Basic Seismology

Introduction and Causes of Earthquakes

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What is Earthquake ?

- Shaking and vibration at the surface of the earth resulting from underground movement along a fault plane or from volcanic activity.
- An earthquake is the result of a sudden release of energy in the Earth's crust that creates seismic waves.
- An earthquake is a sudden and sometimes catastrophic movement of a part of the Earth's surface.

Types of Earthquakes

- EQs can be classified by their mode of generation as follows:
  - **Tectonic Earthquakes**
    - The most common earthquakes
    - Produced when rocks break suddenly in response to the various geological (tectonic) forces
  - **Volcanic Earthquakes**
    - Earthquakes that occurs in conjunction with volcanic activity
    - Earthquakes induced by the movement (injection or withdrawal) of magma
  - **Collapse Earthquakes**
    - Small Earthquakes occurring in regions of underground caverns and mines
    - Caused by the collapse of the roof of the mine or caverns
    - Sometimes produced by massive land sliding
  - **Human cause explosion earthquakes**
    - Produced by the explosion of chemical or nuclear devices

The Causes of Earthquakes

In ancient Japanese folklore, a giant catfish (Namazu) lives in the mud beneath the earth. It is guarded by the god Kashima who restrains the fish with a stone. When Kashima let his guard fall, Namazu thrashes its body, causing violent earthquakes.

The Causes of Earthquakes

In 1891, a Japanese seismologist, Prof. B. Koto, after careful study of the Mino-Owari earthquake noted,

"It can be confidently asserted that the sudden faulting was the actual cause (and not the effect) of the earthquake."

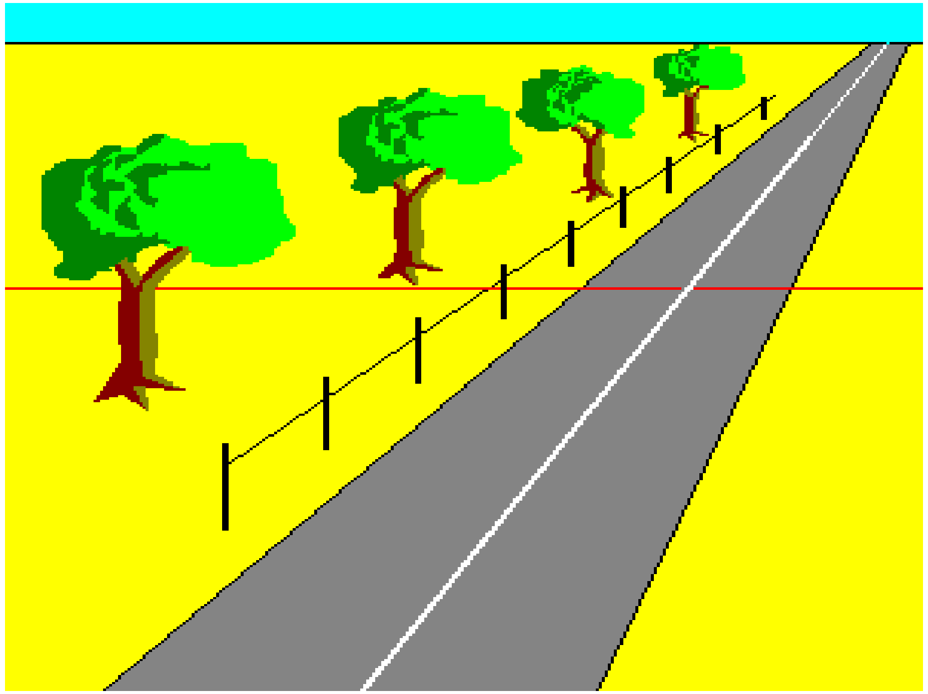
This finding was the start of common acceptance that fractures and faults were the actual mechanism of the earthquake and not its results, and was the basis of the development of the seismology.

Ground Failure by Lateral Fault Movement

Surface rupture caused by Fault dislocation

The Causes of Earthquakes

- Shortly after the San Francisco earthquake of 1906, an American geologist, **Harry Fielding Reid**, investigated the geological aftermath.
- He noticed that a displacement of nearly 6 meters had occurred on certain parts of the San Andreas fault which runs under San Francisco, and he proposed the theory that **strain had been building up over a long period of time and suddenly released in the earthquake**.

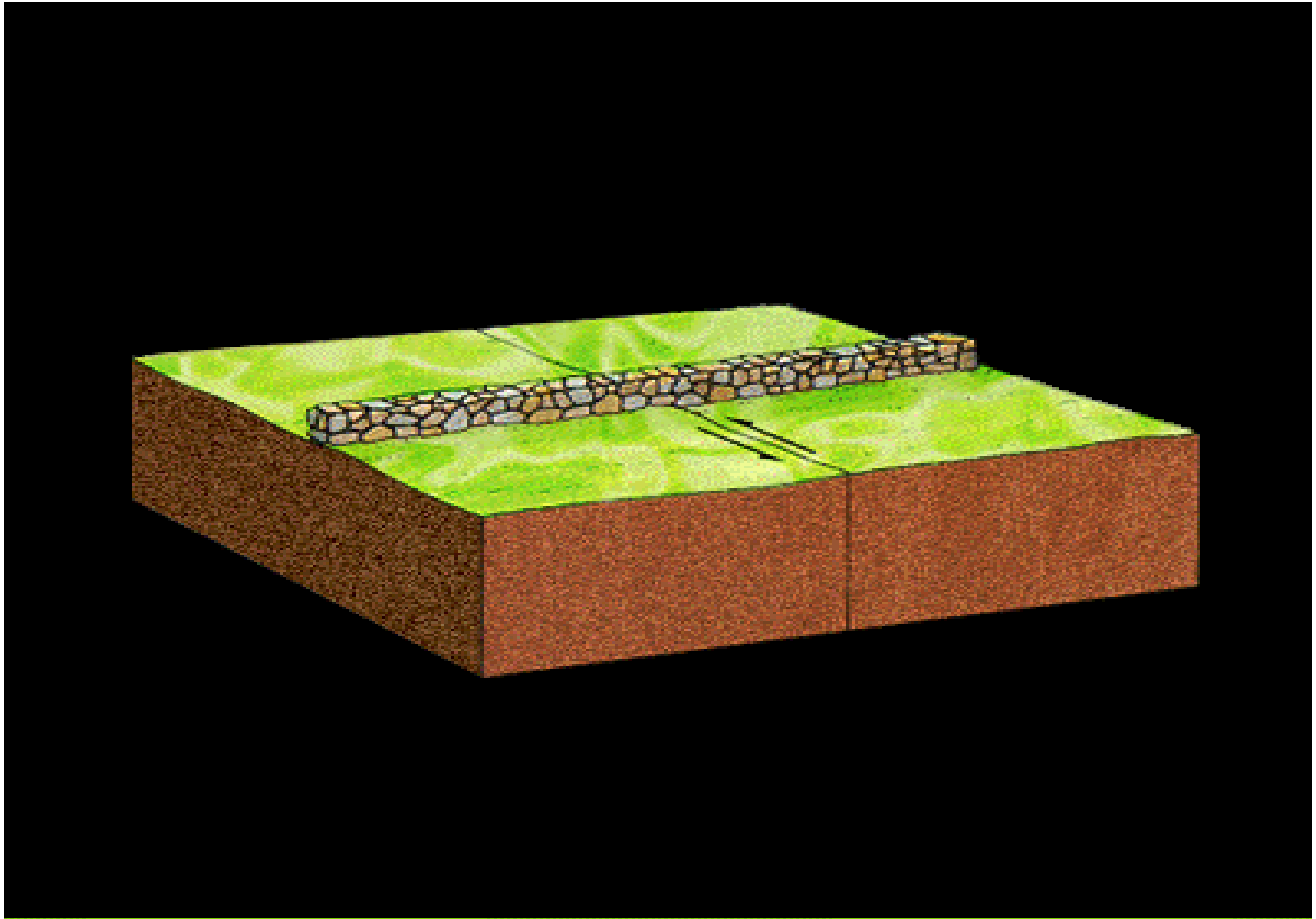


“It is impossible for rock to rupture without first being subjected to elastic strains greater than it can endure. We concluded that the crust in many parts of the earth is being slowly displaced, and the difference between the displacements in neighboring regions set up elastic strains, which may become larger than the rock can endure. A rupture then take place, and the strained rock rebounds under its own elastic stresses, until the strain is largely or wholly relieved.

When a fault ruptures, the elastic energy stored in the rock is released, partly as heat and partly as elastic waves.

In the majority of cases, the elastic rebound on opposite sides of the fault are in opposite directions.

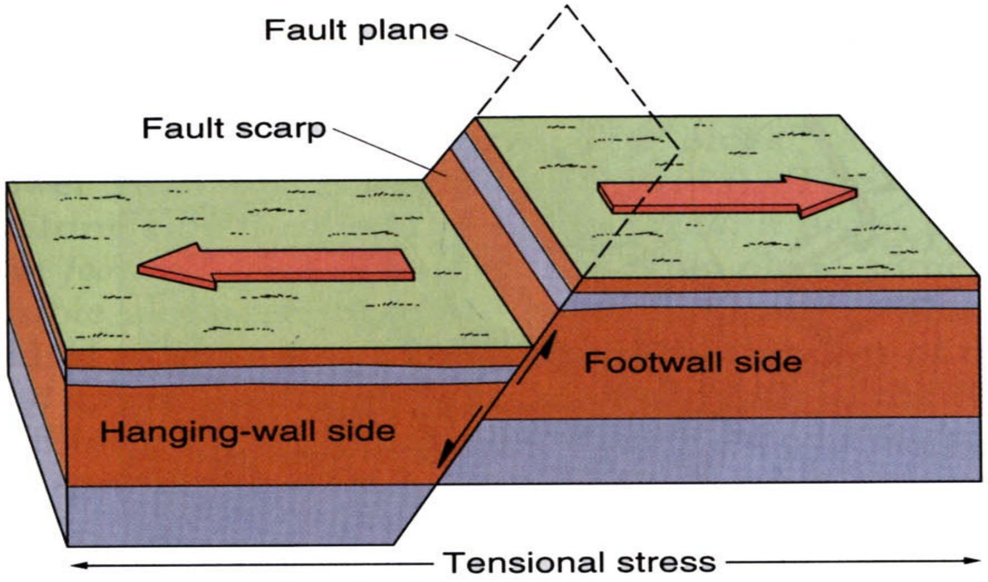
This is known as the **elastic rebound theory**.



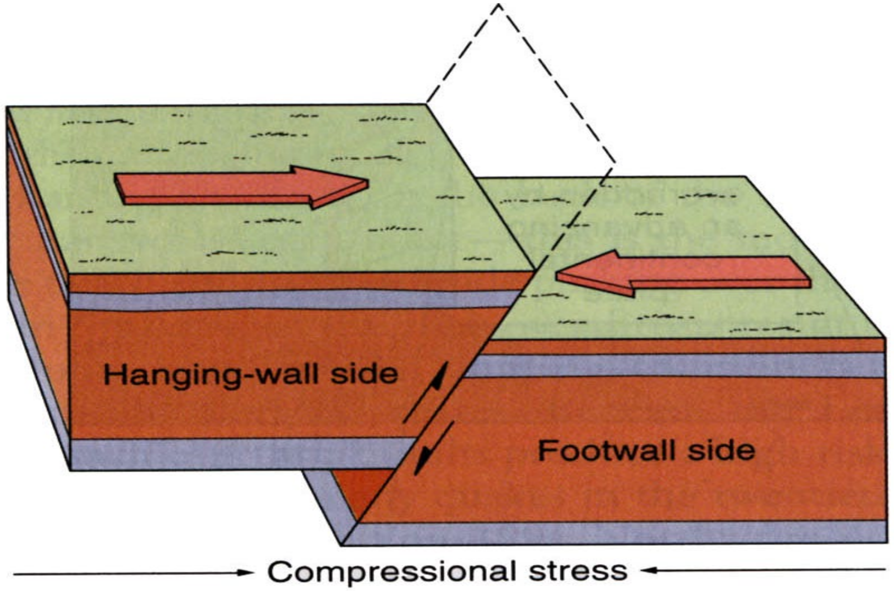
การยืด - การหด Elastic Rebound

Basic Types of Faults

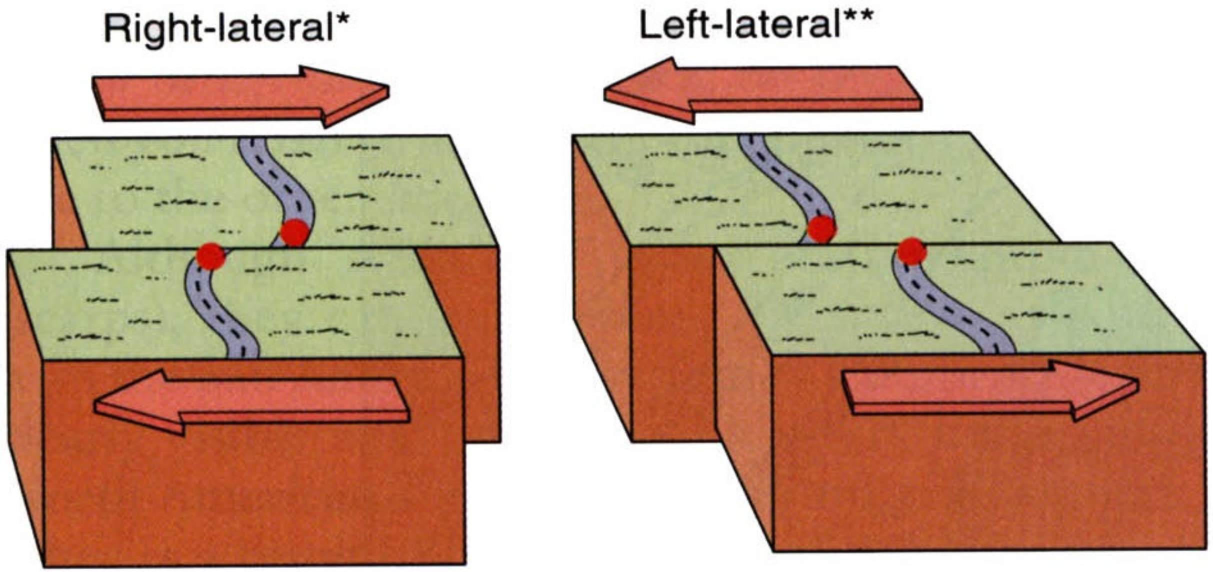
Fault: A fault is a **fracture** along which the blocks of crust on either side have moved relative to one another parallel to the fracture.



(a) Normal fault (tension)



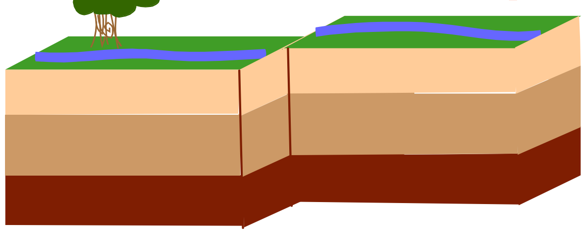
(b) Thrust or reverse fault (compression)



(c) Strike-slip fault (lateral shearing)

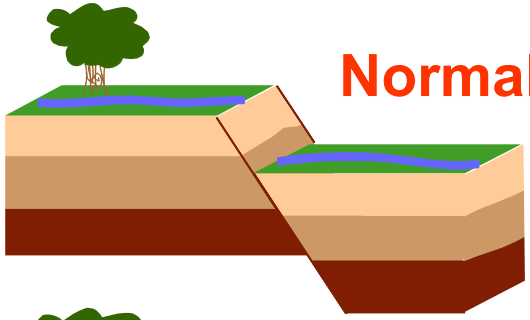
Dip Slip (normal or thrust)

Strike Slip (right or left lateral)

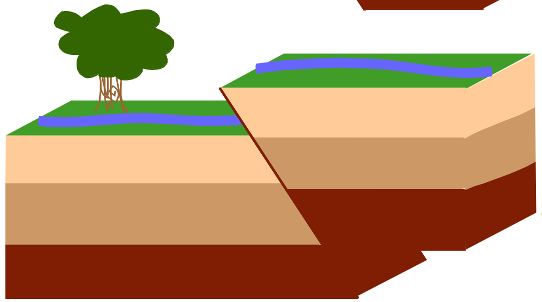


Strike-slip

Strike-slip faults are vertical (or nearly vertical) fractures where the blocks have mostly **moved horizontally**. If the block opposite an observer looking across the fault moves to the right, the slip style is termed right lateral; if the block moves to the left, the motion is termed left lateral.

