# EARTH 270 – DISASTERS AND NATURAL HAZARDS (v. 2018)

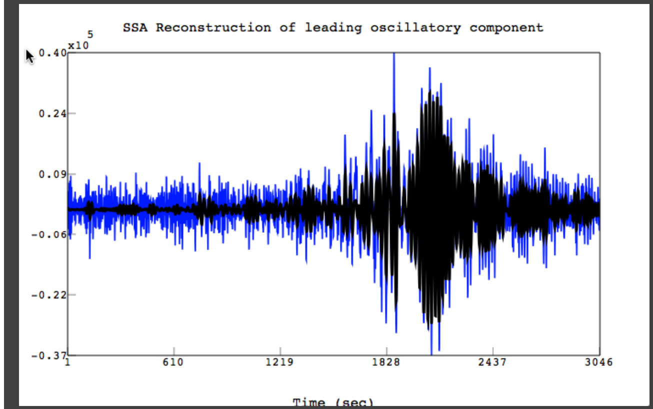
*Kensennuma City, Miyagi Prefecture , Japan, March 2011*

PROFESSOR S.G. EVANS, PhD, PEng (Room 303, Earth Science and Chemistry (ESC) Building)

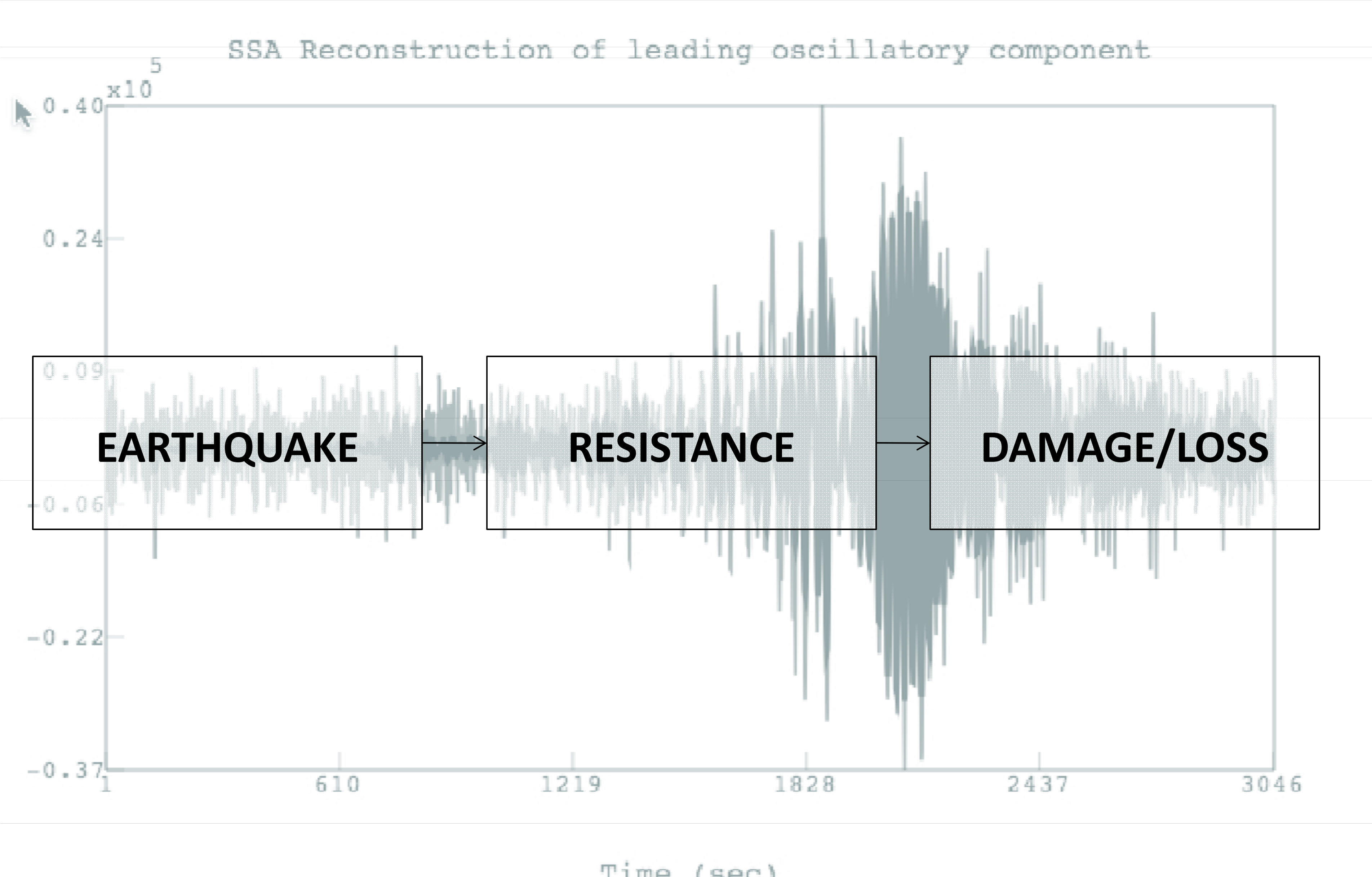
UNIVERSITY OF WATERLOO

