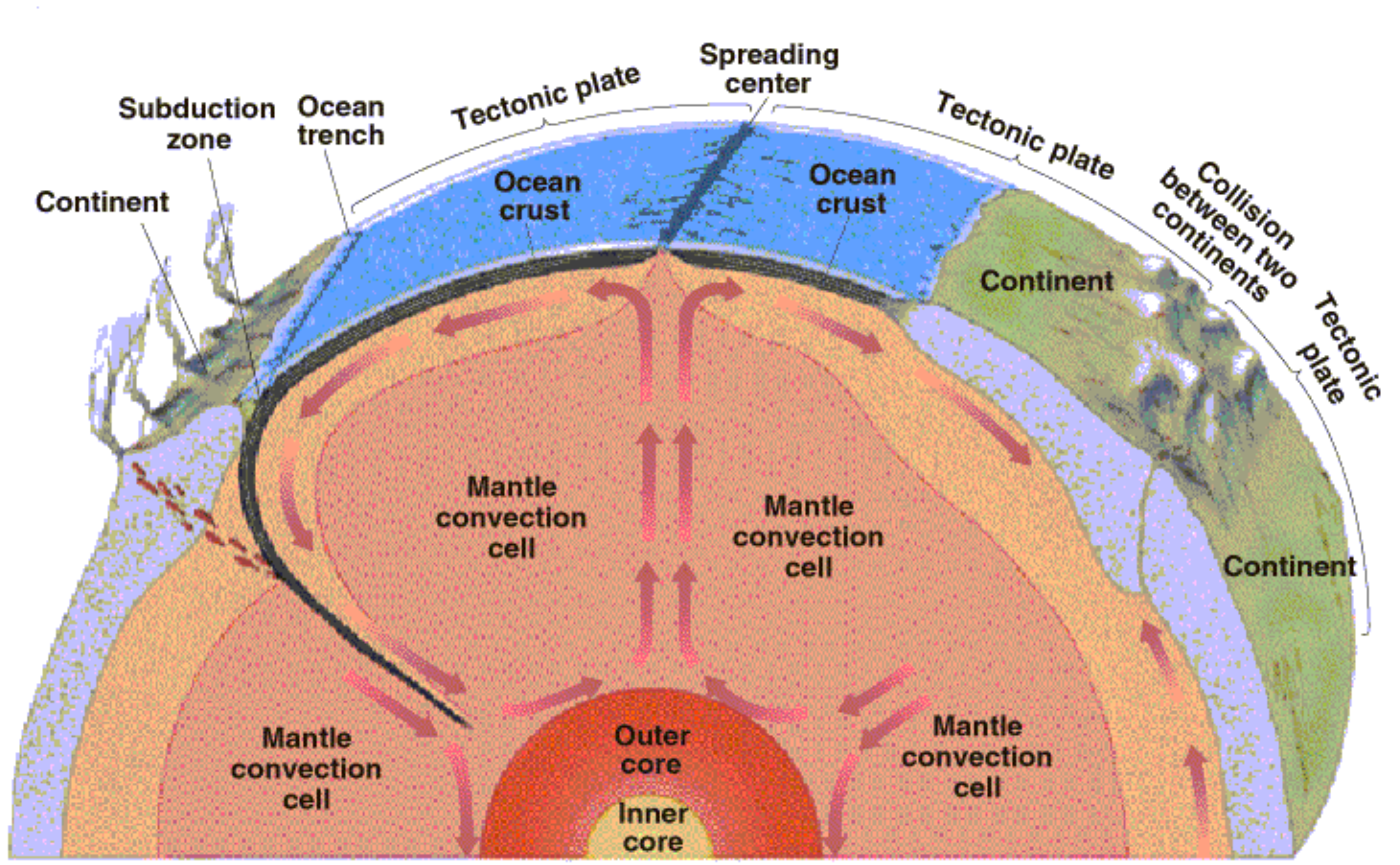


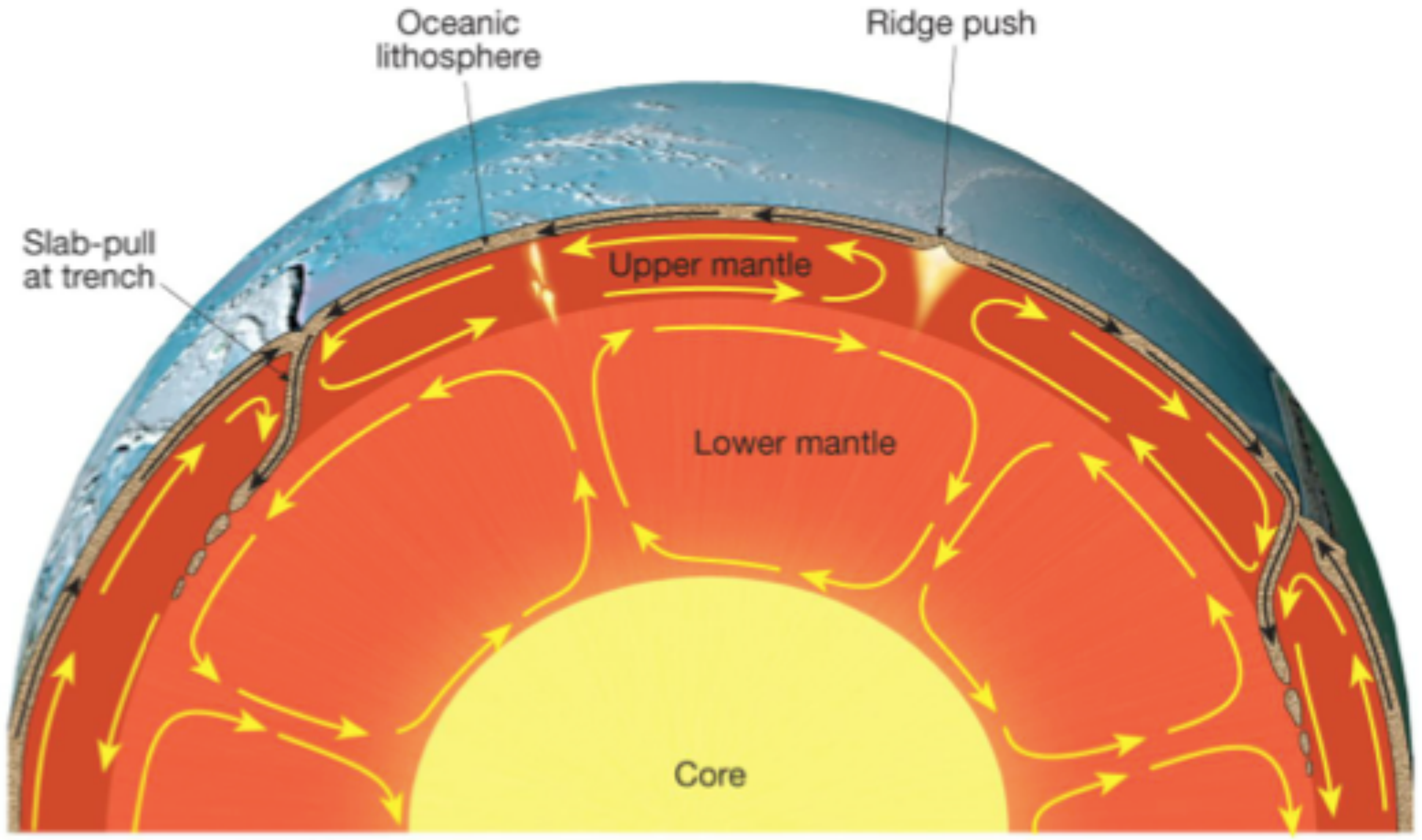
Profile and map view of the San Andreas and related transform faults system. View to the north. Earthquakes occur in the upper, brittle crust. Beneath the transform fault the rocks are more ductile and able to flow to accommodate the relative plates' movement.

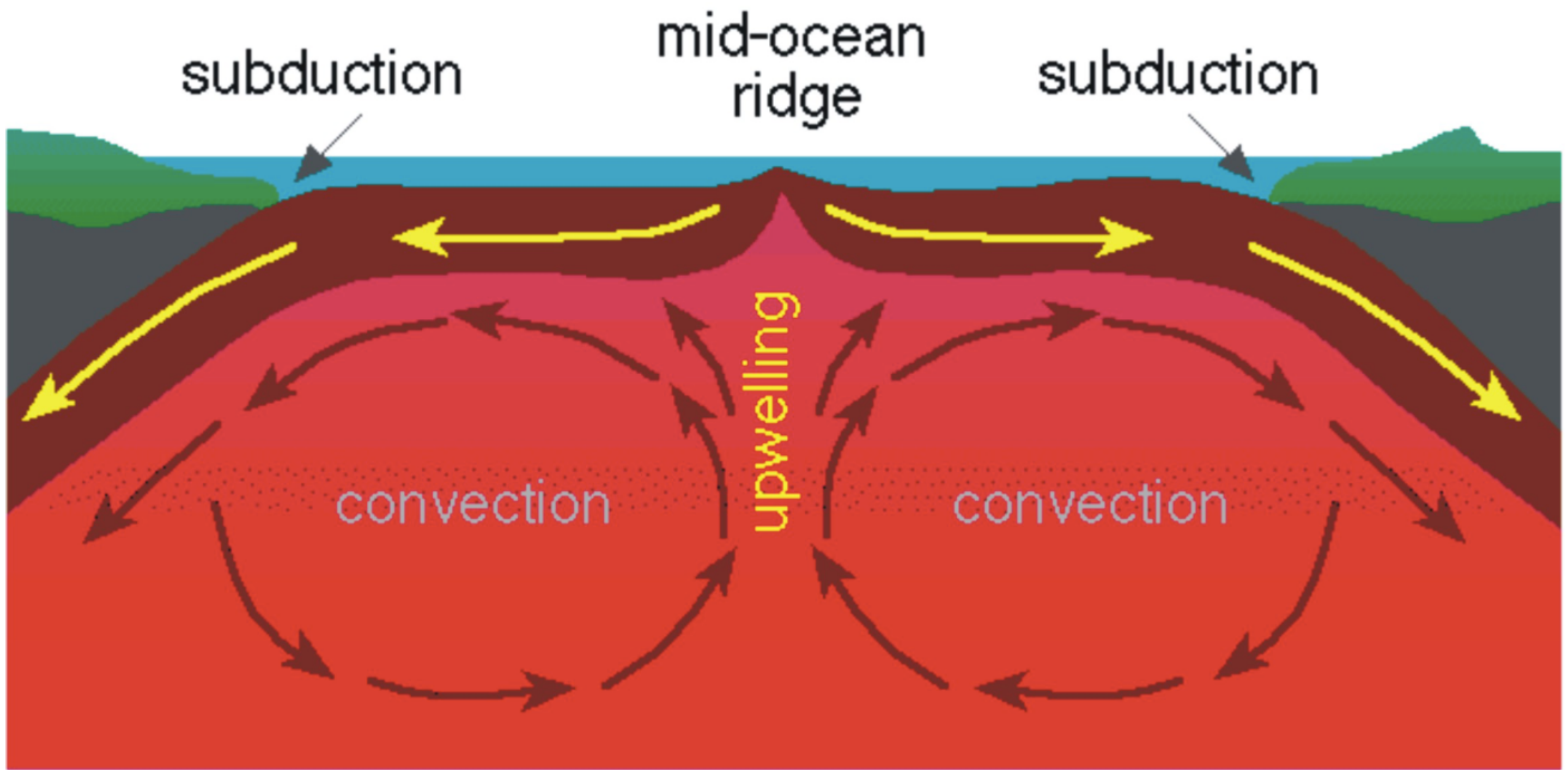


Transform fault zone between the North American and Pacific tectonic plates.

Mantle convection

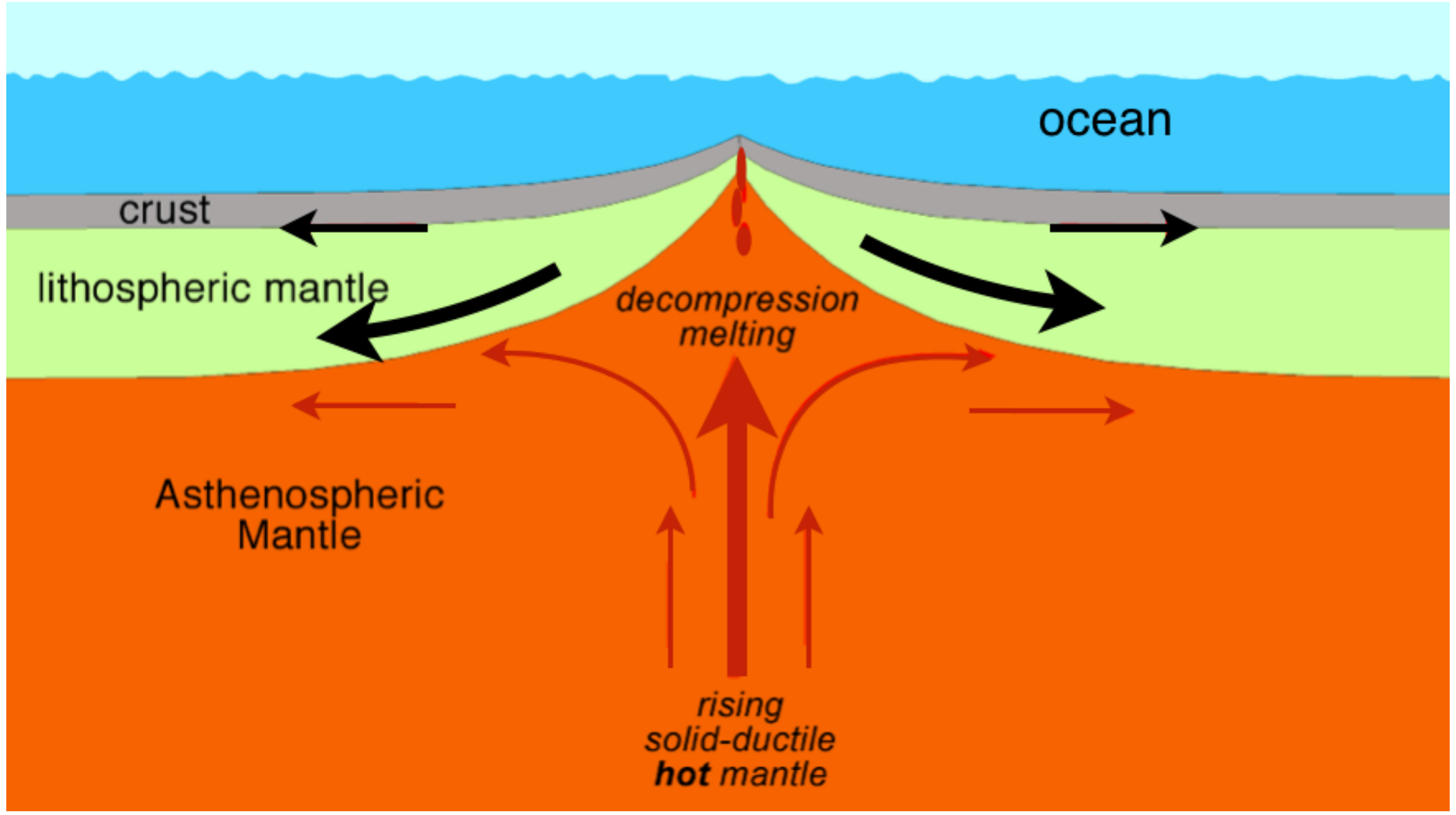




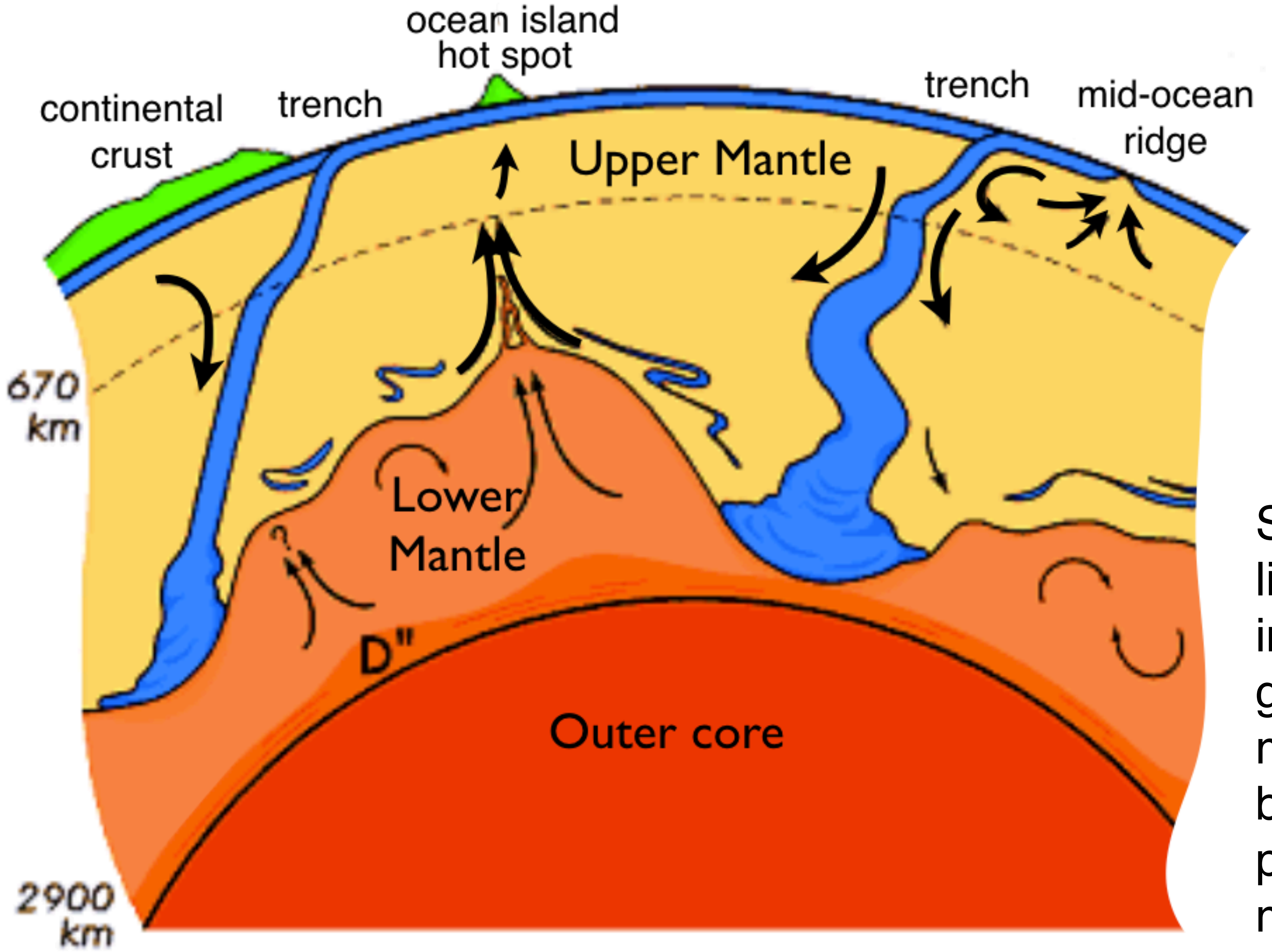


Tectonic Plate Motion

- Ridge push and slab pull are the two main driving forces for plate tectonics.
- The dense oceanic lithosphere sags slightly into the underlying asthenosphere under the influence of gravity. This down-and-outward motion of the lithosphere, called ‘ridge push,’ is a major driving mechanism for plate motion.
- An even more important mechanism for plate motion than ridge push is ‘slab pull,’ which is where cold, dense slabs of old oceanic lithosphere sink back into the mantle down subduction zones, again under the influence of gravity.
- The combination of ridge push and slab pull, together with other, lesser driving forces, creates a circulating flow of material within the mantle that carries the overlying lithospheric plates along.

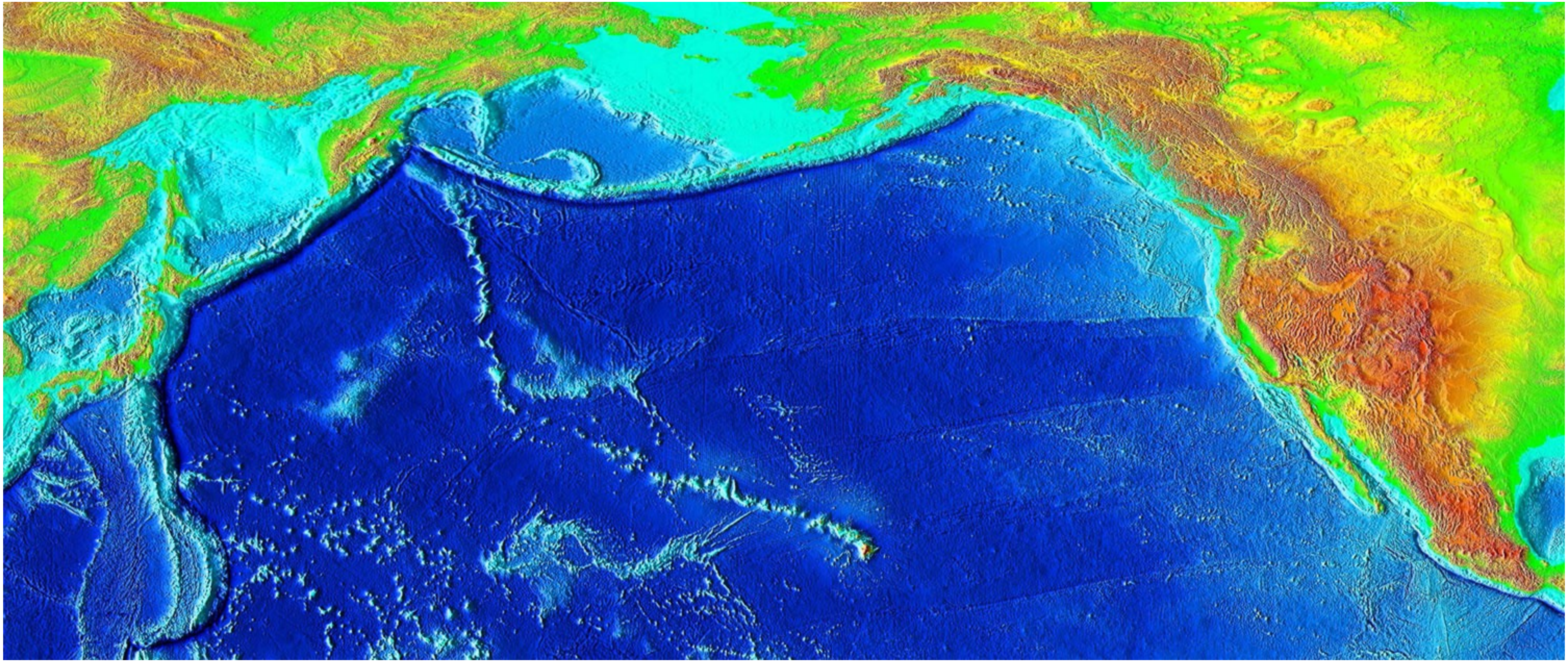


Formation of oceanic crust and lithosphere at a mid-ocean ridge. Heavy black arrows indicate the ridge-push effect that gravity imposes as the lithosphere cools, becomes more dense, and thickens.



Subduction of cold, dense lithosphere slabs (blue) under the influence of gravity. The down-going slab pulls along the adjacent mantle material and eventually becomes indistinguishable in its physical properties from the lower mantle.

Plate tectonics



Hot spot

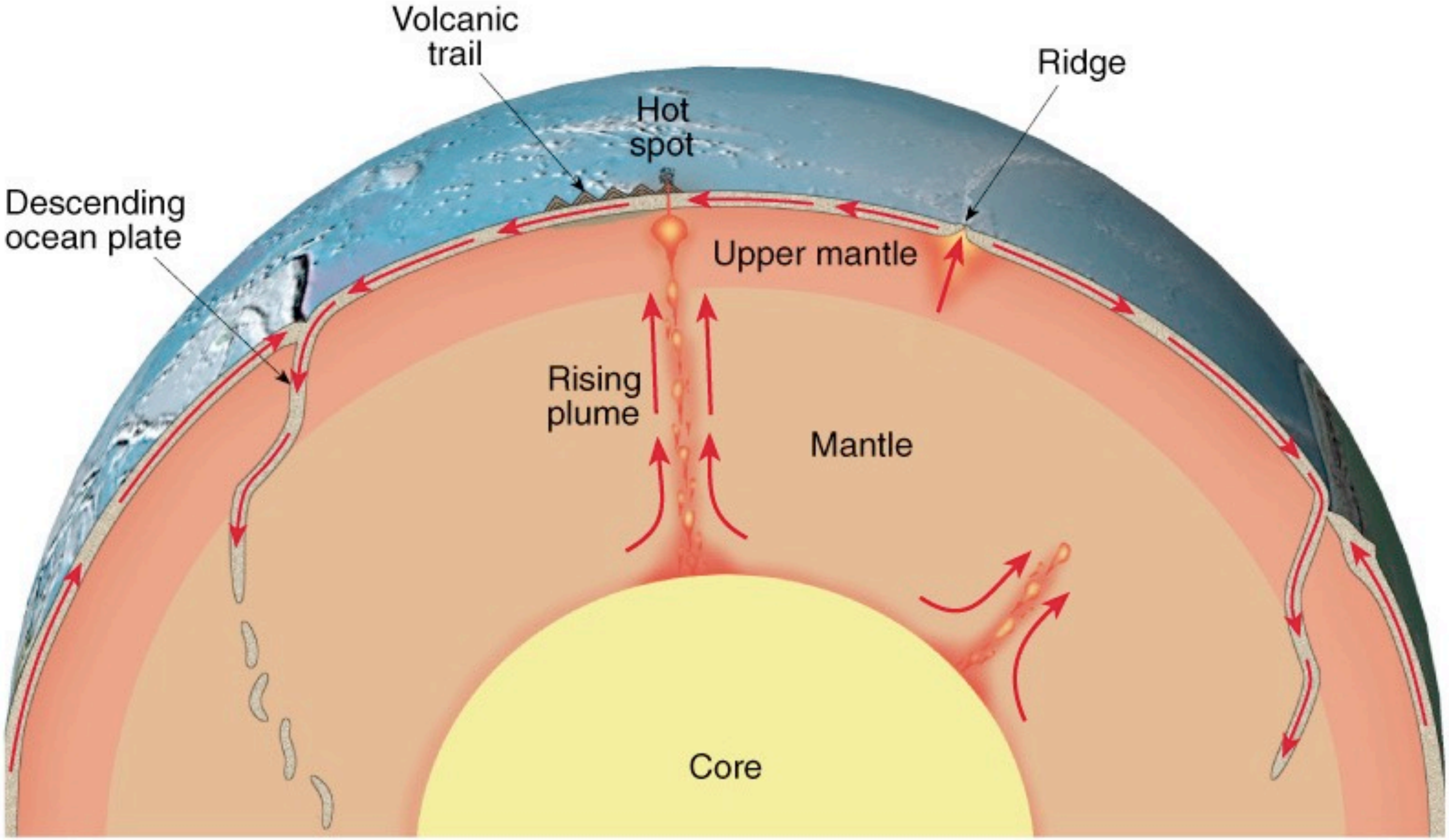

Volcanic trail
Hot spot
Ridge
Descending ocean plate
Upper mantle
Rising plume
Mantle
Core

Plate tectonics

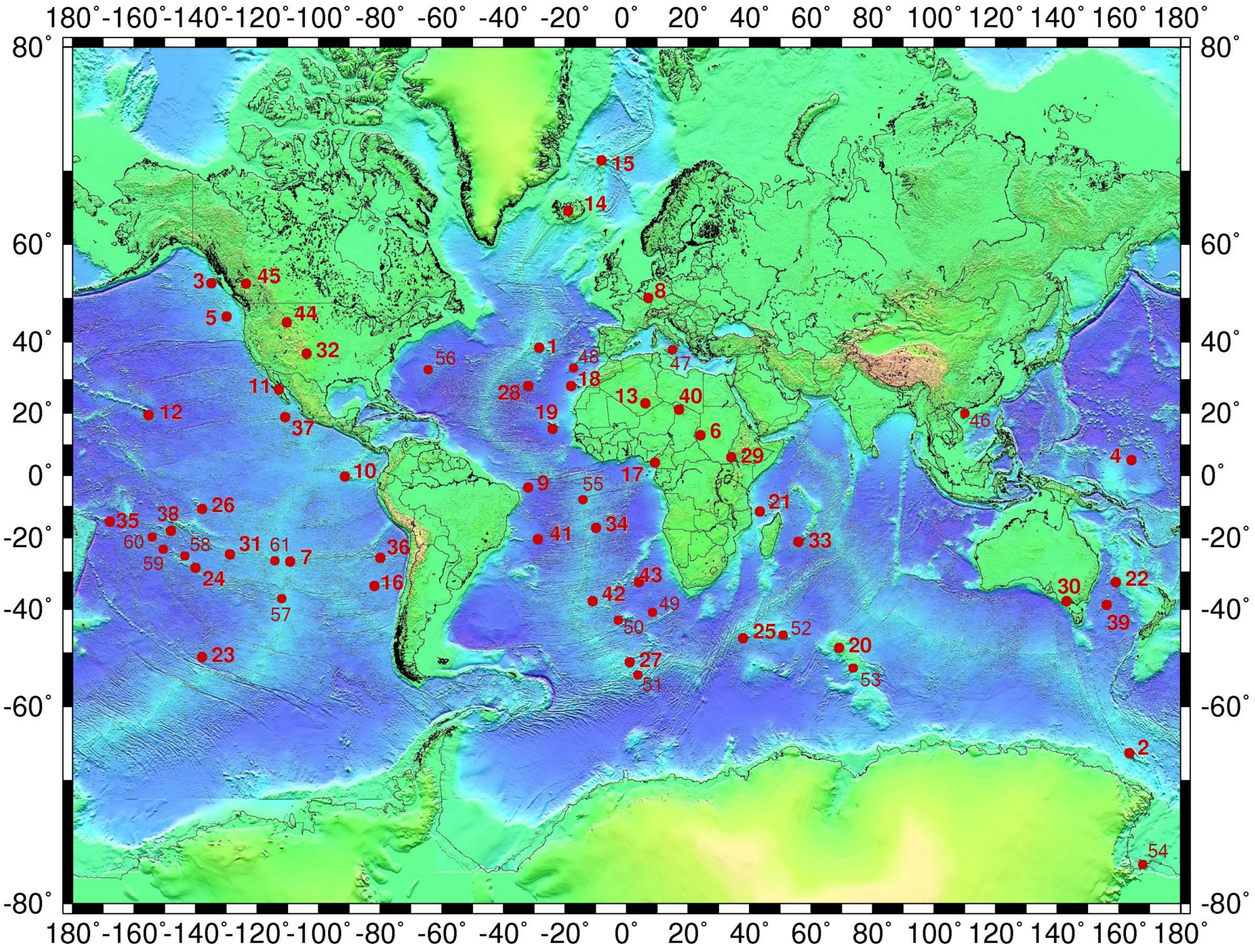
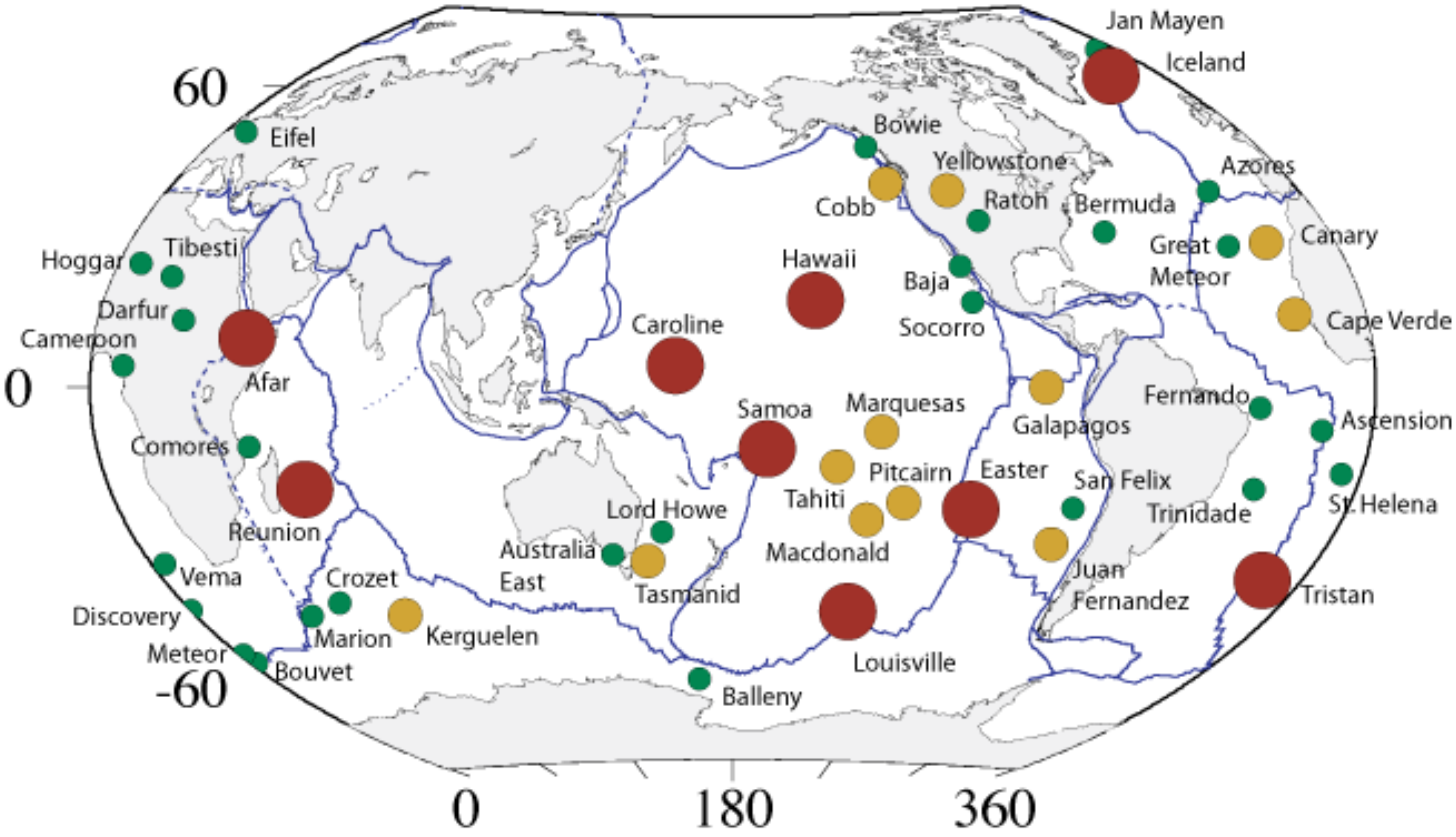