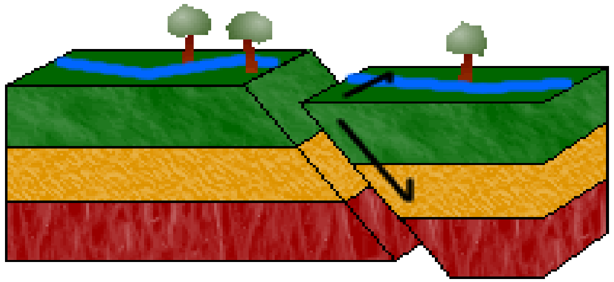


Normal



Thrust

Dip-slip faults are inclined fractures where the blocks have mostly **shifted vertically**. If the rock mass above an inclined fault moves down, the fault is termed **normal**,
whereas if the rock above the fault moves up, the fault is termed **reverse (or thrust)**. **Oblique-slip faults** have significant components of both slip styles.



Oblique-slip

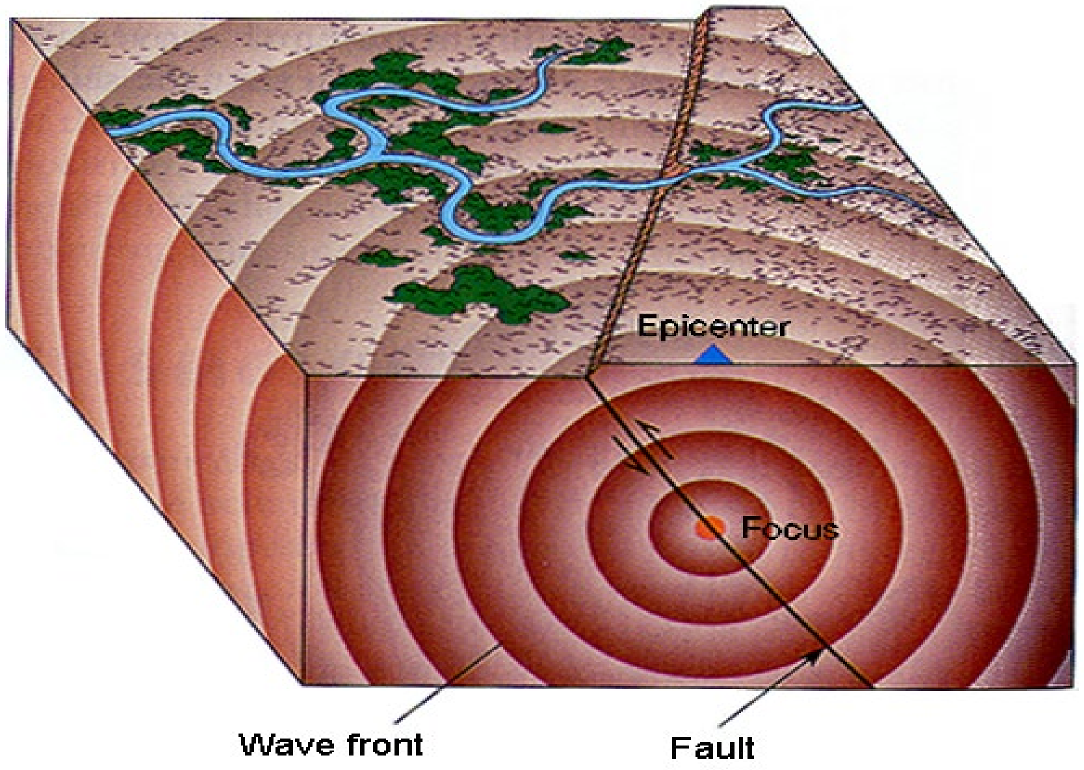
Oblique-slip faults: Oblique-slip faulting suggests **both dip-slip** faulting and **strike-slip** faulting. It is caused by a combination of shearing and tension or compressional forces, e.g., left-lateral normal fault.

Earthquake Rupture

The rupture begins at the earthquake focus within the crustal rock and then spreads outward in all directions in the fault plane.

The boundary of the rupture does not spread out uniformly. Its progress is jerky and irregular because crustal rocks vary in their physical properties and overburden pressure from place to place.

If this rupture reaches the surface (as happens in a minority of shallow earthquakes), it produces a visible fault trace.

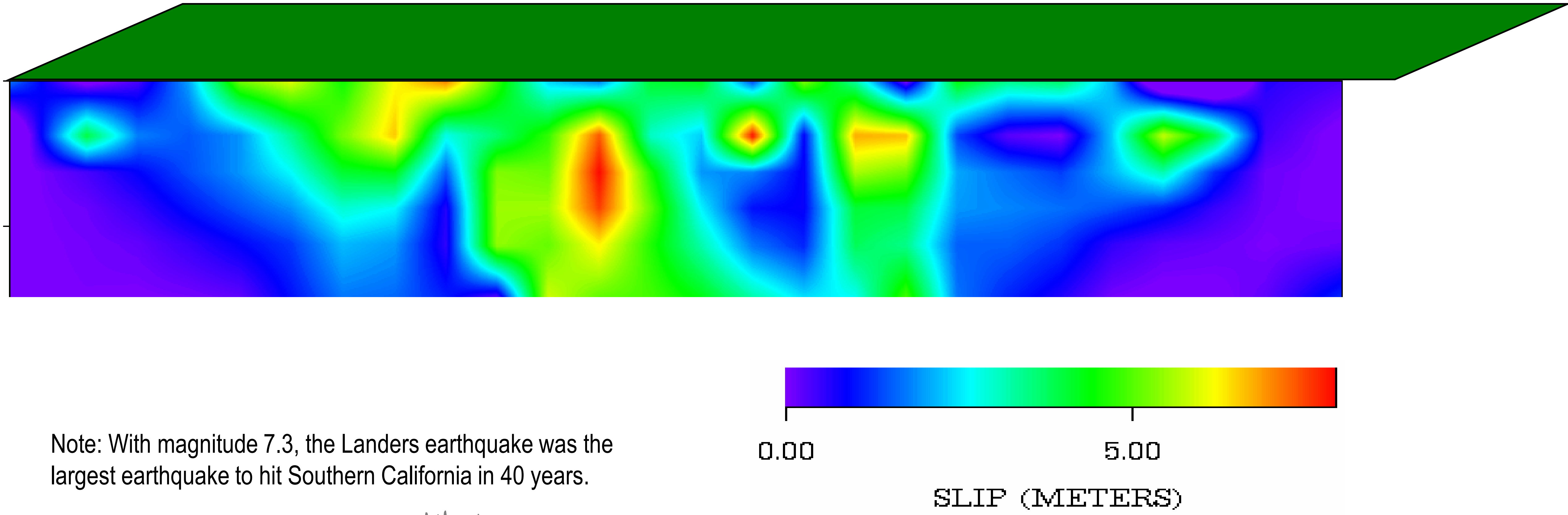


Earthquake Rupture

- Sometimes water in the rupture zone turn into steam, and rock melt down.
- This makes the movement of rocks in rupture zone like a liquid movement.
- So, the rupture in not a dry and cool process, it is a wet and high-temperature process.

Rupture on a Fault

Total Slip in the M7.3 Landers Earthquake (1992)



Note: With magnitude 7.3, the Landers earthquake was the largest earthquake to hit Southern California in 40 years.

Rupture on a Fault

The total rupture length was ~85km (53 miles), and the faults slipped from 2 meters (~6 ft) to a maximum of 6 meters (~18 ft). Nearby faults also experienced triggered slip and minor surface rupture.

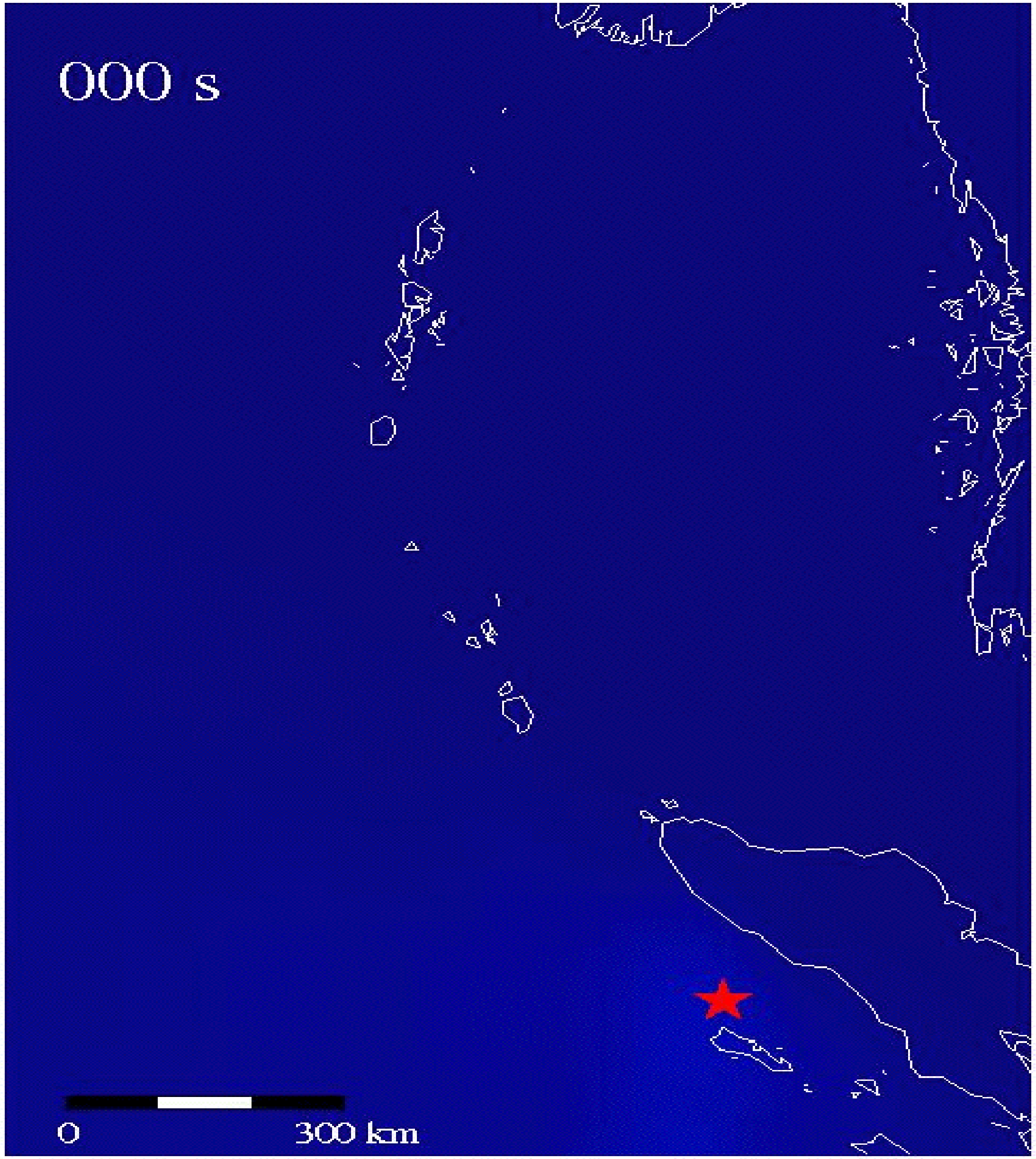
Source: https://scedc.caltech.edu/earthquake/landers1992.html

The 26 December 2004
Indian Ocean Earthquake

Sumatra–Andaman Earthquake

Magnitude: 9.3

Rupture Length: 1200 km



Ishii et al., 2005
Nature

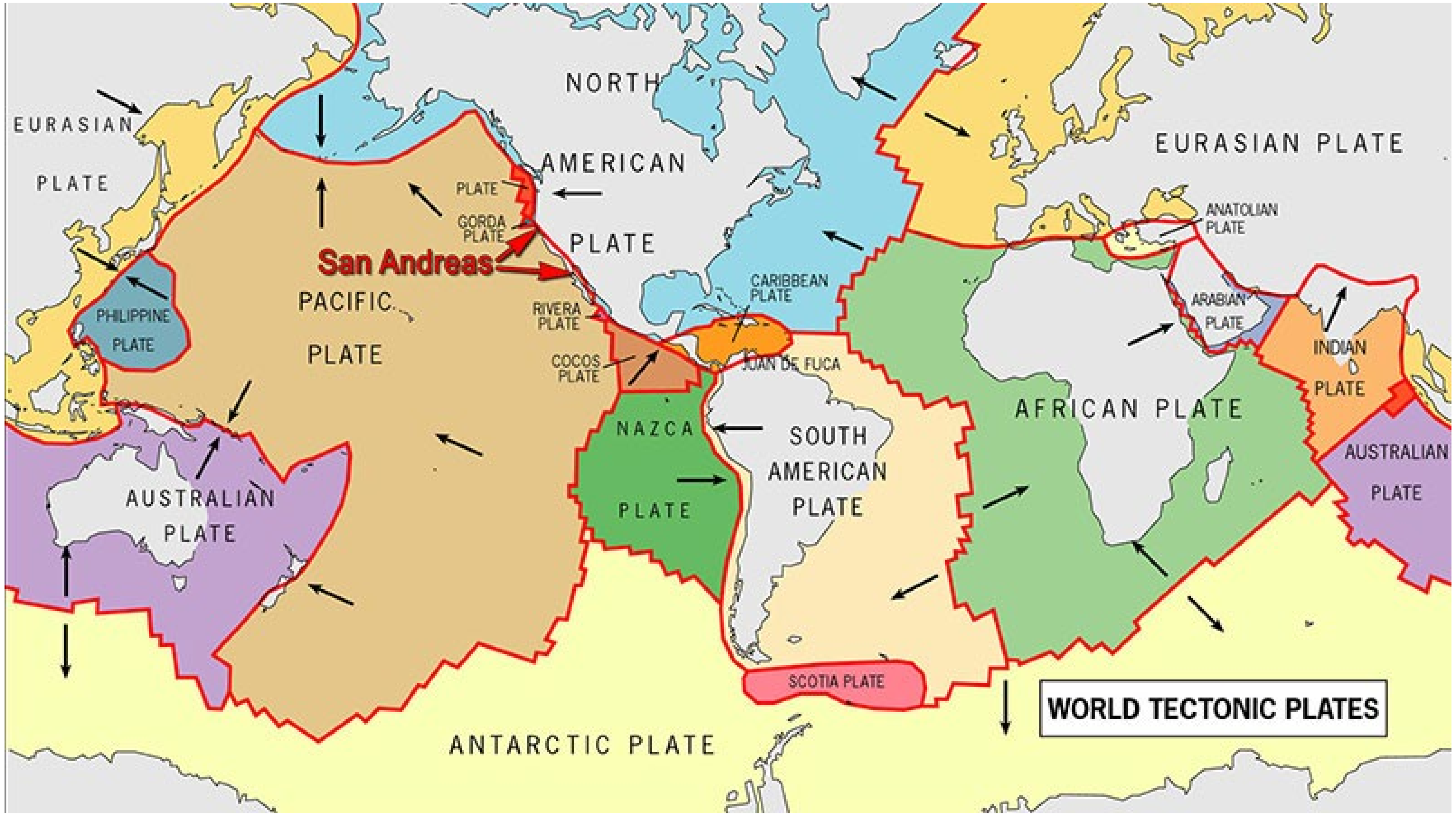
Surface Rupture: Strike-slip Fault Example

Surface Rupture: Normal Fault Example

Dixie Valley-Fairview Peaks, Nevada earthquake. December 16, 1954

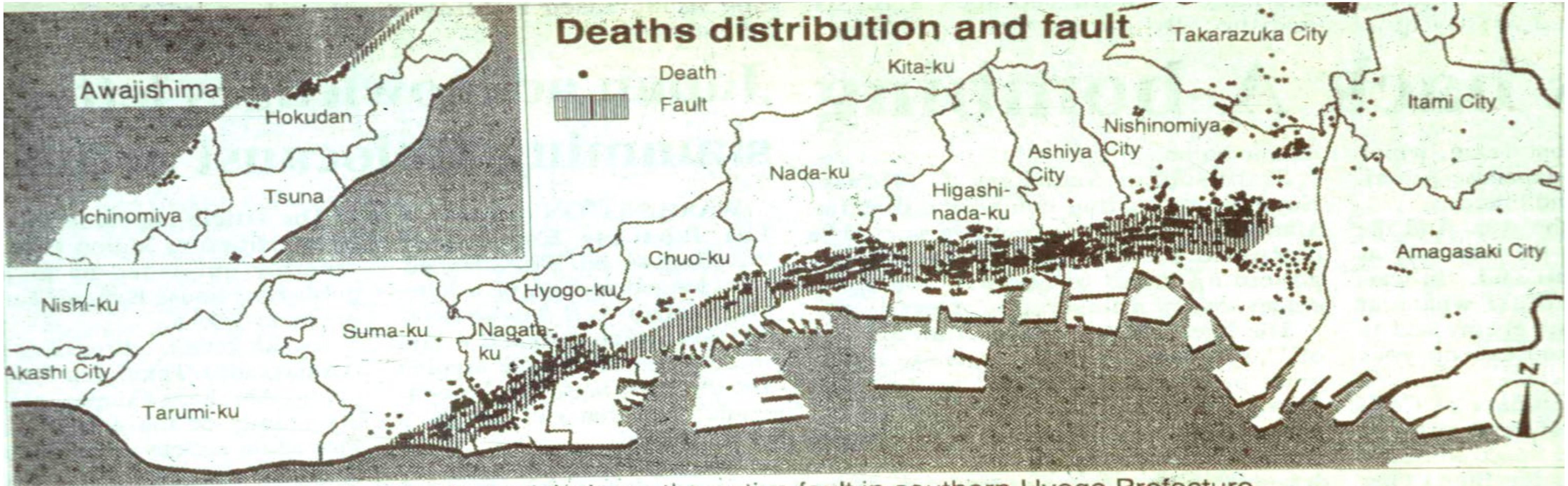
Surface Rupture: Thrust Fault Example

San Andreas Fault



Strong ground shaking above the rupture zone

The 1995 Kobe Earthquake



Map shows the concentration of deaths above the active fault in southern Hyogo Prefecture.