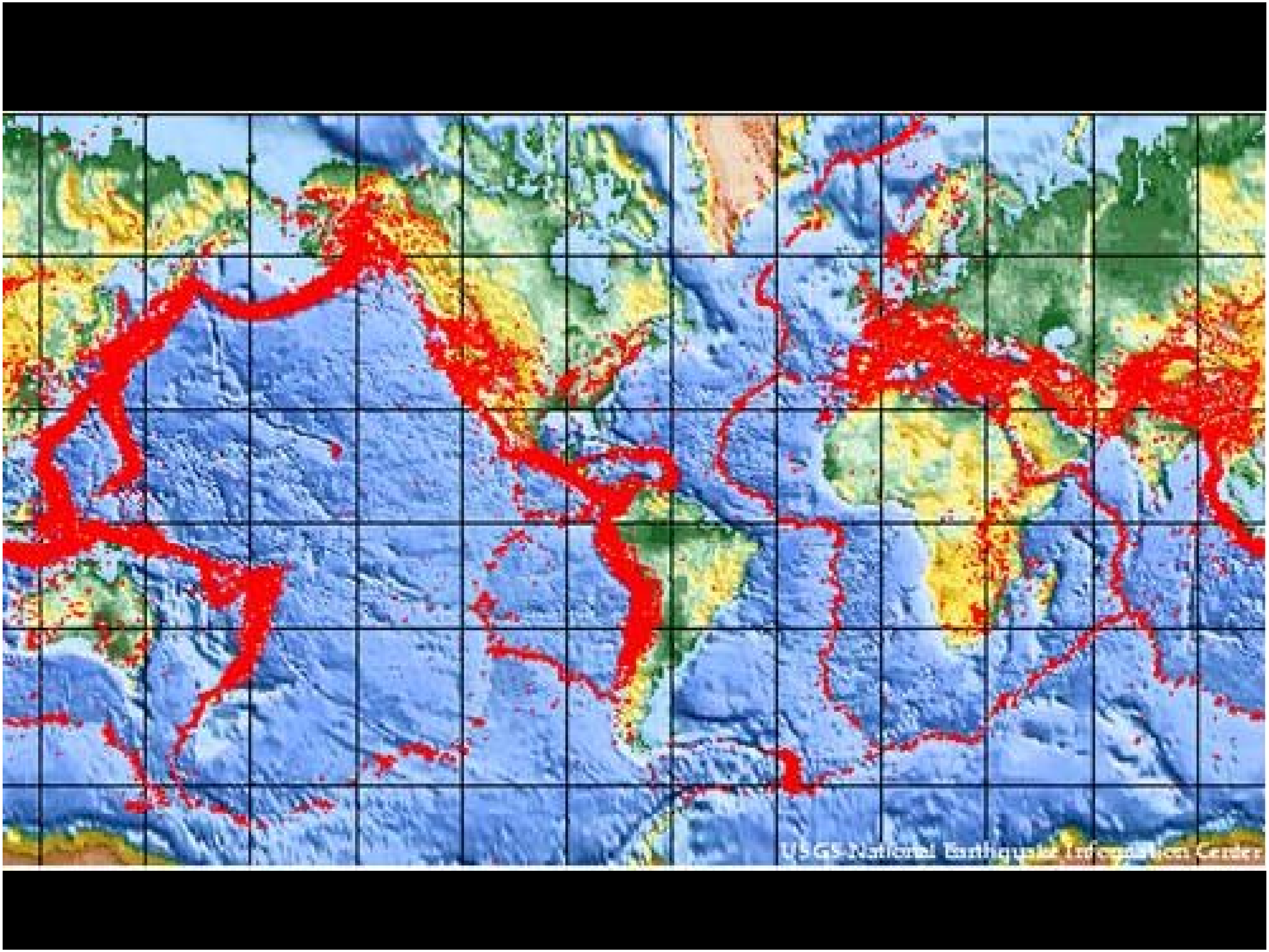
# EARTHQUAKES 1

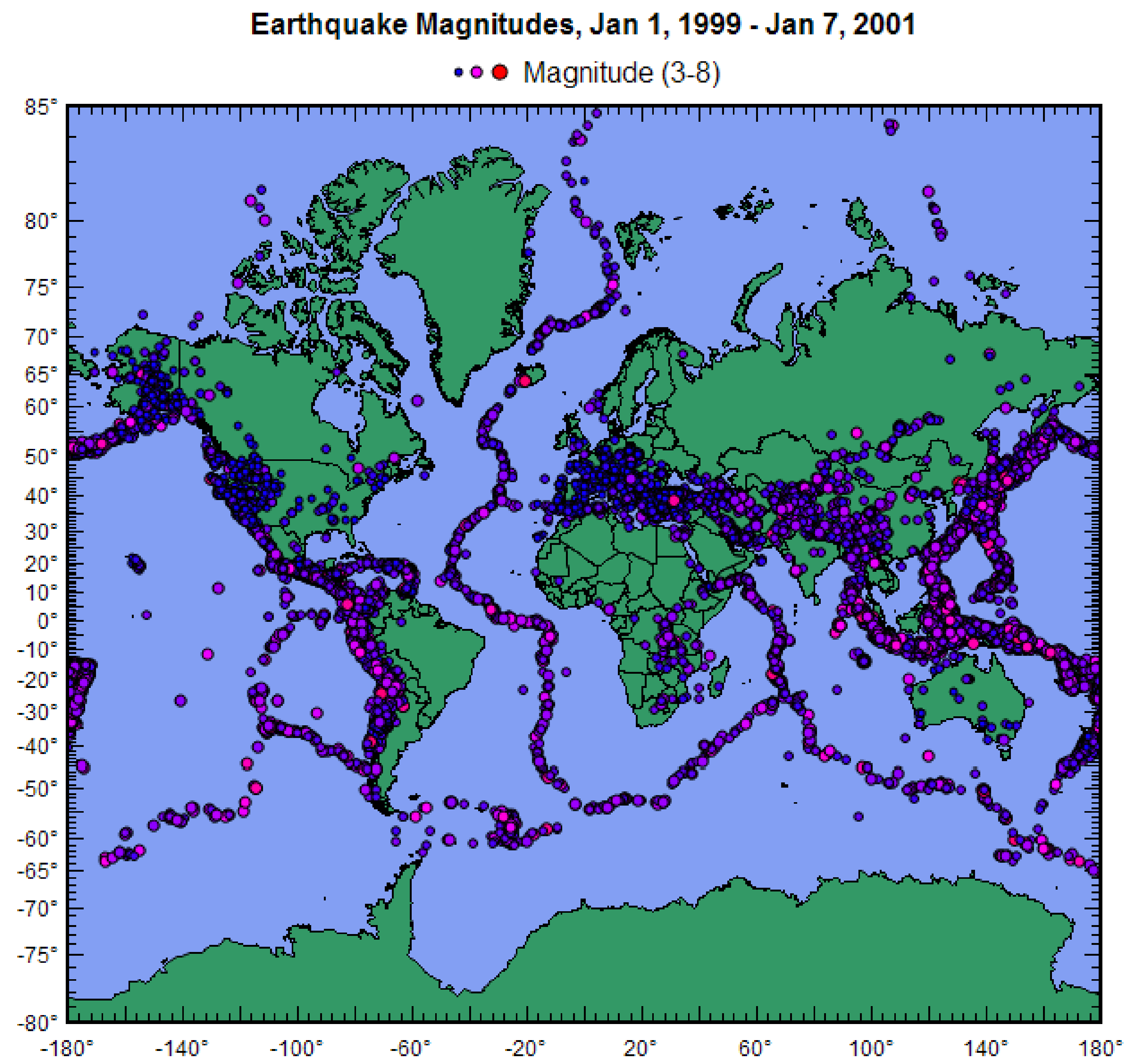




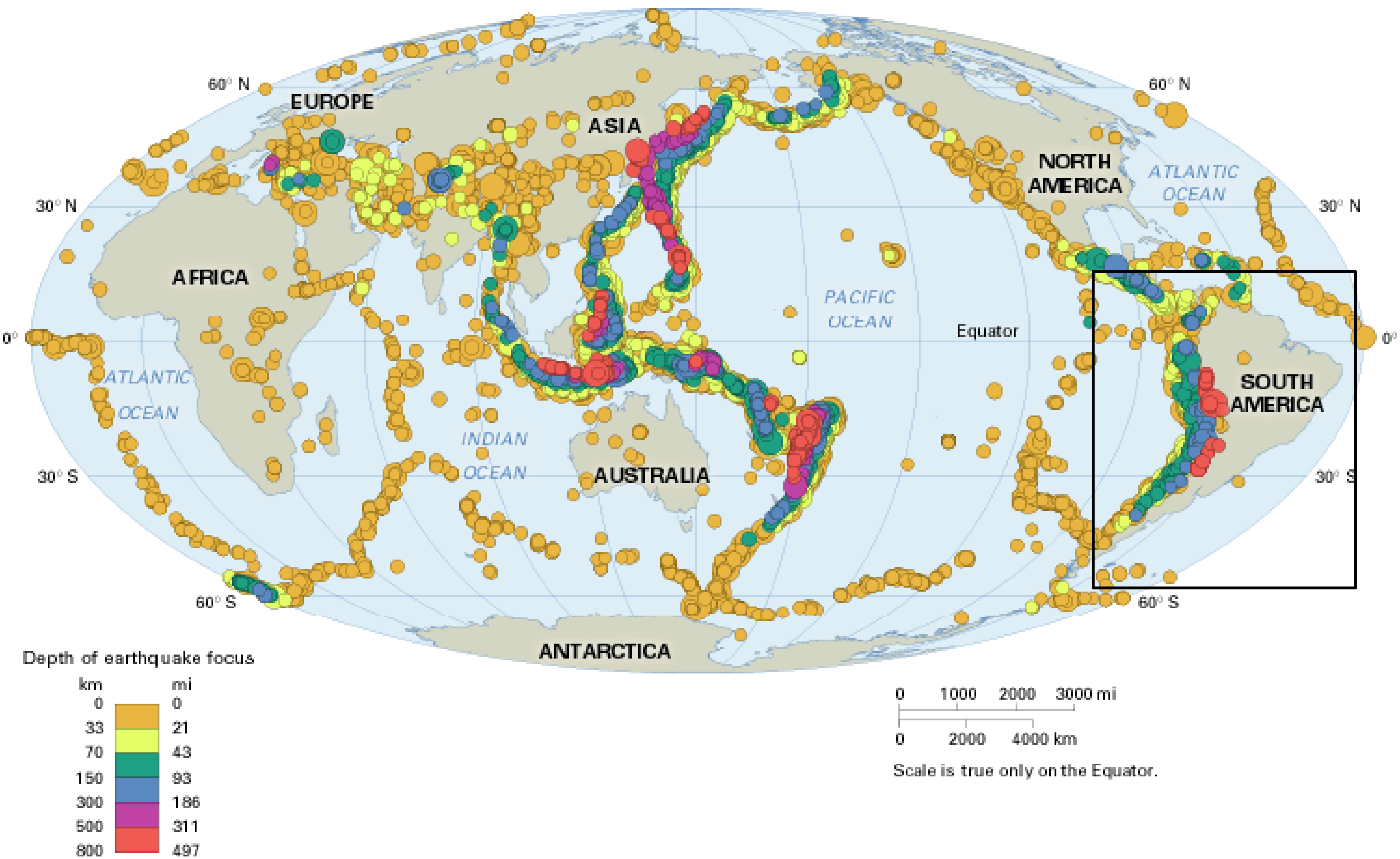

**Earthquake is a sudden slip on a fault (or a new rupture of the crust ) and the resulting ground shaking caused by the radiated seismic energy generated by the slip (rupture) ; slip (rupture) usually caused by tectonic forces but may be caused by magma movement in the vicinity of volcanoes or other sudden stress changes in the crust**


SSA Reconstruction of leading oscillatory component
x10^5
0.40
0.24
0.09
-0.06
-0.22
-0.37
1
610
1219
1828
2437
3046
Time (sec)
EARTHQUAKE
RESISTANCE
DAMAGE/LOSS