Plate tectonics



Foulger (2010)

Preliminary Determination of Epicenters
358,214 Events, 1963 - 1998

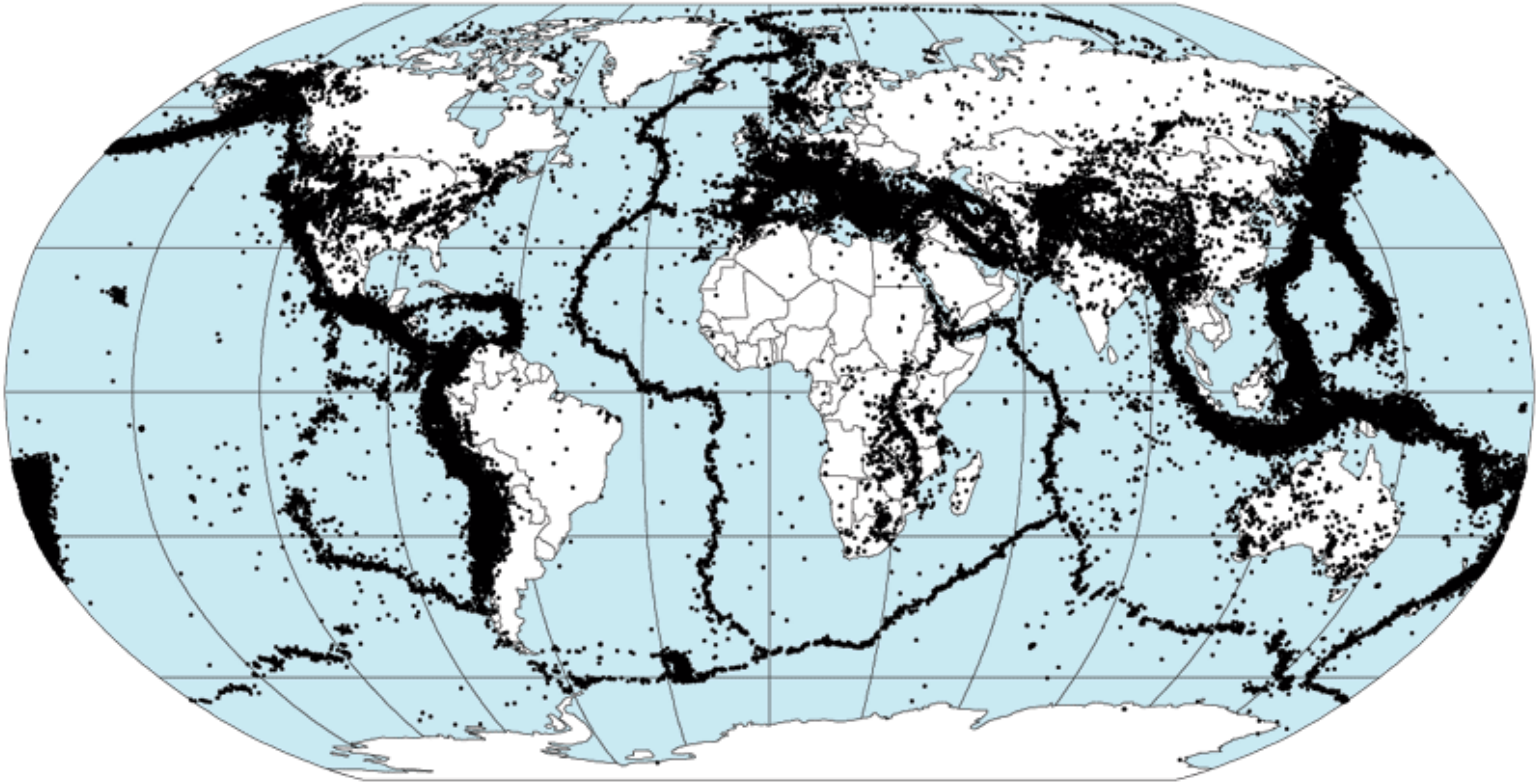


Plate tectonics

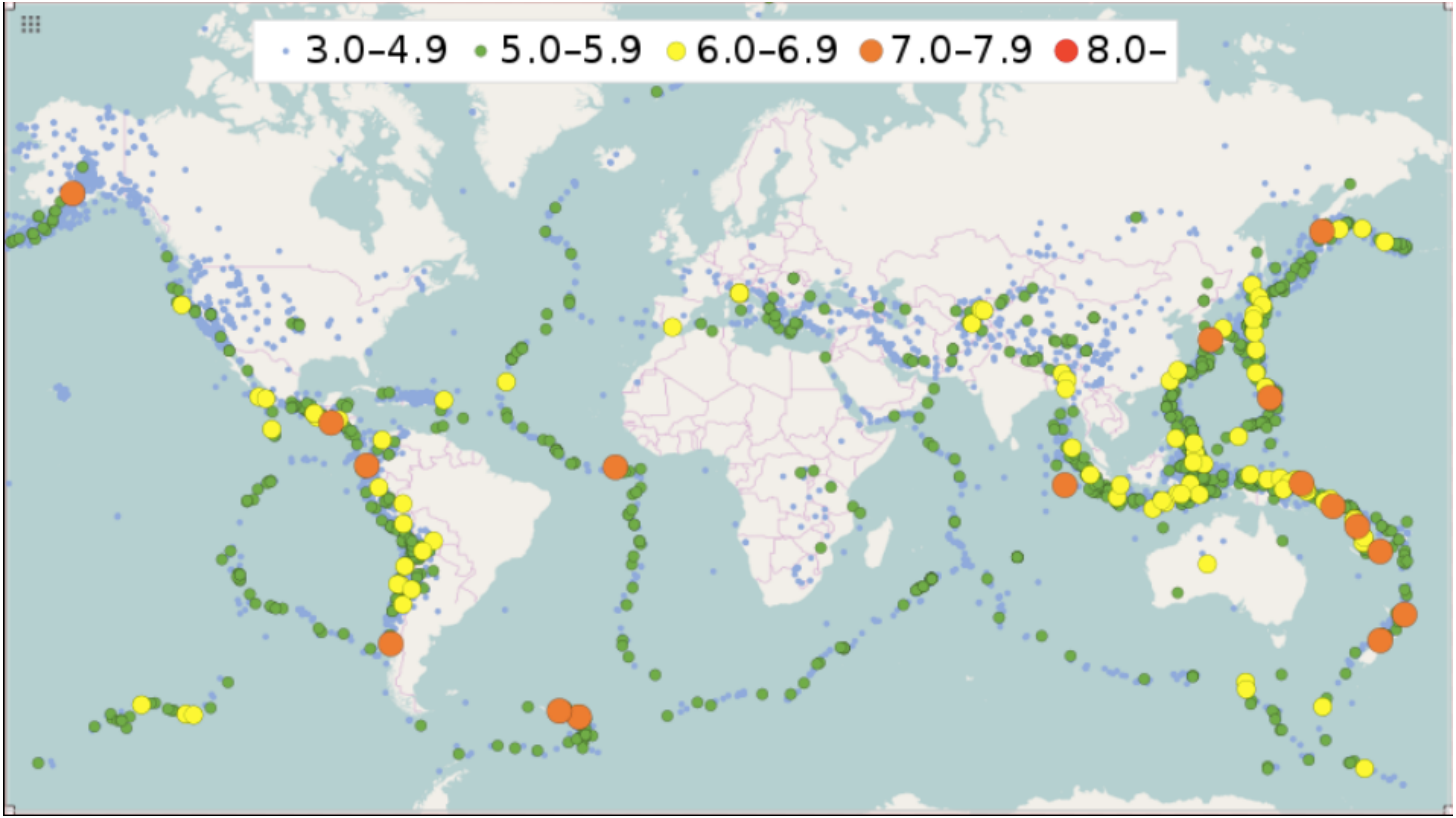


Plate tectonics

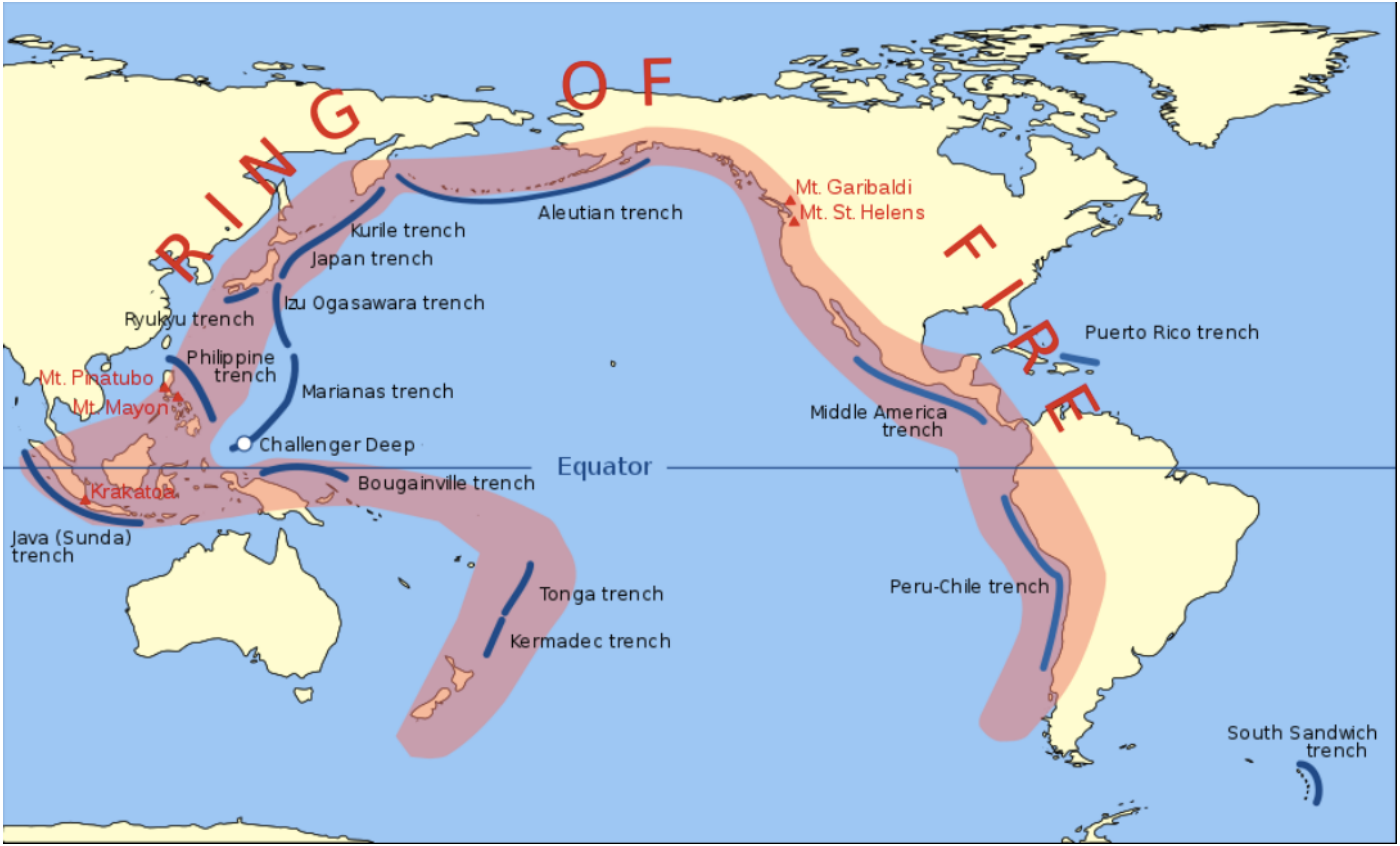


Plate tectonics

Natural Hazards and Disaster

Class 4: Geohazards; Earthquakes

- Types of Geohazards
- Plate Tectonics
- <u>Other Causes of Geohazards</u>
- Earthquakes

Other Causes of Geohazards

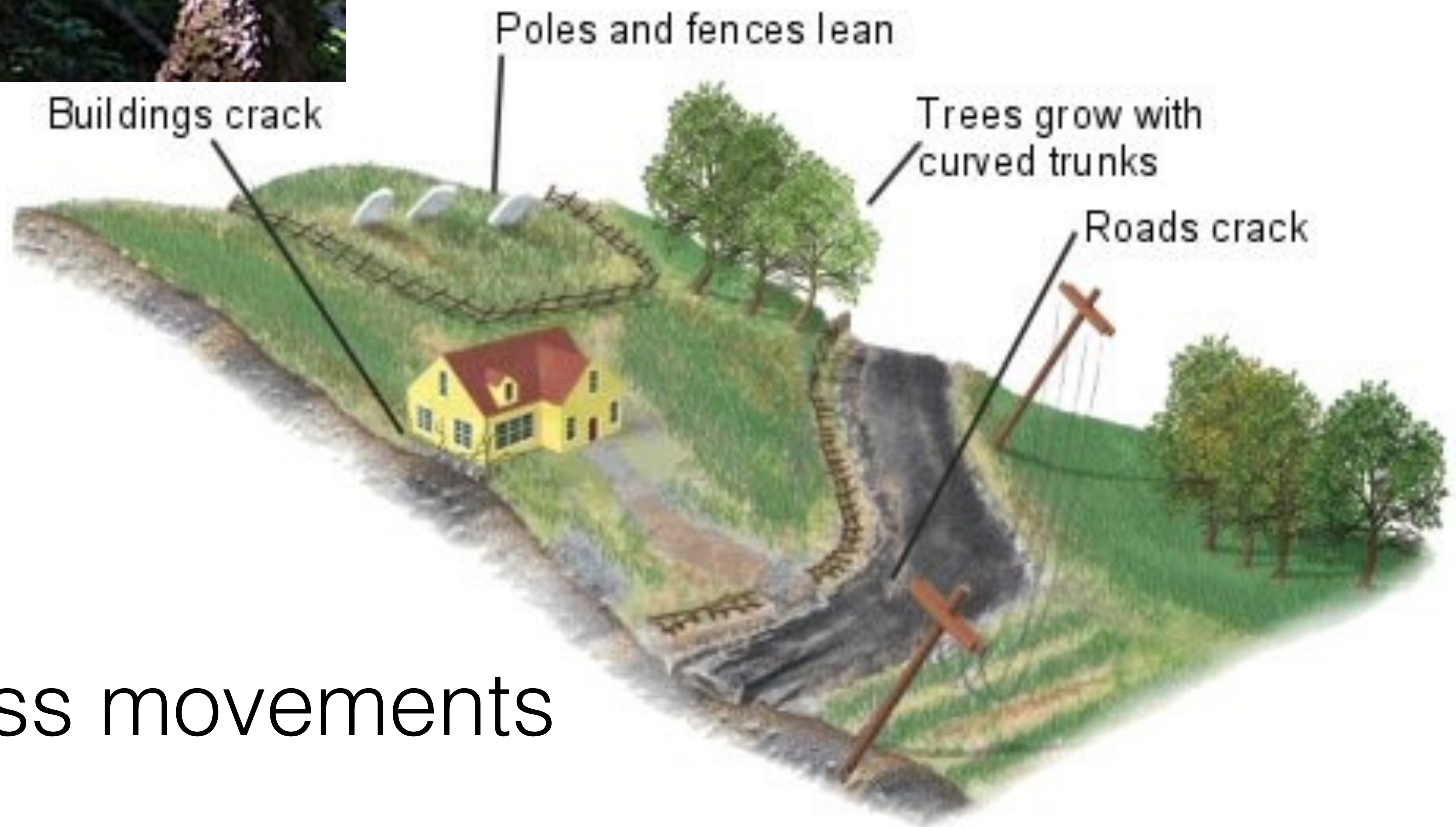
Rockfall

Landslide

Mudslide

Other Causes of Geohazards

soil creep



Mass movements

Other Causes of Geohazards

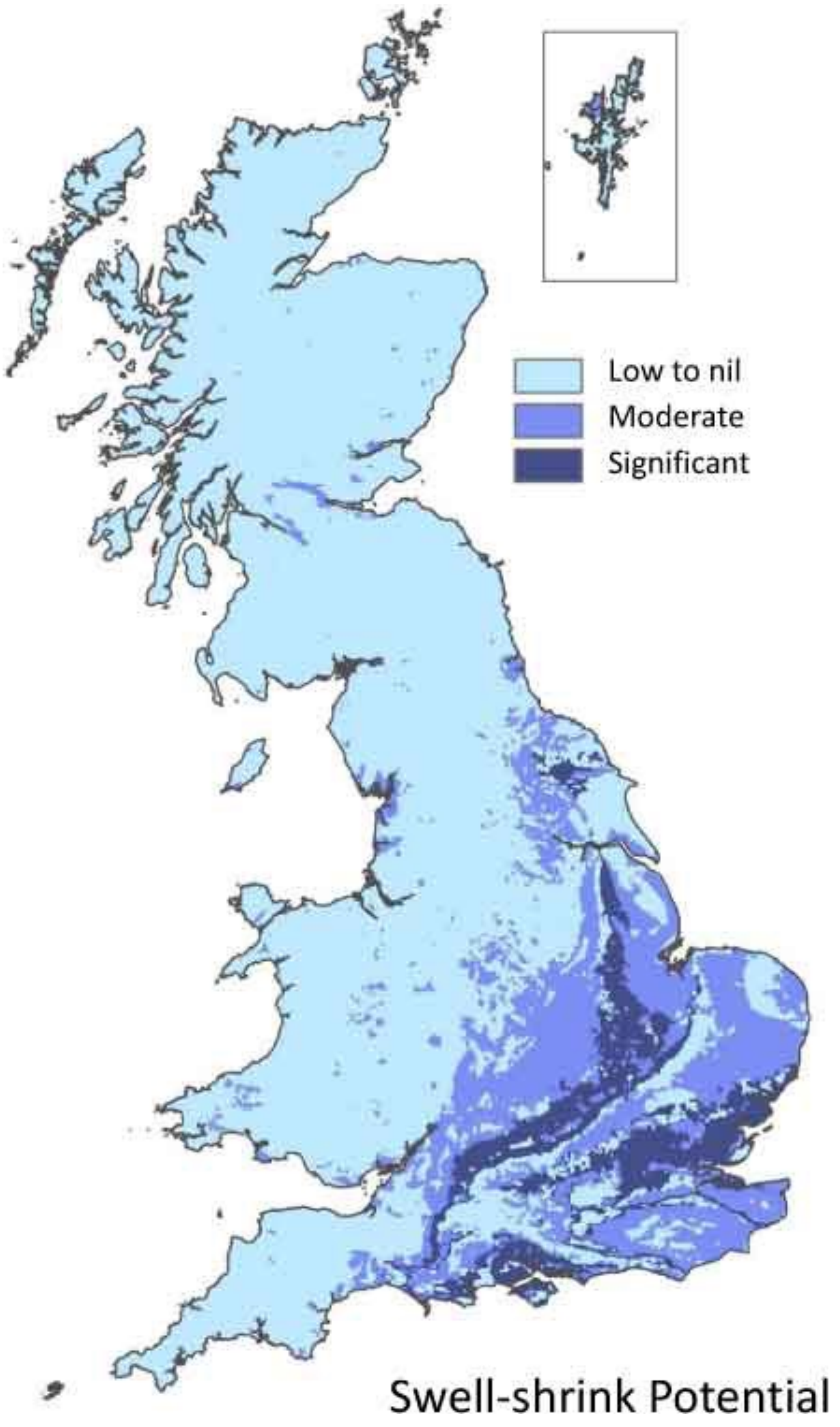
Sink holes



Shrink and swell clays

BGS GeoSure: shrink–swell

Shrinking and swelling of the ground (often reported as subsidence) is one of the most damaging geohazards in Britain today, costing the economy an estimated £3 billion over the past decade.



https://www.bgs.ac.uk/products/geosure/shrink_swell.html

Other Causes of Geohazards

Ground liquefaction

- Soil liquefaction describes a phenomenon whereby a saturated or partially saturated soil substantially loses strength and stiffness.
- This takes place in response to an applied stress.
- Usually, the cause is earthquake shaking or other sudden change in stress condition, causing the soil to behave like a liquid.

https://en.wikipedia.org/wiki/Soil_liquefaction

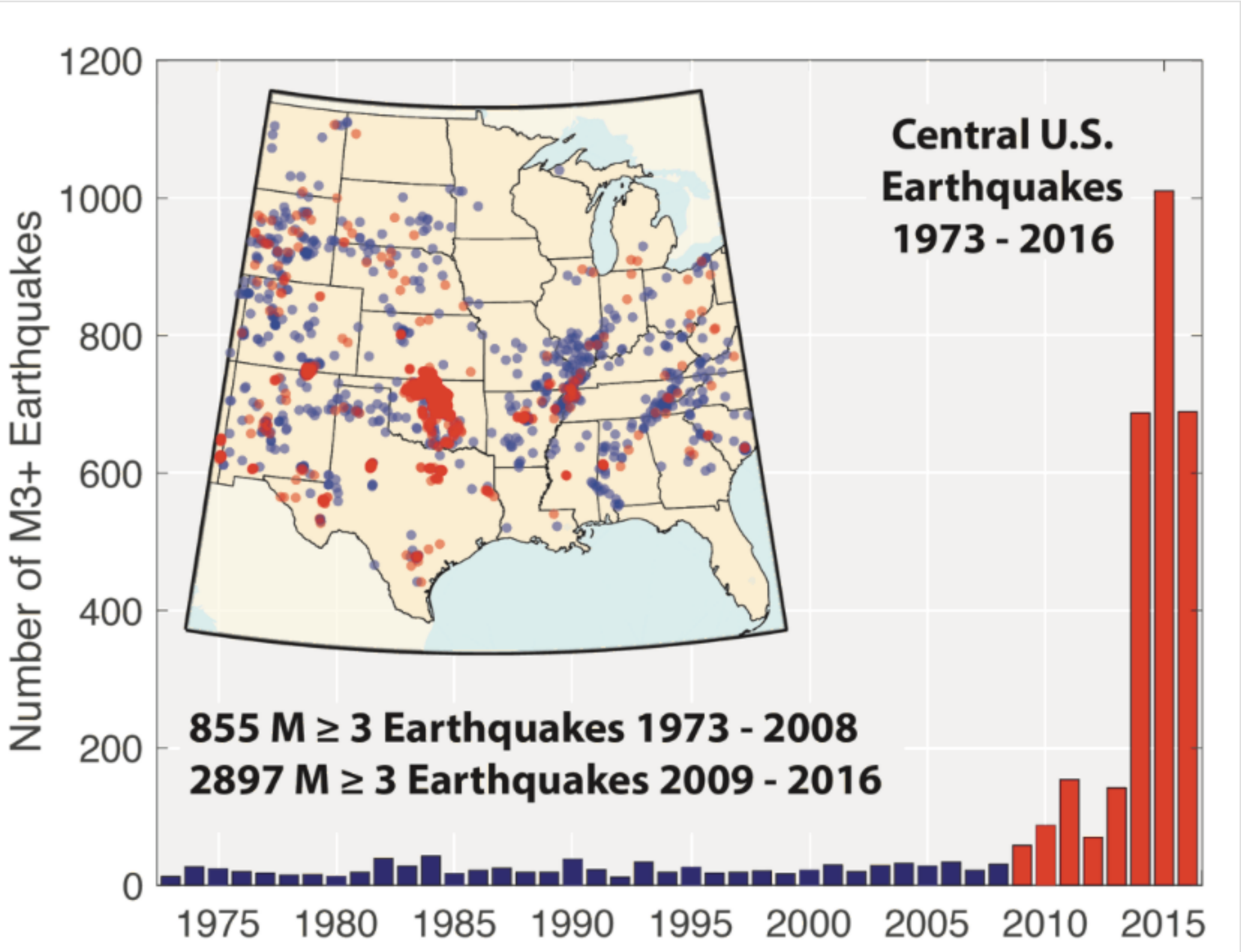
Induced Seismicity

Seismicity can be induced by:

- loading (reservoirs)
- deloading (groundwater)
- injection
- extraction
- hydraulic fracturing (fracking)

- Between the years 1973–2008, there was an average of 21 earthquakes of magnitude three and larger in the central and eastern United States.
- This rate has ballooned to over 600 M3+ earthquakes in 2014 and over 1000 in 2015.

See https://earthquake.usgs.gov/research/induced/edge.php for more detail on injection-induced seismicity



https://earthquake.usgs.gov/research/induced/

Natural Hazards and Disaster

Class 4: Geohazards; Earthquakes

- Types of Geohazards
- Plate Tectonics
- Other Causes of Geohazards
- Earthquakes