Destruction centered above active fault

The deaths caused by the Great Hanshin Earthquake were concentrated along the 25-kilometer-long, three-kilometer-wide coastal zone between Suma-ku, Kobe City, and Nishinomiya City — just above an active fault, a seismologist has found.

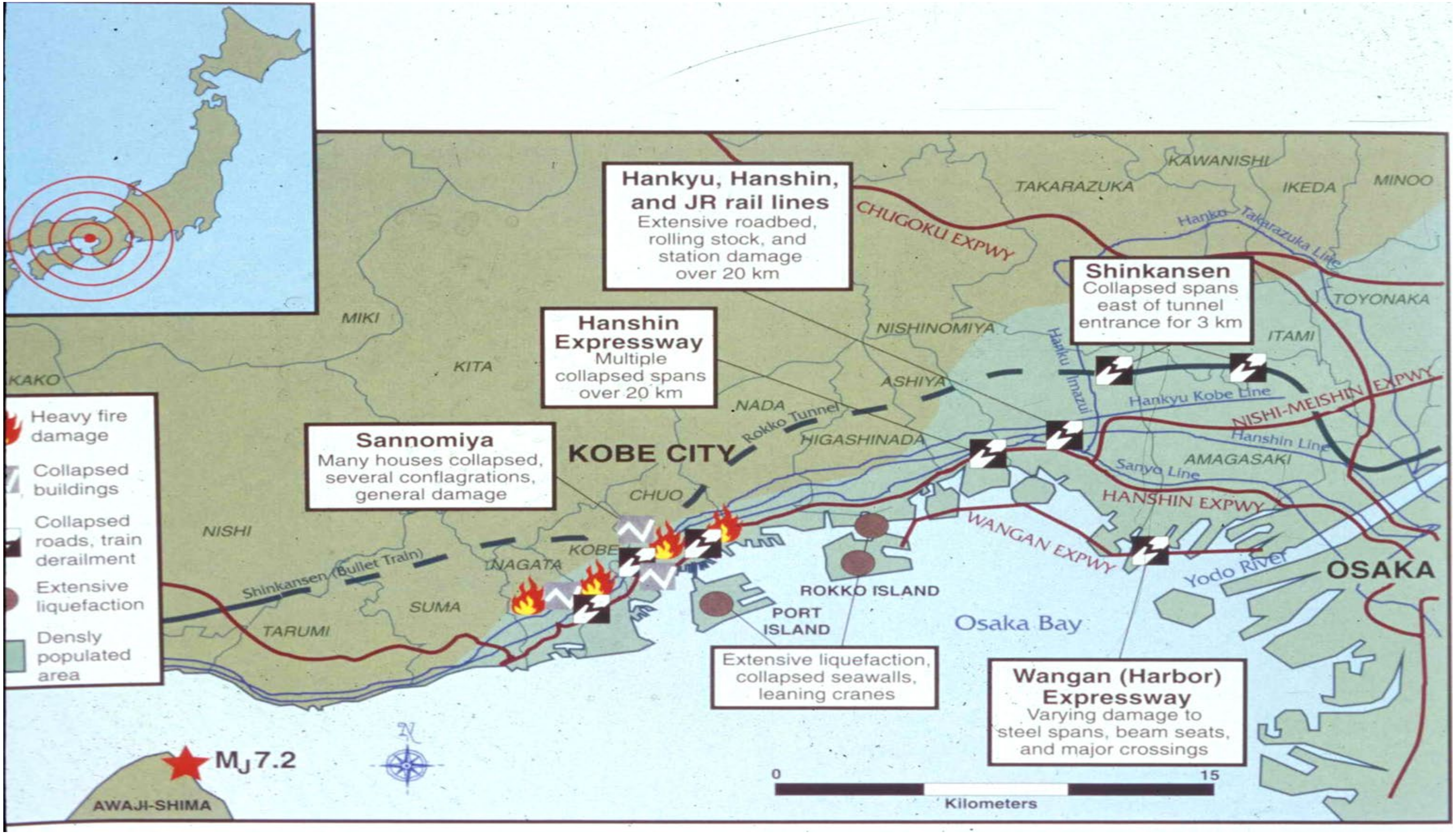
Associate Professor Toshihiko Shima-

after conducting a detailed survey of the quake-devastated areas. He also learned that the active fault shifted largely during the quake.

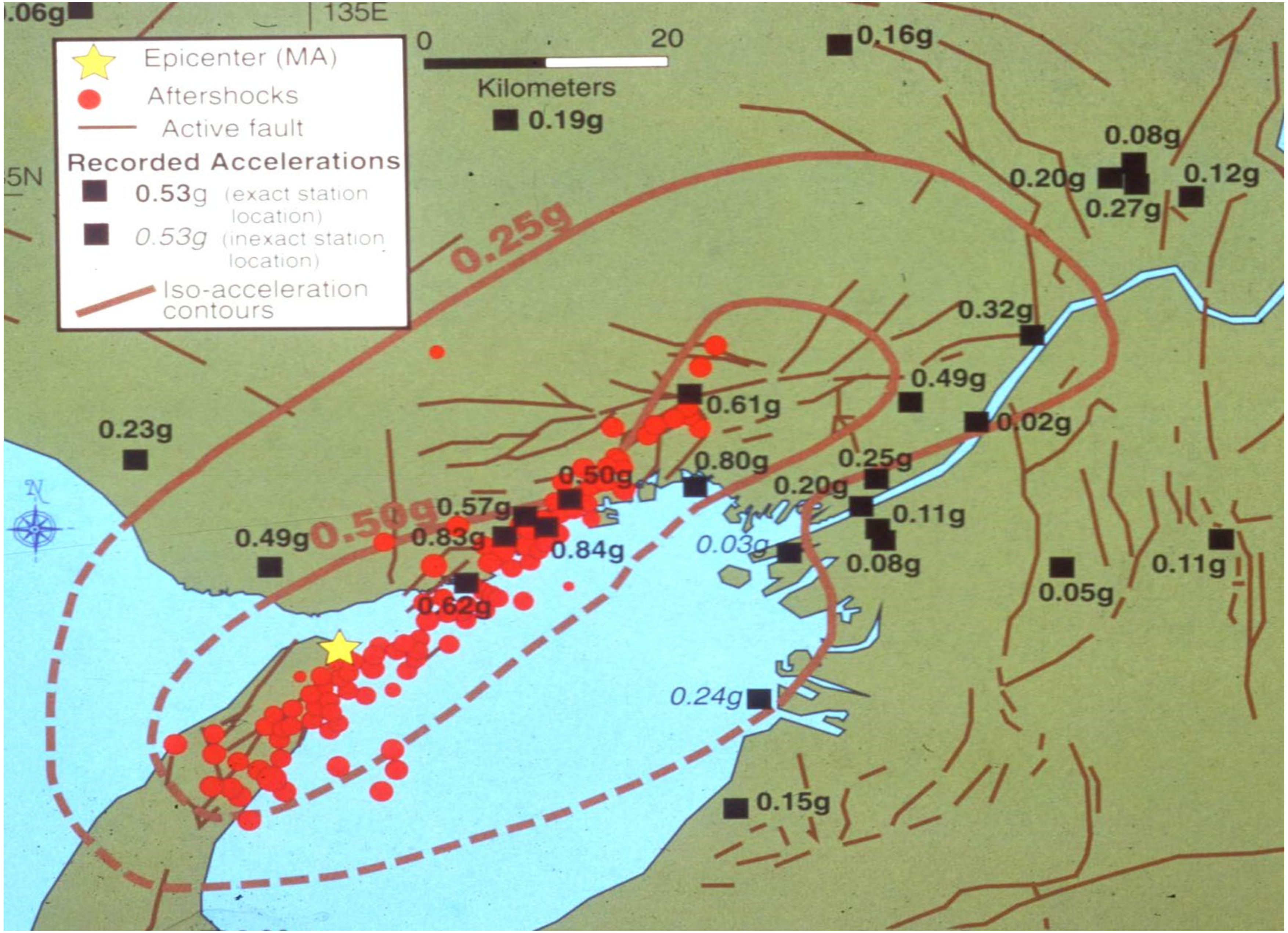
Damage from an earthquake, when it hits urban areas from directly below, tends to concentrate in areas just above the active fault that triggers the quake. A

crushed to death under collapsed build- ings located above the fault.

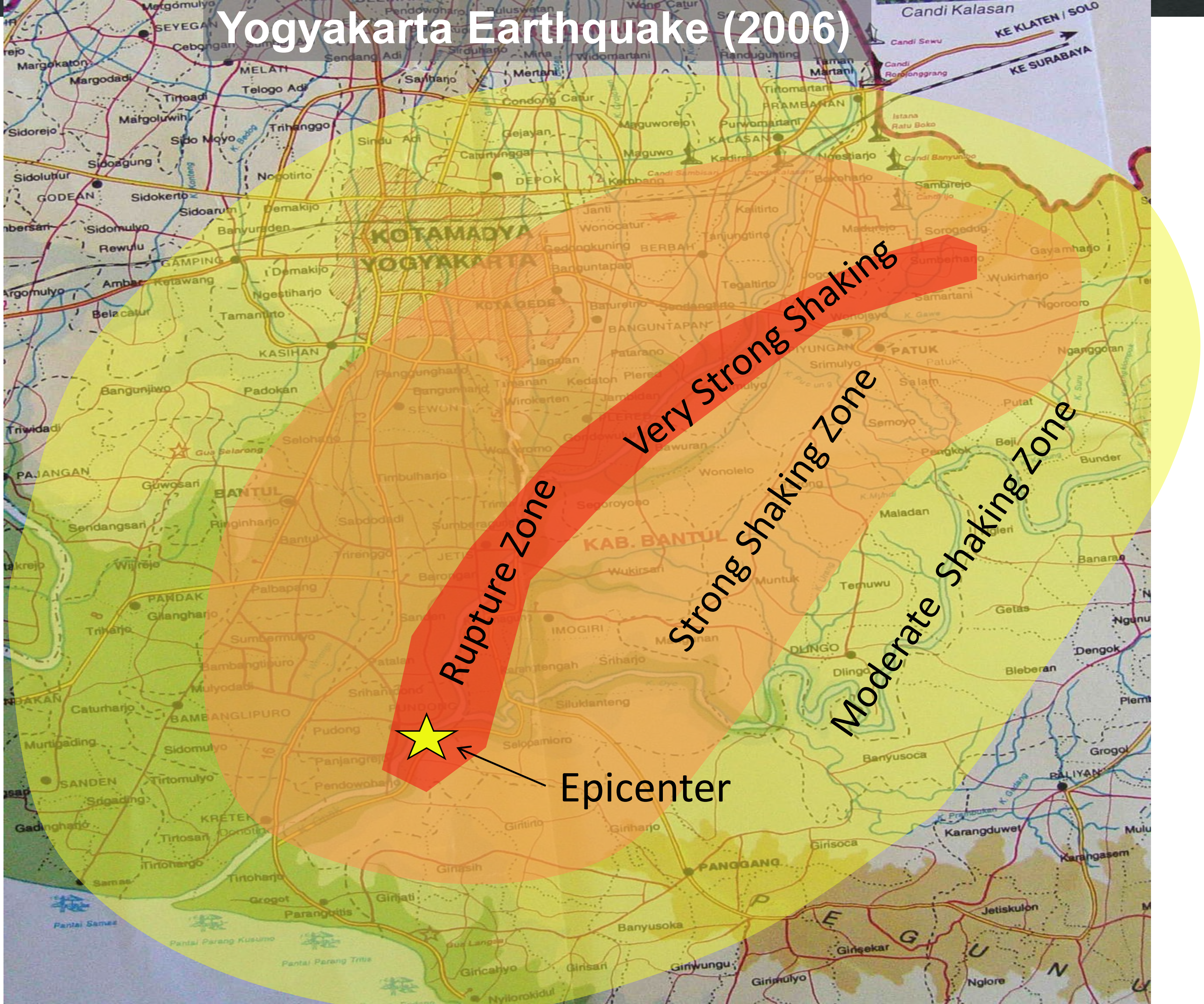
"The Kinki area has a concentration o active faults. But if you try to avoi active faults, you can't find a place t build," says Shimamoto. "You have n choice but to be fully aware of the dan ger of such faults and promote the con struction of disaster-proof towns," h


Hankyu, Hanshin, and JR rail lines
Extensive roadbed, rolling stock, and station damage over 20 km
Hanshin Expressway
Multiple collapsed spans over 20 km
Sannomiya
Many houses collapsed, several conflagrations, general damage
Shinkansen
Collapsed spans east of tunnel entrance for 3 km
Extensive liquefaction, collapsed seawalls, leaning cranes
Wangan (Harbor) Expressway
Varying damage to steel spans, beam seats, and major crossings
Heavy fire damage
Collapsed buildings
Collapsed roads, train derailment
Extensive liquefaction
Densly populated area
KOBE CITY
OSAKA
Osaka Bay
ROKKO ISLAND
PORT ISLAND
AWAJI-SHIMA
M_J 7.2
MIKI
KITA
KAKO
NISHI
SUMA
TARUMI
NAGATA
KOBE
CHUO
NADA
HIGASHINADA
ASHIYA
NISHINOMIYA
TAKARAZUKA
KAWANISHI
IKEDA
MINOO
TOYONAKA
ITAMI
AMAGASAKI
CHUGOKU EXPWY
NISHI-MEISHIN EXPWY
HANSHIN EXPWY
WANGAN EXPWY
Hankyu Takarazuka Line
Hankyu Kobe Line
Hankyu Imazu
Hanshin Line
Sanyo Line
Rokko Tunnel
Shinkansen (Bullet Train)
Yodo River
0
15
Kilometers

The 1995 Kobe Earthquake



Yogyakarta Earthquake (2006)




Bantul, Yogyakarta
Strong Ground Shaking + Unreinforced Masonry Houses
= A Major Disaster