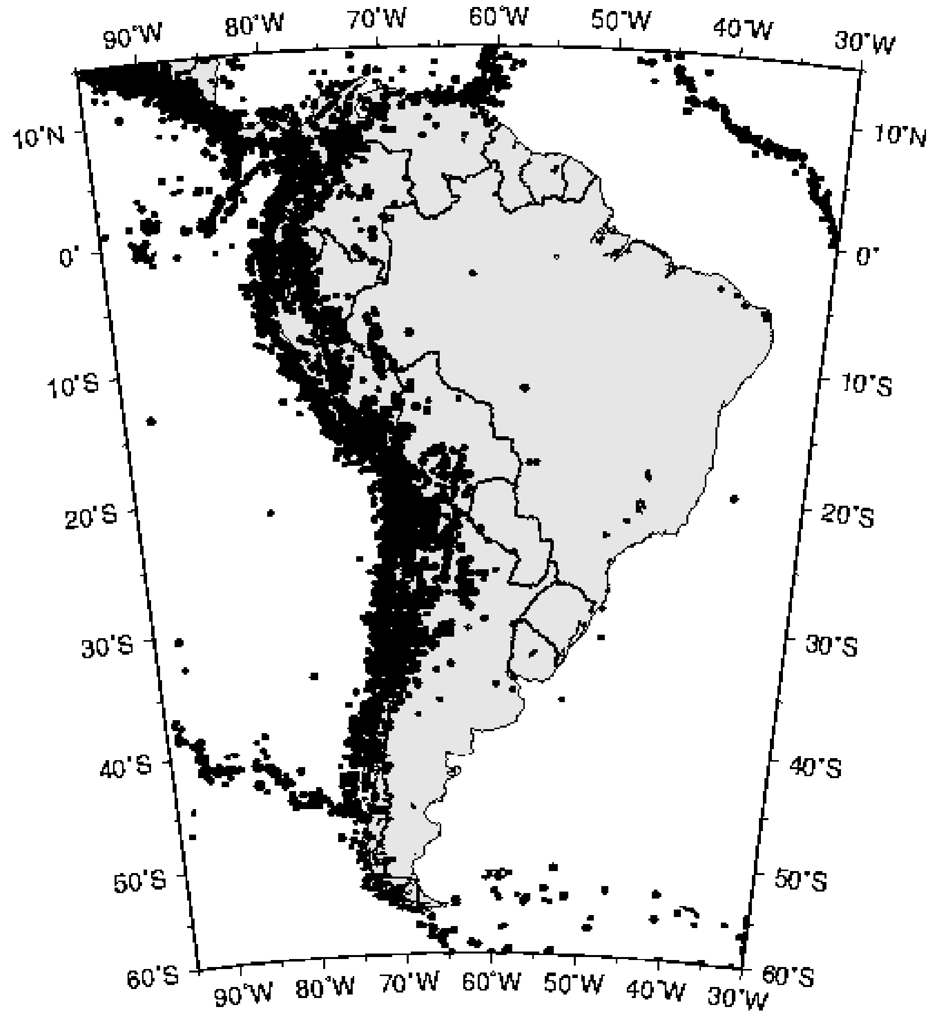

USGS National Earthquake Information Center


Earthquake Magnitudes, Jan 1, 1999 - Jan 7, 2001
Magnitude (3-8)
85°
80°
75°
70°
65°
60°
50°
40°
30°
20°
10°
0°
-10°
-20°
-30°
-40°
-50°
-60°
-65°
-70°
-75°
-80°
-180°
-140°
-100°
-60°
-20°
20°
60°
100°
140°
180°

## Global seismic centres in 1975–99: earthquakes of magnitude 5.5 and greater




Circle size is proportional to earthquake magnitude.




# EPICENTRES OF EARTHQAKES – CENTRAL AND SOUTH AMERICA



1. PLATE TECTONICS
2. DEVELOPMENT OF EVIDENCE
3. PLATE BOUNDARIES
4. IMPLICATIONS FOR NATURAL HAZARDS AND DISASTERS (EARTHQUAKES AND VOLCANOES)