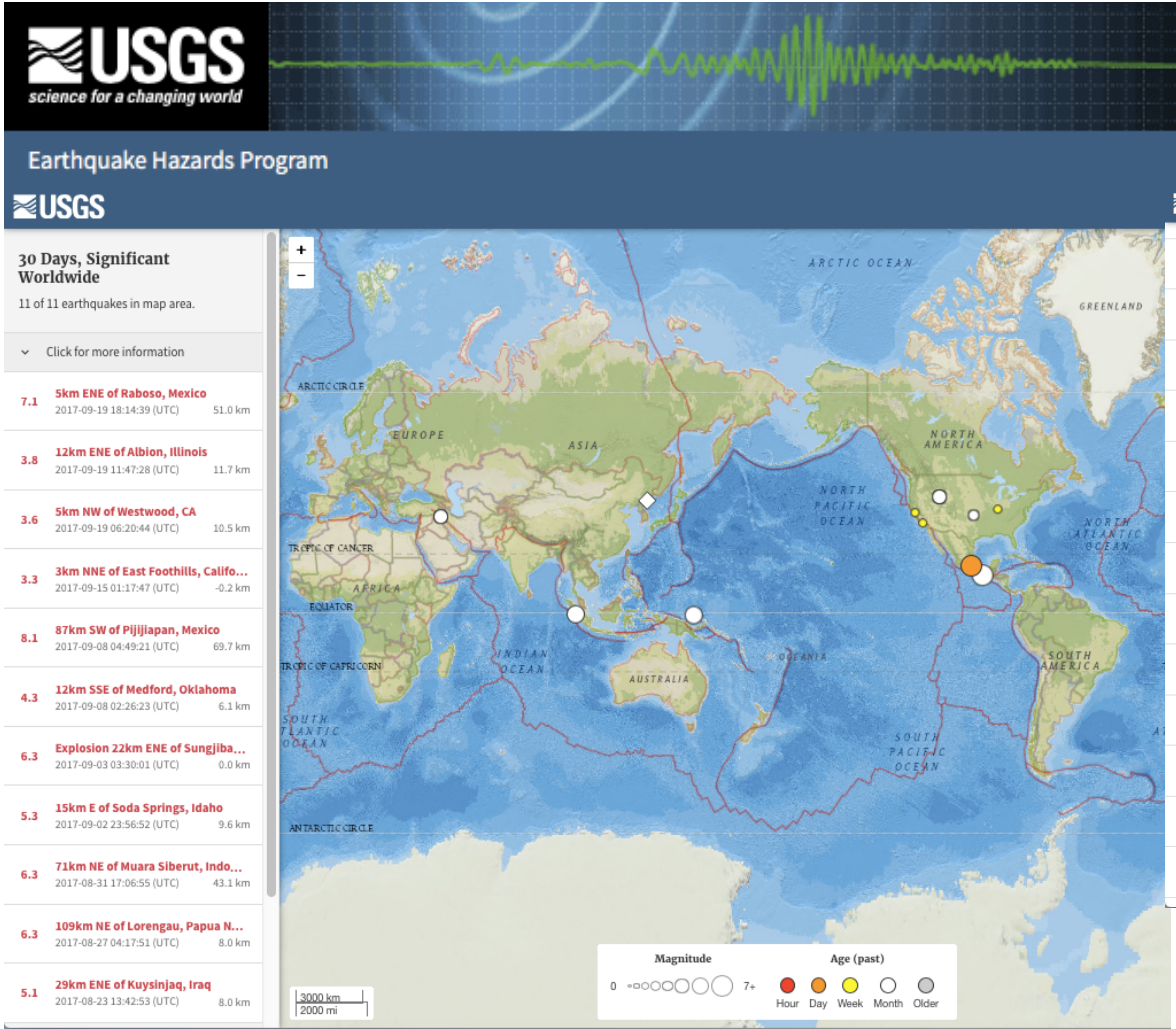
Natural Hazards and Disaster

Class 4: Geohazards; Earthquakes

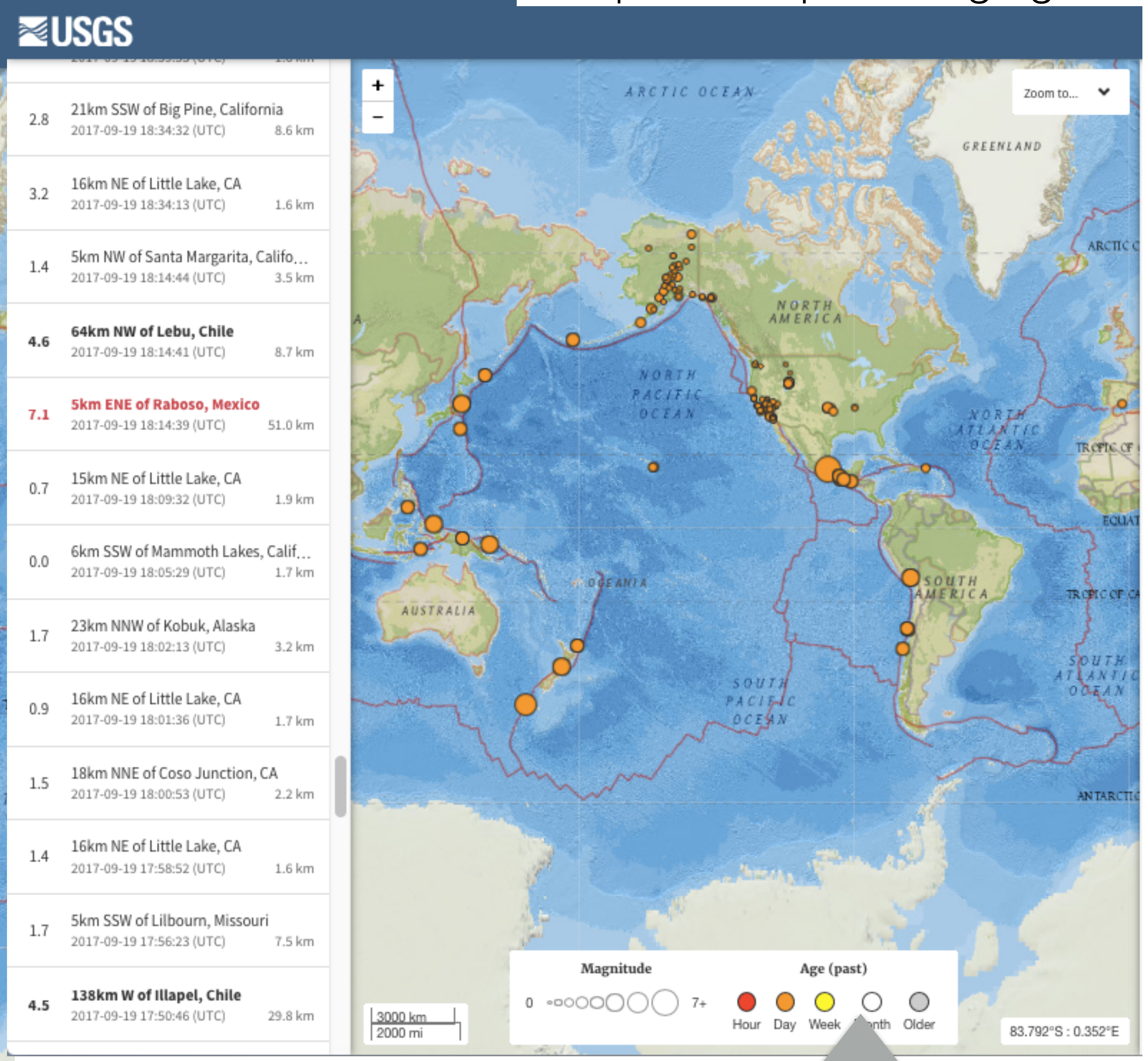
- Location
- Causes
- Magnitude
- Ground shaking
- Recurrence intervals
- Hazard maps

http://earthquake.usgs.gov/eqcenter/recenteqsus/Maps/US10/32.42.-125.-115.php

Earthquakes



http://earthquake.usgs.gov



Last month

24 hours

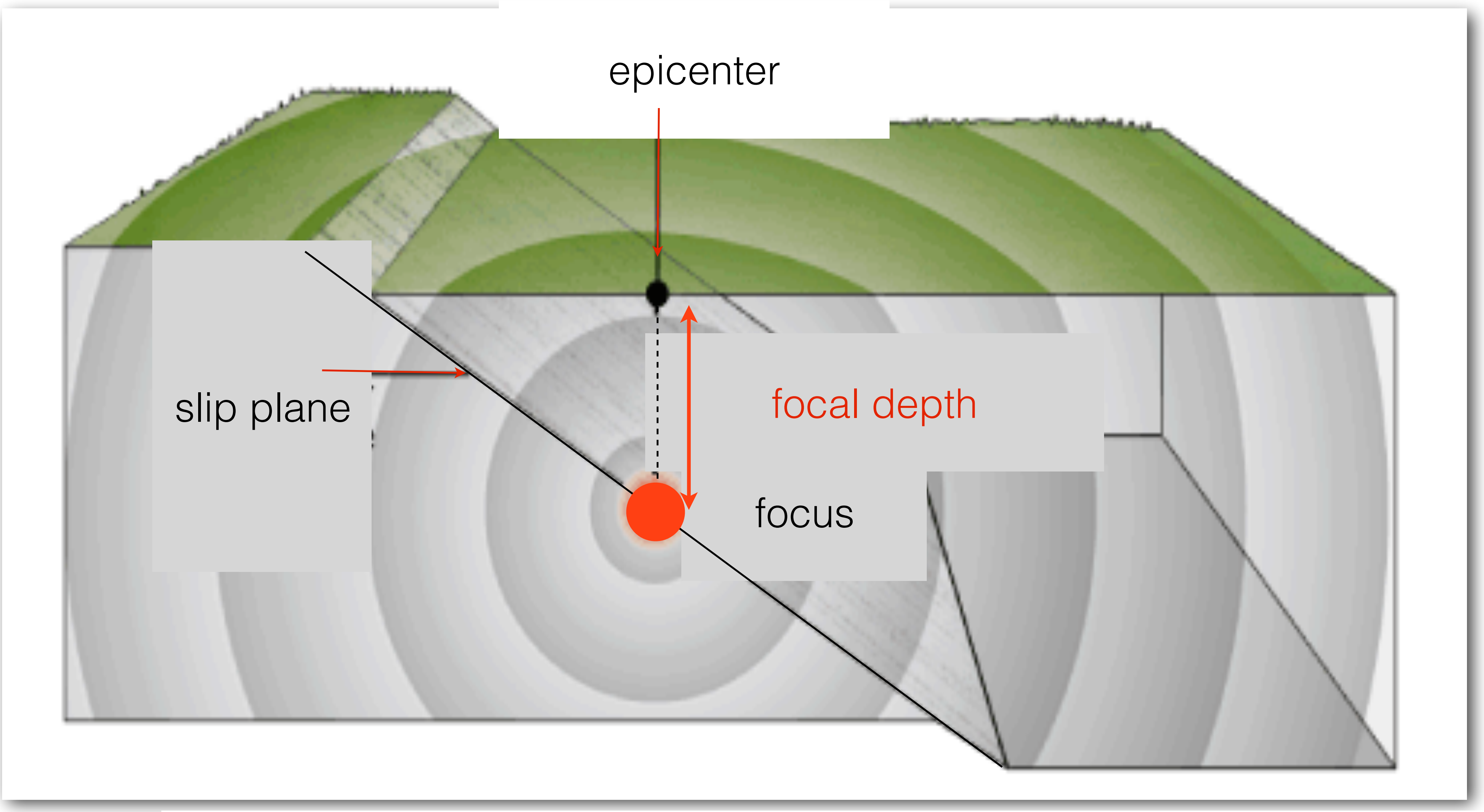
Earthquake Location

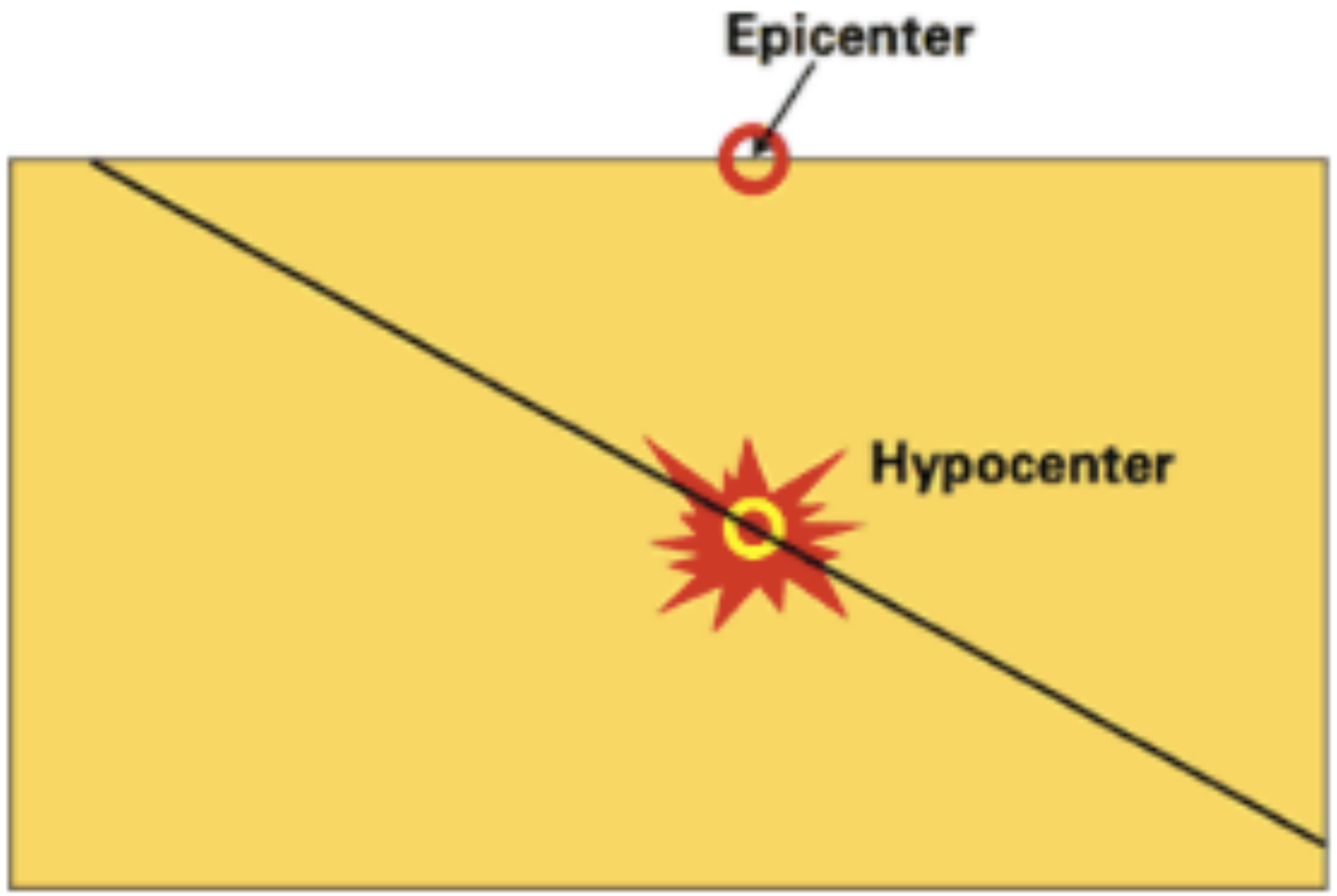
Specifying the location of the earthquake

Epicenter: Latitude, longitude; position on the ground directly above the earthquake

Focal Depth: depth below ground surface where earthquake rupture occurs

Hypocenter (focus): Actual location in the Earth's crust where the earthquake occurs (needs lat, long, and depth)





Earthquake Location

Tectonic Plates are cool, thin and ‘rigid,’ relative to the hot, ductile mantle beneath

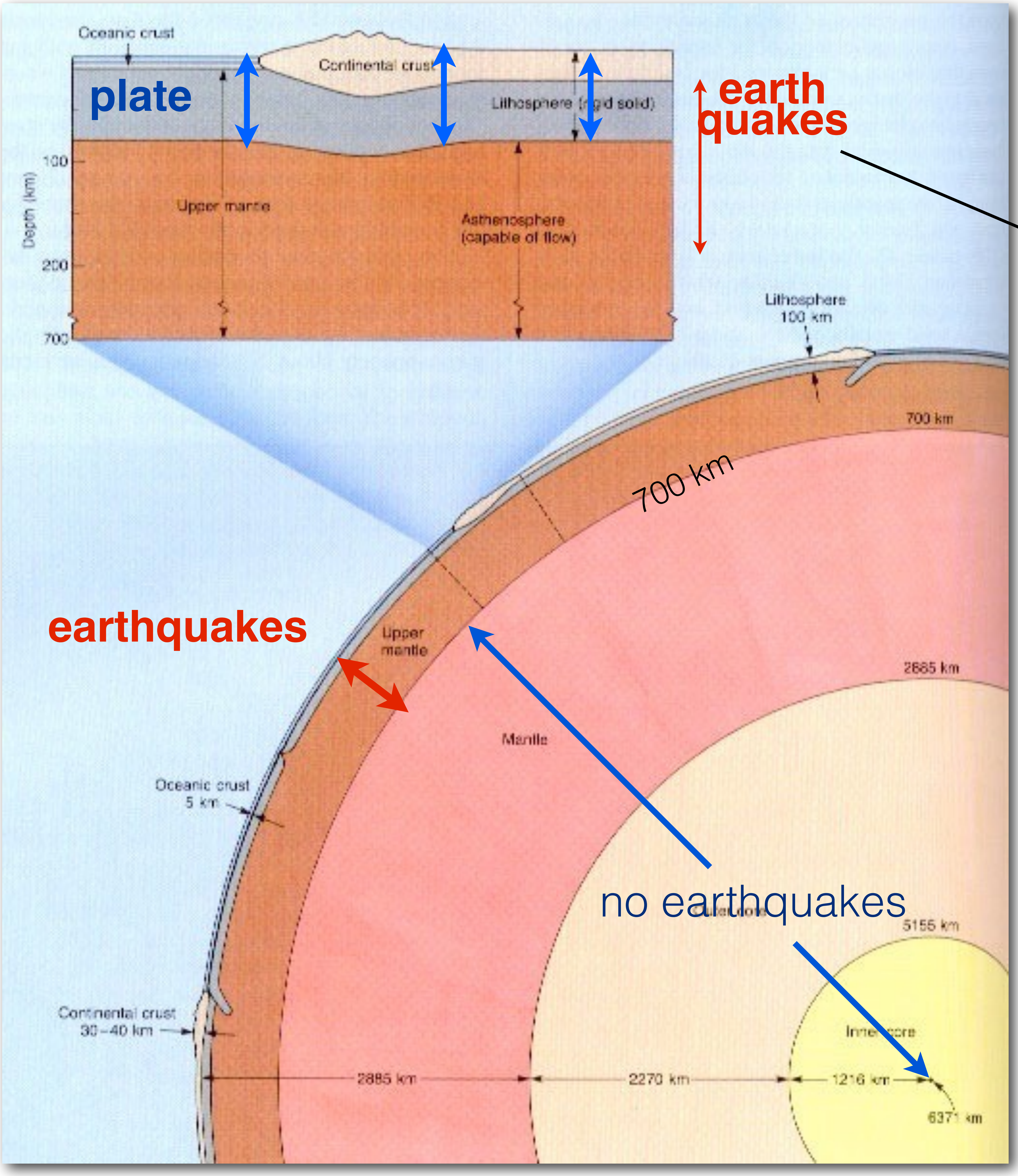
plate = crust + lithosphere

Shallow earthquakes: <70 km

Intermediate: >70 to 300 km

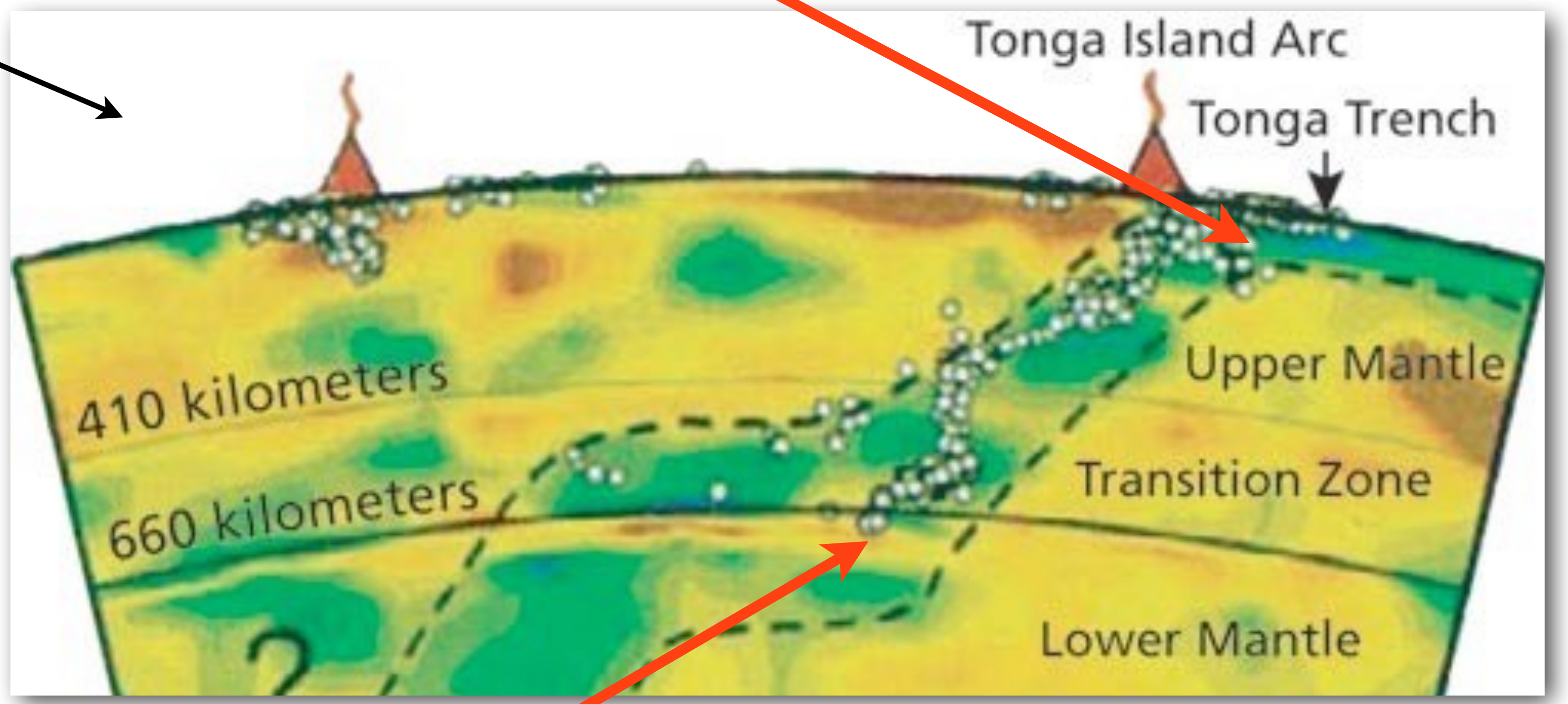
Deep: >300 km

Earthquakes occur within or between tectonic plates and within the upper mantle



http://www.angelfire.com/wv/permianpark/images/fullearth.jpg

Samoa, September 29, 2009
focal depth 10 km



http://www.whoi.edu/cms/images/lstokey/2005/1/v42n2-detrick2en_5301.jpg

Deepest known are at ca. 700 km

Each dot is a recorded earthquake in past 20 yrs

Natural Hazards and Disaster

Class 4: Geohazards; Earthquakes

- Location
- Causes
- Magnitude
- Ground shaking
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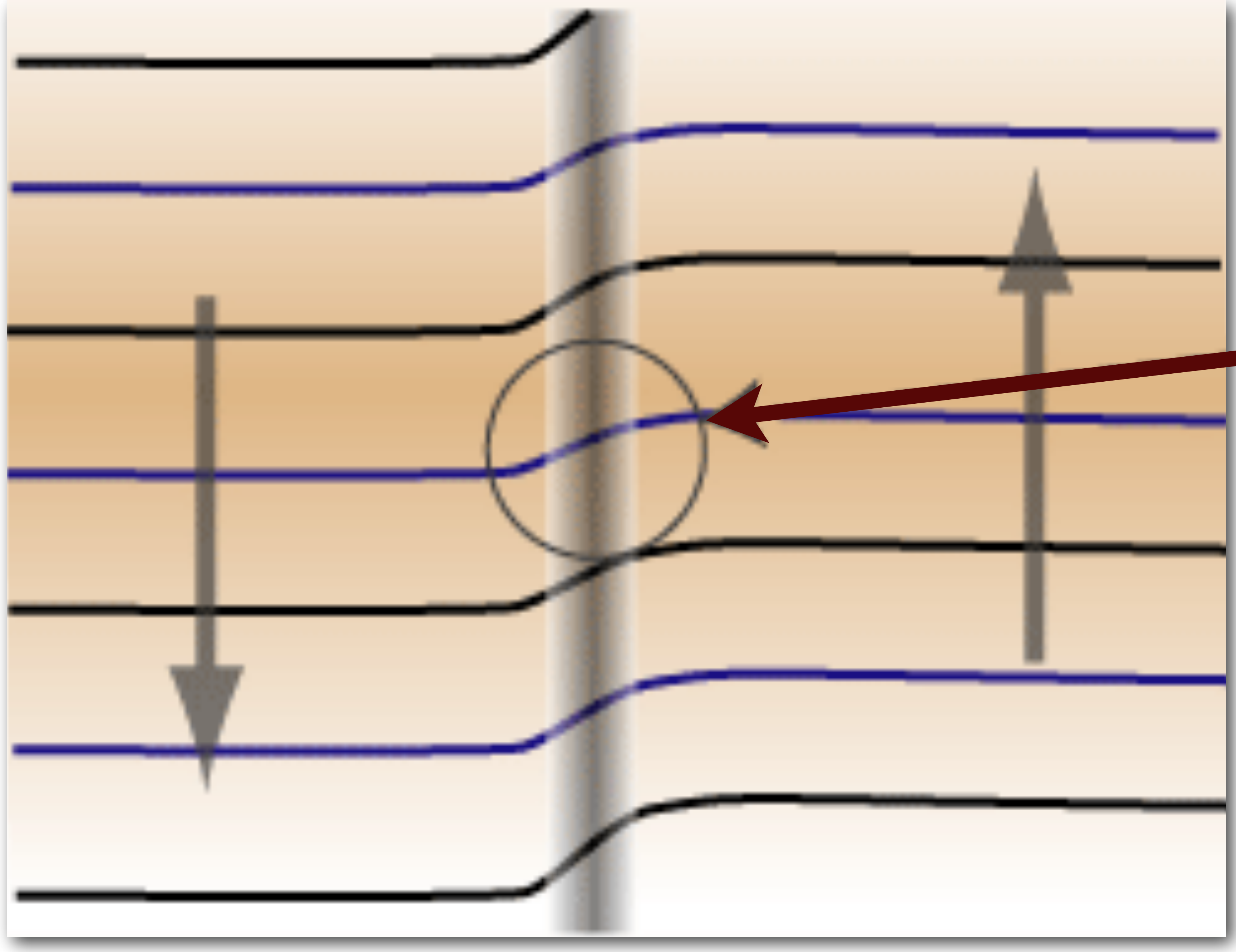
- Hazard maps

http://earthquake.usgs.gov/eqcenter/recenteqsus/Maps/US10/32.42.-125.-115.php

Causes of Earthquakes

Stage 1



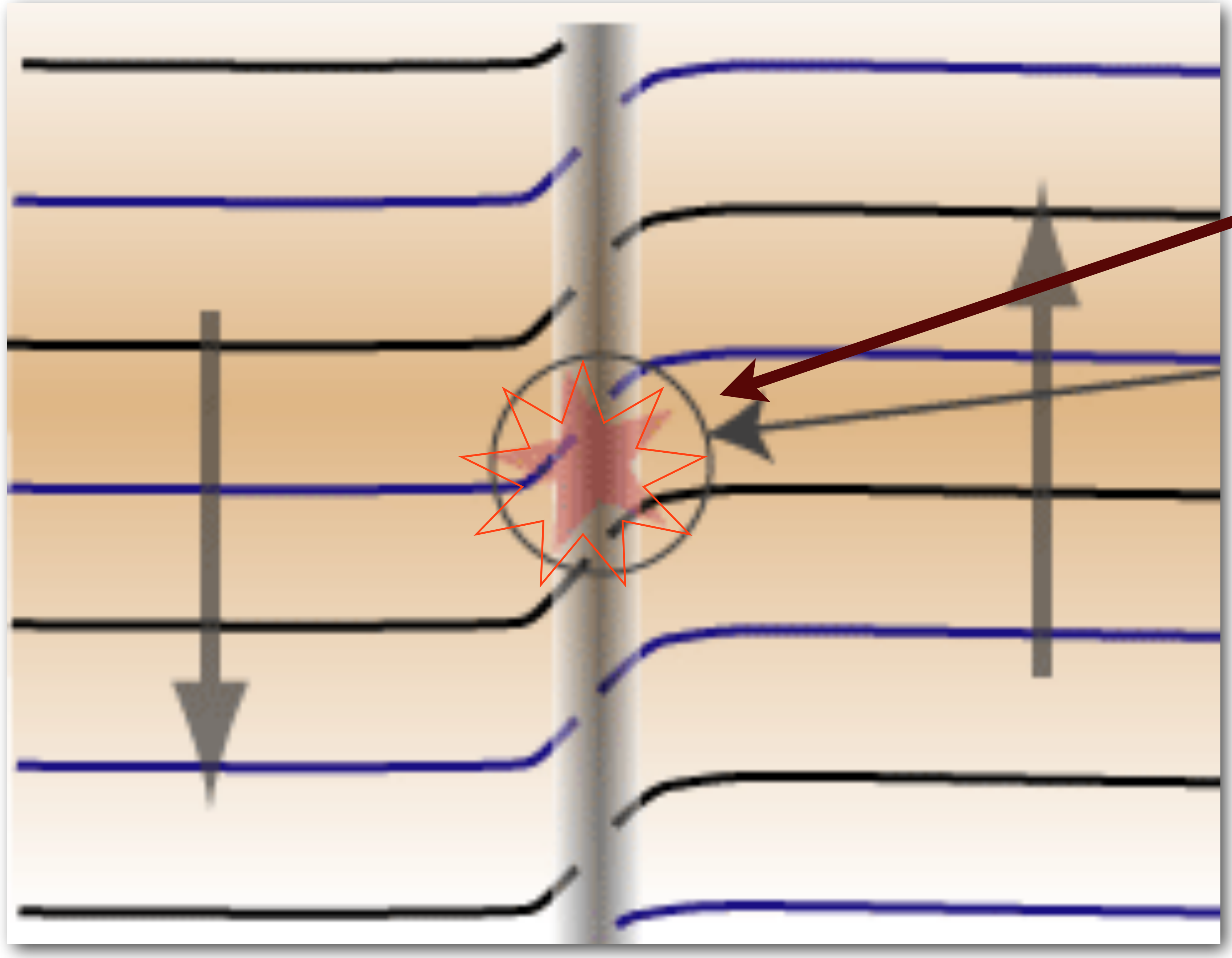
Rock bends a little (or a lot), but doesn't break, yet...

Most earthquakes occur on 'faults' or fracture zones in the Earth's crust when crustal rocks are stretched or slide past each other.

Folded rocks in Pyrenees, Spain

Causes of Earthquakes

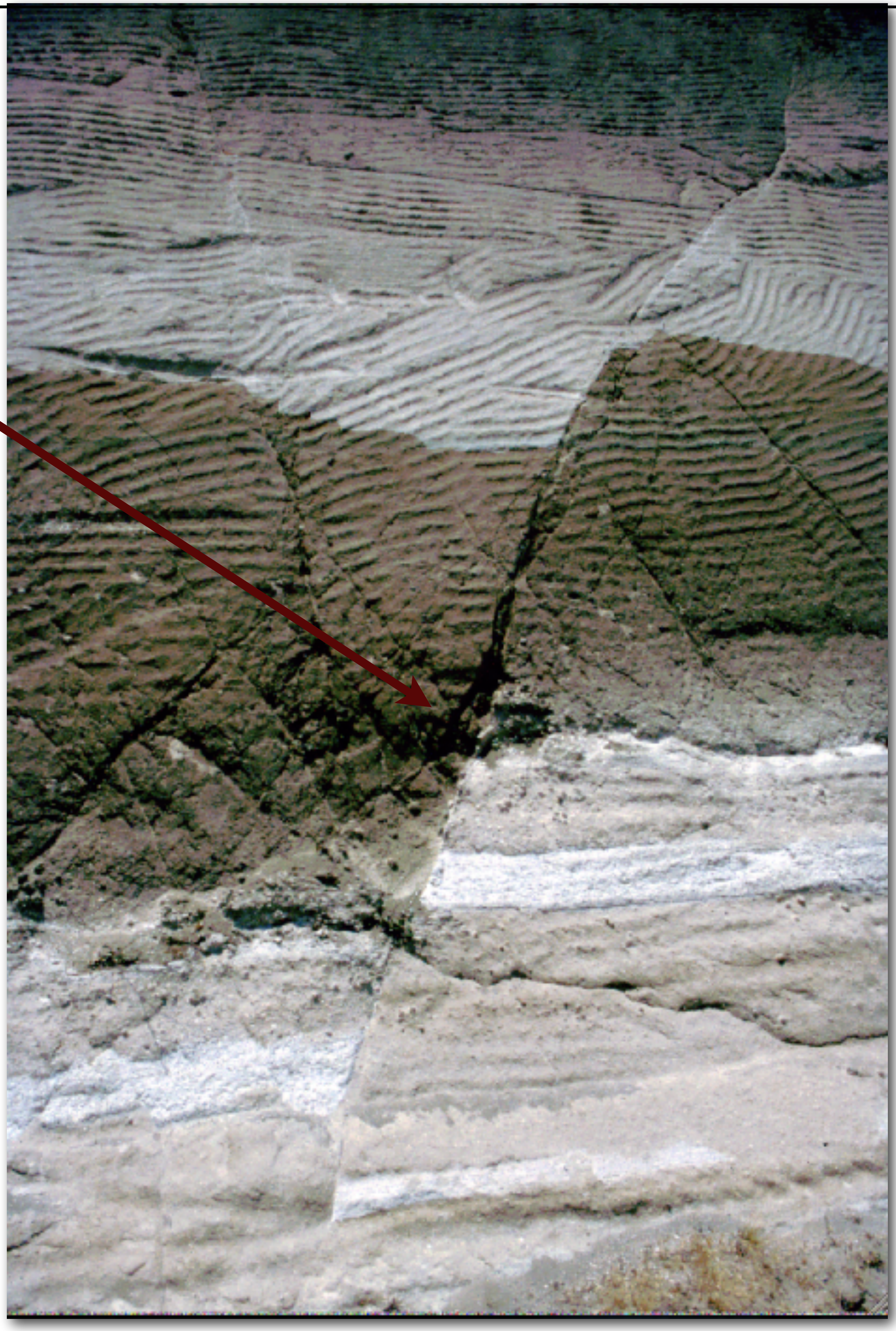
Stage 2



rock breaks...

and when it breaks, it releases a sudden pulse of energy....