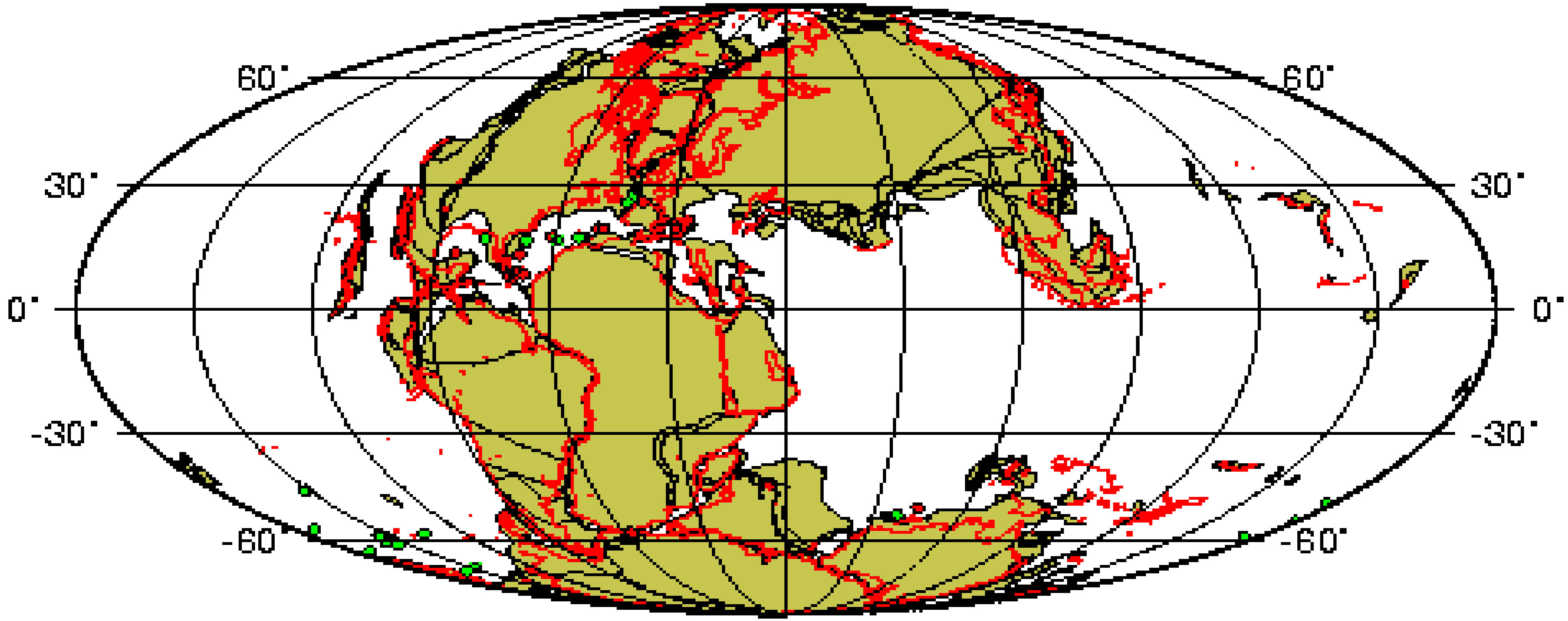
Continental Drift

In 1910 a German meteorologist and astronomer, Alfred Wegener, put forward a theory:

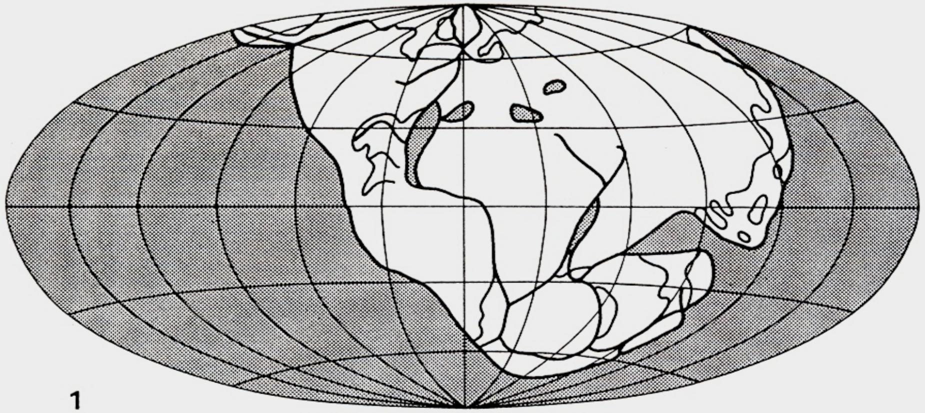
At about 200 million years ago, the earth consisted of only one continent, which he called Pangaea (all lands), and one ocean, Panthalassa (all seas). Eventually, for reasons which Wegener could not explain, this mass of land broke up in mesozoic times—about 150 million years ago—and started to move; firstly into N-S directions, and then into E-W.

He called the process **continental drift**.

Continental Drift



150 My Reconstruction



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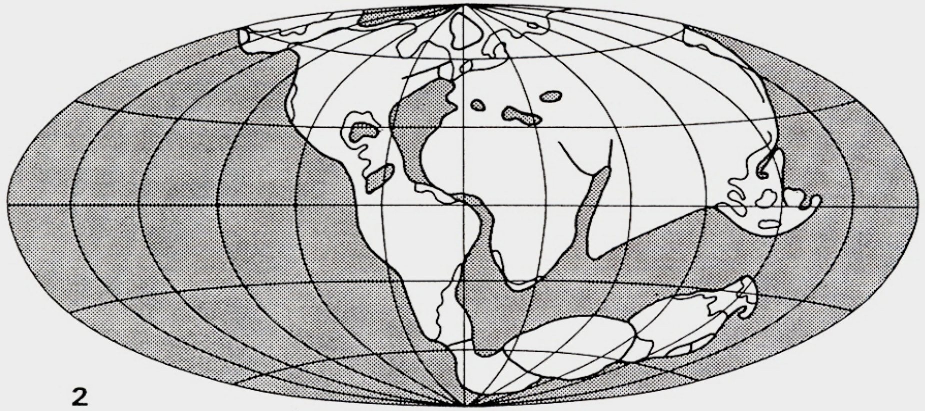

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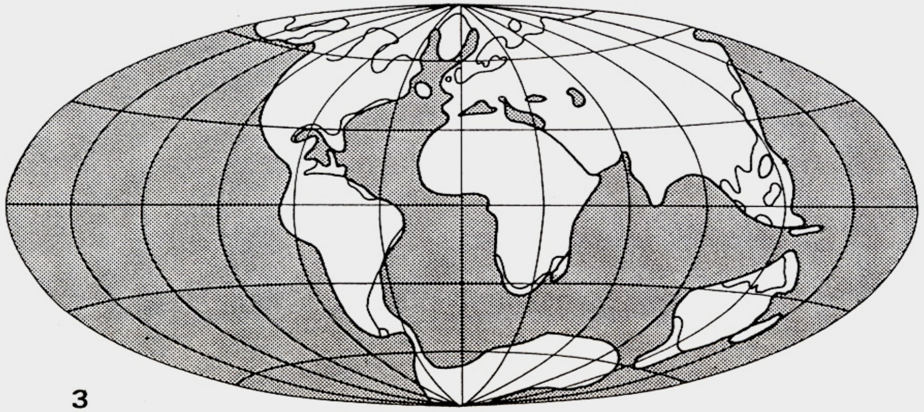


3

Diagrams illustrating Wegener's theory of continental drift.

1 270 million years ago, the continents were united in a single block called Pangaea.
2 150 million years ago, Pangaea started to divide. North America and Europe were still united. It is now believed that North and South America were apart at this stage.
3 1 million years ago, the continents were beginning to assume the shapes and positions we know today.

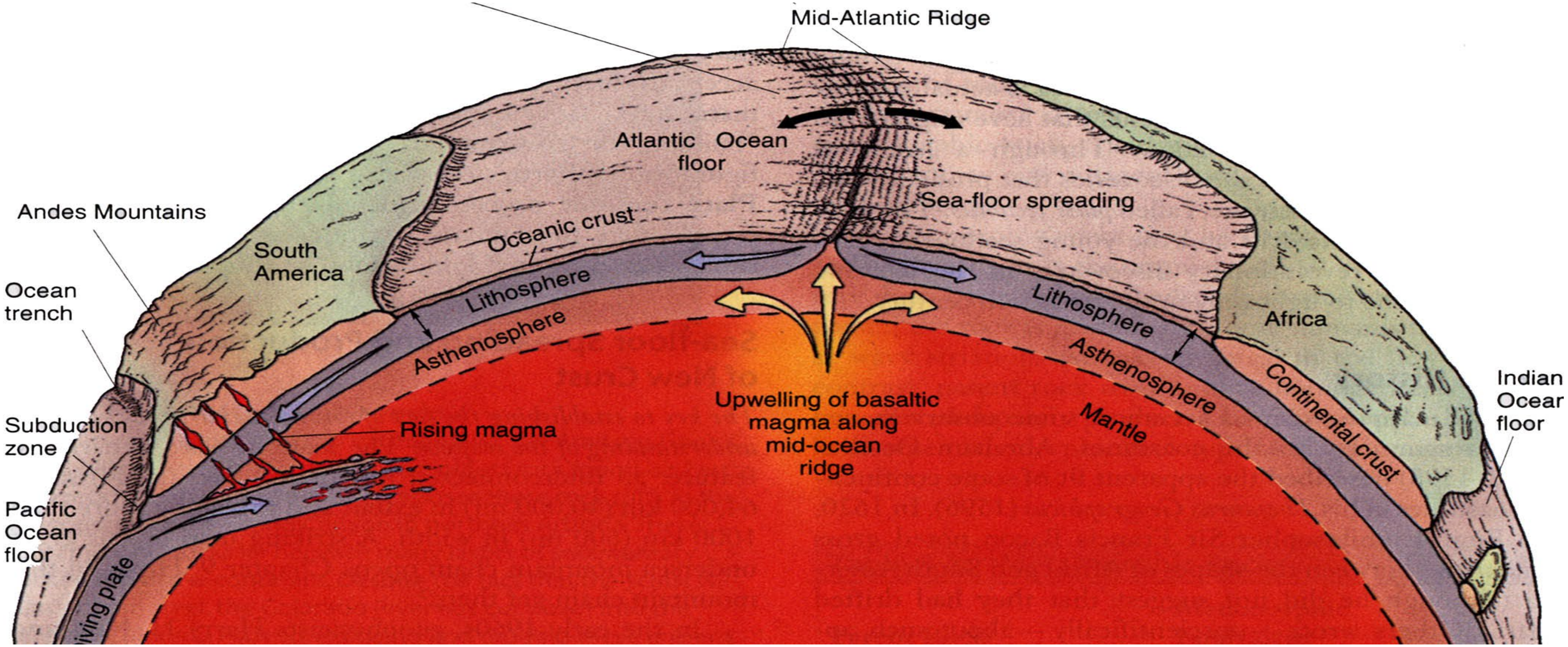
Continental Drift

- Initially the Wegener theory was too fanciful for many, and at the existing level of scientific knowledge it could not be proved.
- Wegener was roundly condemned.

- After the discovery of submarine mountain ranges and many more evidence in later years, the Wegener theory became a widely accepted theory.
- This was also the starting point of the **theory of plate tectonics**.
- The impact of the theories of plate tectonics and continental drift was immense and was the great breakthrough that the earth sciences had needed for so long.