# LOCATION OF EARTHQUAKE EPICENTRES

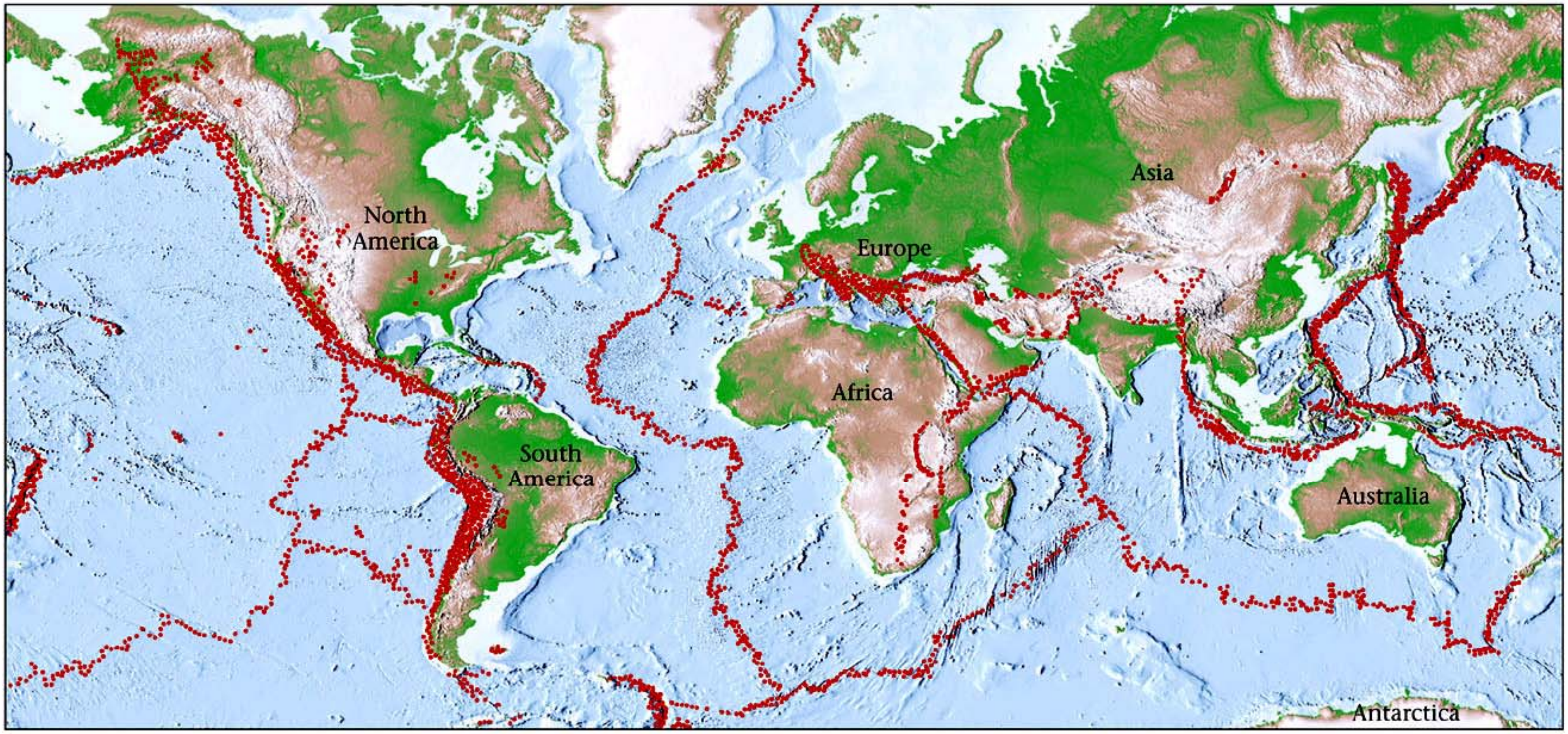
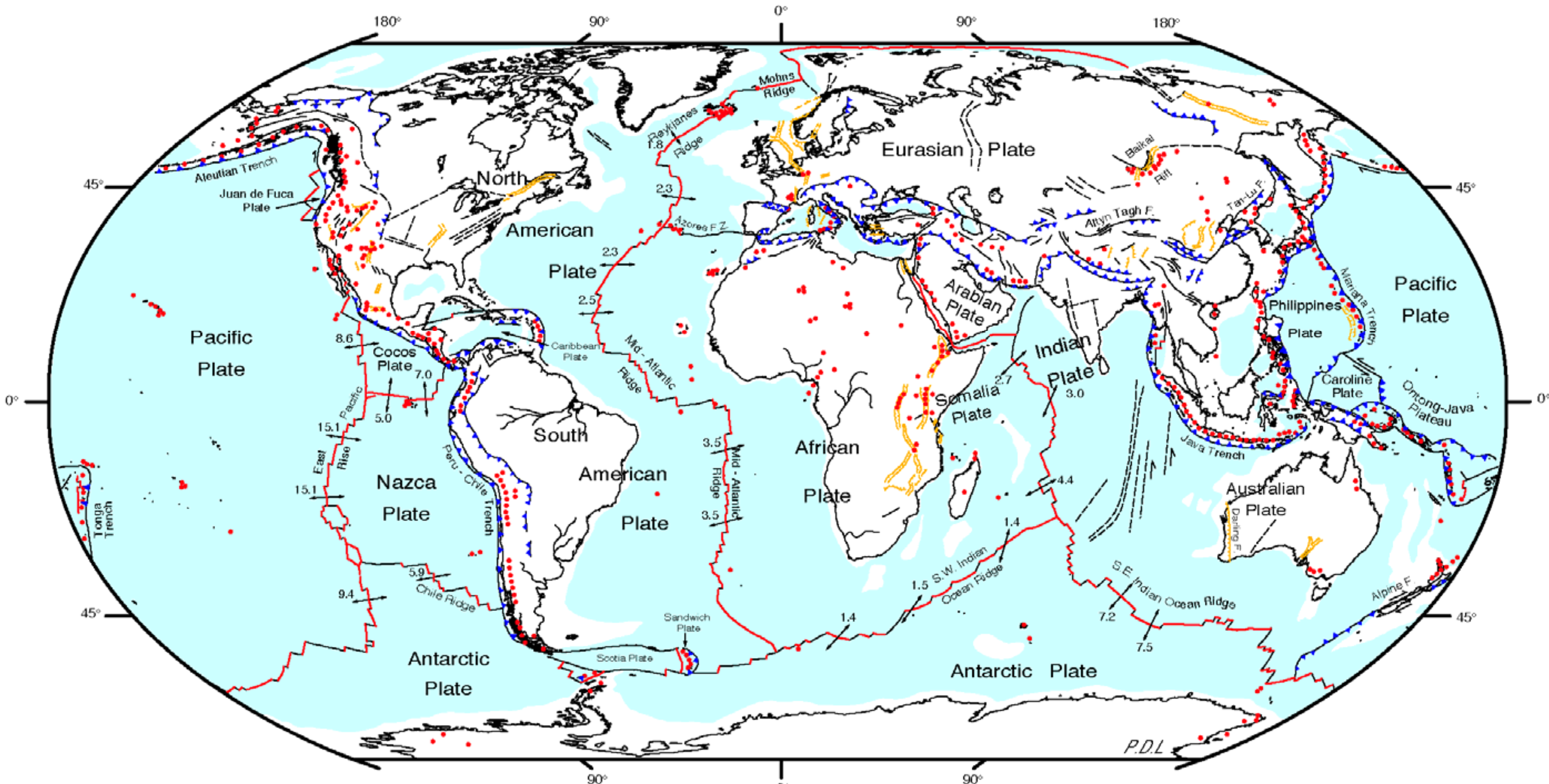