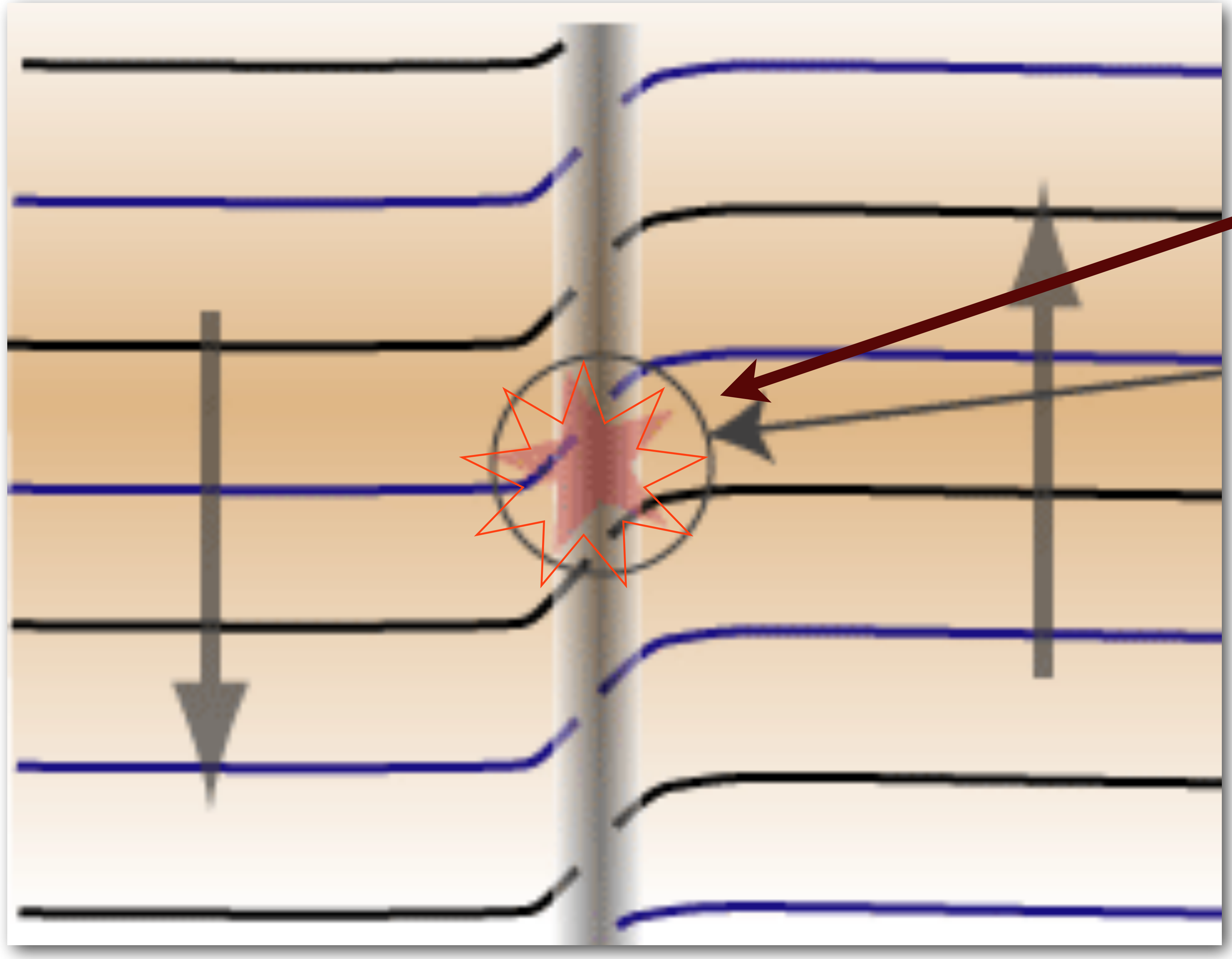
this can be a very small ‘crack,’ or...



fault in volcanic rocks Kingman, AZ

Causes of Earthquakes

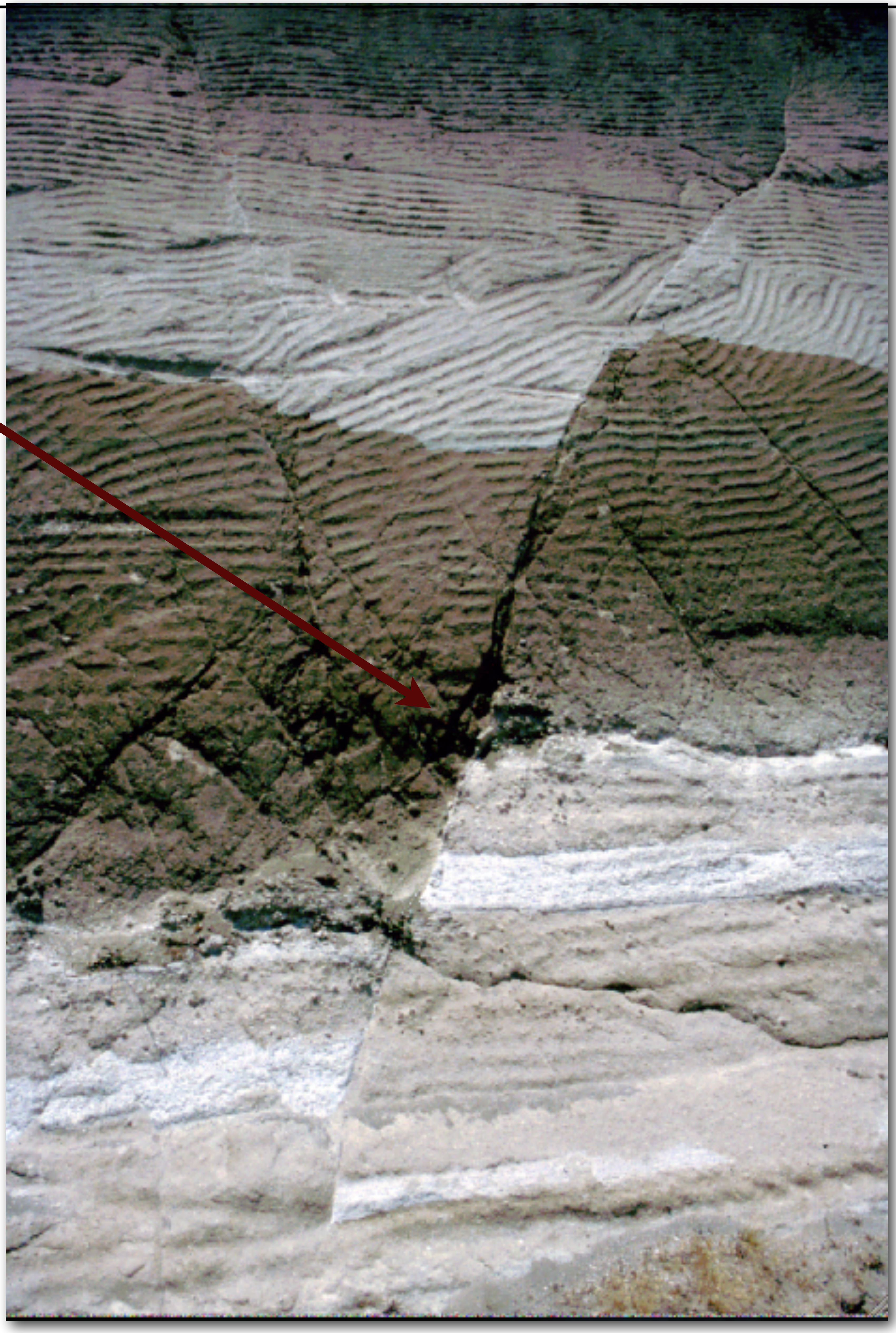
Stage 2



rock breaks...

and when it breaks, it releases a sudden pulse of energy....

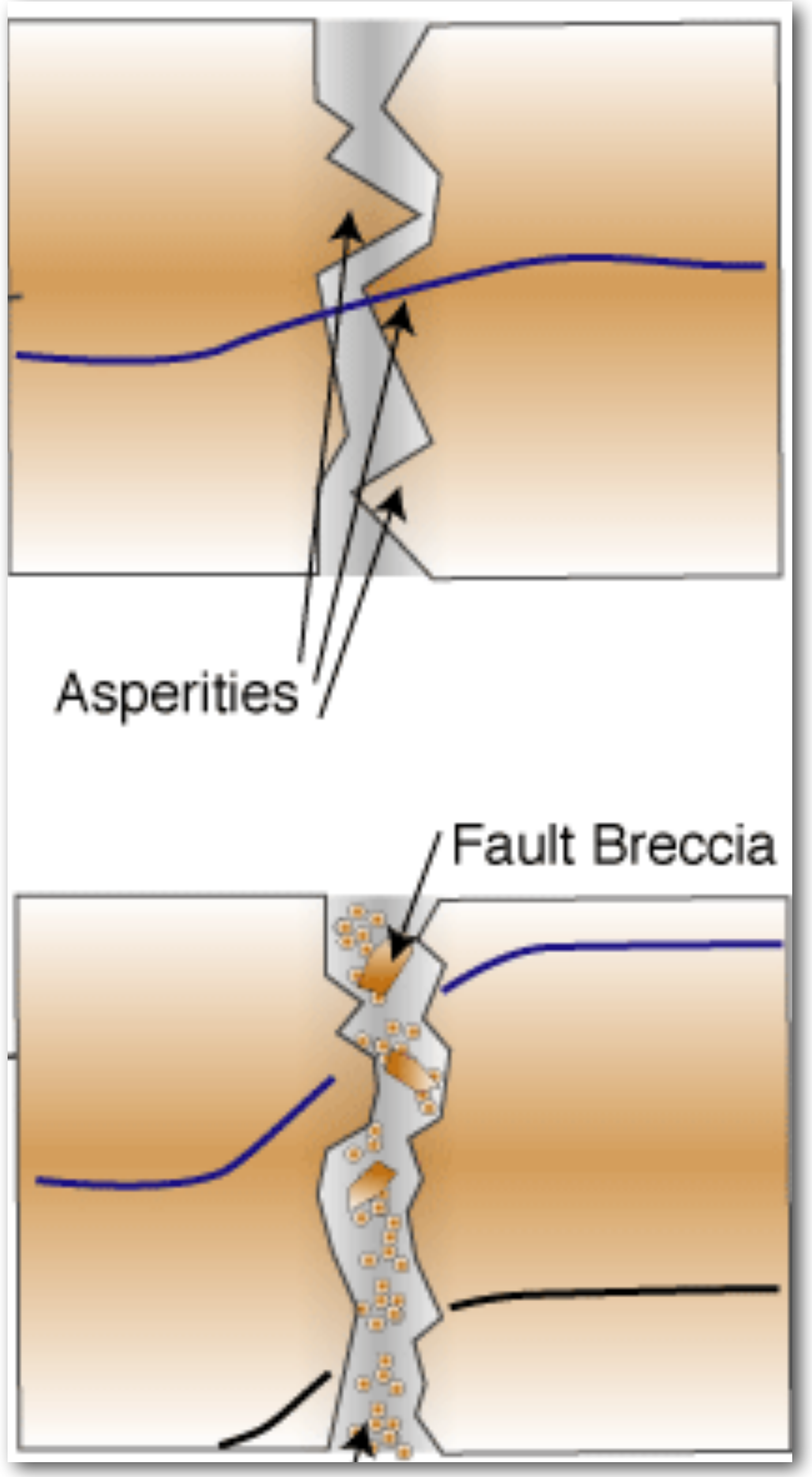
Earthquake!



fault in volcanic rocks Kingman, AZ

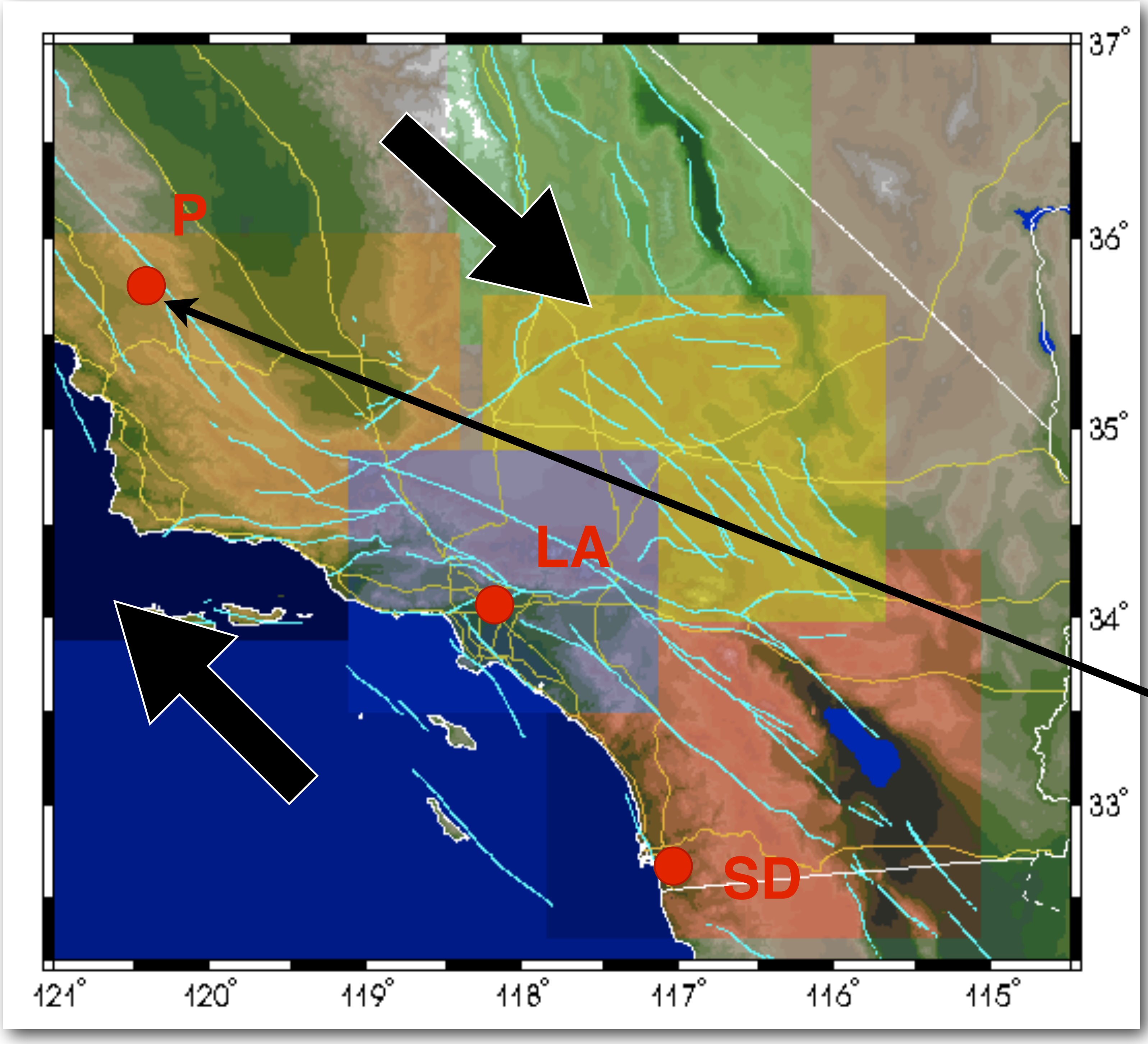
Causes of Earthquakes

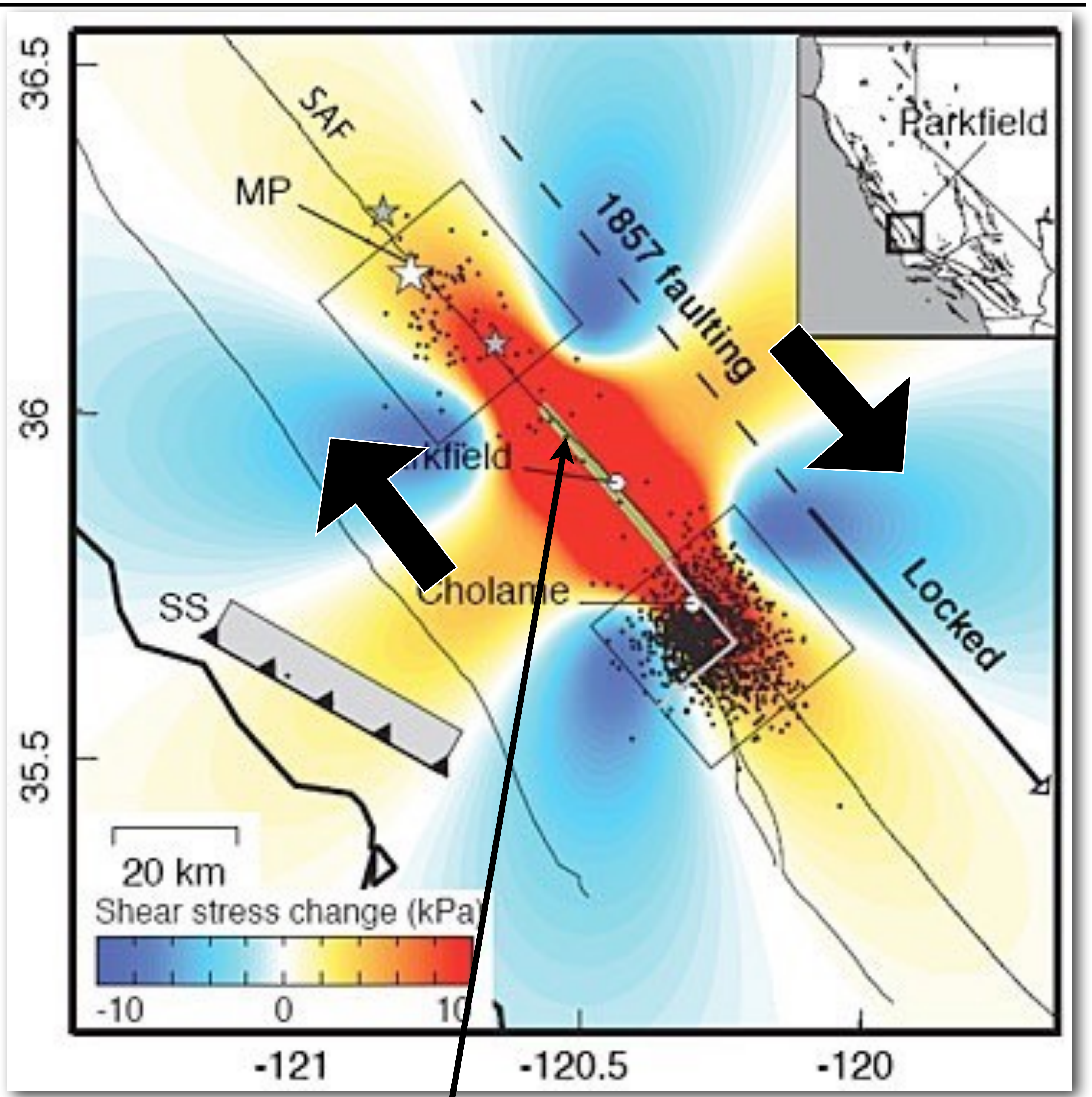
- Faults ‘stick’ as they slide past one another;
- Friction (resistance to sliding) causes stress to build up at sticking point



can be small scale or large scale

San Andreas fault zone, southern CA



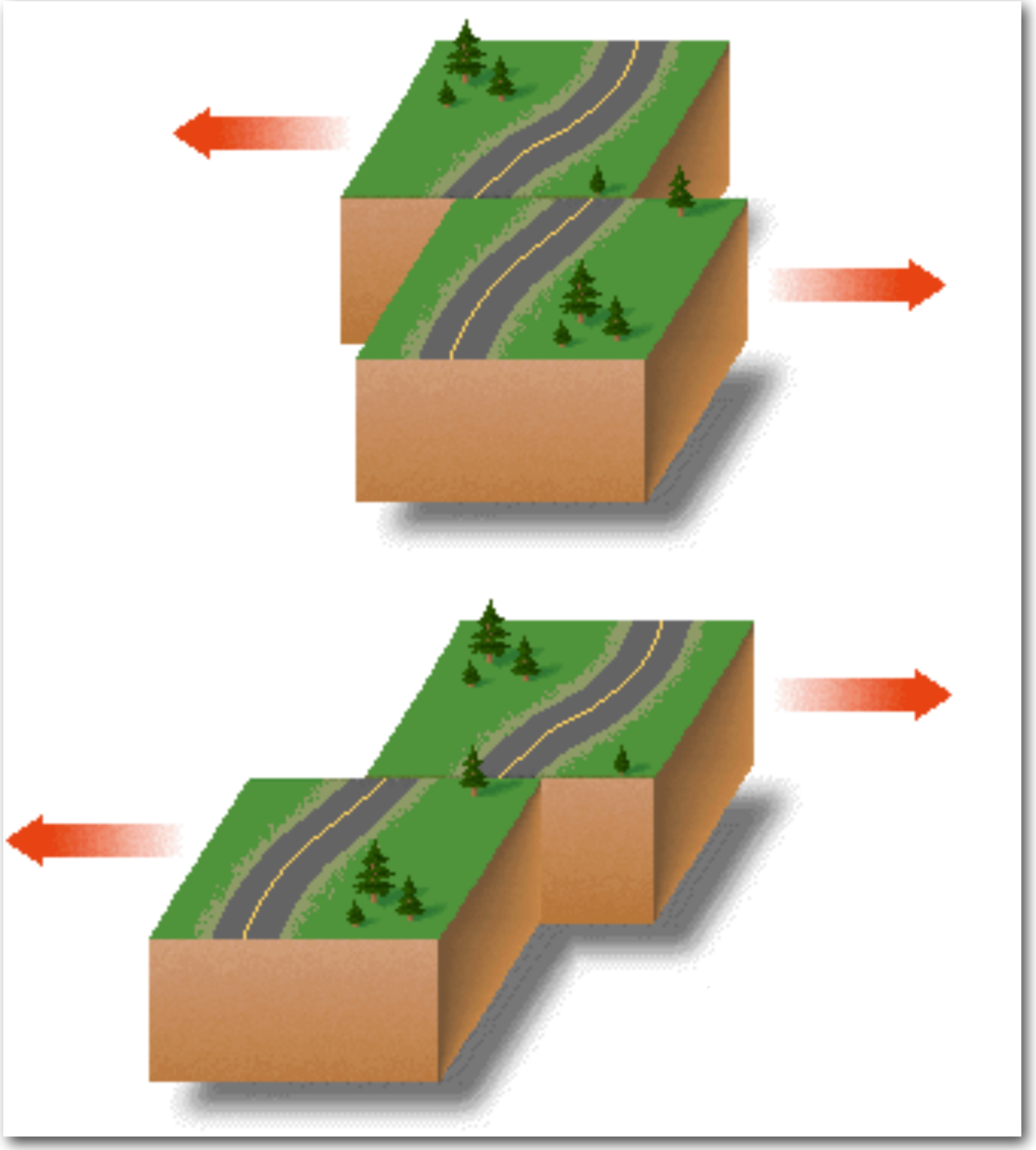


http://berkeley.edu/news/media/releases/2009/07/images/parkfield.jpg

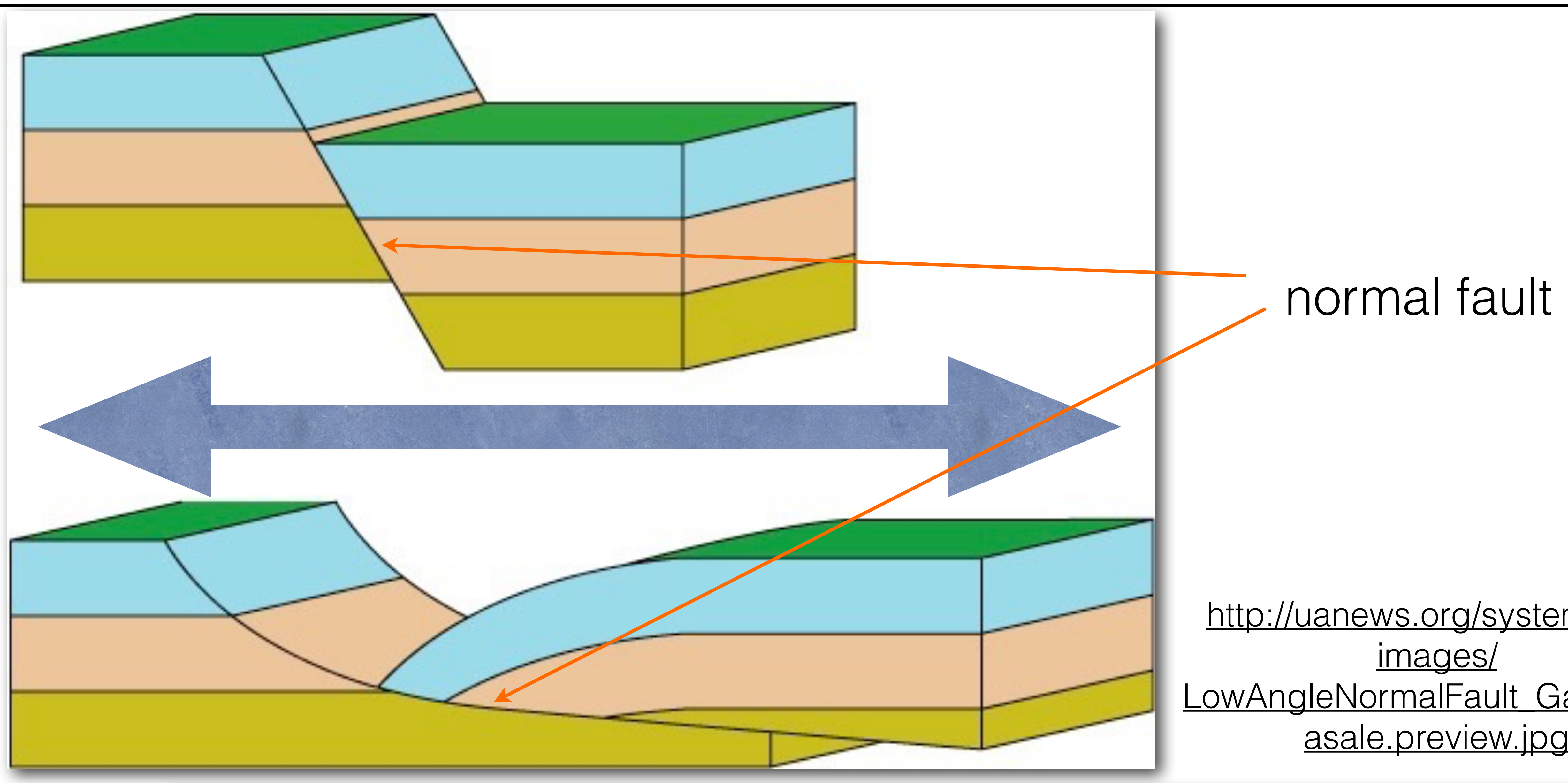
stress build-up in locked section of fault

Causes of Earthquakes

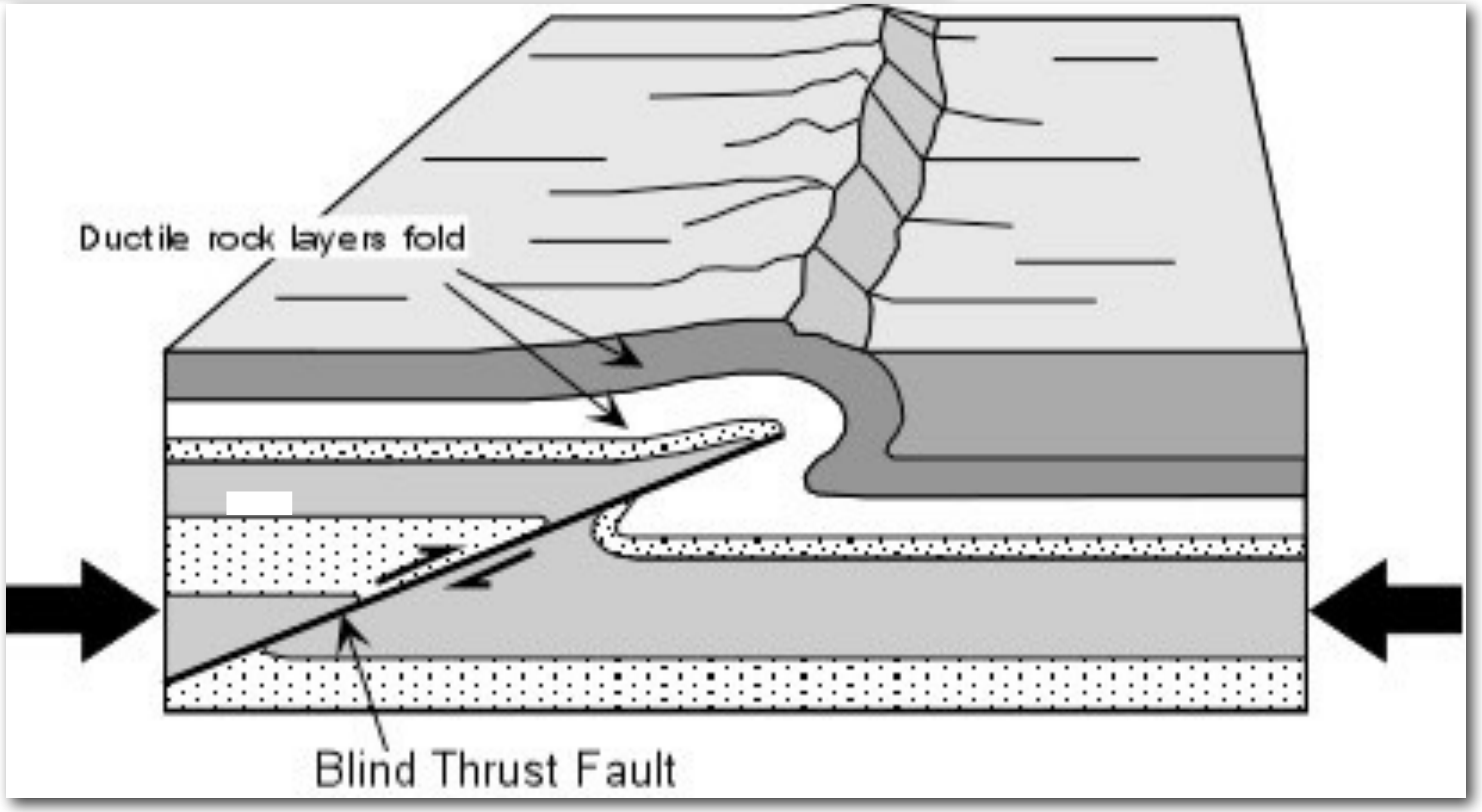
Most earthquakes occur on ‘faults’ or fracture zones in the Earth’s crust when crustal rocks are stretched or slide past each other or over each other.



http://www.scec.org/education/public/roots/pictures/strslipv.gif



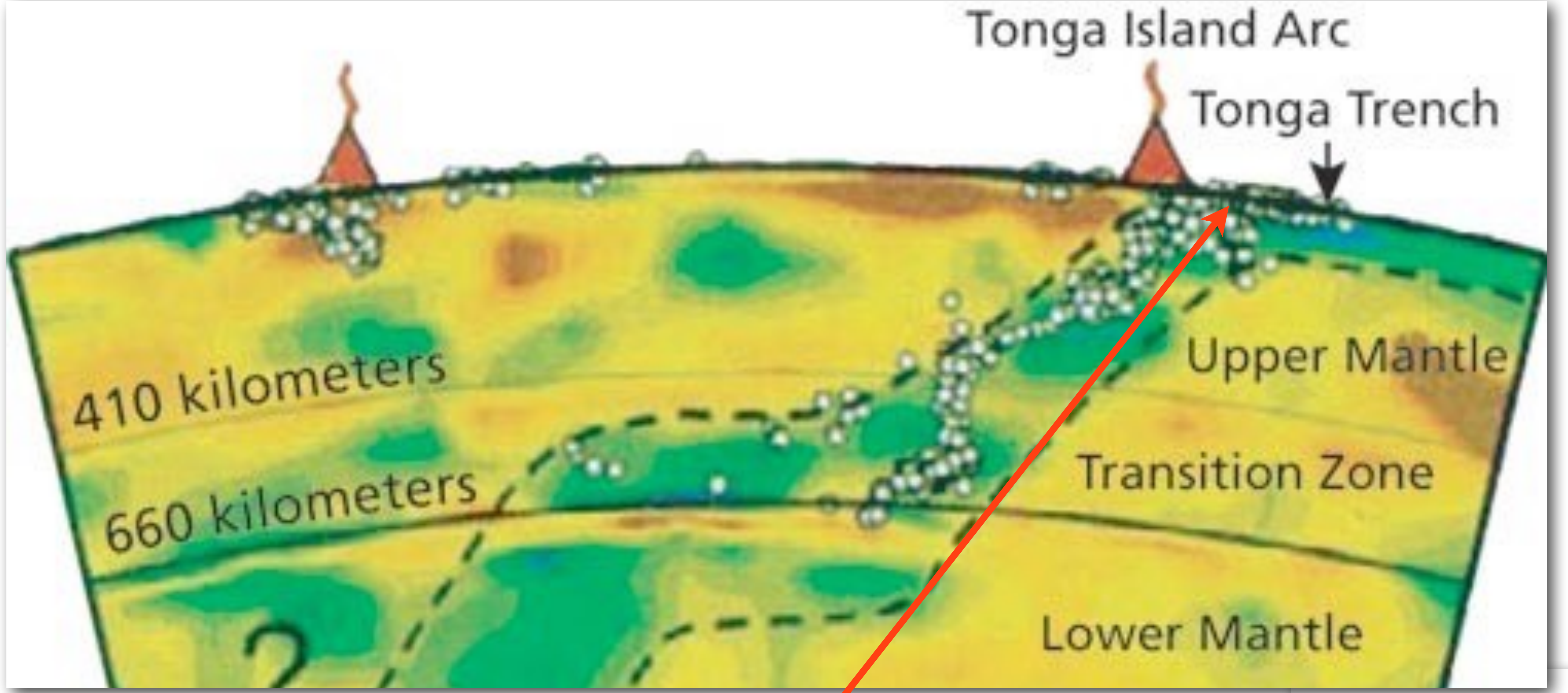
http://uanews.org/system/files/images/LowAngleNormalFault_GabrieleCasale.preview.jpg