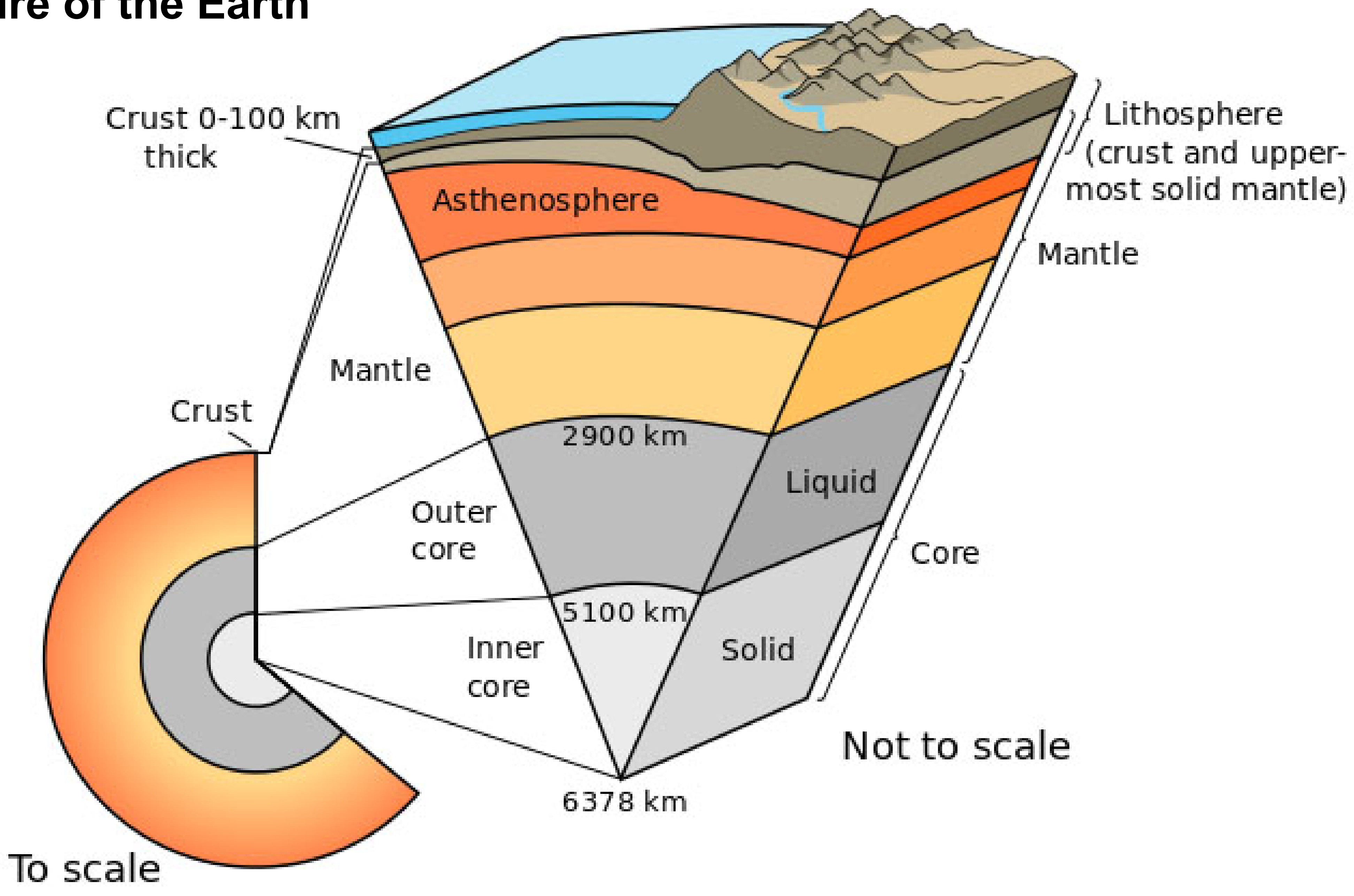
Plate Tectonics

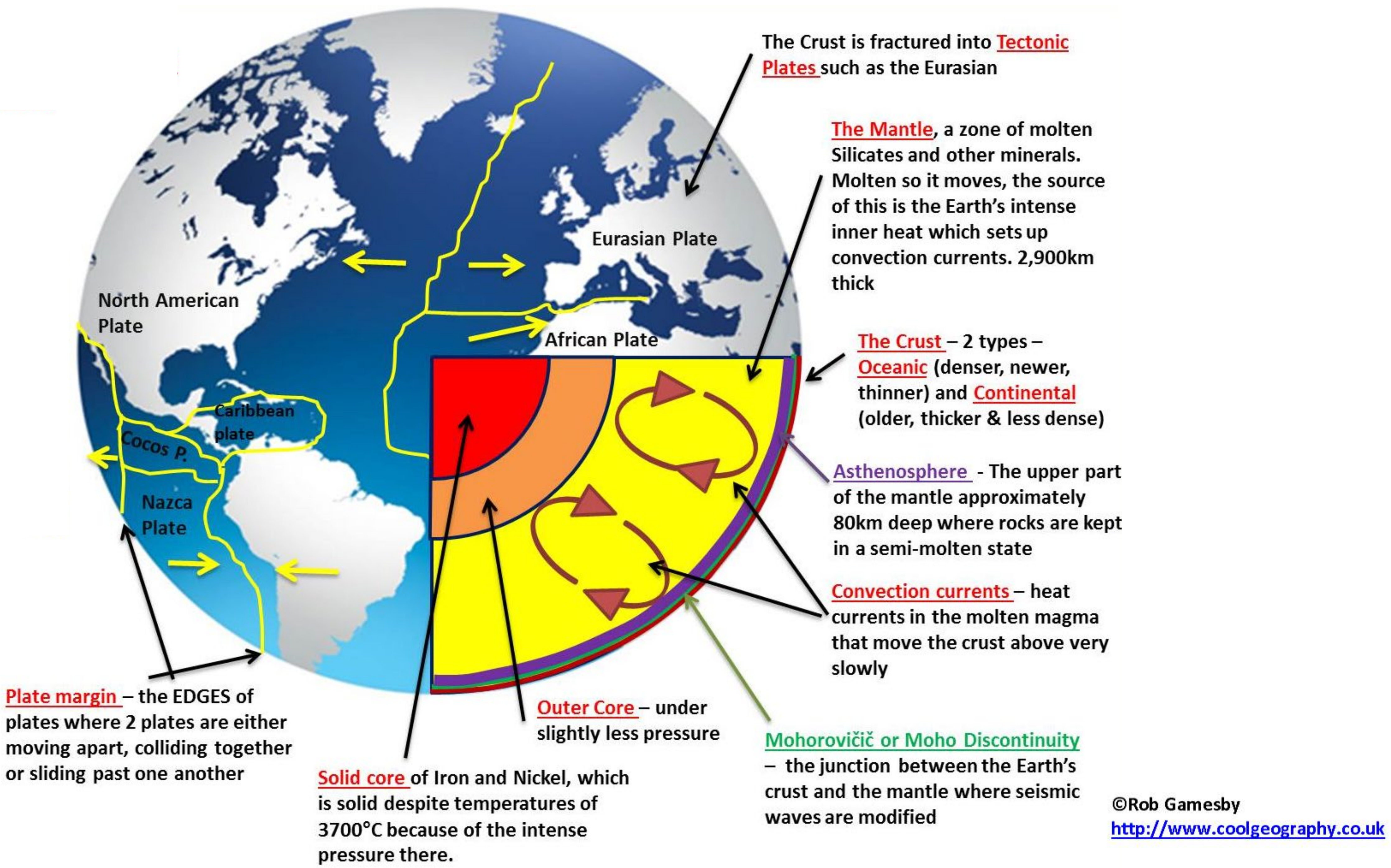
The basic idea of "plate tectonics" is that the earth's outer shell (called the lithosphere) consists of several large and fairly stable slabs of solid rock called plates.



The thickness of each plate is about 80 km. The plate moves horizontally, relative to neighboring plates, on a layer of softer rock.

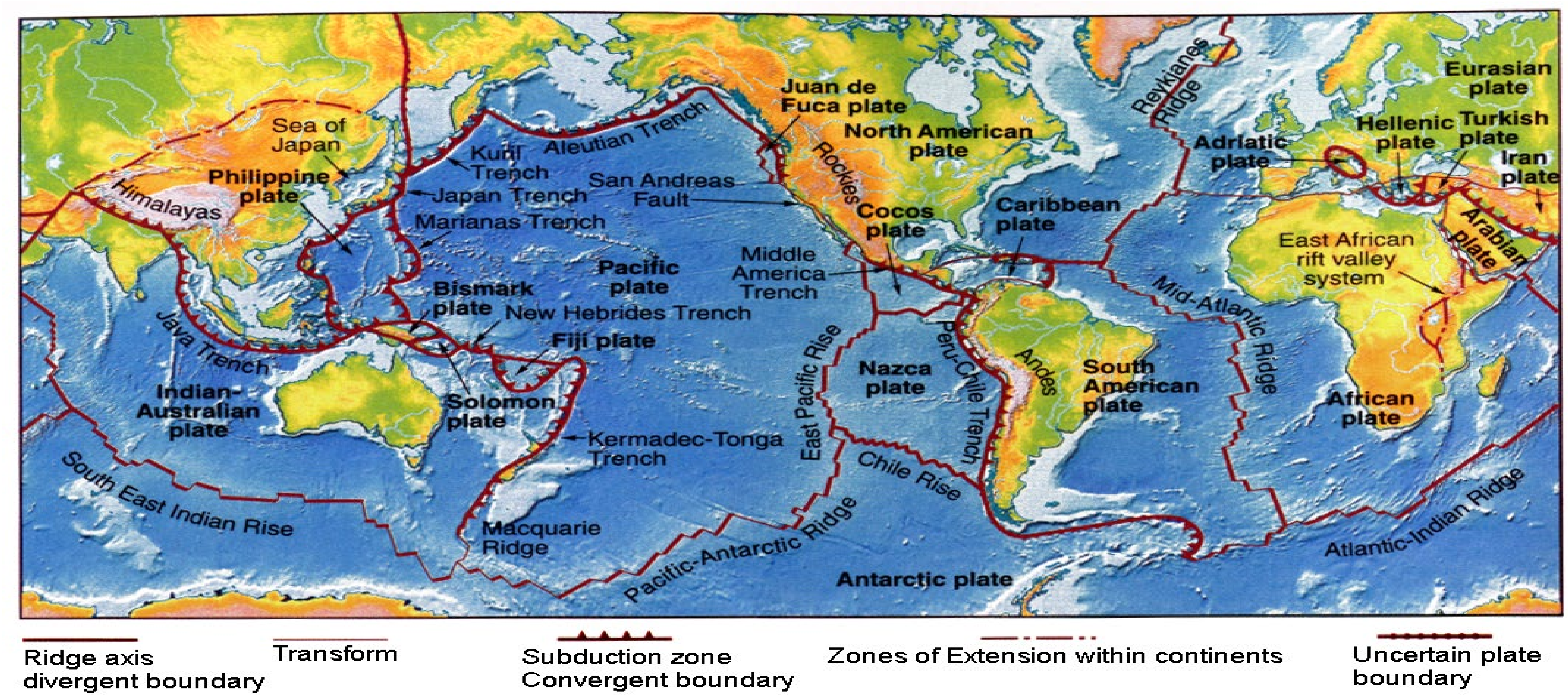
Internal Structure of the Earth





The Crust is fractured into Tectonic Plates such as the Eurasian
The Mantle, a zone of molten Silicates and other minerals. Molten so it moves, the source of this is the Earth's intense inner heat which sets up convection currents. 2,900km thick
Eurasian Plate
North American Plate
African Plate
The Crust – 2 types – Oceanic (denser, newer, thinner) and Continental (older, thicker & less dense)
Caribbean plate
Cocos P.
Nazca Plate
Asthenosphere - The upper part of the mantle approximately 80km deep where rocks are kept in a semi-molten state
Convection currents – heat currents in the molten magma that move the crust above very slowly
Plate margin – the EDGES of plates where 2 plates are either moving apart, colliding together or sliding past one another
Outer Core – under slightly less pressure
Mohorovičič or Moho Discontinuity – the junction between the Earth's crust and the mantle where seismic waves are modified
Solid core of Iron and Nickel, which is solid despite temperatures of 3700°C because of the intense pressure there.
©Rob Gamesby
http://www.coolgeography.co.uk

Tectonic Plates



Earth’s 14 Tectonic Plates and their Movements

Convergence plate boundary: subduction zone etc.
Divergence plate boundary: Plates diverges at mid-ocean ridges
Transform fault: Plates move laterally each other

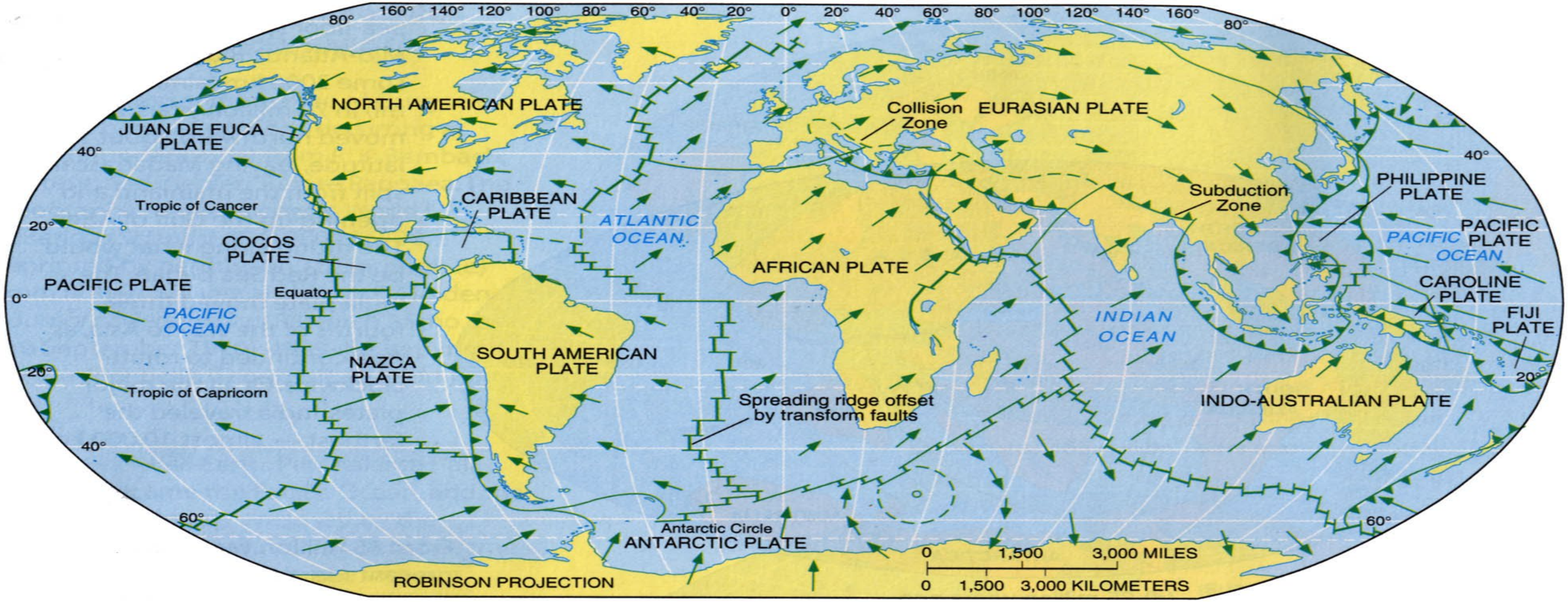
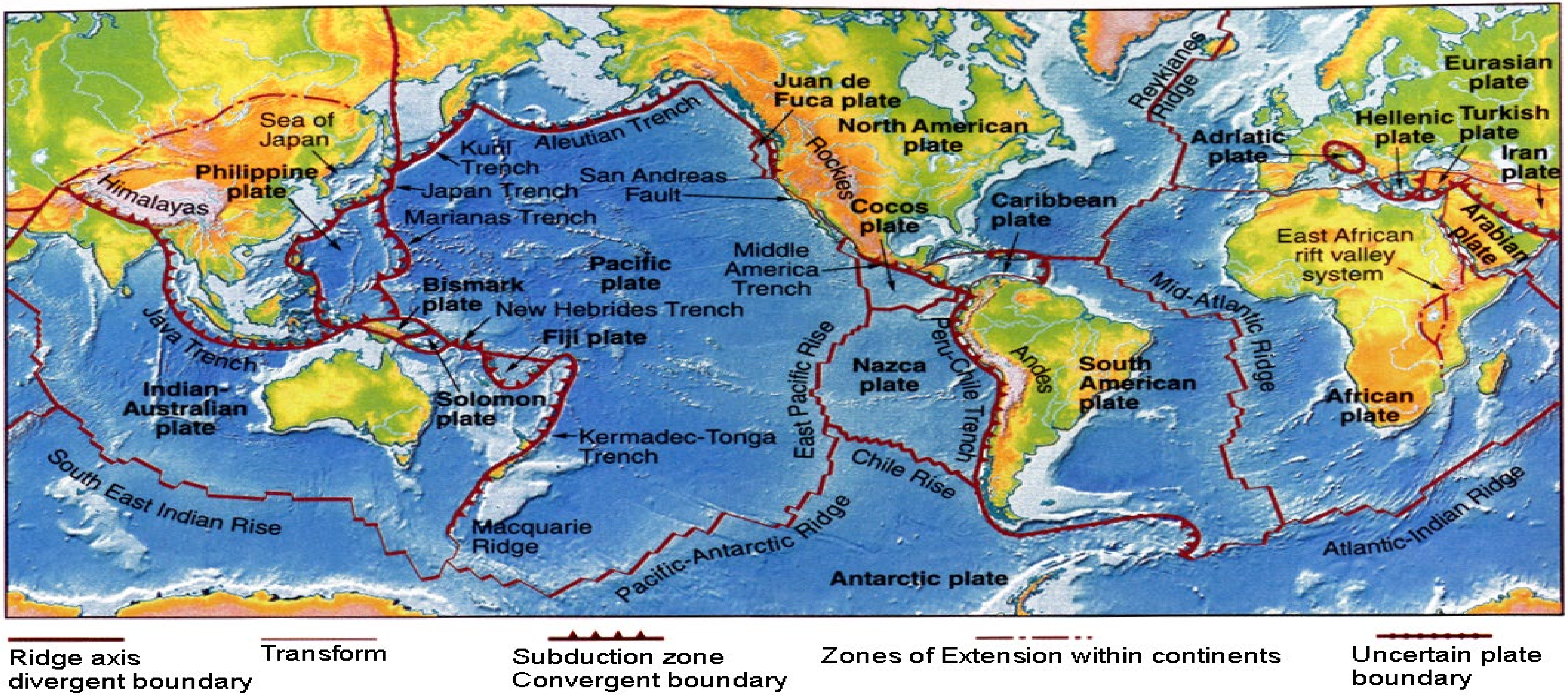


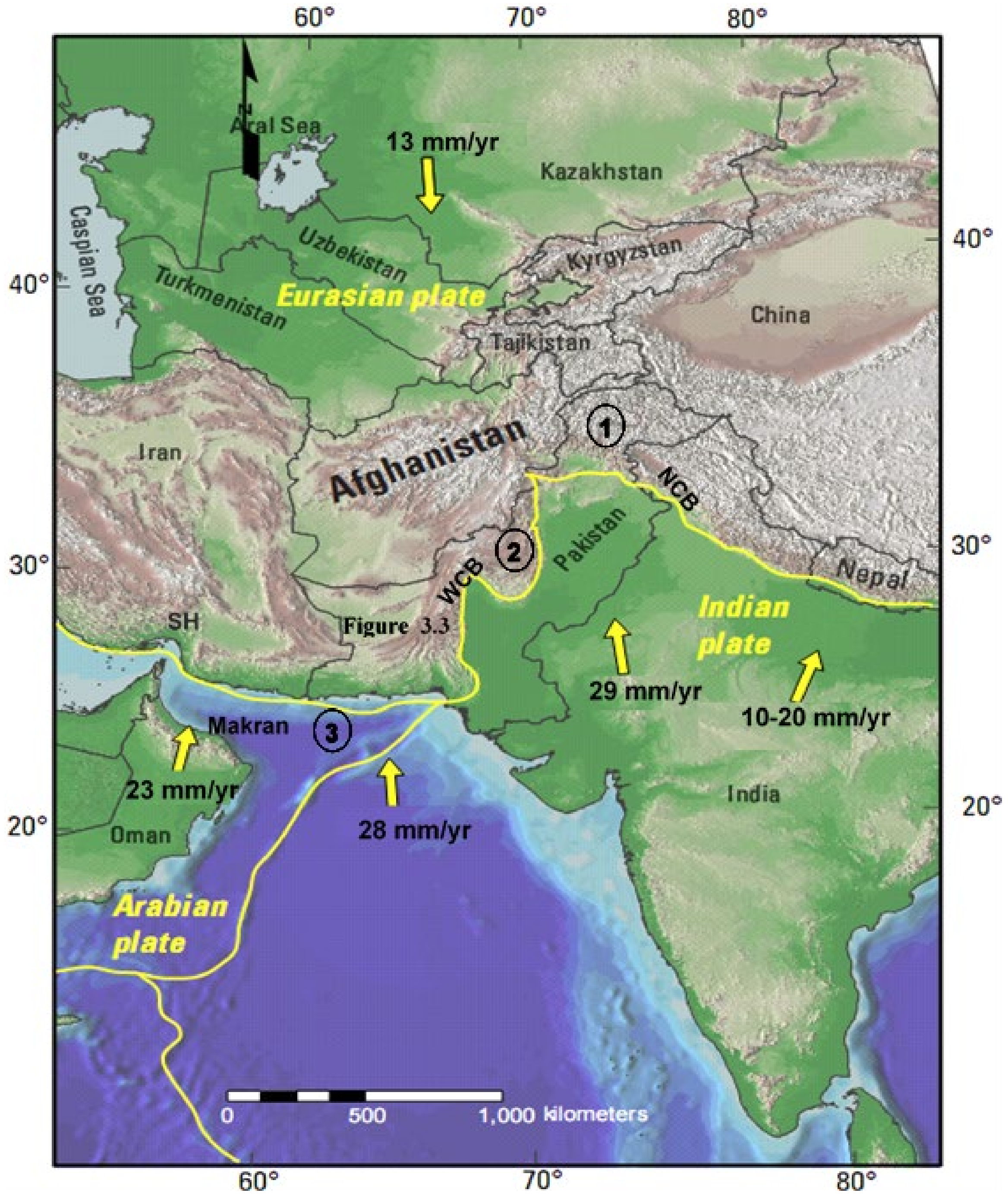
Figure 8-16 Earth’s 14 lithospheric plates and their movements.
Each arrow represents 20 million years of movement, the longer arrows indicating that the Pacific and Nazca plates are moving more rapidly than the Atlantic plates. [Adapted from U.S. Geodynamics Committee.]