FIGURE 4.5

*Earth: Portrait of a Planet*, 2nd Edition

# PLATE BOUNDARIES, EARTHQUAKES, ACTIVE FAULTS, AND VOLCANOES




**GLOBAL TECTONIC ACTIVITY MAP OF THE EARTH**

Tectonism and Volcanism of the Last One Million Years

**DTAM - 1**

NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

Robinson Projection

Mainly oceanic crust

Mainly continental crust

October 2002

LEGEND

Actively-spreading ridges and transform faults

Total spreading rate, cm/year

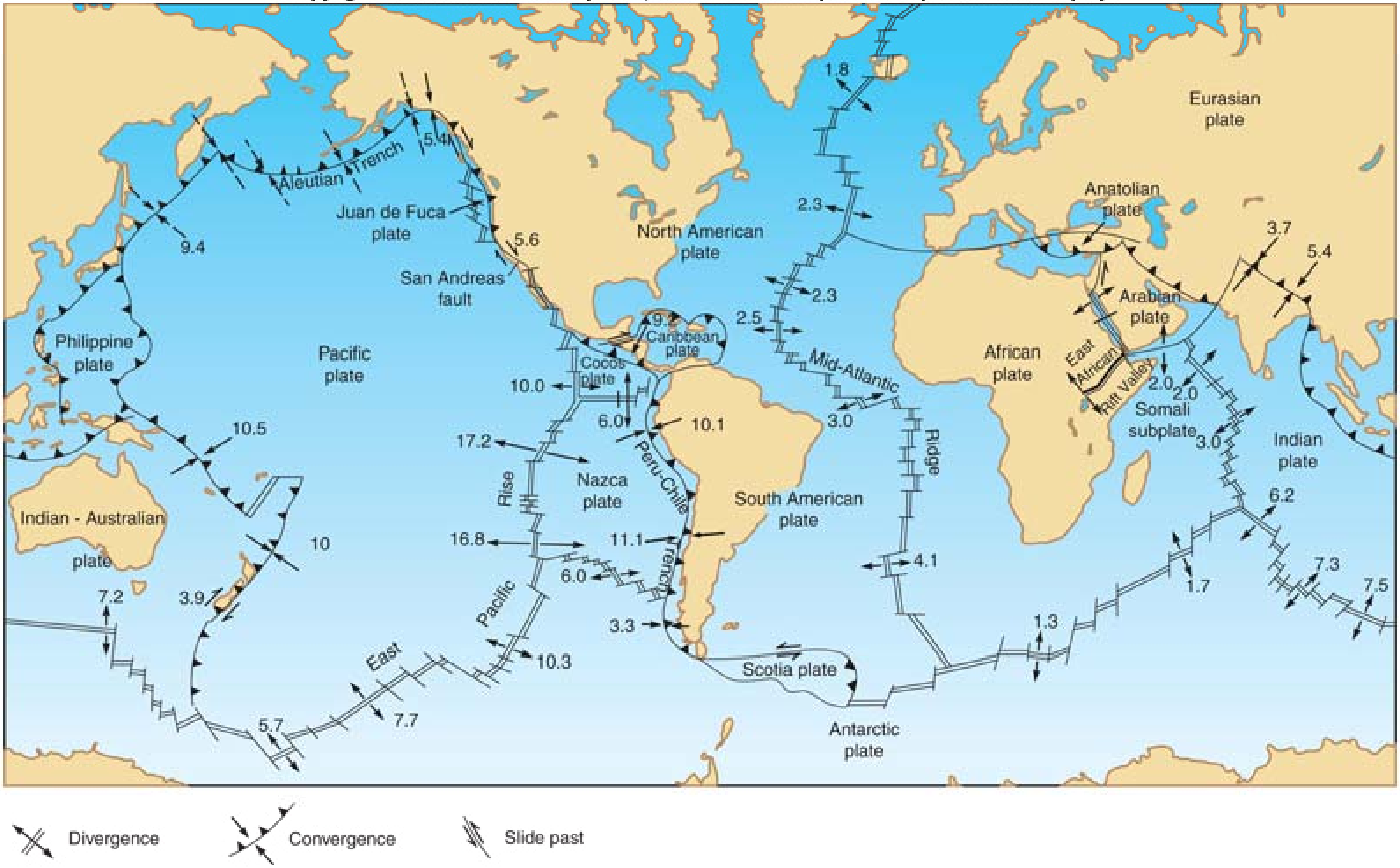
Major active fault or fault zone; dashed where nature, location, or activity uncertain