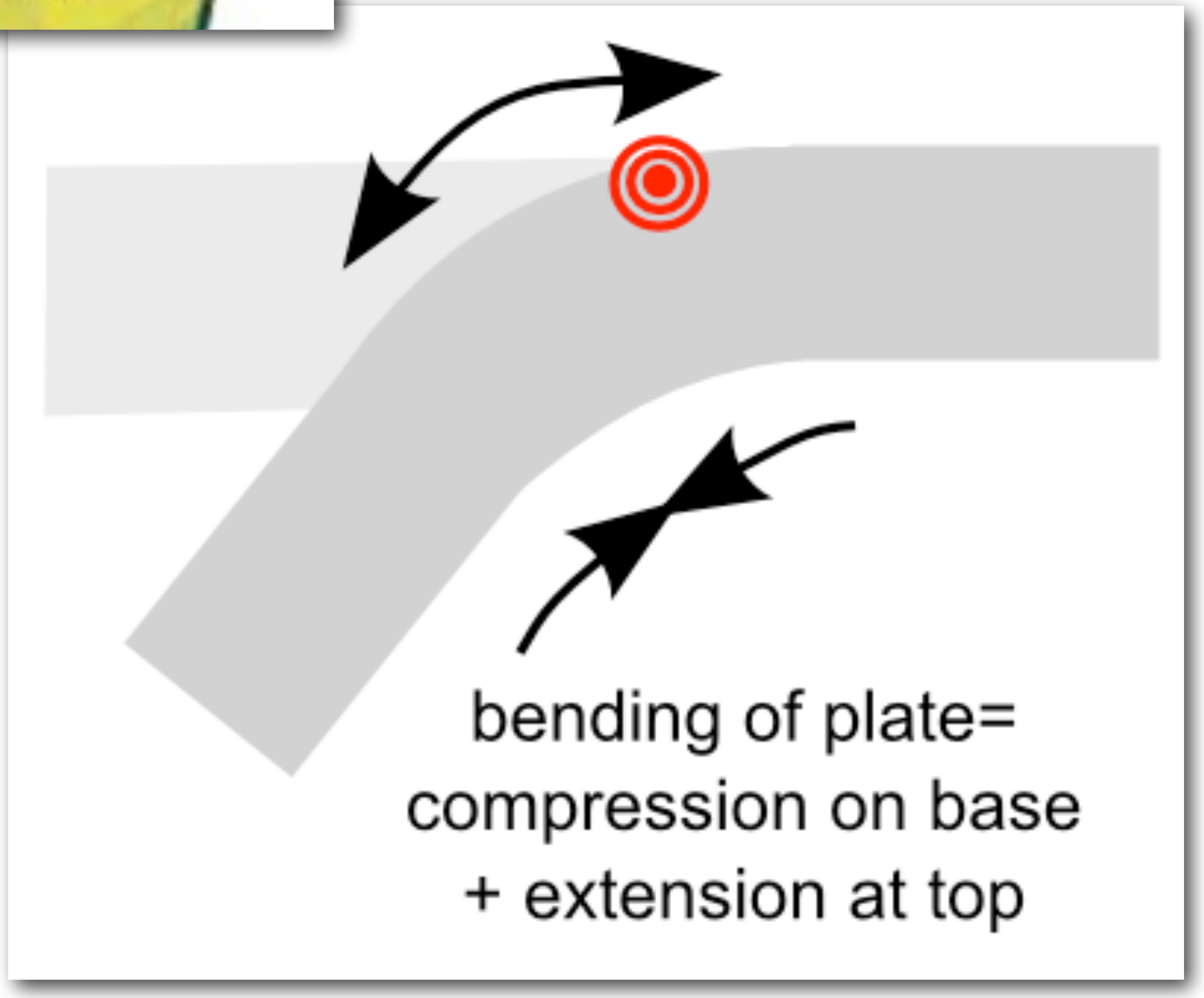
http://earthsci.org/processes/struct/equake1/blindyhrust.jpg

Three main types of ‘faults’ or fracture zones in the Earth’s crust:

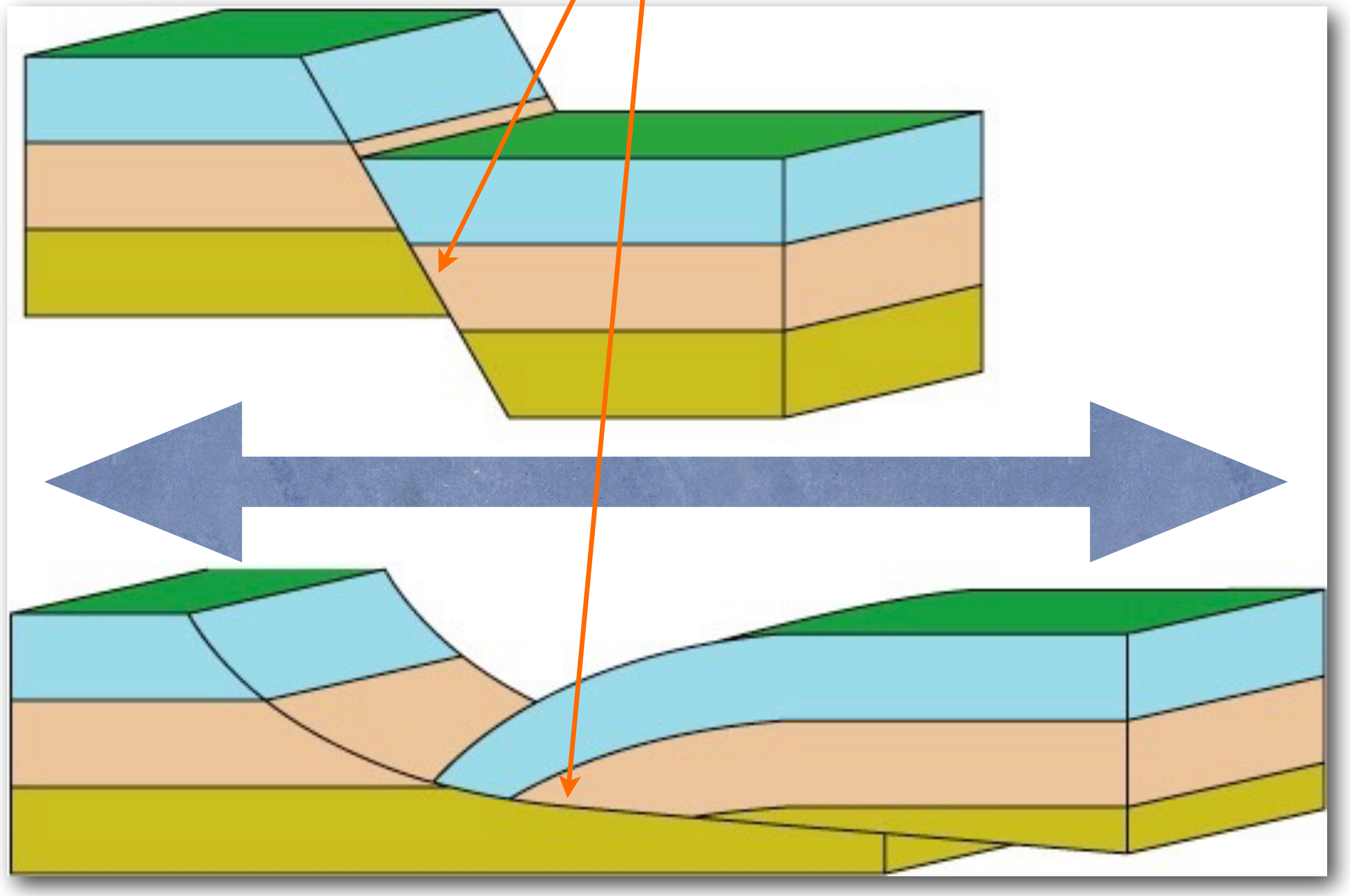
(a) when crustal rocks are stretched



e.g., Samoa earthquake



normal fault



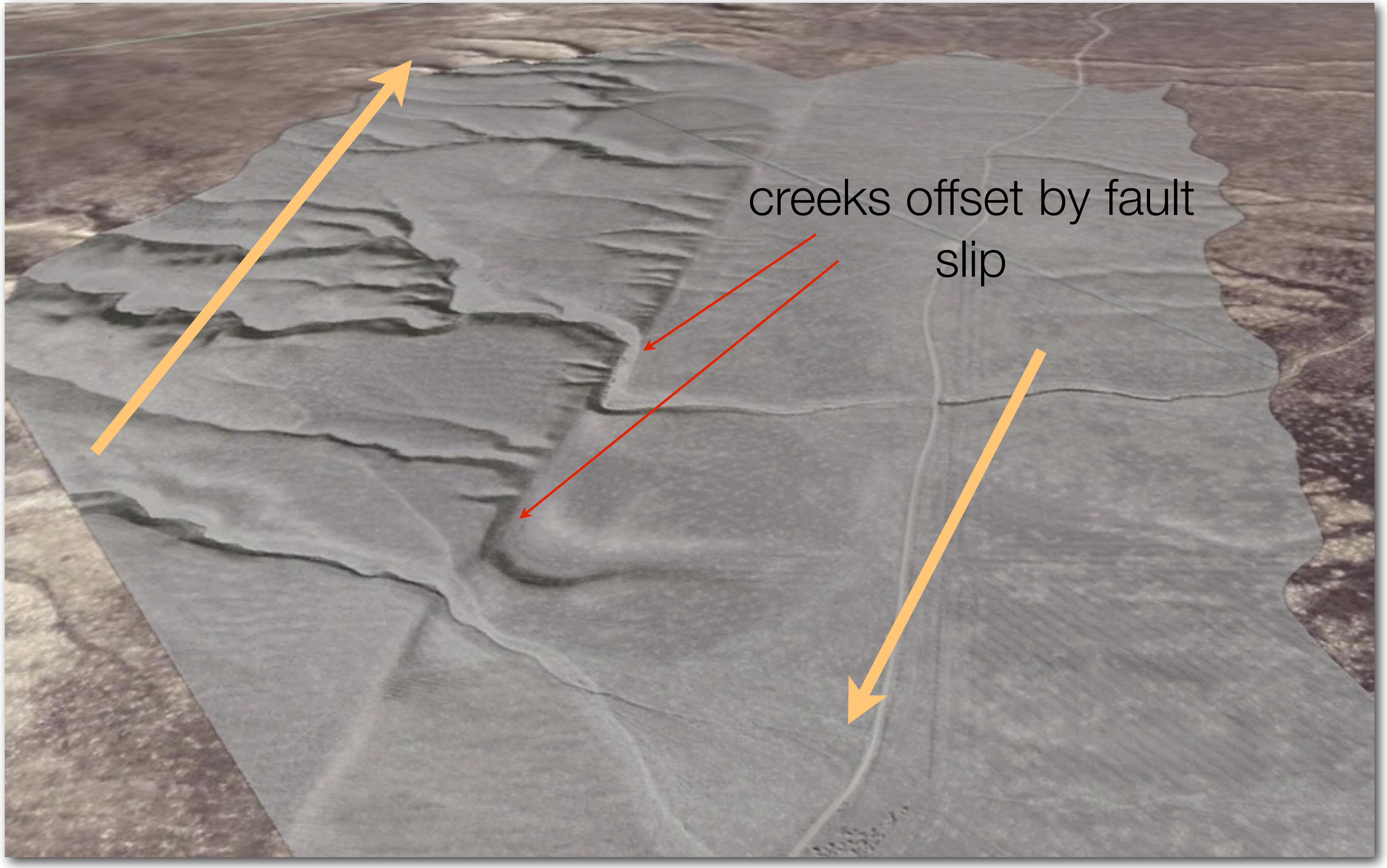
http://uanews.org/system/files/images/LowAngleNormalFault_GabrieleCasale.preview.jpg

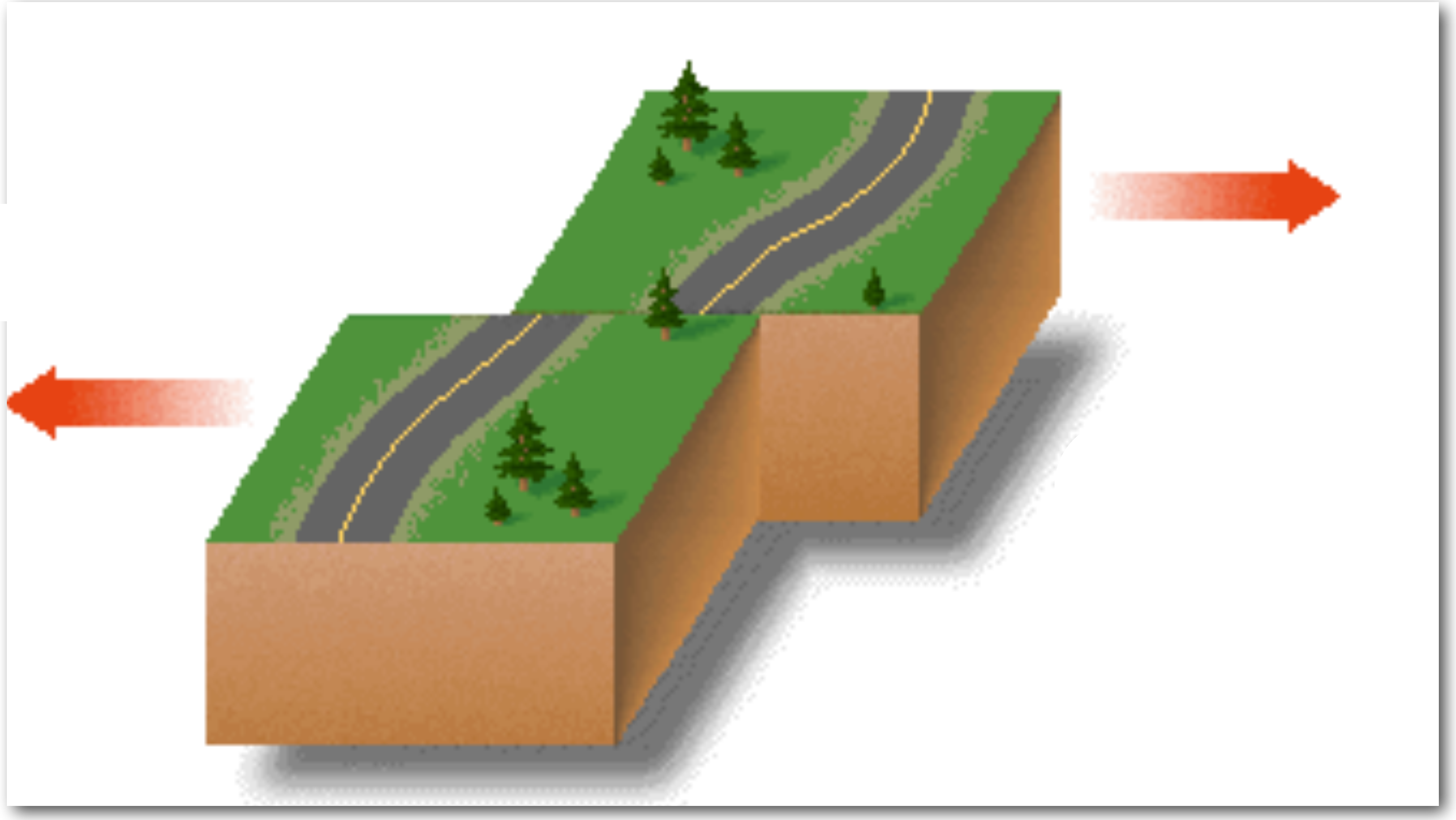
Causes of Earthquakes

Three main types of 'faults' or fracture zones in the Earth's crust:

(a) when crustal rocks are stretched

(b) when they slide past each other

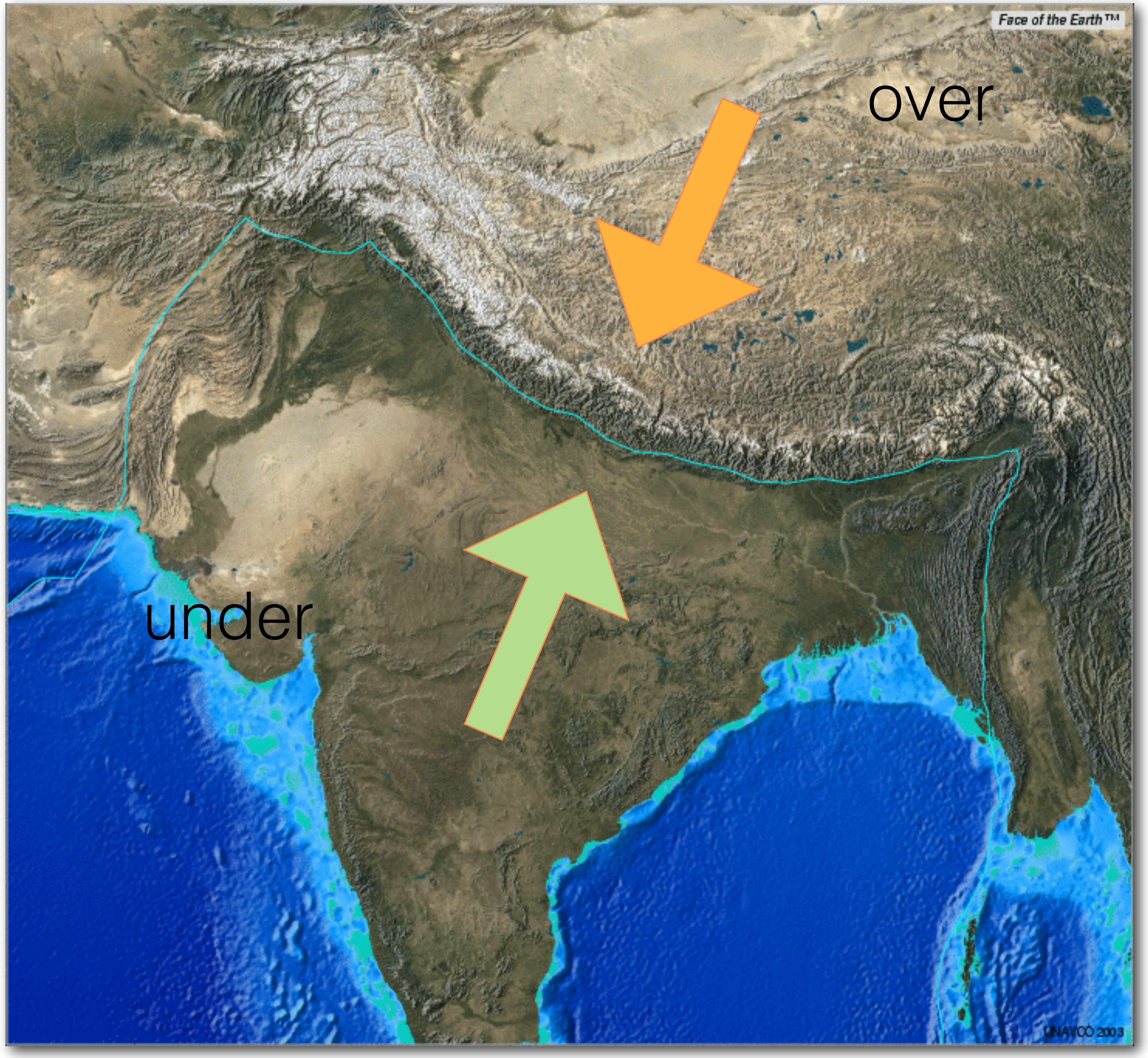


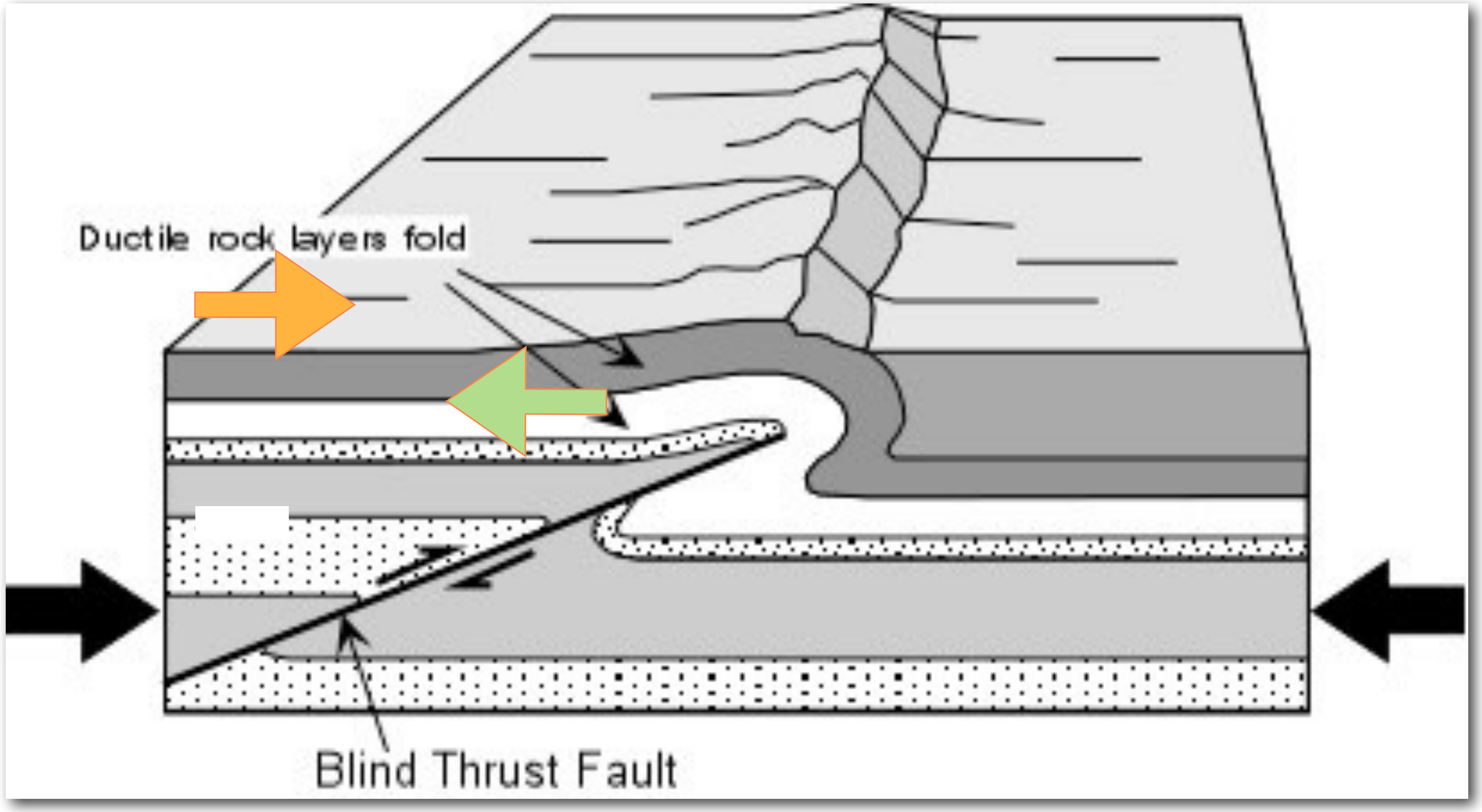


http://www.scec.org/education/public/roots/pictures/strslipv.gif

e.g., San Andreas fault zone
(aerial view looking S along fault)

Three main types of ‘faults’ or fracture zones in the Earth’s crust:
(a) when crustal rocks are stretched
(b) when they slide past each other
(c) when they slide over each other





http://earthsci.org/processes/struct/equake1/blindyhrust.jpg

e.g., Alps-Zagros-Himalayan mountains

Natural Hazards and Disaster

Class 4: Geohazards; Earthquakes

- Location
- Causes
- Magnitude
- Ground shaking
- Recurrence intervals
- Hazard maps

http://earthquake.usgs.gov/eqcenter/recenteqsus/Maps/US10/32.42.-125.-115.php

Magnitude of Earthquakes

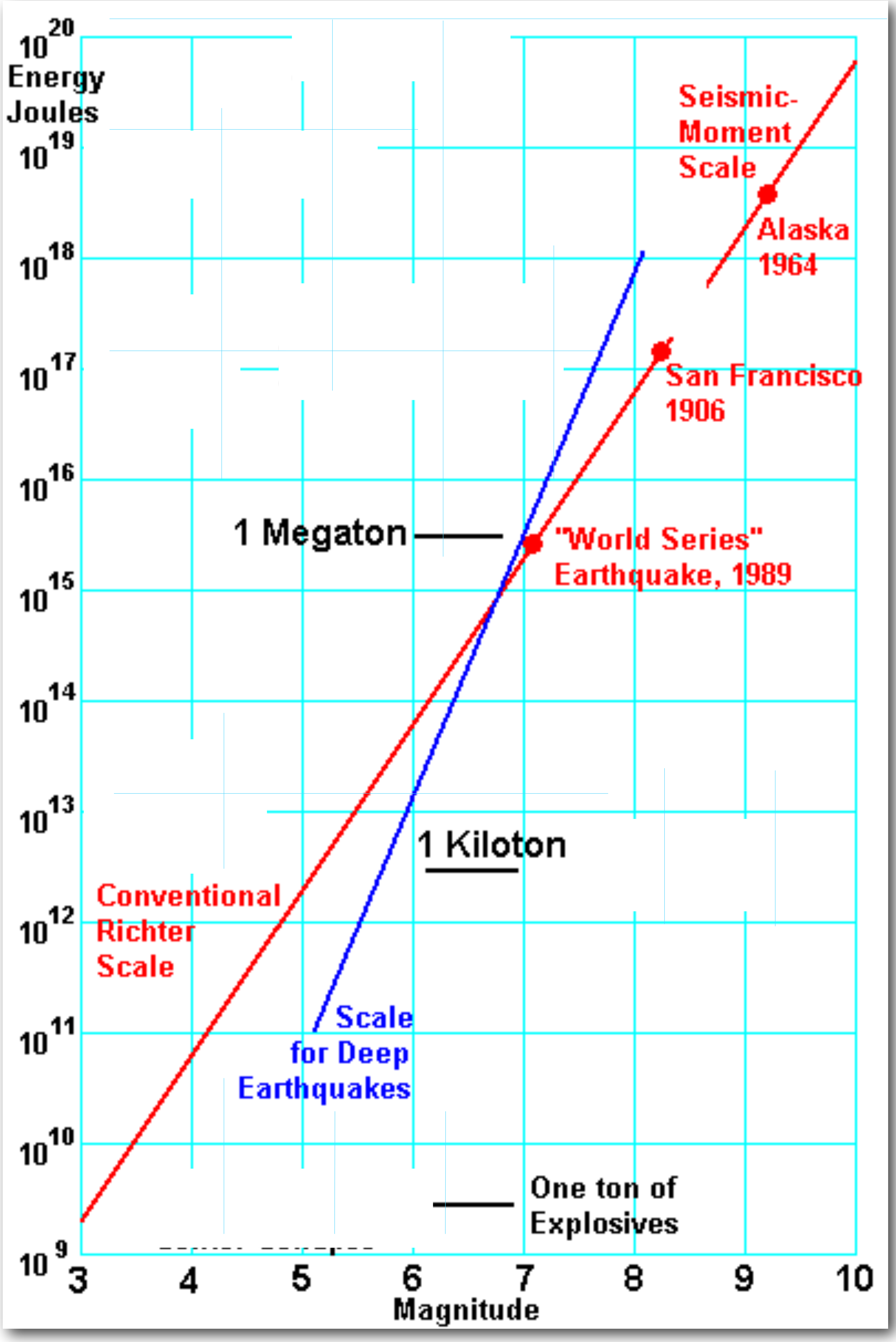
Magnitude:
a number that characterizes the relative size of an earthquake. based on measurement of the maximum motion recorded by a seismograph.

Several scales; most commonly used are:
(1) local magnitude (M_L), commonly referred to as "Richter magnitude",
(2) surface-wave magnitude (M_s),
(3) body-wave magnitude (M_b), and
(4) moment magnitude (M_w).

Scales 1-3 have limited range and applicability and do not satisfactorily measure the size of the largest earthquakes.

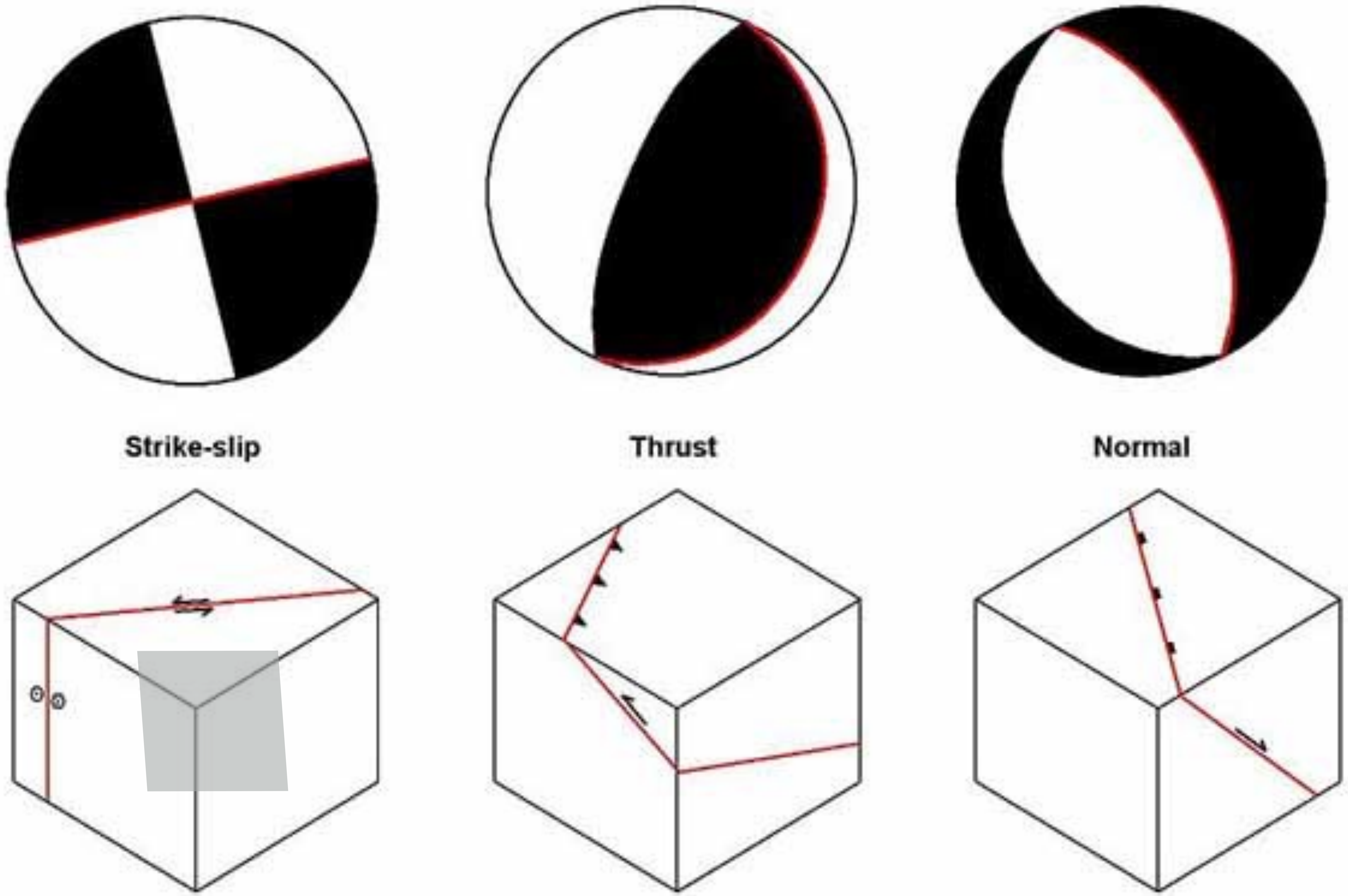
Earthquake Moment Magnitude, M_W

- is uniformly applicable to all sizes of earthquakes but is more difficult to compute than the other types
- based on the concept of
  seismic moment = area x displacement of fault rupture
- measured on a logarithmic scale
- measures total amount of energy released (w = 'work')



http://www.uwgb.edu/DutchS/Graphics-Geol/SEISMOL/MagScale0.gif

Magnitude of Earthquakes



Types of ‘beachball plot’ associated with different fault end-members
(nodal plane in red parallel to fault)

Magnitude of Earthquakes

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a number that characterizes the relative size of an earthquake. based on measurement of the maximum motion recorded by a seismograph.