Plate Tectonics

- The rate of plate movement ranges from 1 to 10 centimeters per year.
- At the plate edges where there is contact with adjoining plates, boundary tectonic forces act on the rock causing physical and chemical changes in them.
- This is where the massive and radical geological changes (including earthquakes) occur.

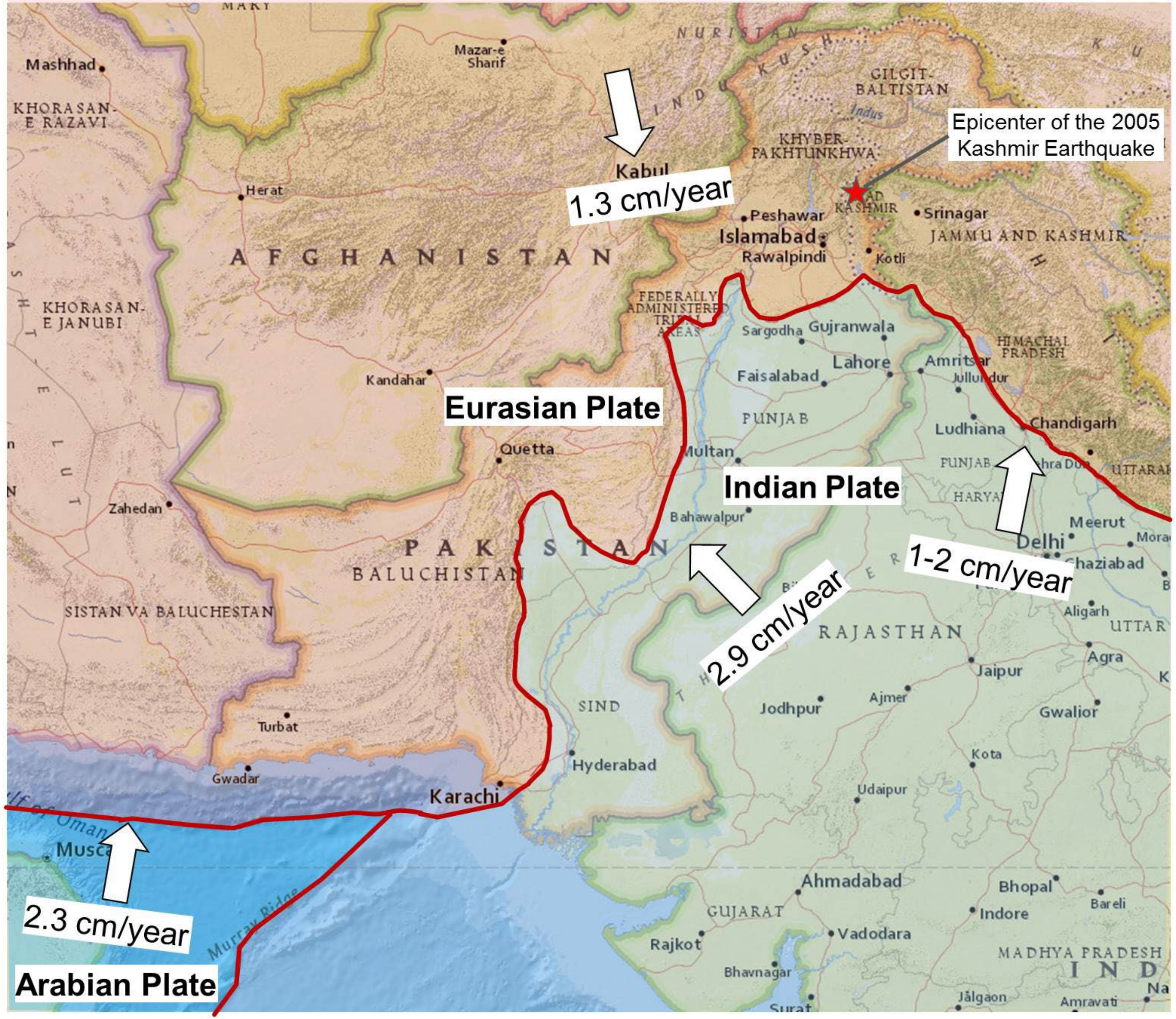
Tectonic Plates



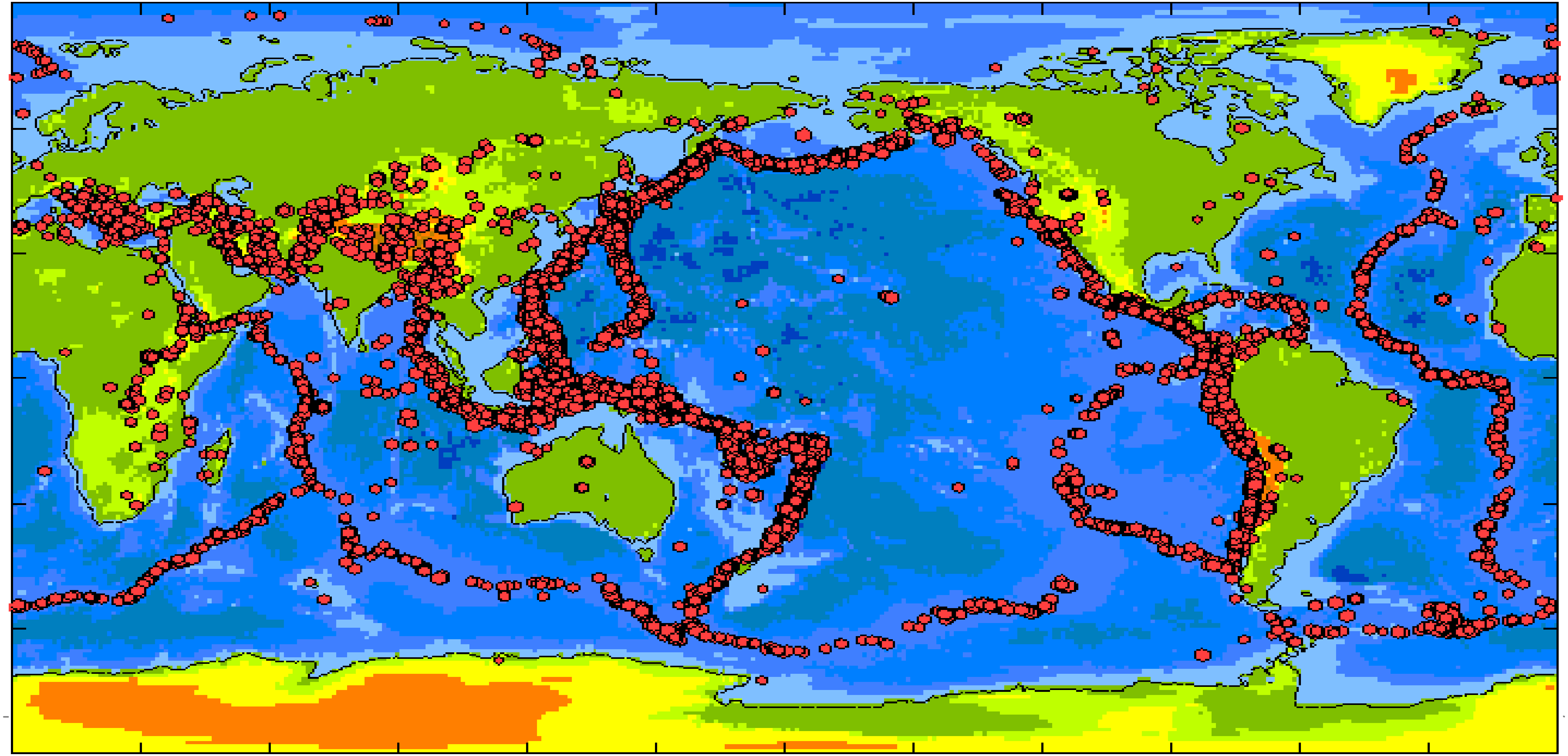


(Modified from Ruleman et al., 2007)

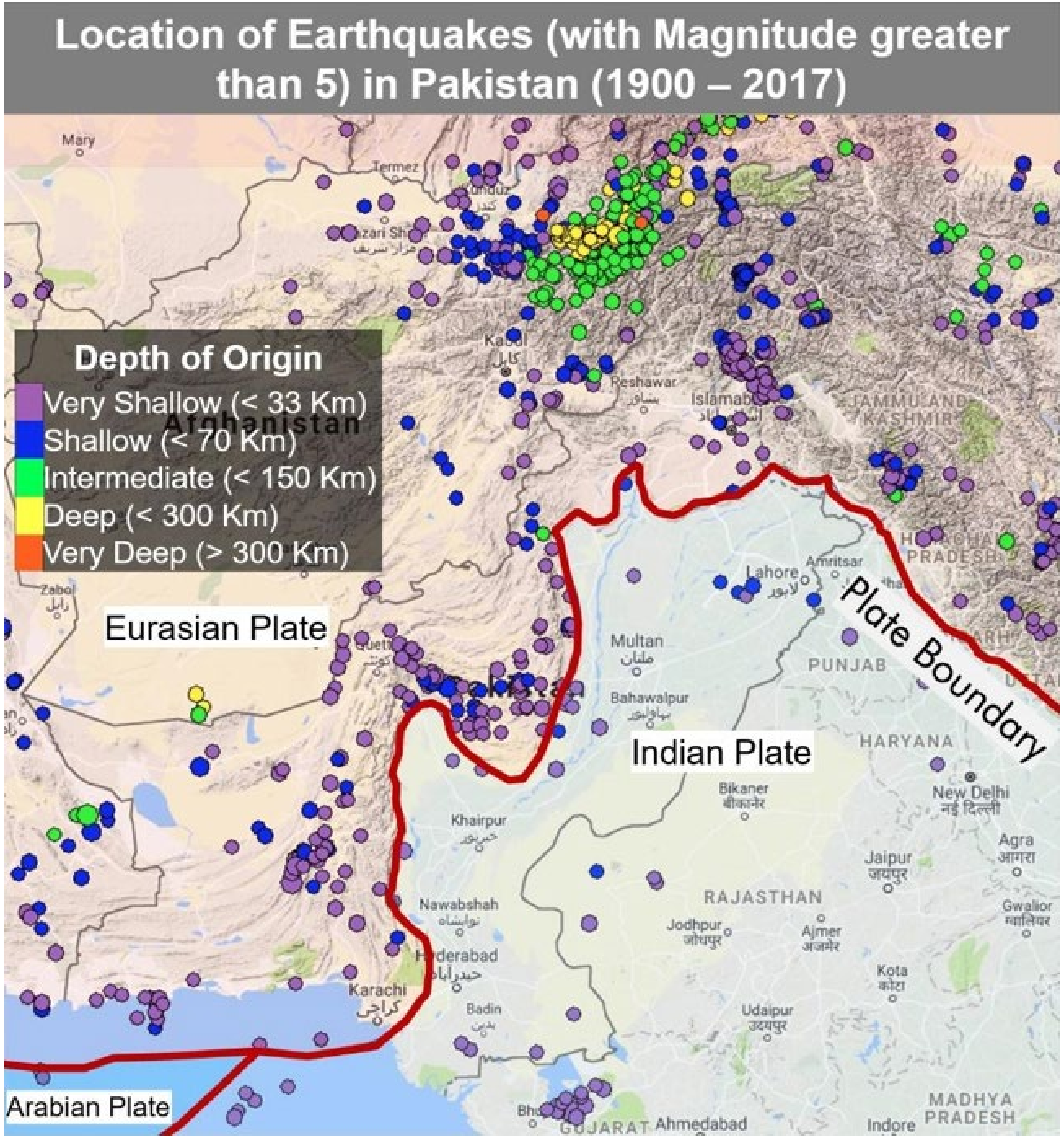
Source: Zaman S. (2016) Probabilistic Seismic Hazard Assessment and Site-Amplification Mapping for Pakistan


Epicenter of the 2005 Kashmir Earthquake
1.3 cm/year
Eurasian Plate
Indian Plate
2.9 cm/year
1-2 cm/year
2.3 cm/year
Arabian Plate

Where do earthquakes occur ?