Normal fault or rift; hachures on downthrown side

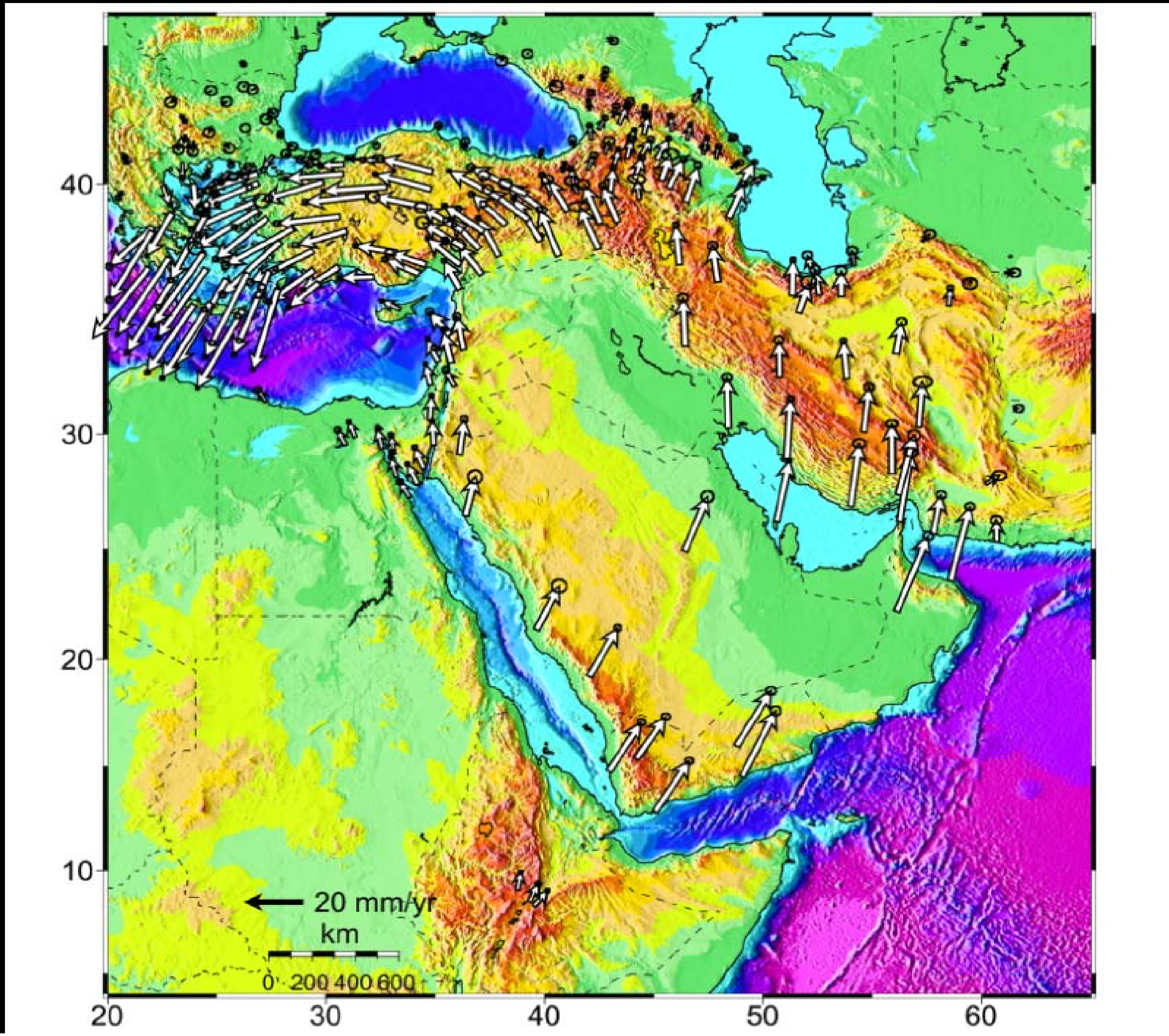
Reverse fault (overthrust, subduction zones); generalized; barbs on upthrown side

Volcanic centers active within the last one million years; generalized. Minor basaltic centers and seamounts omitted.