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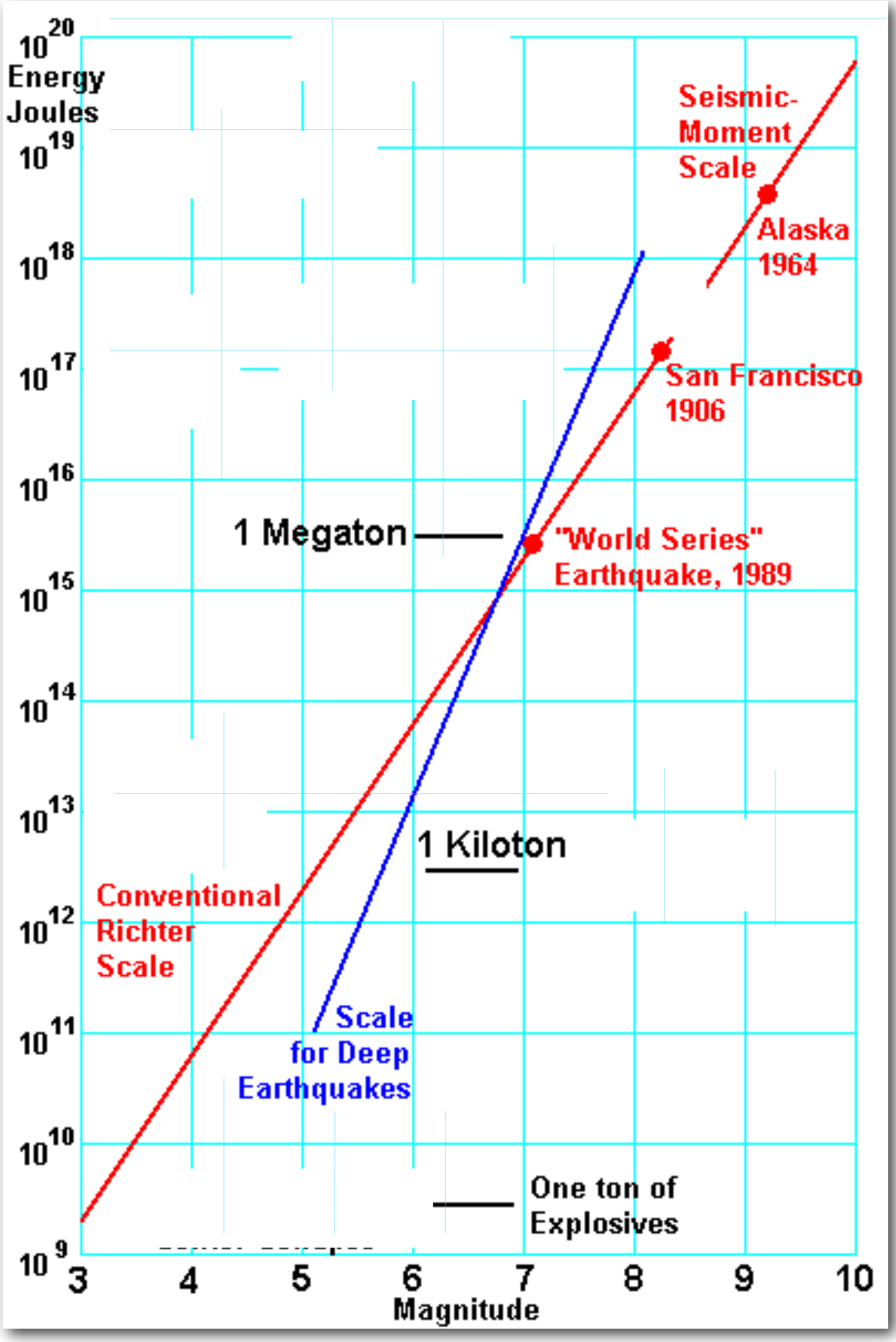
(4) moment magnitude (M_w).

Scales 1-3 have limited range and applicability and do not satisfactorily measure the size of the largest earthquakes.

The moment magnitude M_w is a dimensionless value defined by Kanamori (1977) as

$$M_w = \frac{2}{3}\log_{10}(M_0) - 10.7,$$

where M_0 is the seismic moment in dyne·cm (10^{-7} N·m). The constant values in the equation are chosen to achieve consistency with the magnitude values produced by earlier scales.



http://www.uwgb.edu/DutchS/Graphics-Geol/SEISMOL/MagScale0.gif

Kanamori, H., 1977, The energy release of great earthquakes, *J Geophys Res*, **82,** 2981–2987.

Magnitude of Earthquakes

MAGNITUDE M_W	IMPACT	FREQUENCY
2.5 or less	Usually not felt; recorded by seismographs	900,000 per year
2.5 to 5.4	Often felt; minor damage	10,000 per year
5.5 to 6.0	Slight structural damage	500 per year
6.1 to 6.9	Significant structural damage	100 per year
7.0 to 7.9	Major earthquake; serious damage	20 per year
8.0 or greater	Great earthquake; extremely destructive	0.2 per year

http://geoinfo.nmt.edu/publications/periodicals/litegeology/images/dogquake_small.gif

Note: Impact depends strongly on the depth of the earthquake, also the mechanism.

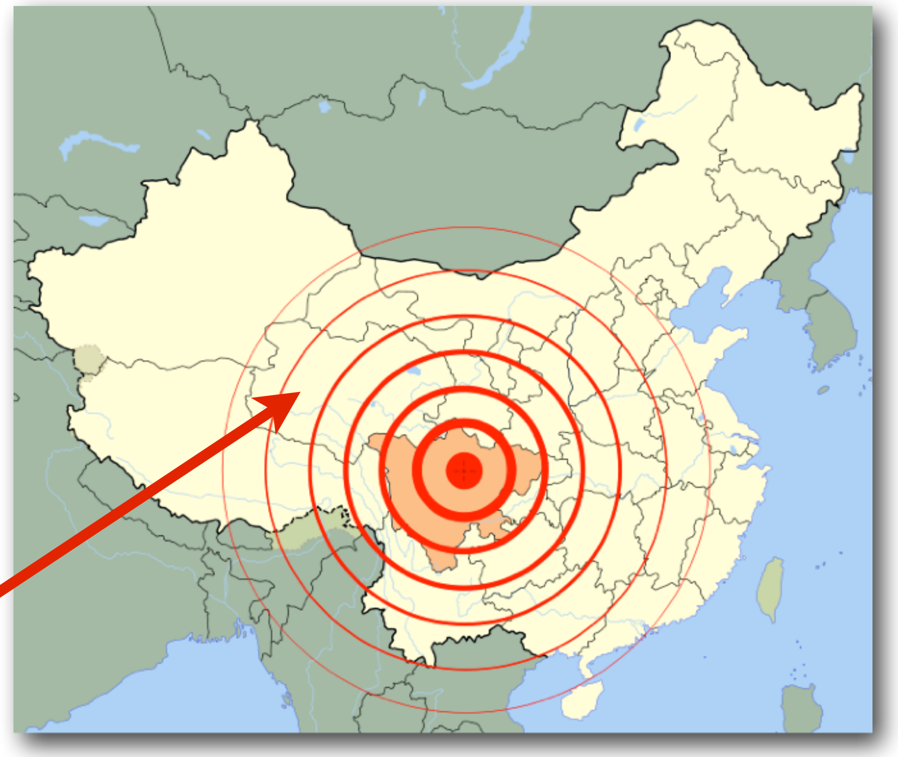
20 largest earthquakes recorded

	Mag	Location	Date (UTC)	Time (UTC)	Latitude	Longitude
1.	9.5	ChileValdivia Earthquake	1960-05-22	19:11	38.14°S	73.41°W
2.	9.2	Great Alaska Earthquake	1964-03-28	03:36	60.91°N	147.34°W
3.	9.1	Sumatra-Andaman Islands Earthquake	2004-12-26	00:58	3.30°N	95.98°E
4.	9.1	Tohoku Earthquake	2011-03-11	05:46	38.30°N	142.37°E
5.	9.0	Kamchatka, Russia	1952-11-04	16:58	52.62°N	159.78°E
6.	8.8	ChileMaule Earthquake	2010-02-27	06:34	36.12°S	72.90°W
7.	8.8	1906 Ecuador–Colombia Earthquake	1906-01-31	15:36	0.96°N	79.37°W
8.	8.7	Rat Islands Earthquake	1965-02-04	05:01	51.25°N	178.72°E
9.	8.6	Assam, Tibet	1950-08-15	14:09	28.36°N	96.45°E
10.	8.6	off West Coast of Northern Sumatra	2012-04-11	08:39	2.33°N	93.06°E
11.	8.6	Indonesia Nias Earthquake	2005-03-28	16:10	2.09°N	97.11°E
12.	8.6	Andreanof Islands, Alaska	1957-03-09	14:23	51.50°N	175.63°W
13.	8.6	Unimak Island Earthquake, Alaska	1946-04-01	12:29	53.49°N	162.83°W
14.	8.5	Banda Sea	1938-02-01	19:04	5.05°S	131.61°E
15.	8.5	Atacama, Chile	1922-11-11	04:33	28.29°S	69.85°W
16.	8.5	Kuril Islands	1963-10-13	05:18	44.87°N	149.48°E
17.	8.4	Kamchatka, Russia	1923-02-03	16:02	54.49°N	160.47°E
18.	8.4	Southern Sumatra, Indonesia	2007-09-12	11:10	4.44°S	101.37°E
19.	8.4	Peru Earthquake	2001-06-23	20:33	16.27°S	73.64°W
20.	8.4	JapanSanriku Japan	1933-03-02	17:31	39.21°N	144.59°E

Magnitude of Earthquakes

Some important earthquakes in recent years

Tangshan, China 1976	M_W 7.8	240,000 killed
Sumatra, 2004	M_W 9.1	>250,000 killed *
Haiti, 2010	M_W 7.0	>80,000 killed
Sichuan, China 2008	M_W 7.9	>69,000 killed
Manjil, Iran 1990	M_W 7.7	>40,000 killed
Japan, 2011	M_W 9.0	>16,000 killed *
Bam, Iran 2003	M_W 6.5	>15,000 killed
Kobe, Japan 1995	M_W 6.9	5,500 killed
Northridge, CA 1994	M_W 6.7	72 killed



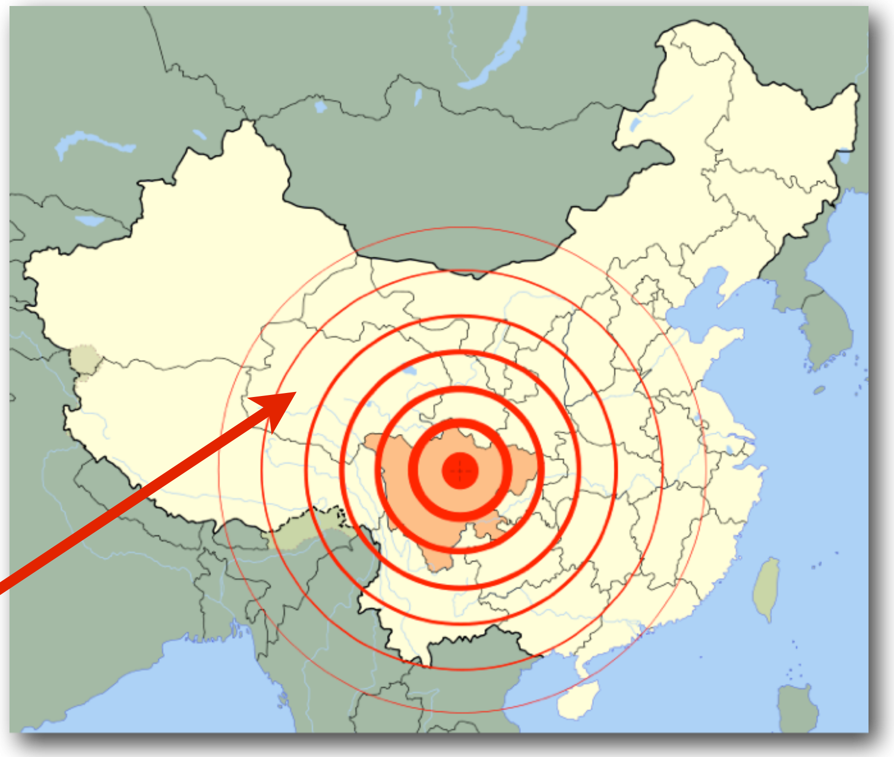
http://noeljenkins.files.wordpress.com/2007/01/bam_ir2726.JPG

http://www.iranmap.com/images/cities/bamafter.jpg

Magnitude of Earthquakes

Some important earthquakes in recent years

Tangshan, China 1976	M_W 7.8	240,000 killed	
Sumatra, 2004	M_W 9.1	>250,000 killed	*
Haiti, 2010	M_W 7.0	>80,000 killed	
Sichuan, China 2008	M_W 7.9	>69,000 killed	
Manjil, Iran 1990	M_W 7.7	>40,000 killed	
Japan, 2011	M_W 9.0	>16,000 killed	*
Bam, Iran 2003	M_W 6.5	>15,000 killed	
Kobe, Japan 1995	M_W 6.9	5,500 killed	
Northridge, CA 1994	M_W 6.7	72 killed	



http://noeljenkins.files.wordpress.com/2007/01/bam_ir2726.JPG

Why the big range in casualties?

http://www.iranmap.com/images/cities/bamafter.jpg

Magnitude of Earthquakes

Intensity:

- A number describing the severity of an earthquake in terms of its effects on the earth's surface and on humans and their structures.
- Several scales exist, but the ones most commonly used in the United States are
  1. Modified Mercalli scale and the
  2. Rossi-Forel scale.
- Intensity for a specific earthquake depends on location, unlike the magnitude, which is one number for each earthquake.

The Mercalli **intensity** scale is a seismic scale used for measuring the **intensity** of an **earthquake**. It measures the effects of an **earthquake.**

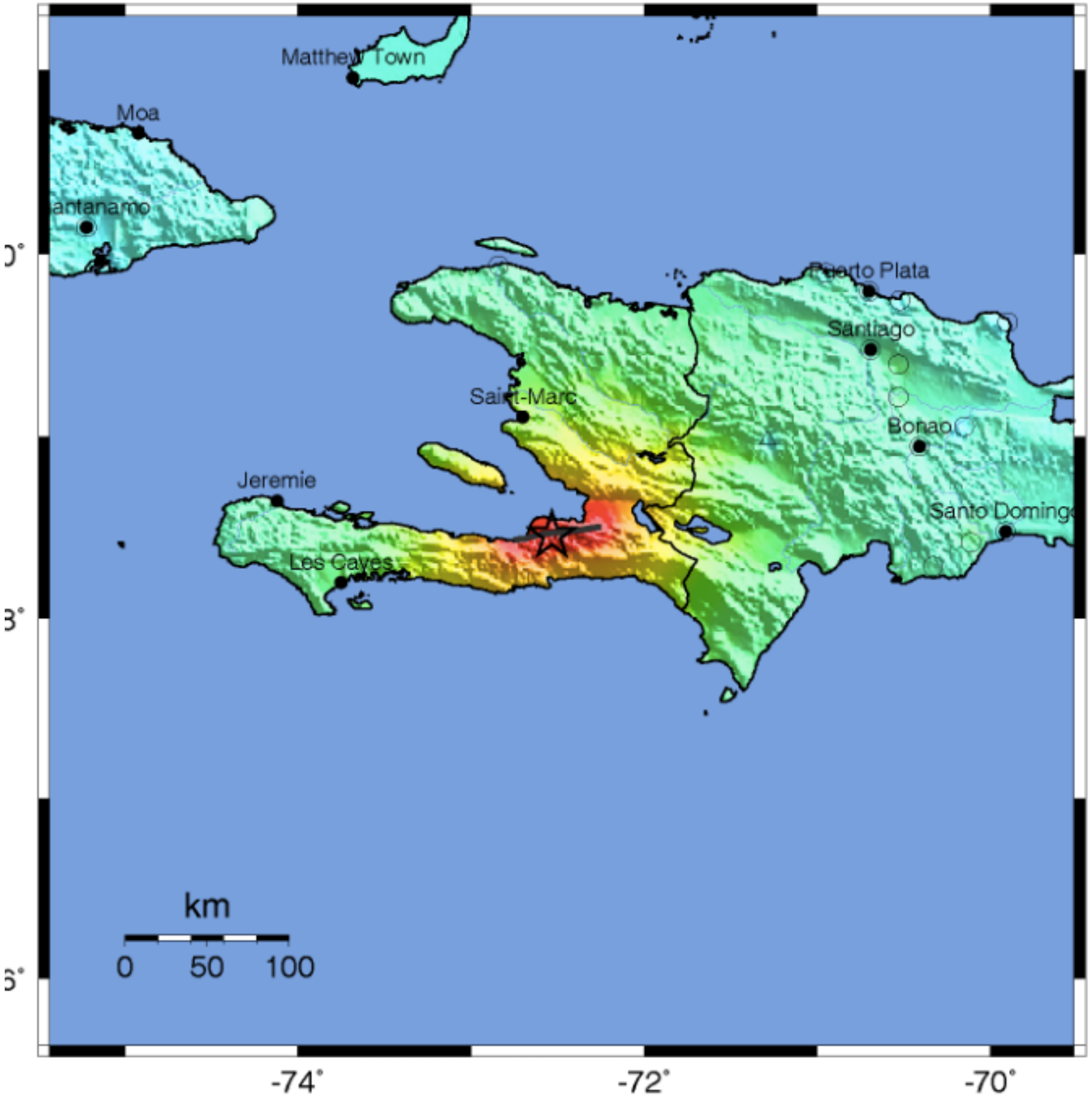
I. Not felt	Not felt except by very few under especially favorable conditions.
II. Weak	Felt only by a few people at rest, especially on upper floors of buildings.
III. Weak	Felt quite noticeably by people indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV. Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V. Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI. Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII. Very strong	Damage negligible in buildings 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.
VIII. Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX. Violent	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. Liquefaction.
X. Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
XI. Extreme	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII. Extreme	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Magnitude of Earthquakes

12 January 2010, Mw = 7.0, Depth: 13 km

USGS ShakeMap : HAITI REGION

Tue Jan 12, 2010 21:53:10 GMT M 7.0 N18.46 W72.53 Depth: 13.0km ID:2010rja6



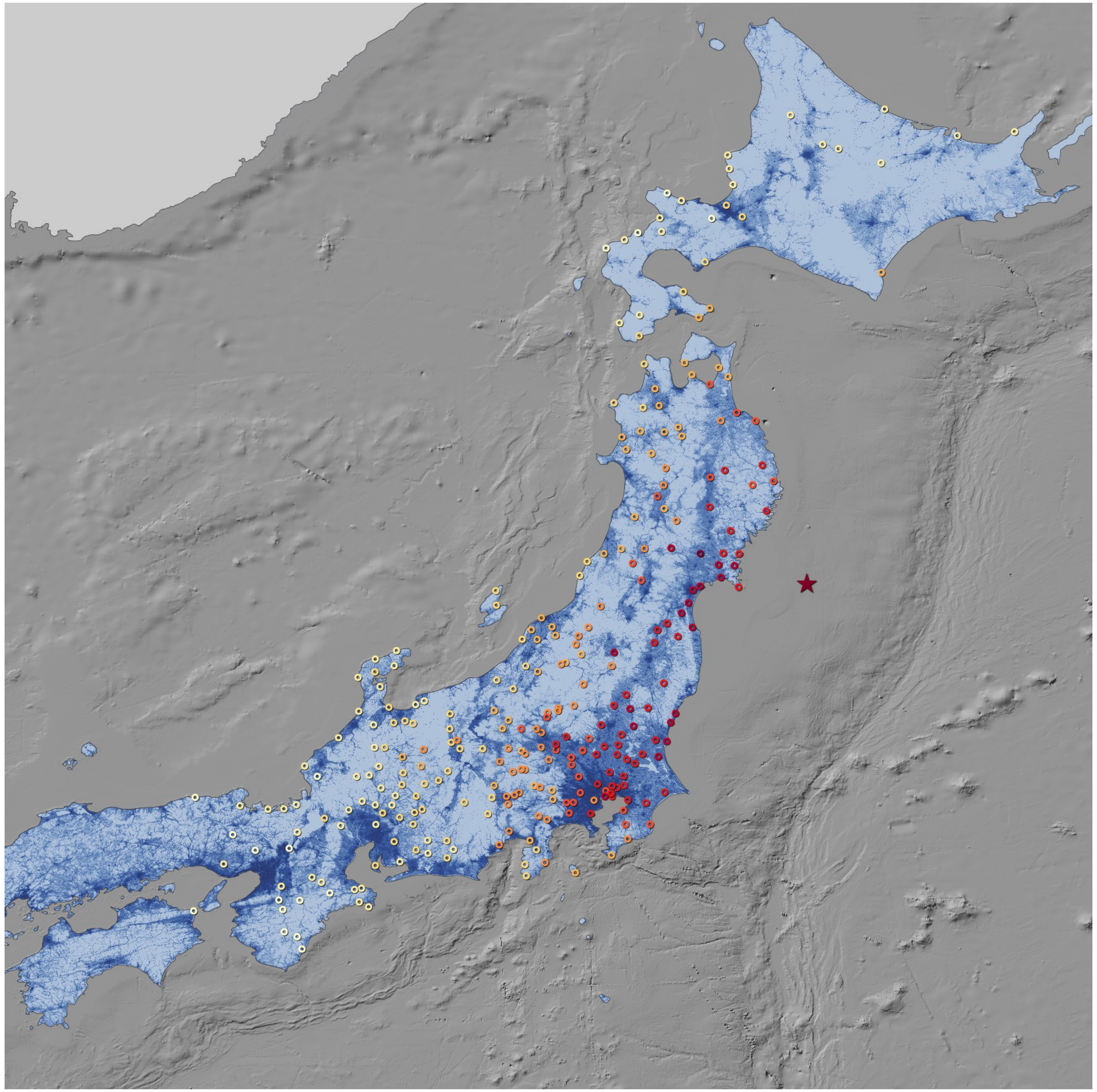
Map Version 7 Processed Wed Jan 13, 2010 06:53:11 PM MST -- NOT REVIEWED BY HUMAN

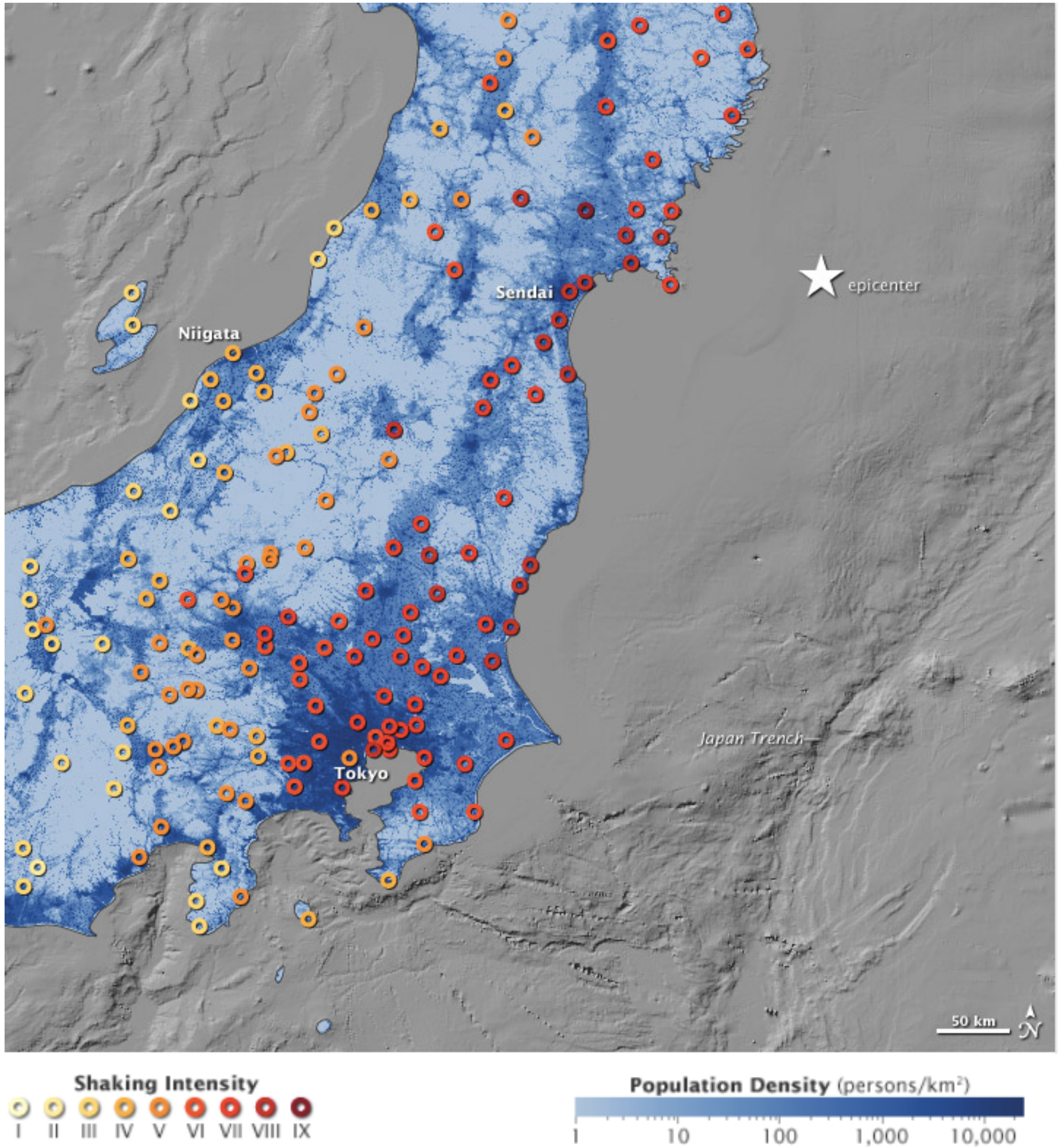
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Map Version 7 Processed Wed Jan 13, 2010 06:53:11 PM MST -- NOT REVIEWED BY HUMAN

Magnitude of Earthquakes

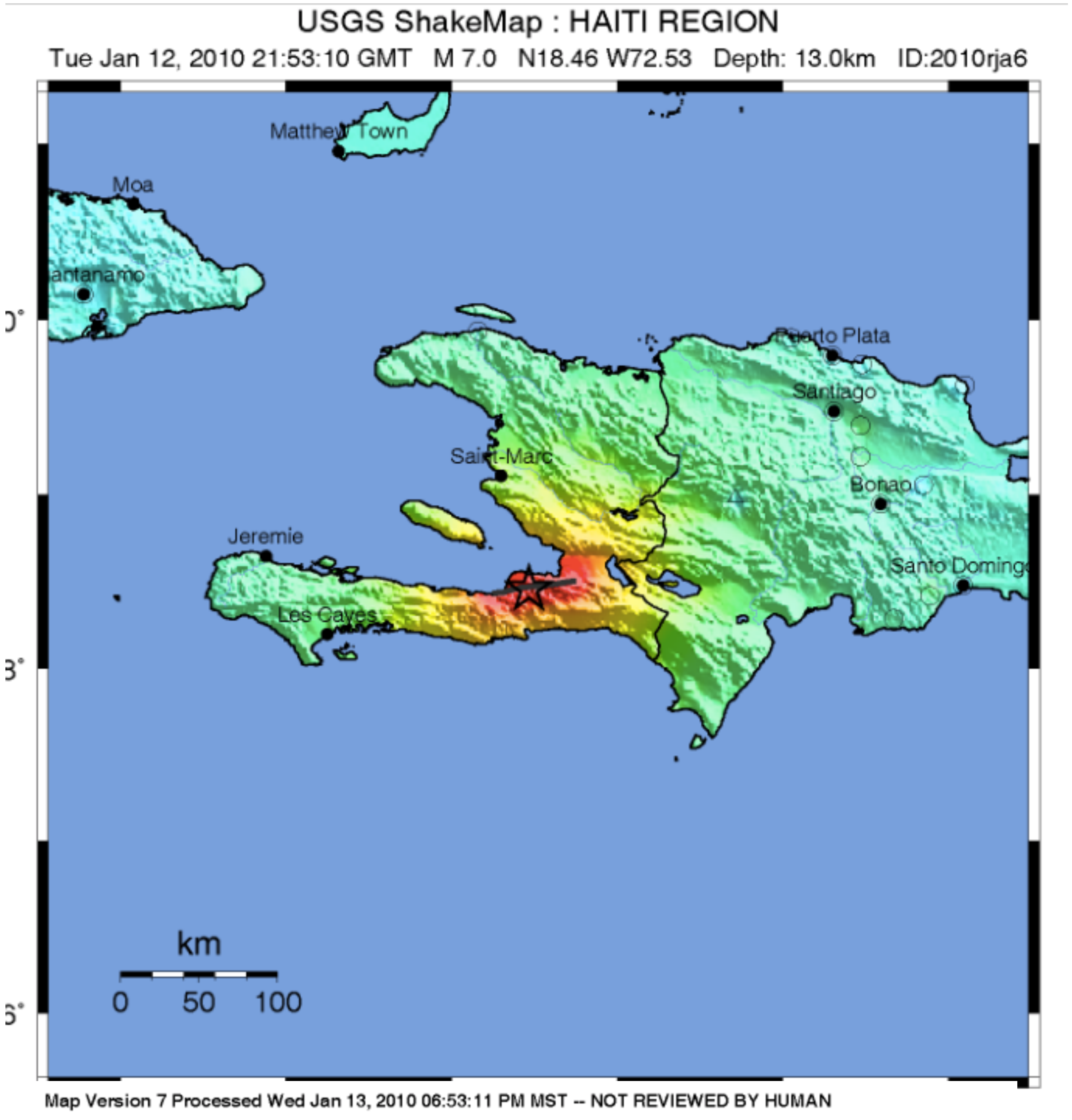
11 March 2011, Mw = 9.0-9.1, Depth: 29 km