Seismicity of Pakistan



Three Main Types of Plate Boundaries

Convergent Plate Boundary: When the two plates “bump” into each other

https://jig.space/view/embed?jig=v4Ga2VKw

Divergent Plate Boundary: When the two plates “pull away” from each other

https://jig.space/view/embed?jig=0xKBaZGa

Transform Plate Boundary: When the two plates “slide past” each other

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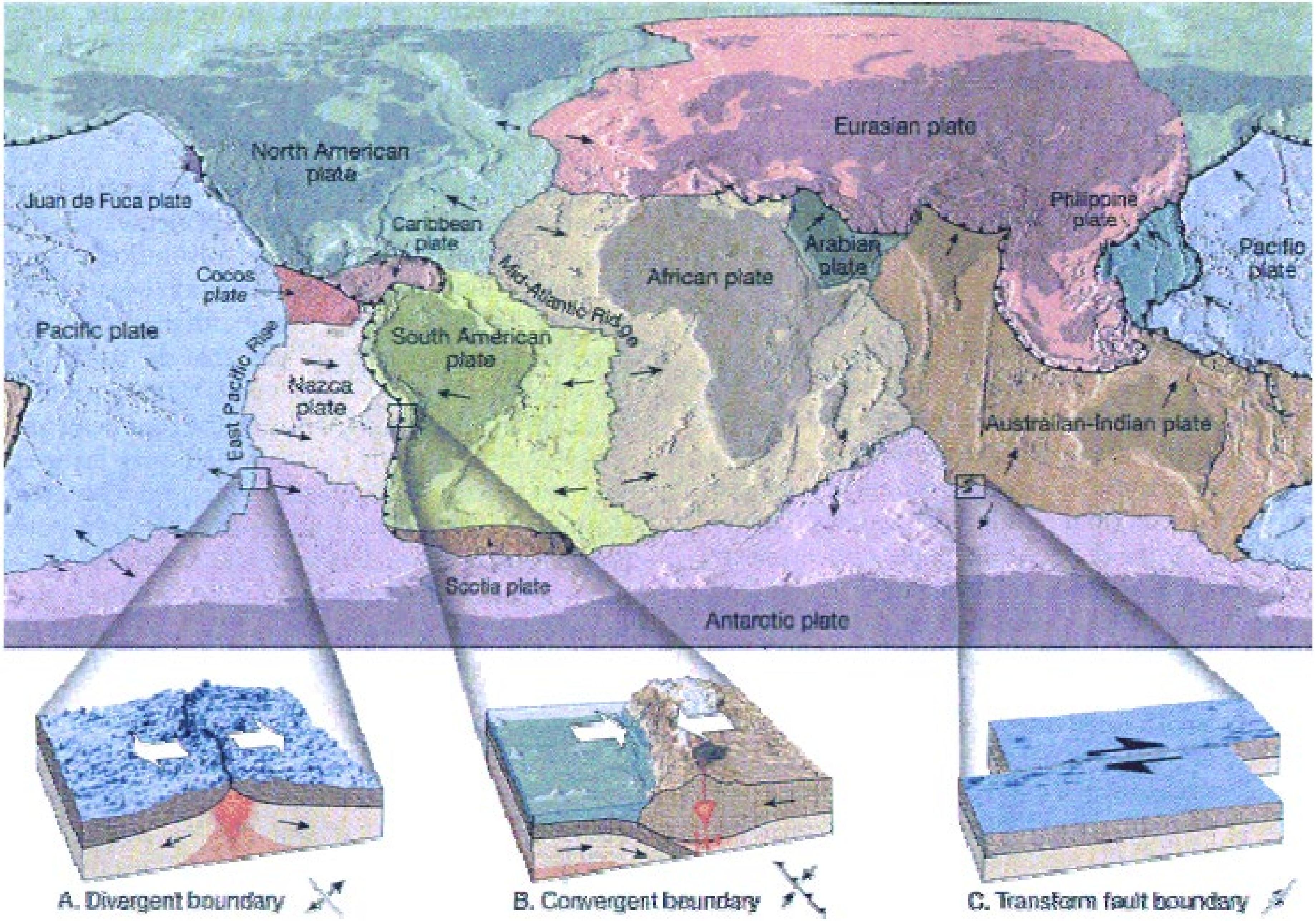
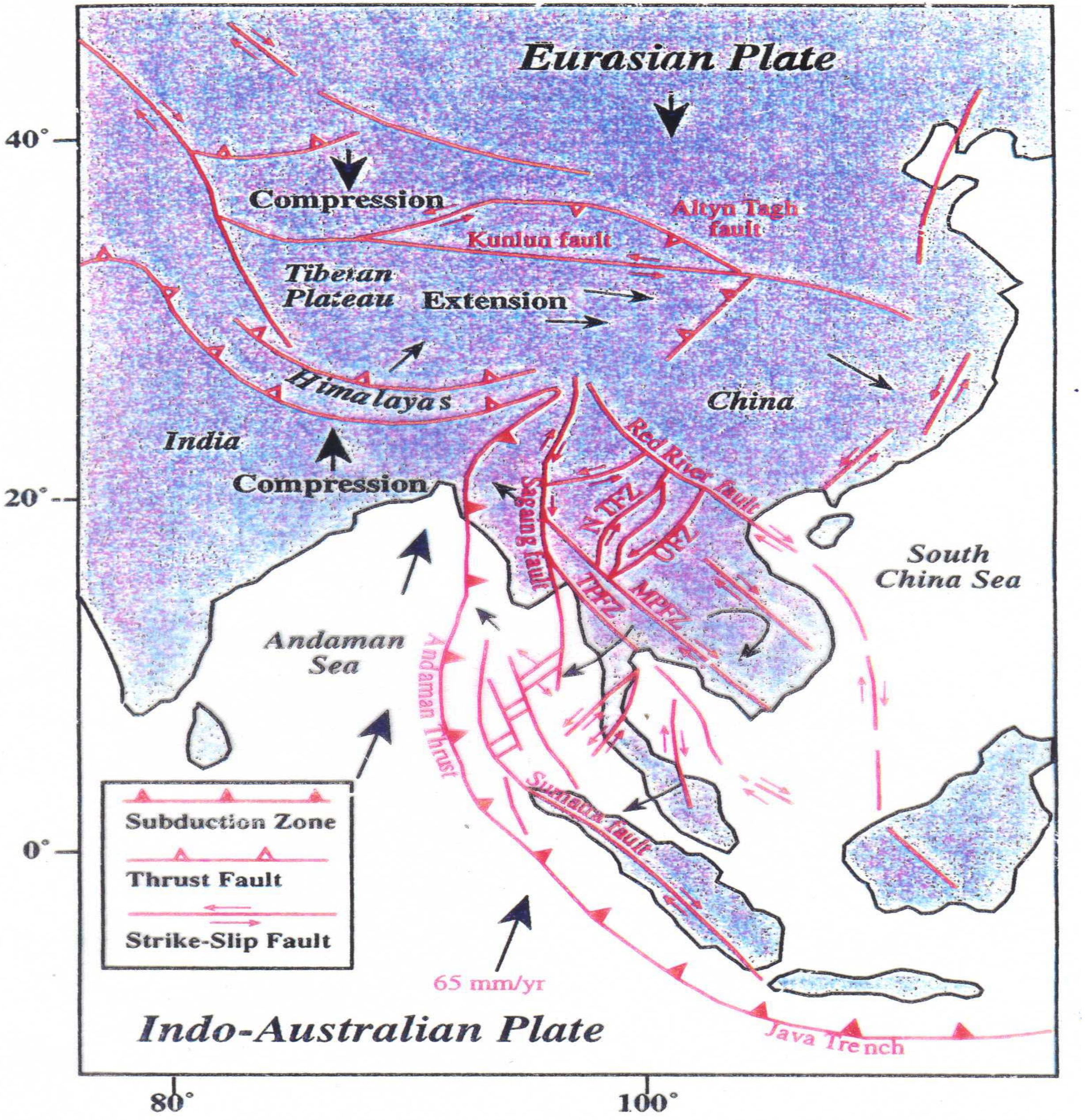


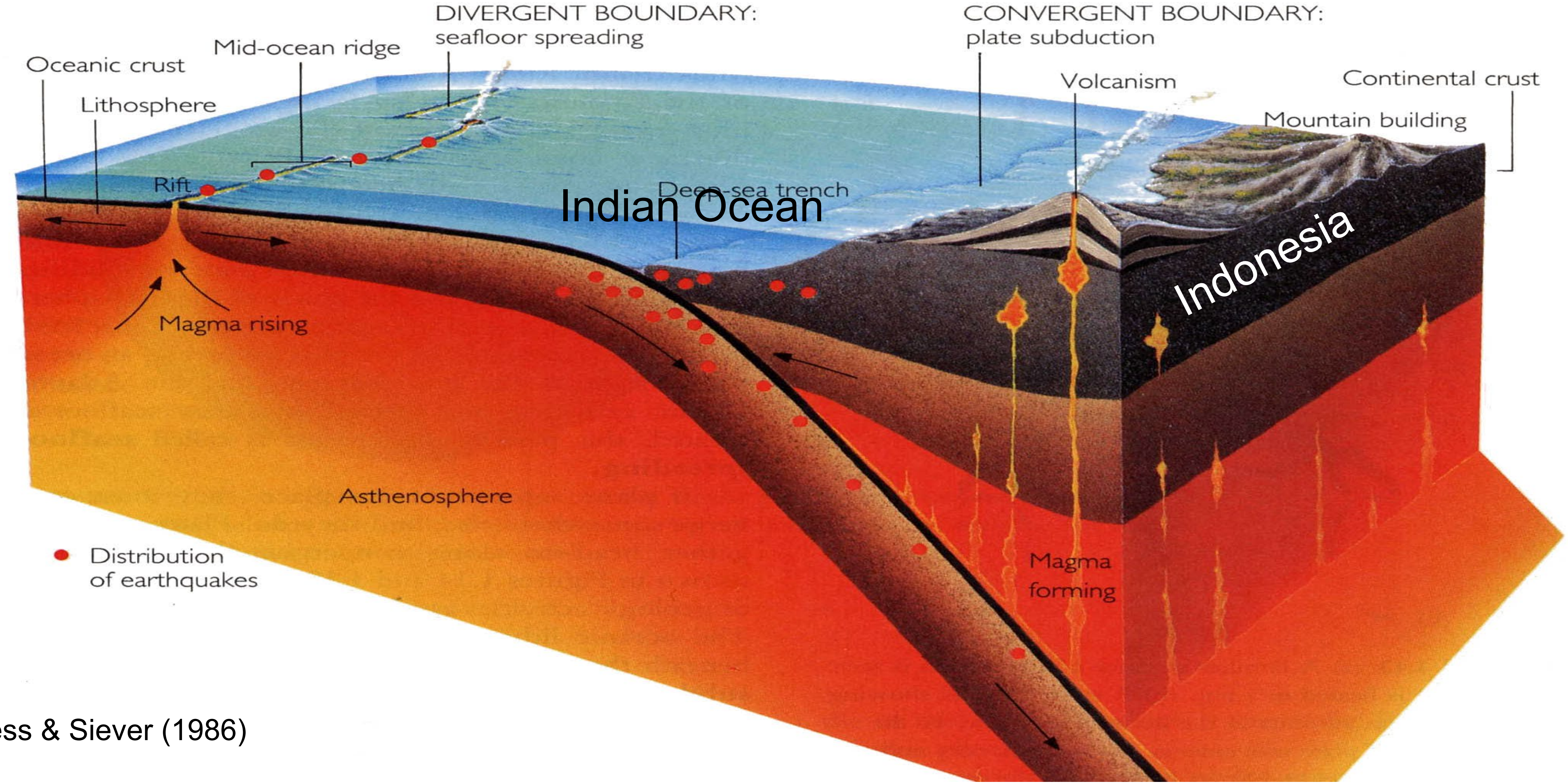
Eurasian plate
North American plate
Juan de Fuca plate
Caribbean plate
Philippine plate
Arabian plate
Pacific plate
Cocos plate
African plate
Mid-Atlantic Ridge
Pacific plate
South American plate
East Pacific Rise
Nazca plate
Australian-Indian plate
Scotia plate
Antarctic plate
A. Divergent boundary
B. Convergent boundary
C. Transform fault boundary

Tectonic Map of South-East Asia

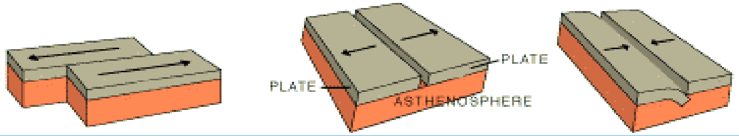


(after Polachan et al., 1991)

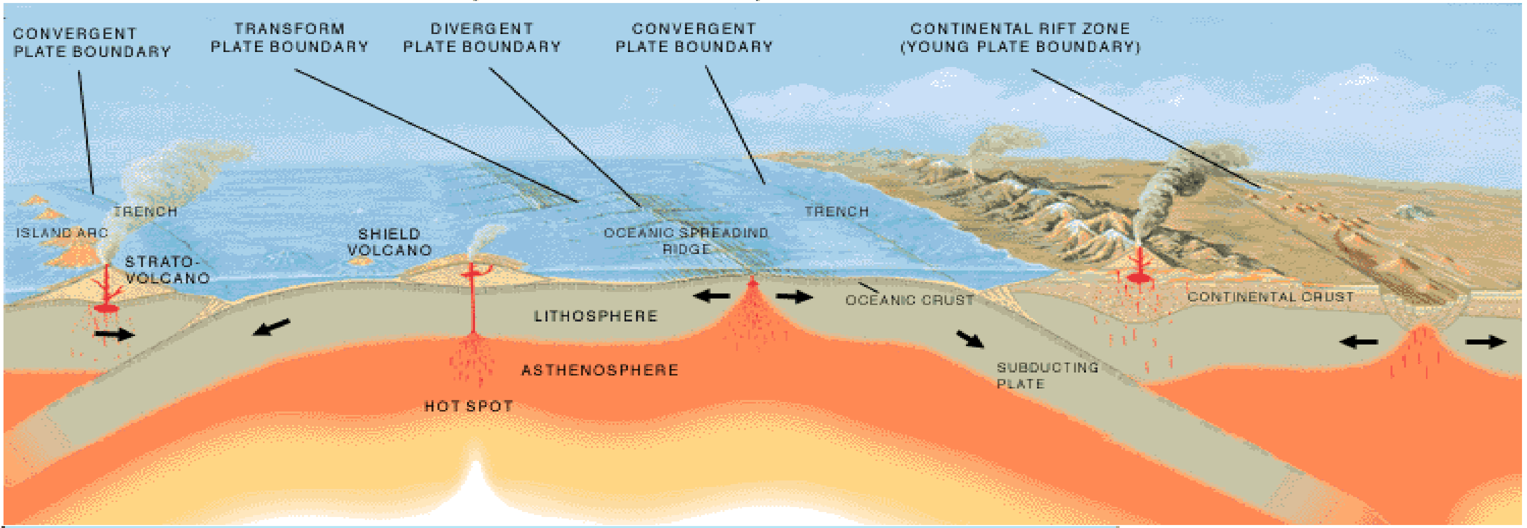
New tectonic plate is created at mid-ocean ridges by the upwelling and cooling of magma (molten rock) from the Earth's mantle. In order to conserve mass, the horizontally moving plates are believed to be absorbed at the ocean trenches where a subduction process carries the tectonic plate downward into the Earth's interior.

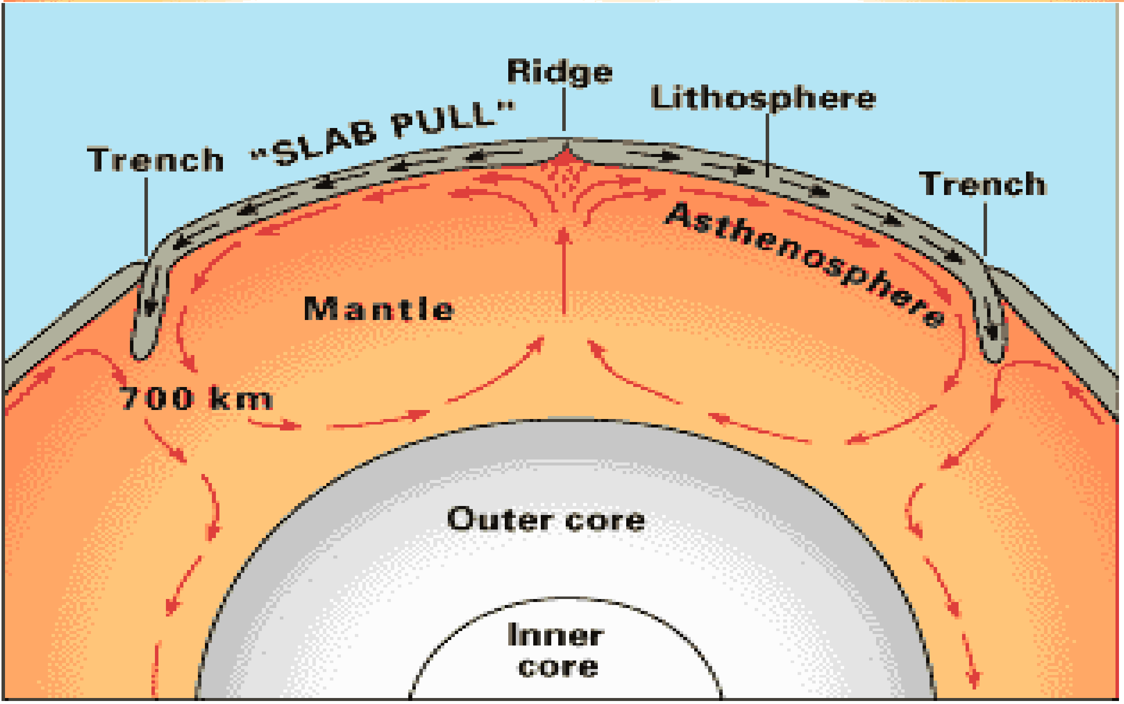


Press & Siever (1986)



Crustal Movements and Plate Boundaries





An **oceanic spreading ridge** is the fracture zone along the ocean bottom where molten mantle material comes to the surface, thus creating new crust. This fracture can be seen beneath the ocean as a line of ridges that form as molten rock reaches the ocean bottom and solidifies.

An **oceanic trench** is a linear depression of the sea floor caused by the subduction of one plate under another.

Three types of plate convergence

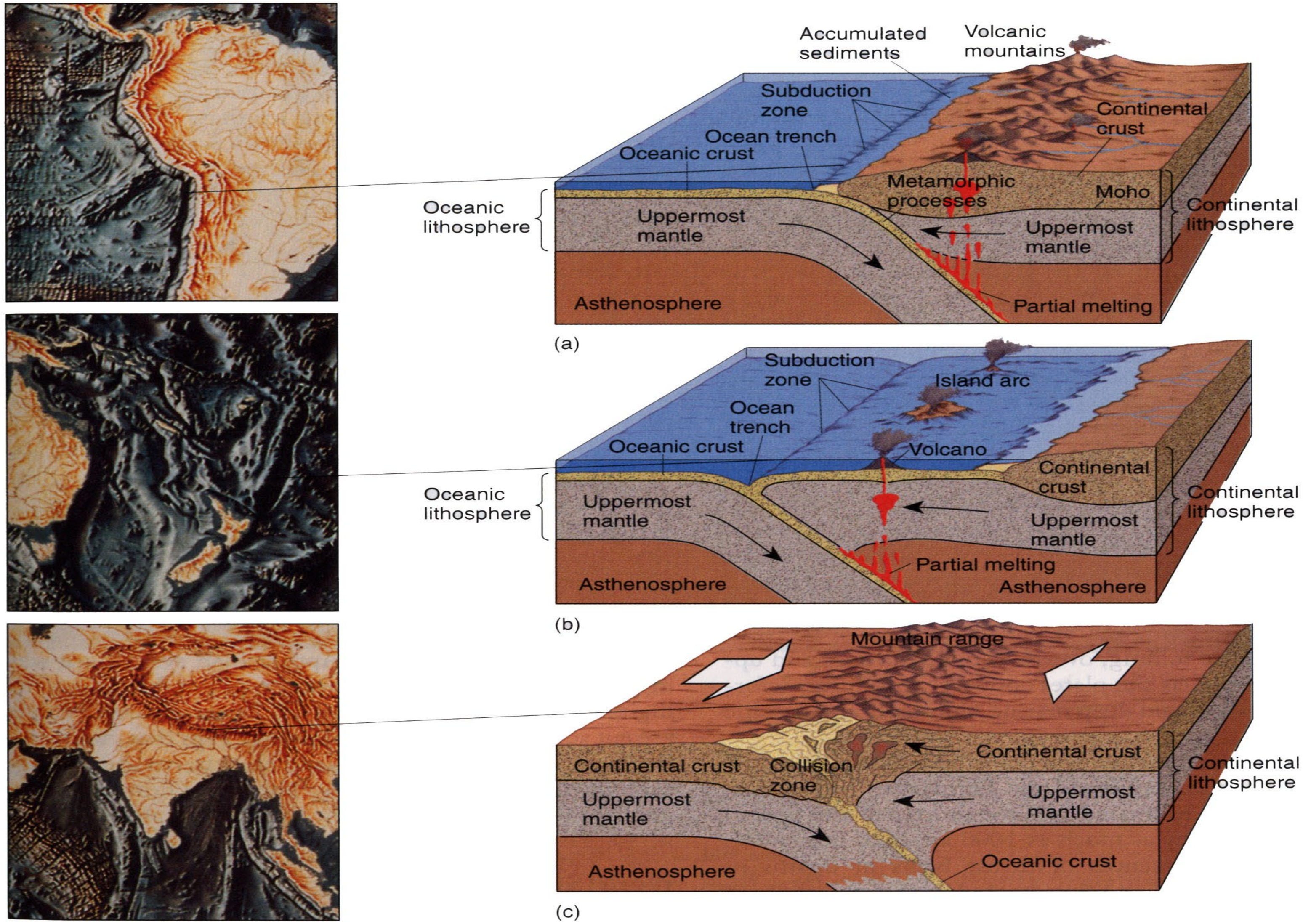


Figure 9-15 **Three types of plate convergence.**
Real-world examples illustrate three types of crustal collisions. Oceanic–continental (example: Nazca plate–South American plate collision and subduction) (a); oceanic–oceanic (example: New Hebrides Trench near Vanuatu, 16° S, 168° E) (b); and, continental–continental (example: India plate and Eurasian landmass collision and resulting Himalayan Mountains) (c). [Inset illustrations derived from *Floor of the Oceans,* 1975, by Bruce C. Heezen and Marie Tharp. © 1980 by Marie Tharp.]

- *This plate tectonics theory has a number of implications for our understanding of earthquakes.*

- **First**, many more earthquakes will occur along the edges of the interacting plates (**interplate earthquakes**) than within the plate boundaries (**intraplate earthquakes**).

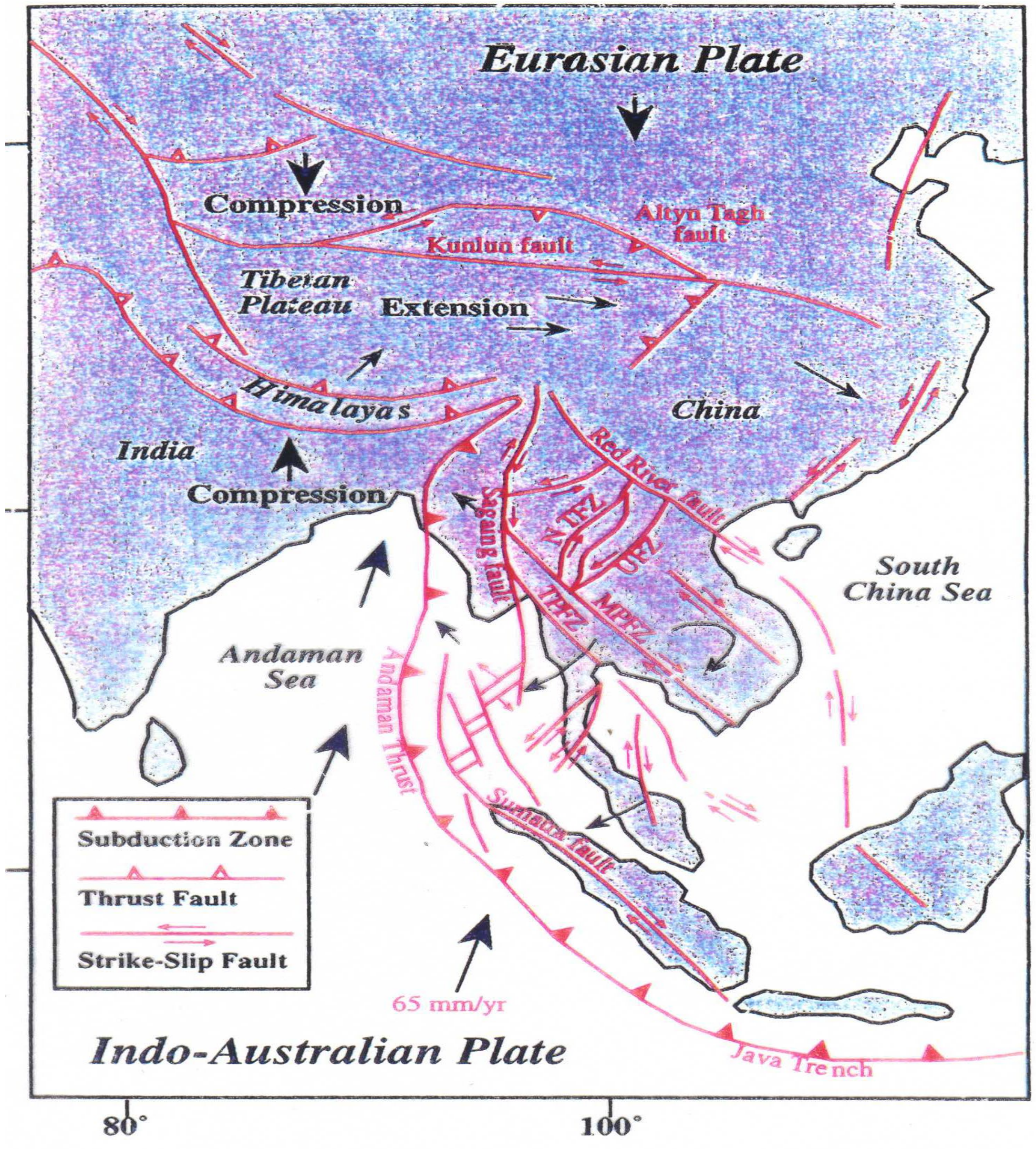
- **Second**, because the directions of forces on plates vary across them, the mechanism of the sources of earthquakes and their size differ in different parts of a plate.

    - *Only about 10% of the world's earthquakes occur along the ocean ridge system. In contrast, earthquakes occurring where plate boundaries converge, such as trenches, contribute about 90 %.*

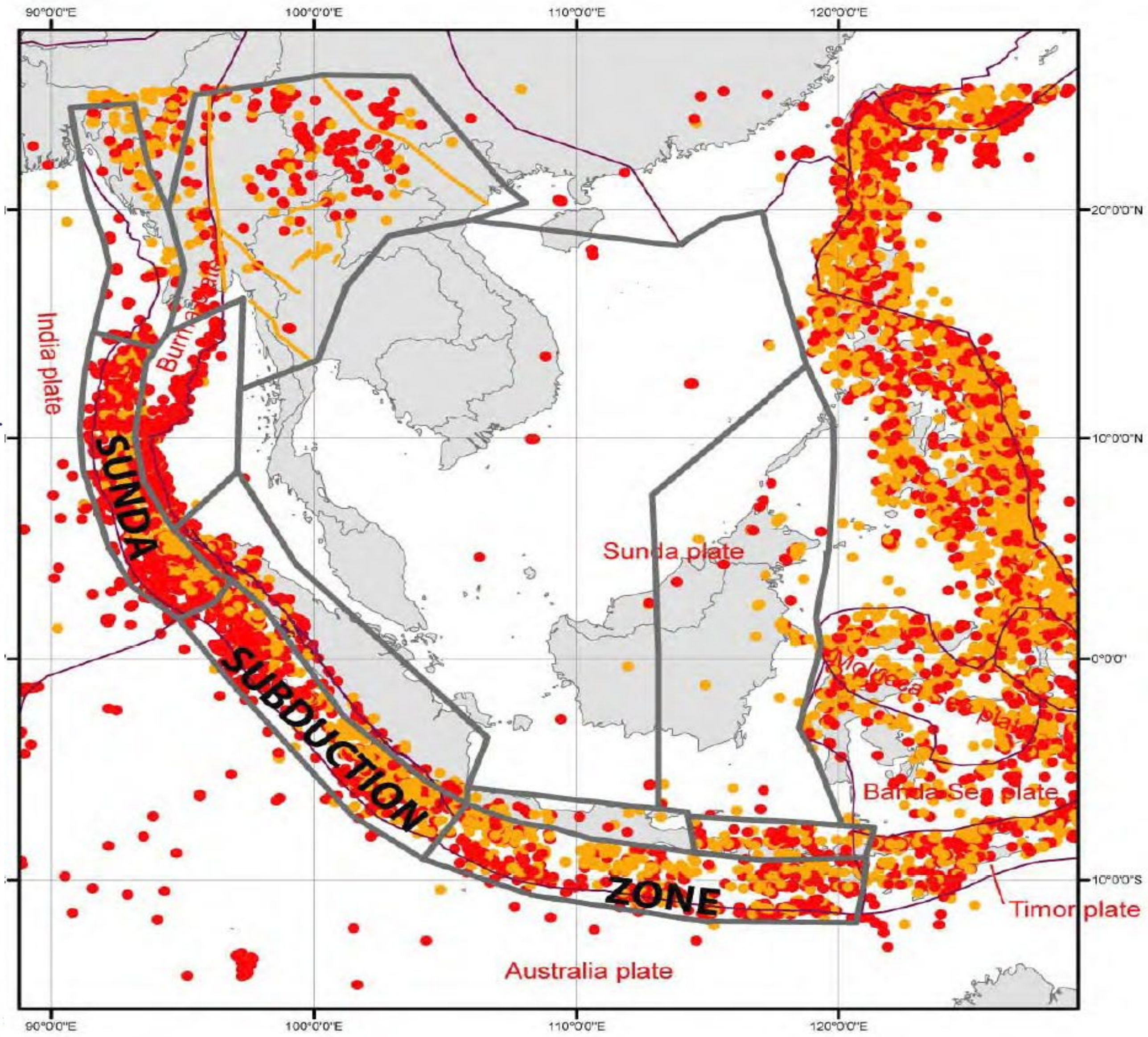
- **Third**, the grand scale of the plate pattern and the steady rate of plate spreading imply that along a plate edge the slip should, on average, be a constant value over many years.

    - *This idea suggests that the historical patterns of distance and time intervals between major earthquakes along major plate boundaries provide at least crude indication of places at which large earthquakes might occur.*

Tectonic Map

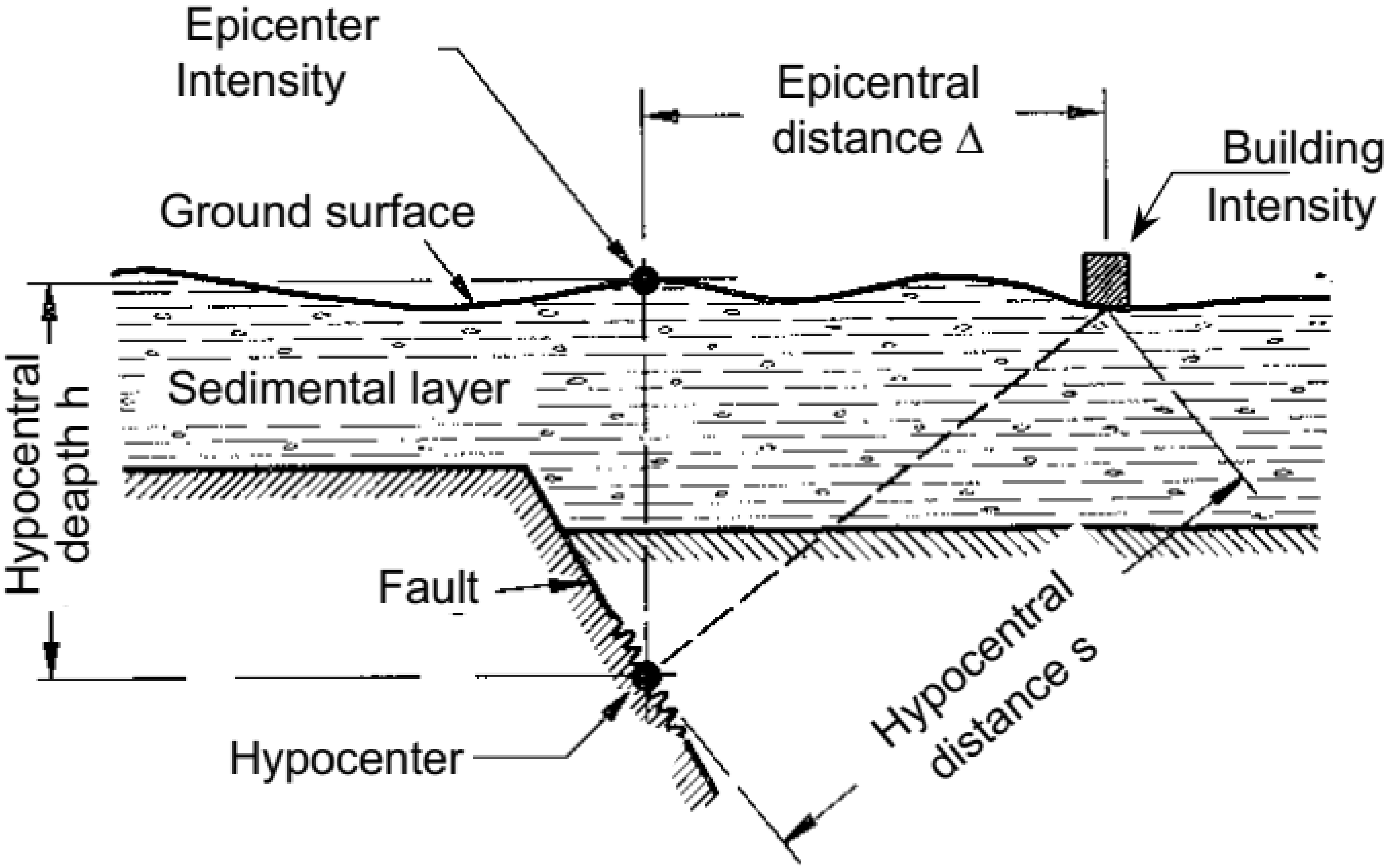


(after Polachan et al., 1991)



- focal-depth less than 30 km
- focal-depth between 30 km and 50 km
- plate-boundary or major fault
- Seismic zone boundary

Seismicity Map



Epicenter
Intensity
Epicentral
distance Δ
Building
Intensity
Ground surface
Sedimental layer
Hypocentral
deapth h
Fault
Hypocenter
Hypocentral
distance s

Thank you for your attention