Magnitude of Earthquakes

12 January 2010, Mw = 7.0, Depth: 13 km



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

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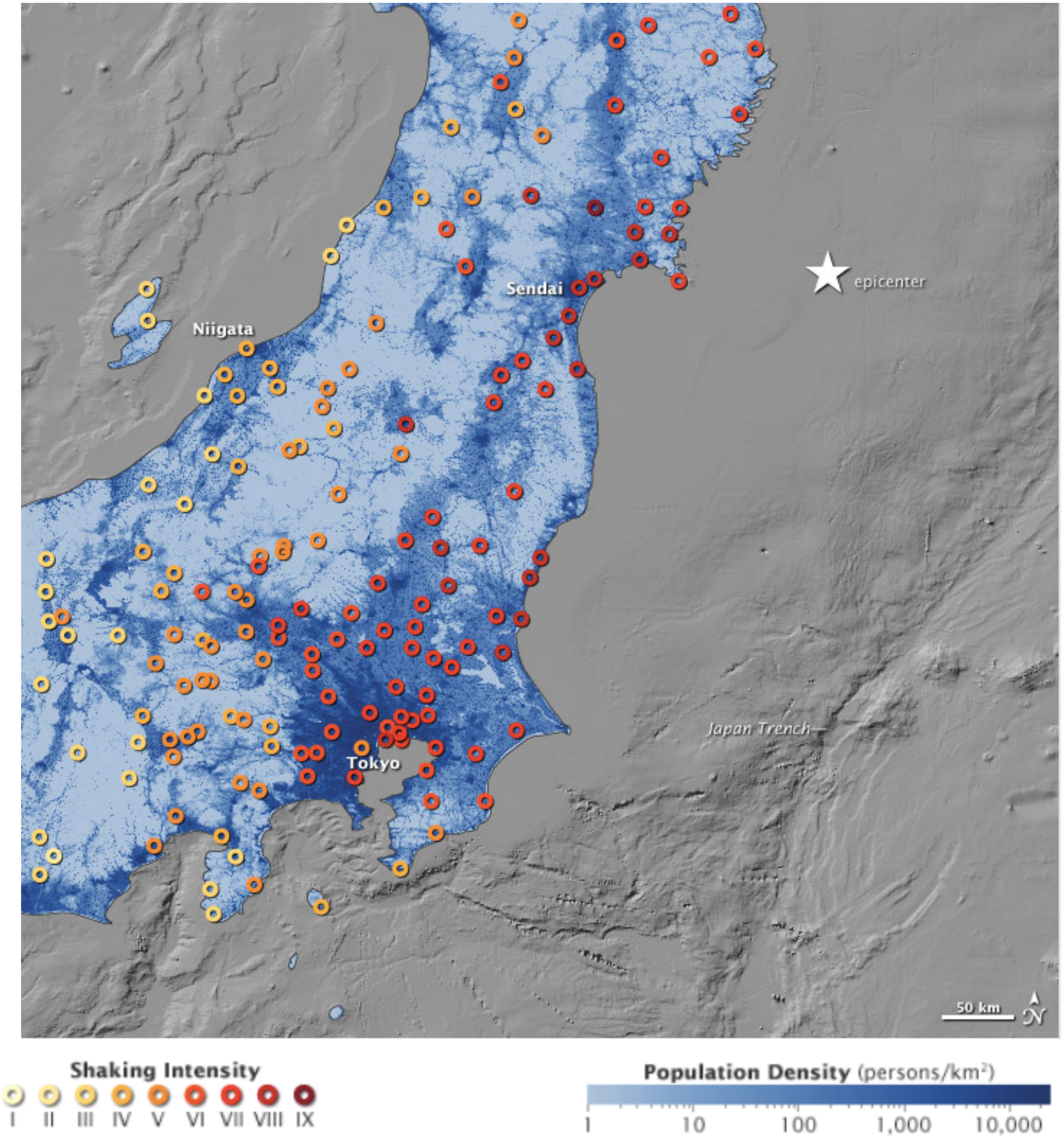


Natural Hazards and Disaster

Class 4: Geohazards; Earthquakes

- Location
- Causes
- Magnitude
- Ground shaking
- Recurrence intervals
- Hazard maps

http://earthquake.usgs.gov/eqcenter/recenteqsus/Maps/US10/32.42.-125.-115.php

Ground Shaking

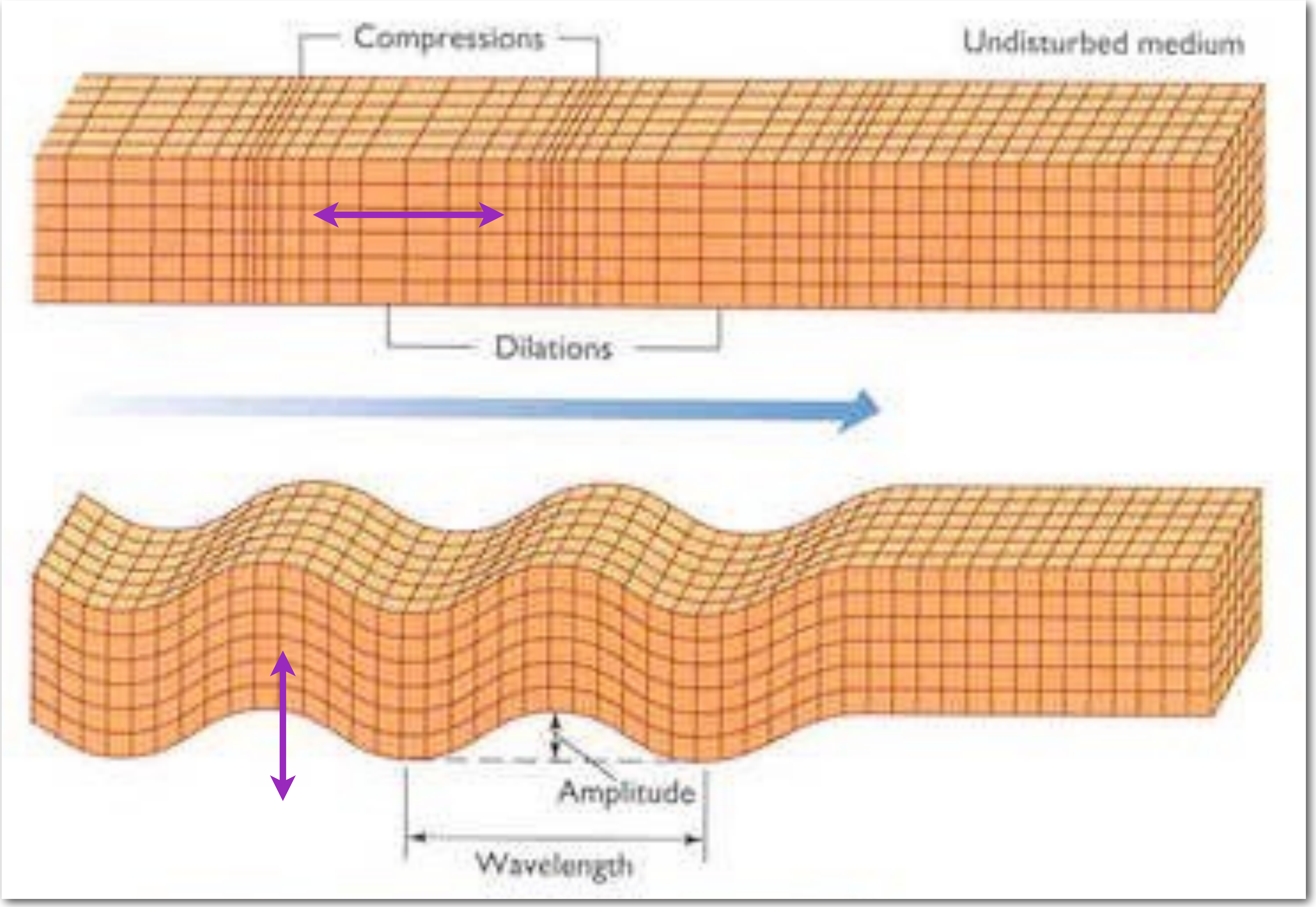
Earthquake energy (seismic energy) is released as a wave through the rock

Two components to the wave:

Compressional, P wave

Shear, S wave

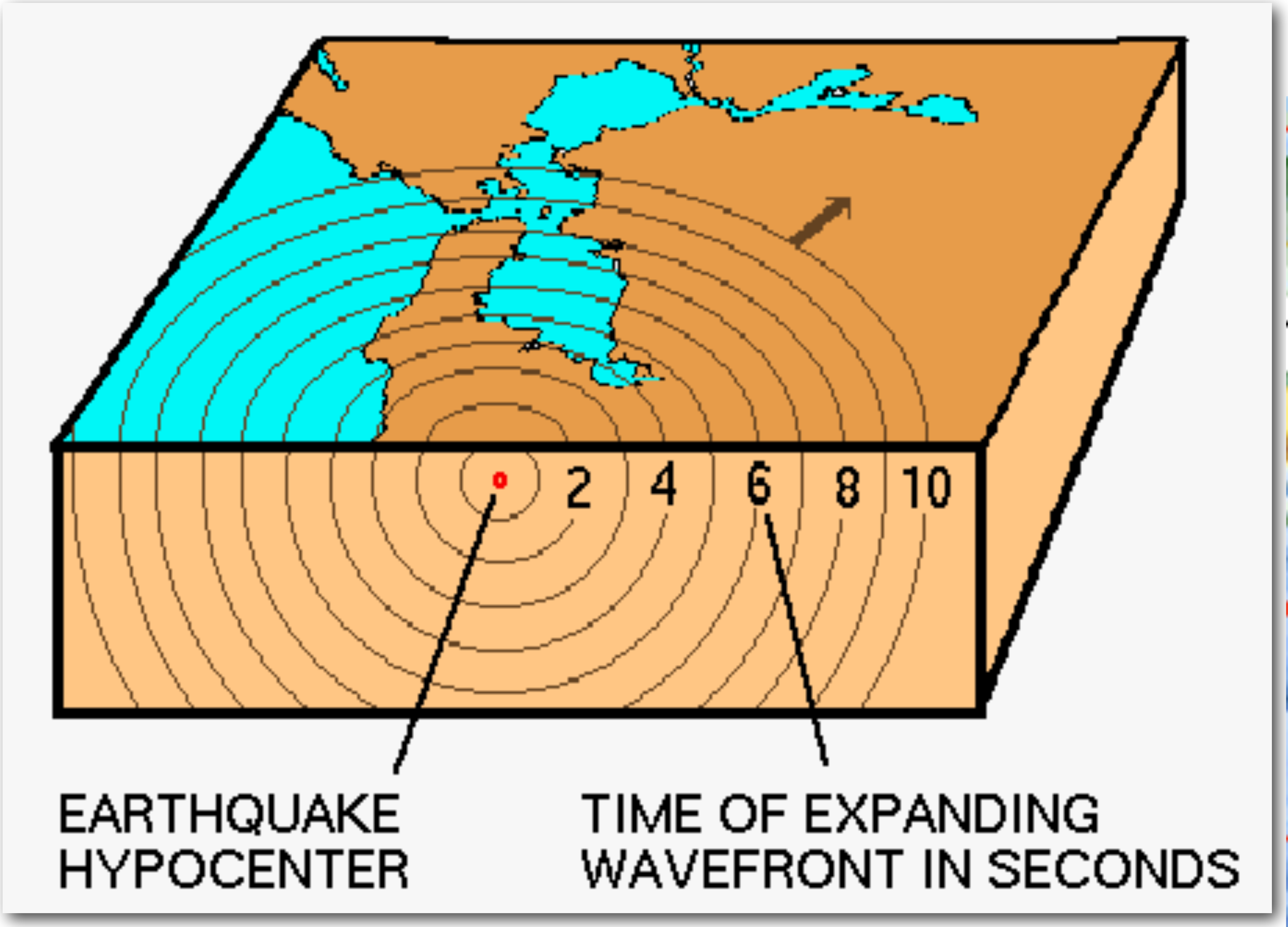
P waves and S waves have different velocities



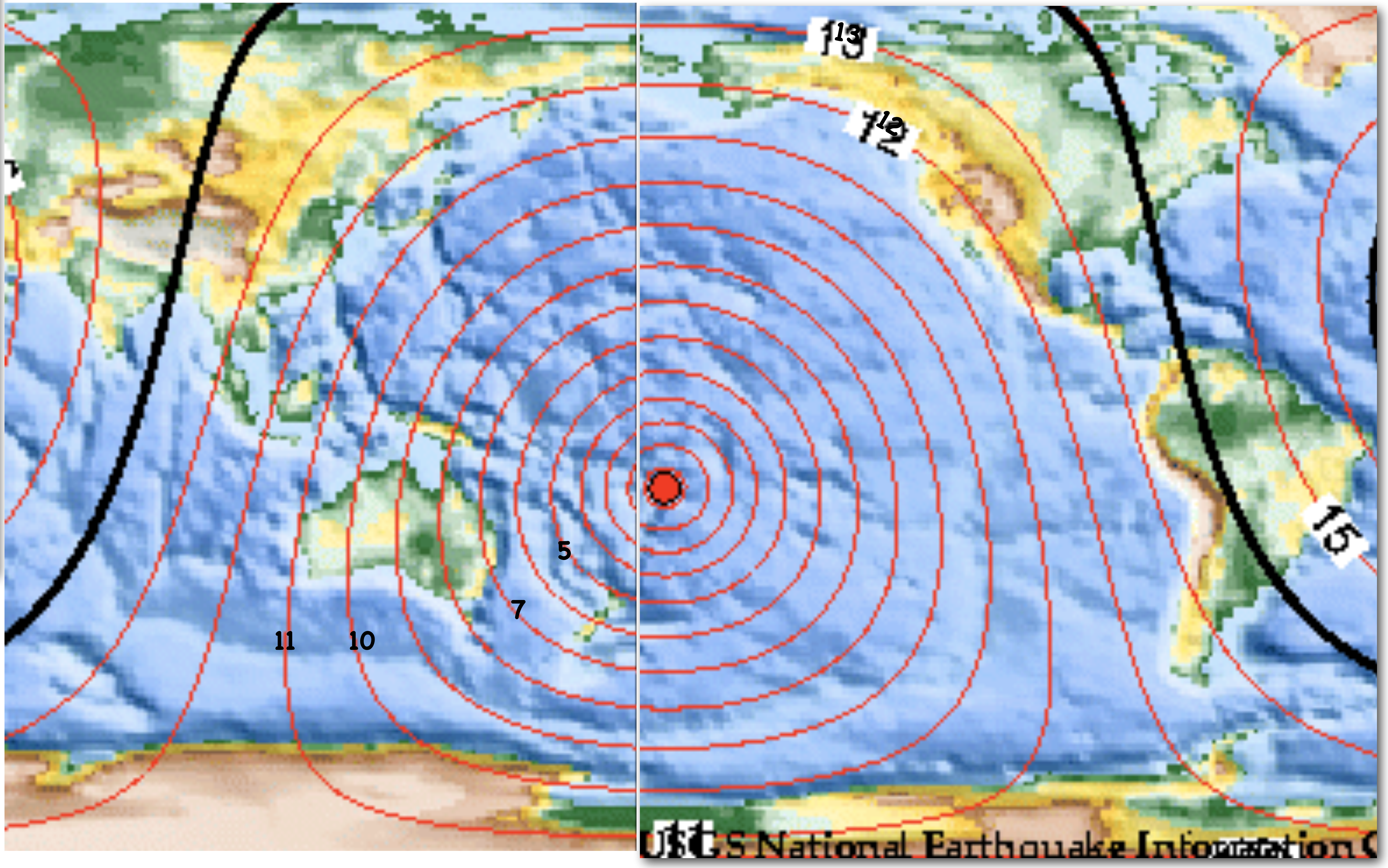
http://earthquake.usgs.gov/learning/faq/images/psdiag.jpg

Ground Shaking

Seismic energy wavefront expands rapidly outward in all directions



http://earthquake.usgs.gov/learning/faq/images/blockwave.gif

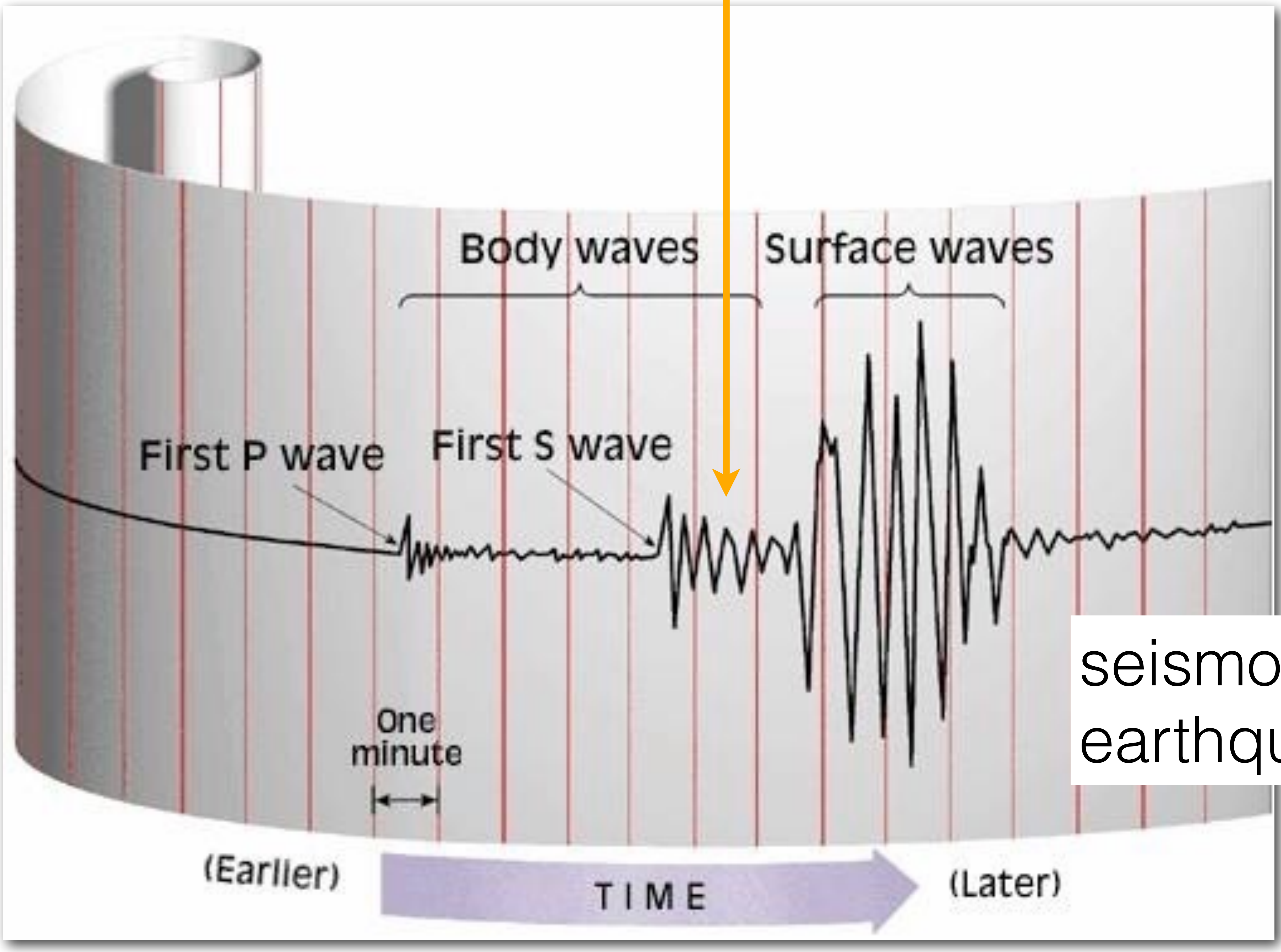


P wave travel times (in minutes) for Samoa earthquake of 09/29/09

Ground Shaking

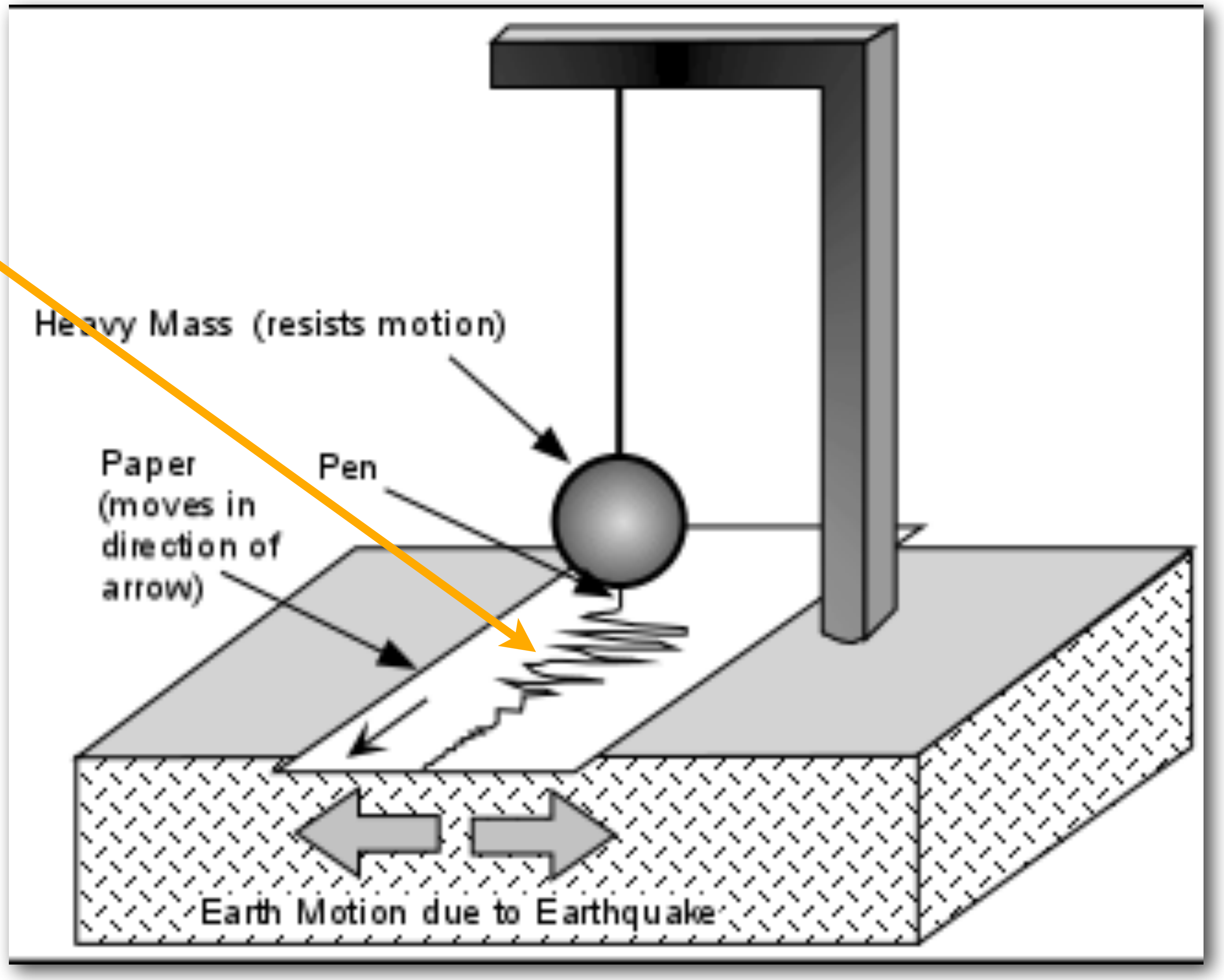
Seismograms (drawings made by seismometers)

Record arrival of P and S waves



http://www.showme.net/~fkeller/quake/images2/pwave2.jpg

seismogram of a distant earthquake



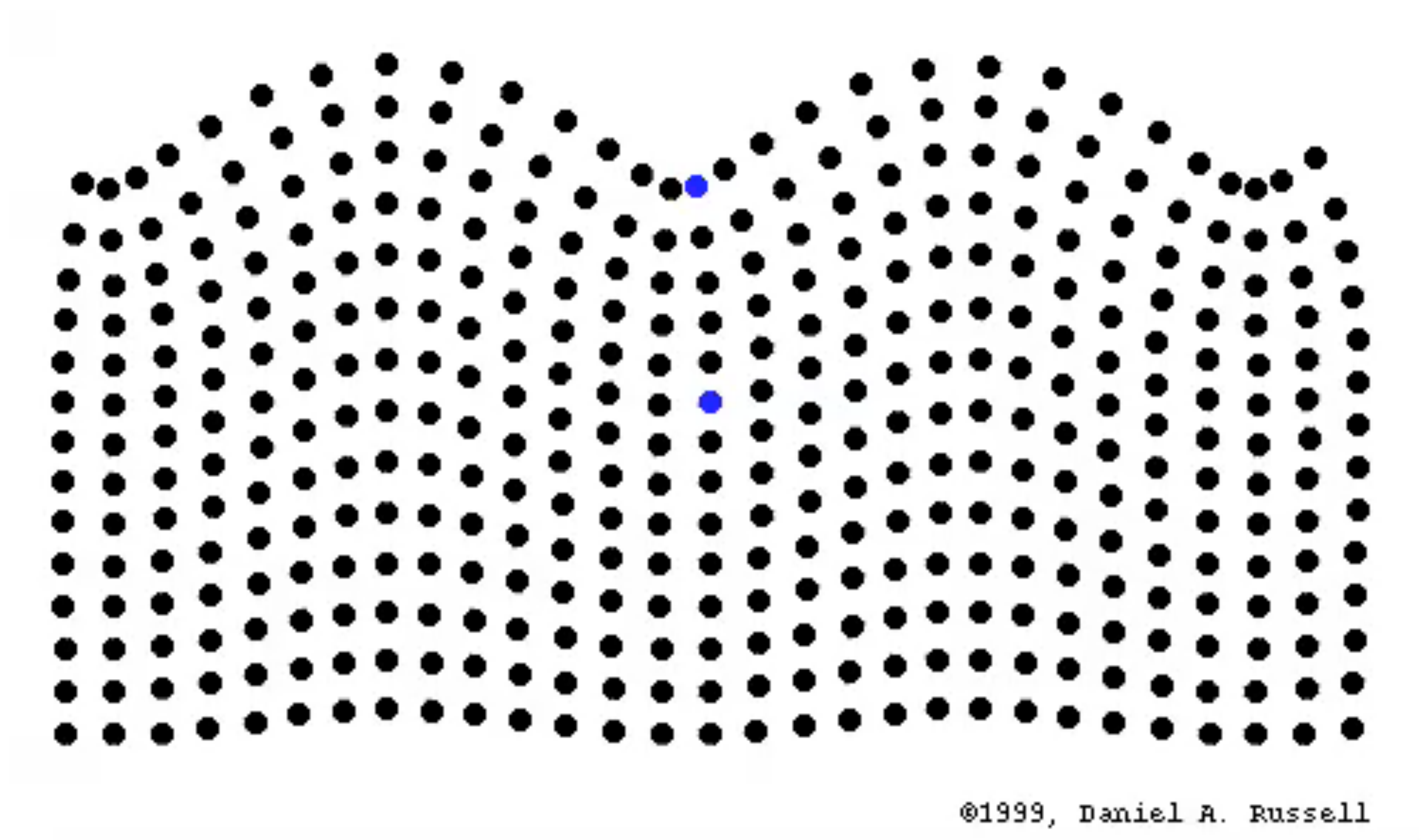
http://www.tulane.edu/~sanelson/images/seismograph.gif

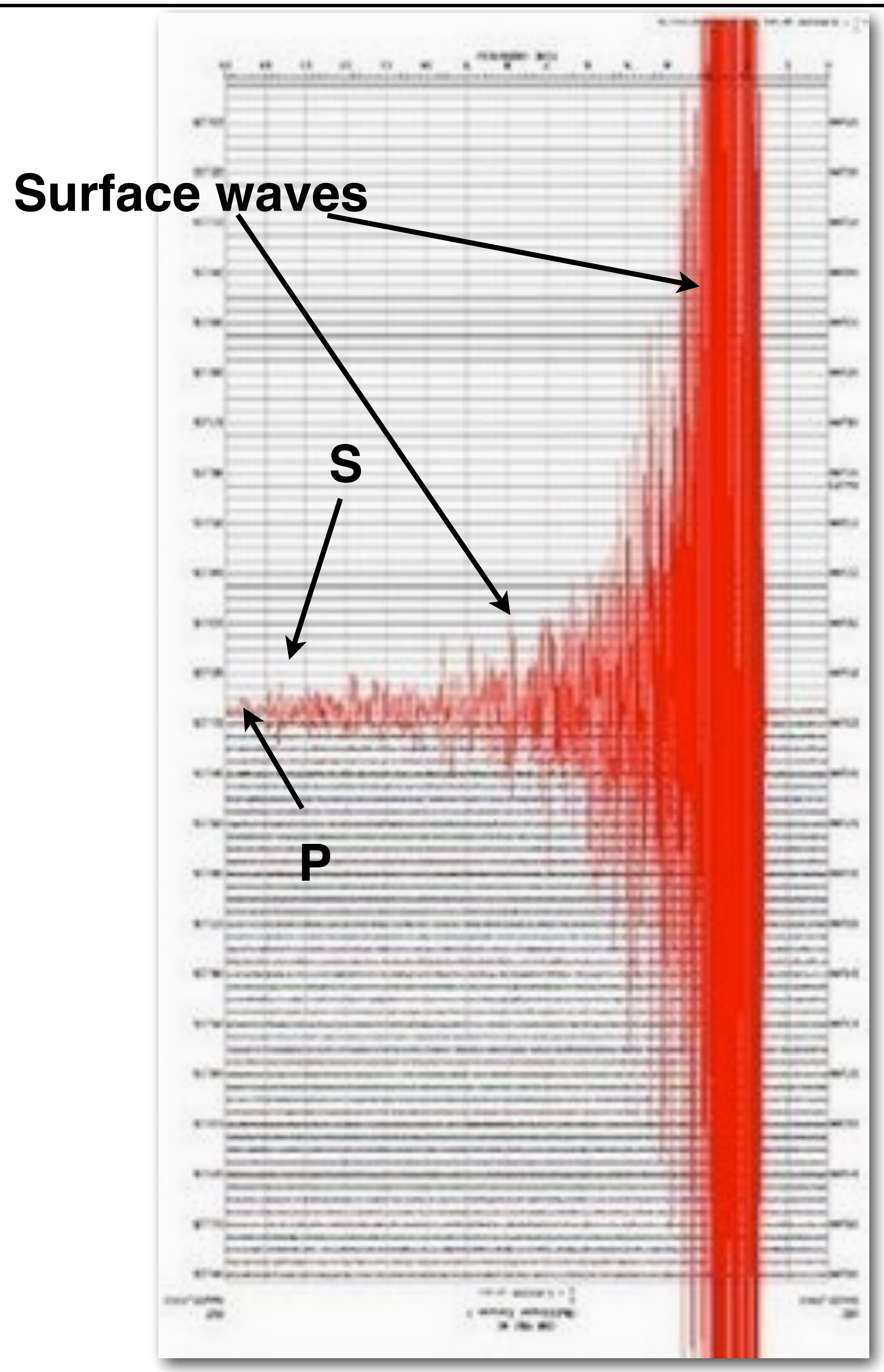
P waves travel fastest, arrive first!

Magnitude of Earthquakes

It's the Surface Waves that cause ground shaking and do the most damage!

seismograph for Samoa earthquake
09/29/09





http://news.yahoo.com/nphotos/Samoa-seismograph/photo//090929/photos_wl_pc_afp/e4b3a34480d36b1fb185a36b299d6d13//s:/afp/20090929/wl_asia_afp/samoaquake

Magnitude of Earthquakes

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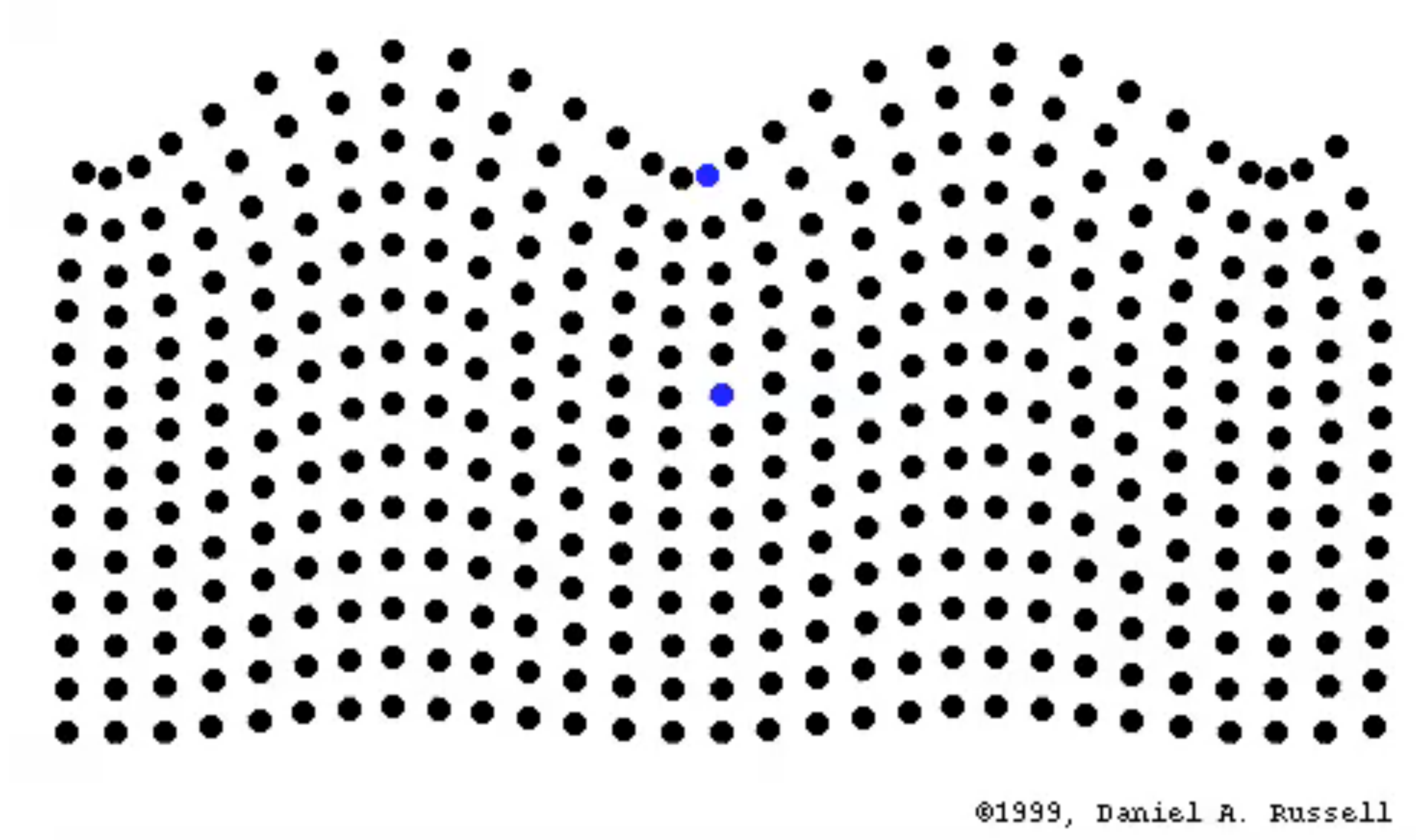
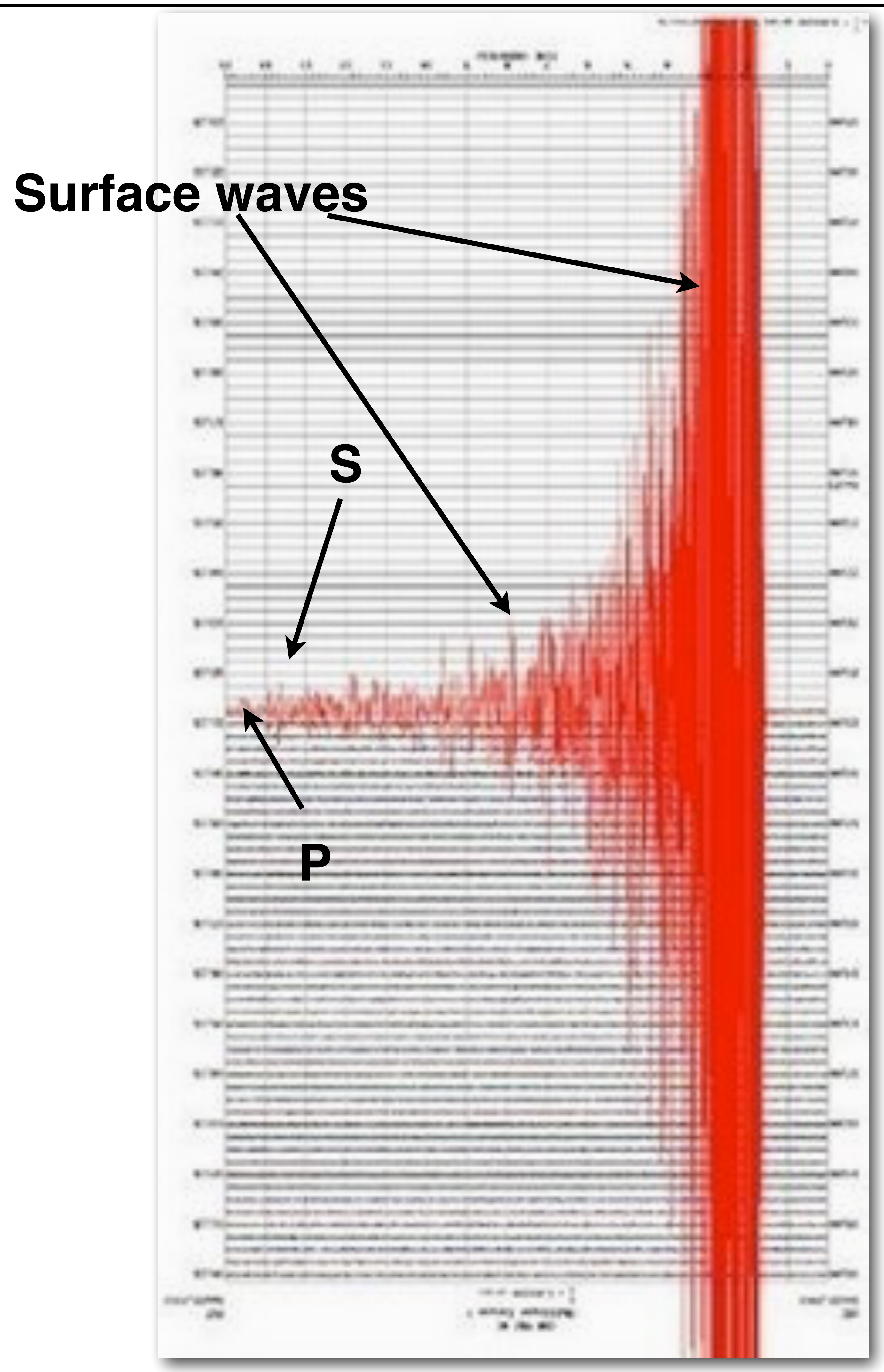




http://news.yahoo.com/nphotos/Samoa-seismograph/photo//090929/photos_wl_pc_afp/e4b3a34480d36b1fb185a36b299d6d13//s:/afp/20090929/wl_asia_afp/samoaquake

Natural Hazards and Disaster

MITIGATION & ADAPTATION RESEARCH INSTITUTE
MARI
OLD DOMINION UNIVERSITY

Class 4: Geohazards; Earthquakes

- Location
- Causes
- Magnitude
- Ground shaking
- Recurrence intervals
- Hazard maps

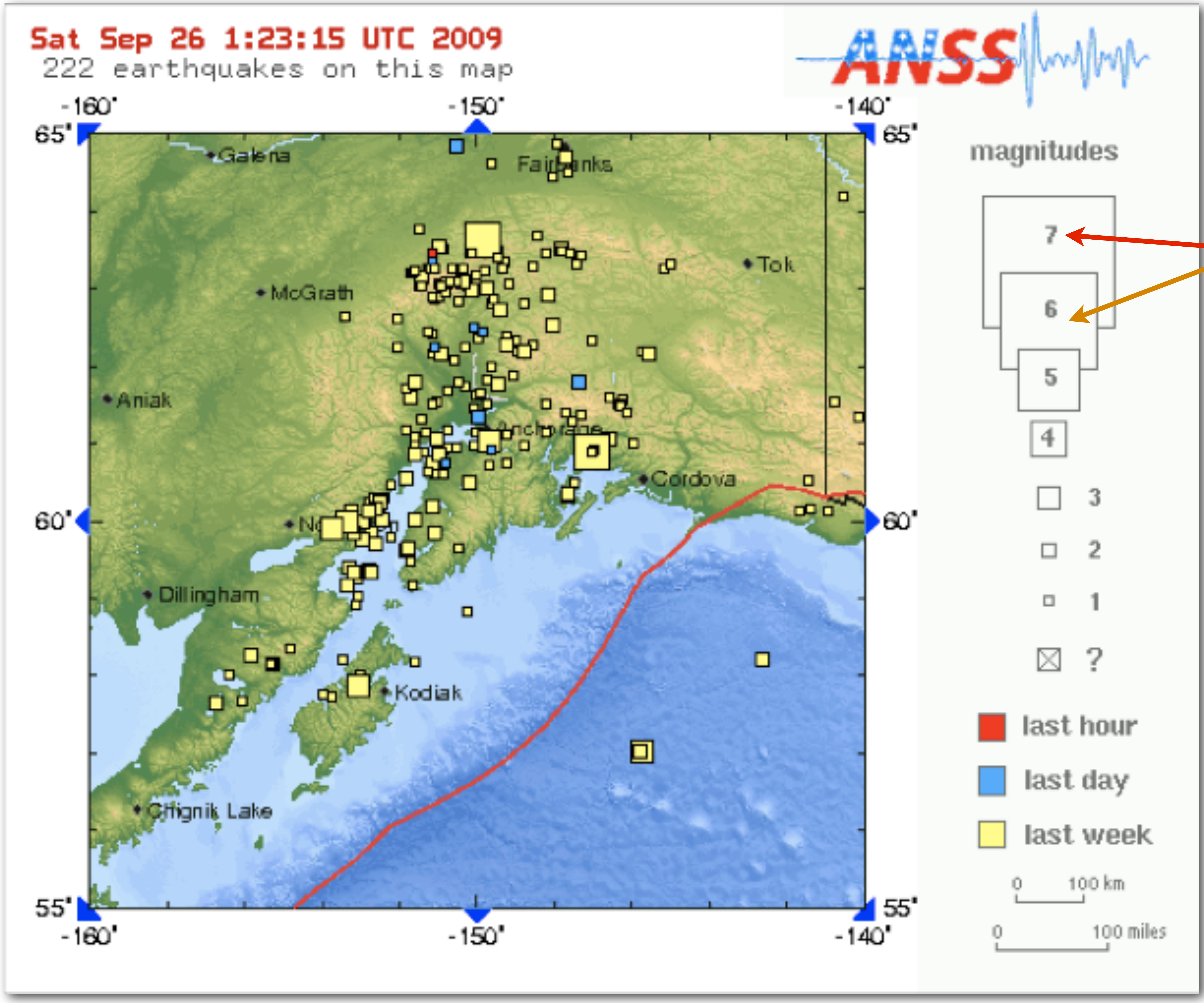
http://earthquake.usgs.gov/eqcenter/recenteqsus/Maps/US10/32.42.-125.-115.php

Recurrence Interval

T_R: average time between earthquakes of a particular size

$$T_R = N/n$$

- N is number of years
- in the record
- n is number of events



Recurrence interval of large magnitude earthquakes is important to know for risk governance.

Earthquakes during the week of Sept 20-27, 2009 - Alaska

http://earthquake.usgs.gov/eqcenter/recenteqsus/Maps/AK10/55.65.-160.-140.php

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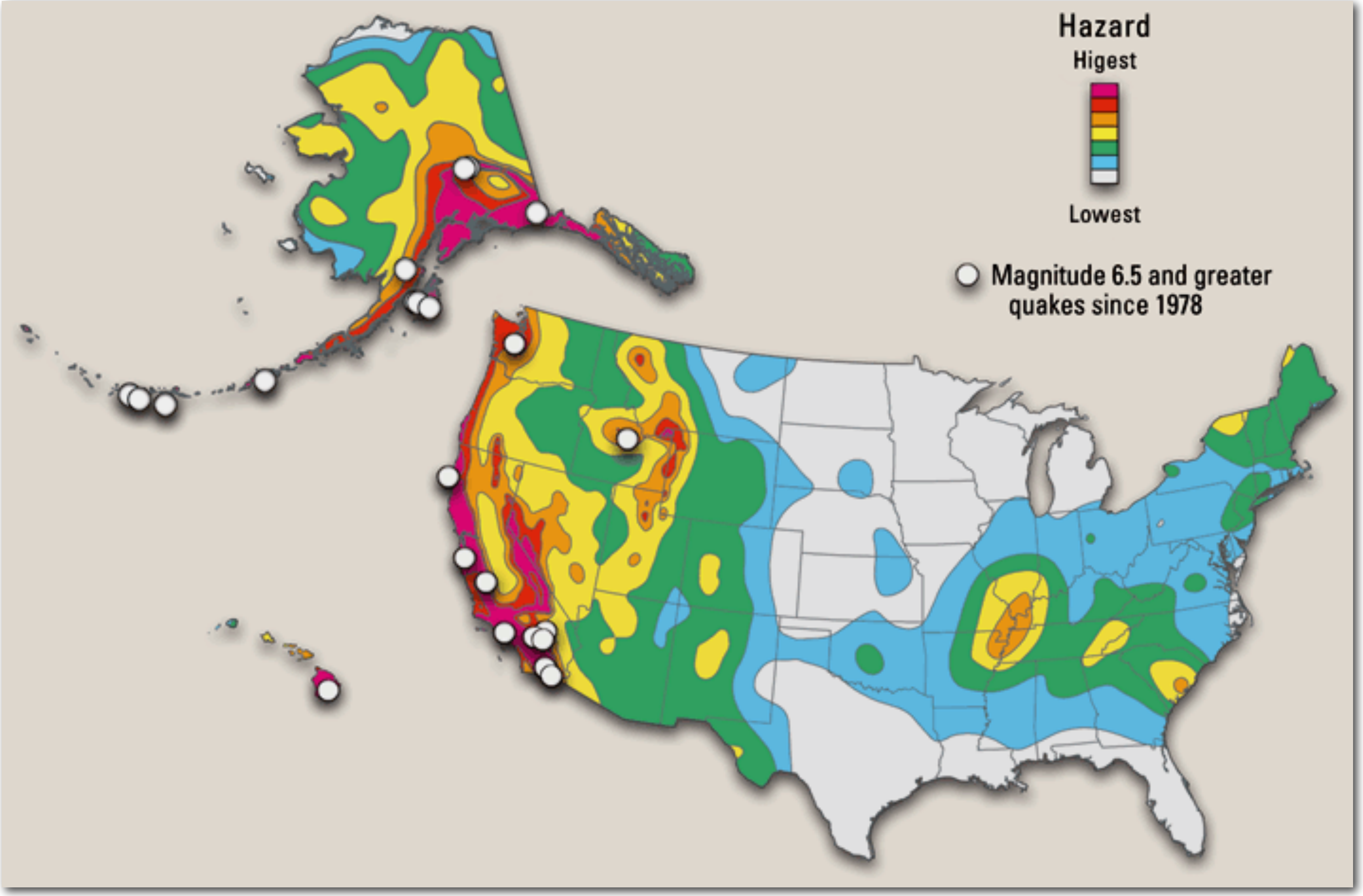
http://earthquake.usgs.gov/eqcenter/recenteqsus/Maps/US10/32.42.-125.-115.php

Hazard Maps

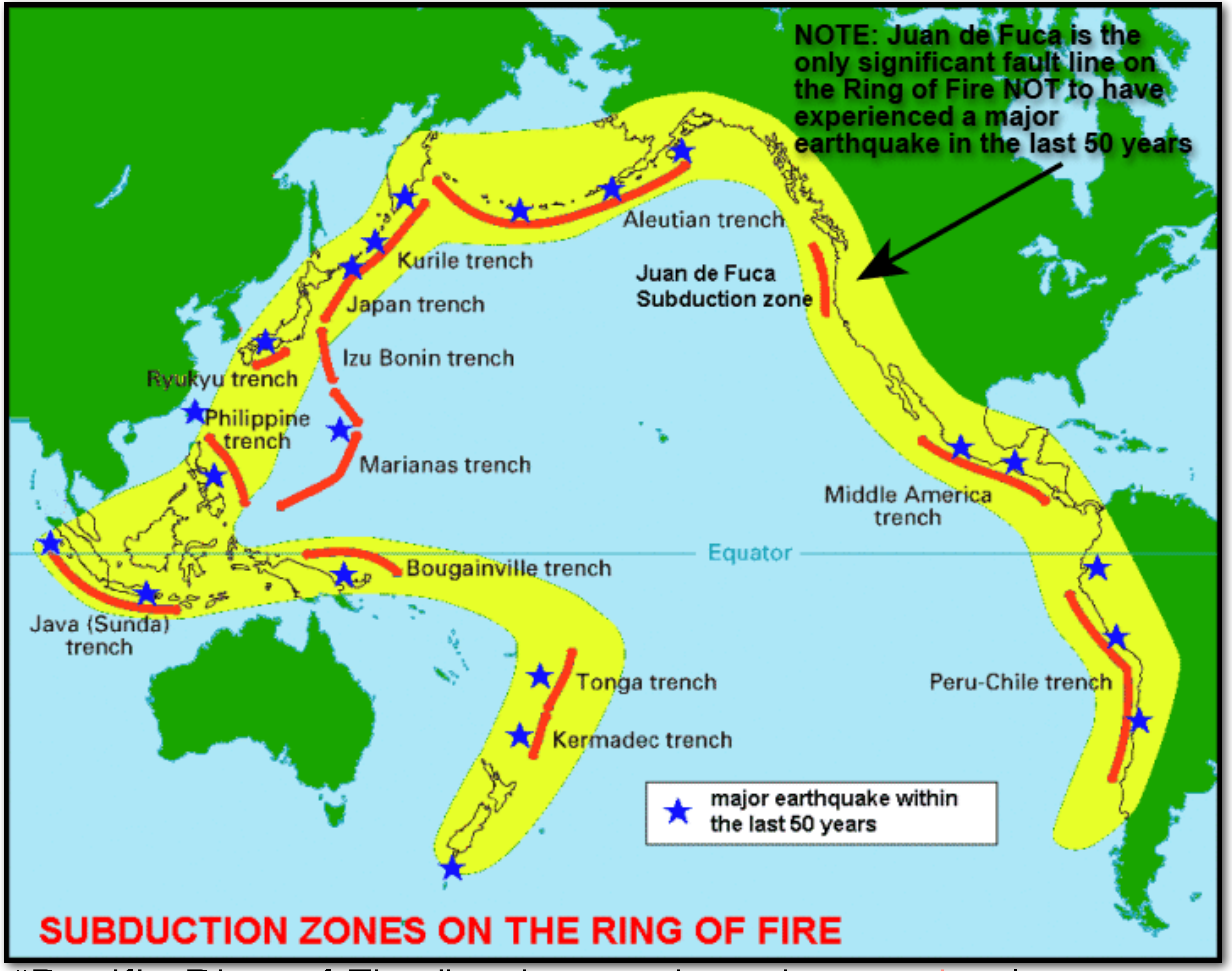
Hazard maps are based on known recurrence intervals



http://web.ics.purdue.edu/~braile/edumod/eqhazard/eqhazard2_files/image003.gif

Convergent boundaries:

(a) subduction zones



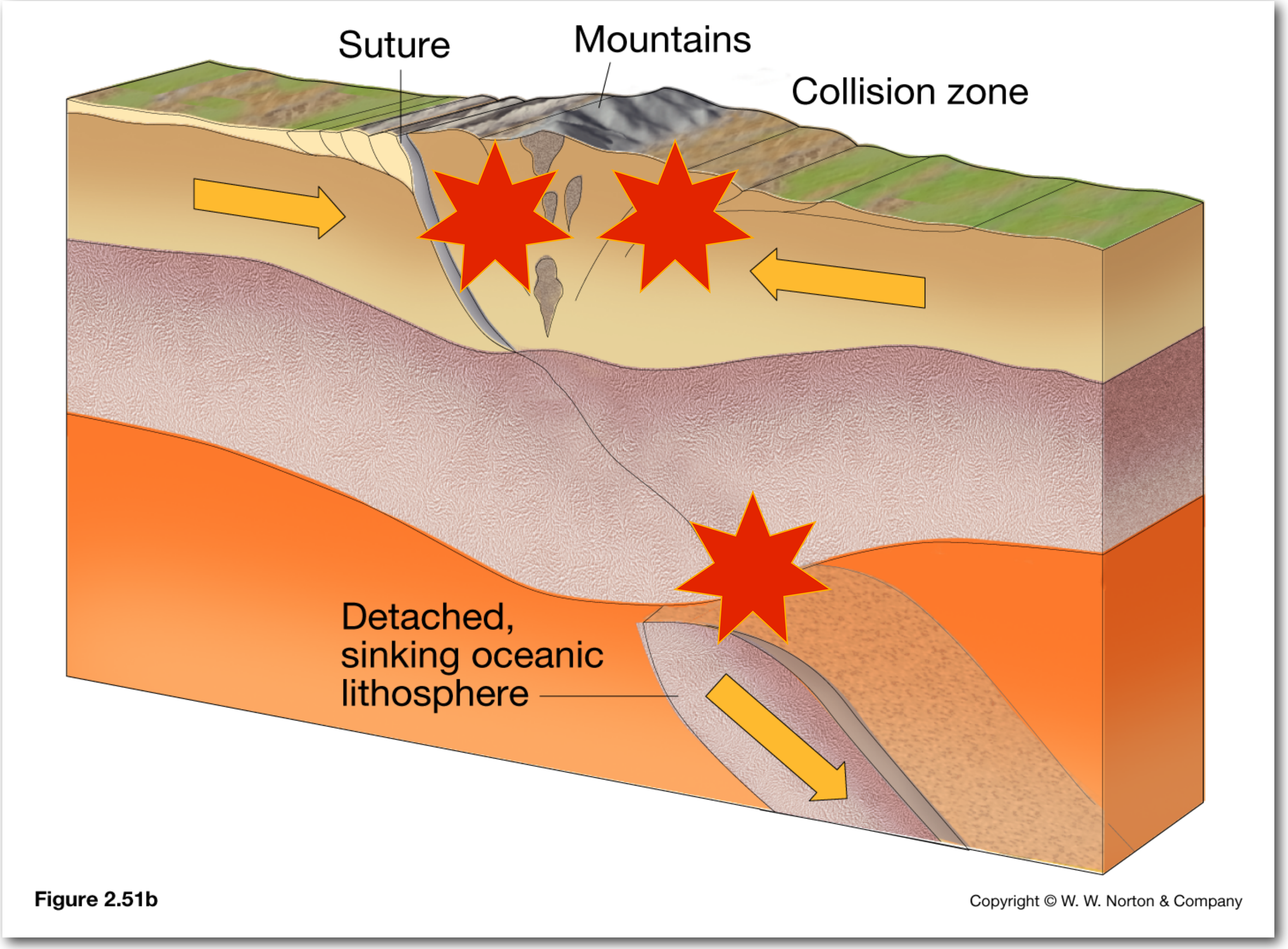
"Pacific Ring of Fire:"active earthquakes and volcanoes

http://www.standeyo.com/Reports/041222.EQ.warning/West.Coast/ring.of.fire.gif

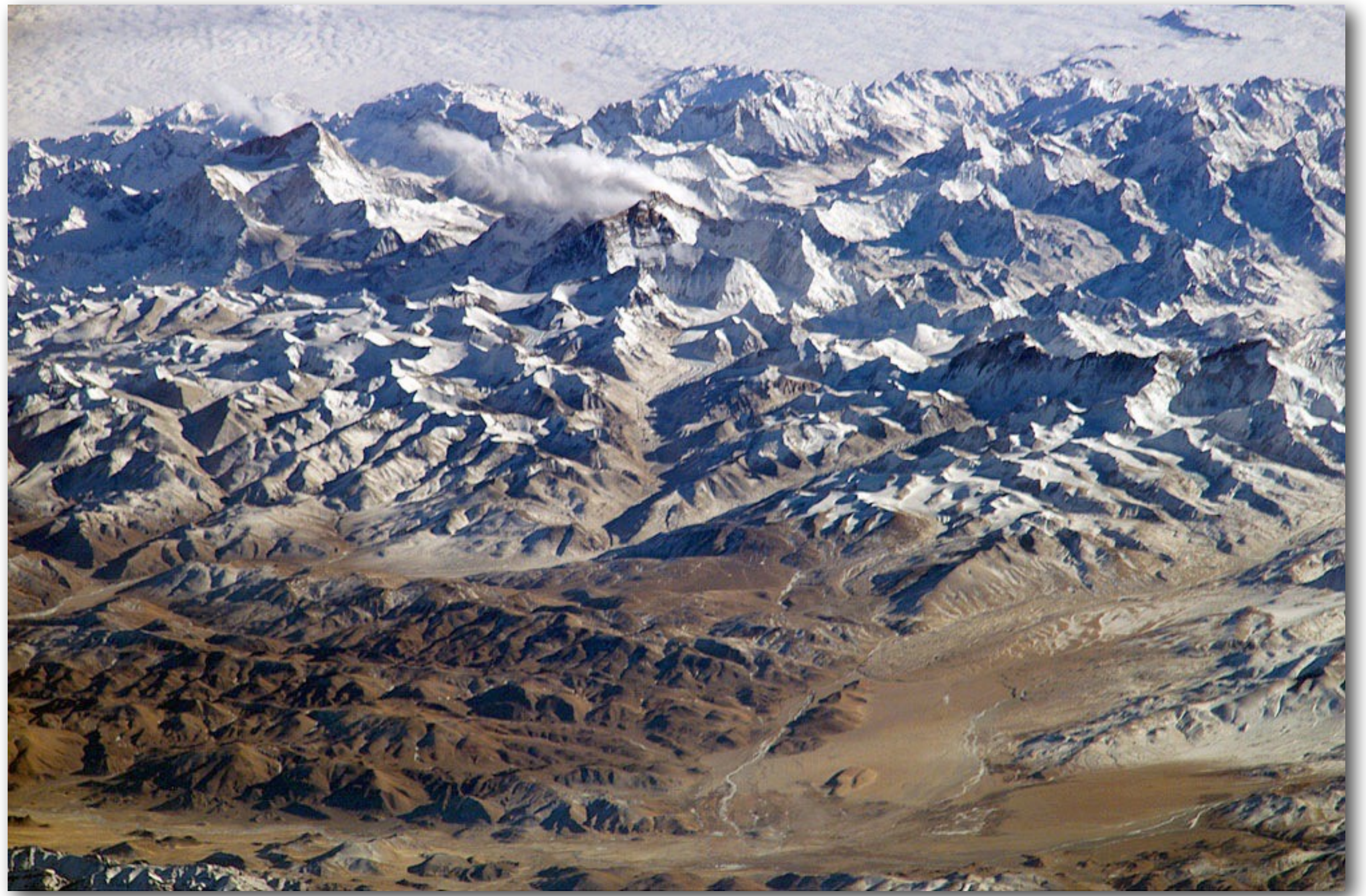
Convergent boundaries:

(b) collision zones

e.g., Himalayas, Zagros Mts. (Iran), Alps, China



very large earthquakes - hardly any volcanoes



http://upload.wikimedia.org/wikipedia/commons/7/79/Himalayas.jpg

http://i.telegraph.co.uk/telegraph/multimedia/archive/01112/earthquake-damage-_1112578c.jpg

Sichuan province, China 2008

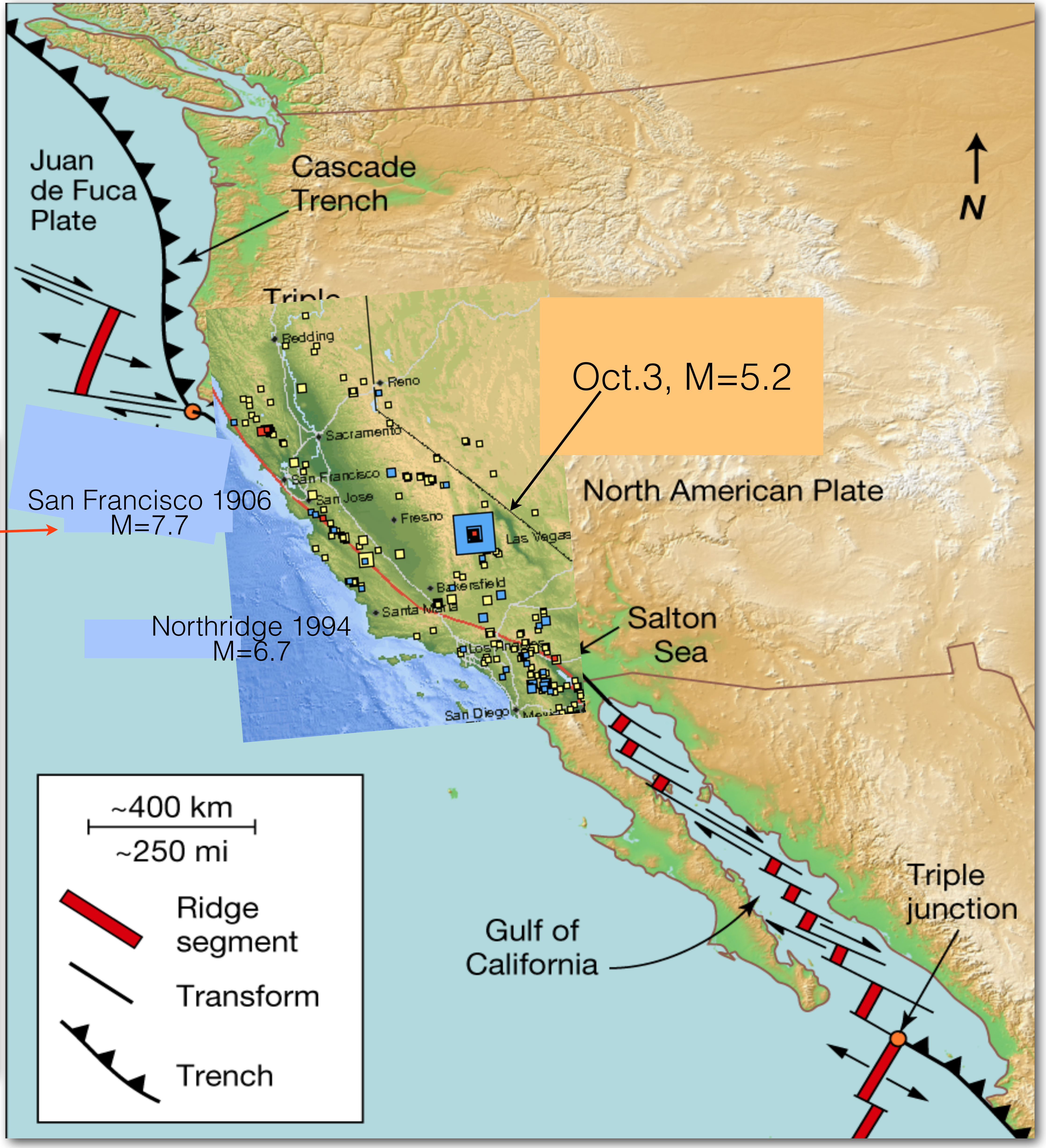
Transform boundaries:

e.g., California, New Zealand

- Mostly shallow depth,
- Can be large magnitude and have destructive ground shaking

Very Sticky! Lots of Earthquakes.

http://earthquake.usgs.gov/regional/states/events/images/1906_04_18_016_small.gif



Hazard Maps

http://www.shakeout.org