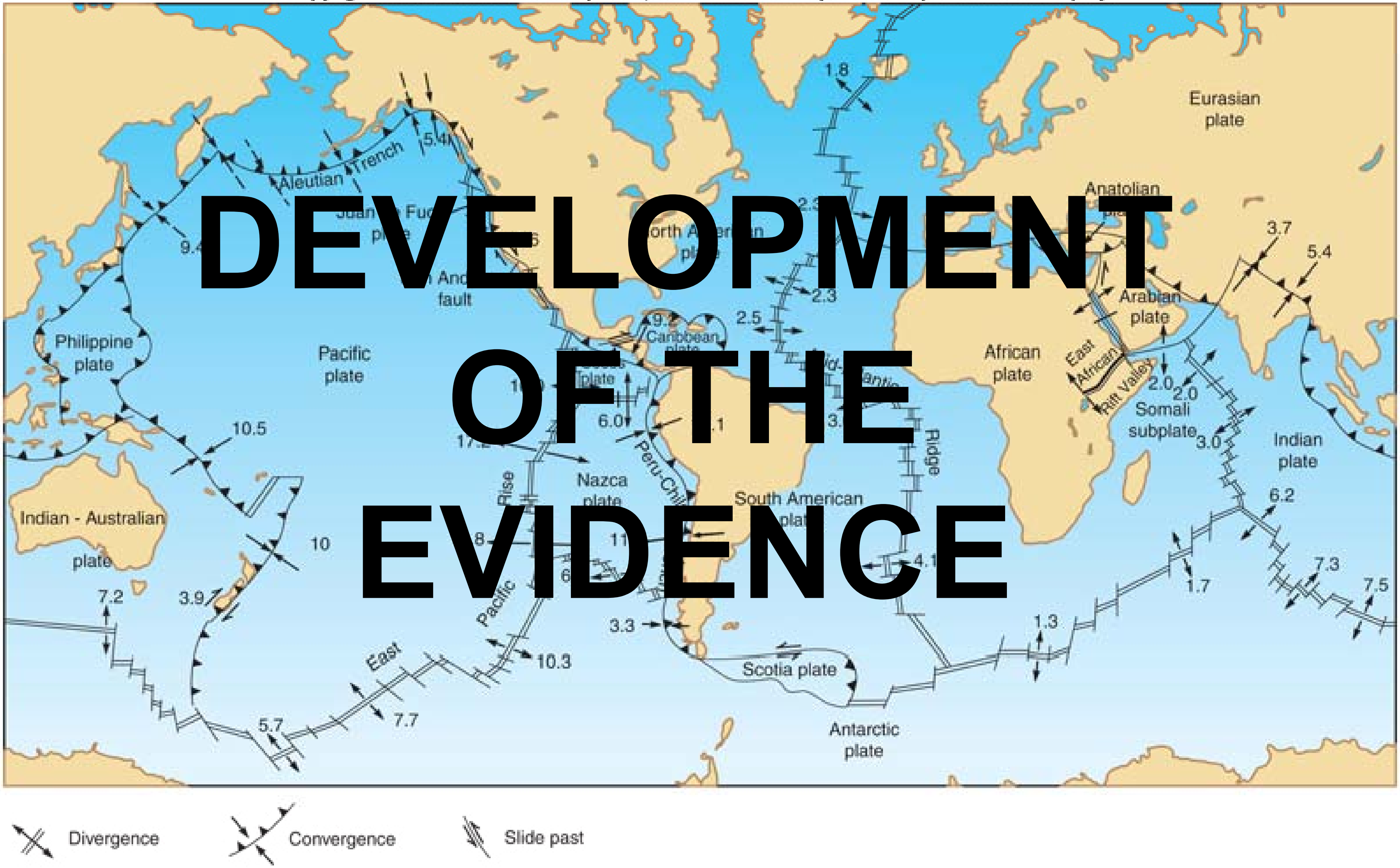
G221.001


Eurasian plate
Anatolian plate
Arabian plate
African plate
East African Rift Valley
Somali subplate
Indian plate
North American plate
Juan de Fuca plate
San Andreas fault
Aleutian Trench
Pacific plate
Philippine plate
Indian - Australian plate
Caribbean plate
Cocos plate
Nazca plate
South American plate
Peru-Chile Trench
Mid-Atlantic Ridge
East Pacific Rise
Scotia plate
Antarctic plate
1.8
2.3
2.3
2.5
3.0
4.1
5.4
5.6
9.4
9.2
10.0
10.1
6.0
17.2
16.8
11.1
6.0
3.3
10.5
10
3.9
7.2
5.7
7.7
10.3
1.3
1.7
6.2
7.3
7.5
3.0
2.0
2.0
3.7
5.4
Divergence
Convergence
Slide past

# MEASURED SURFACE VELOCITIES USING GPS



# DEVELOPMENT OF THE EVIDENCE



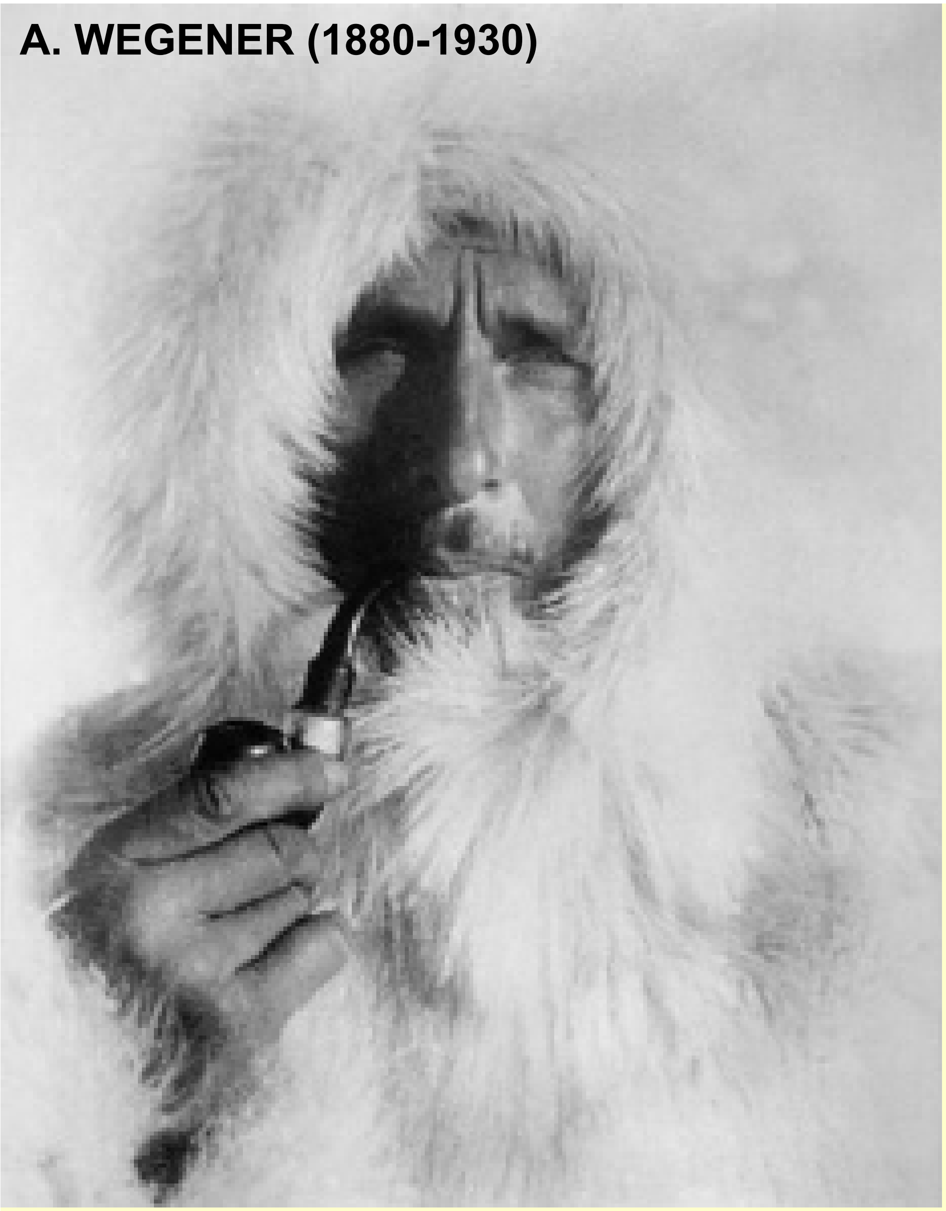
# COMPUTER FIT OF THE SOUTHERN CONTINENTS

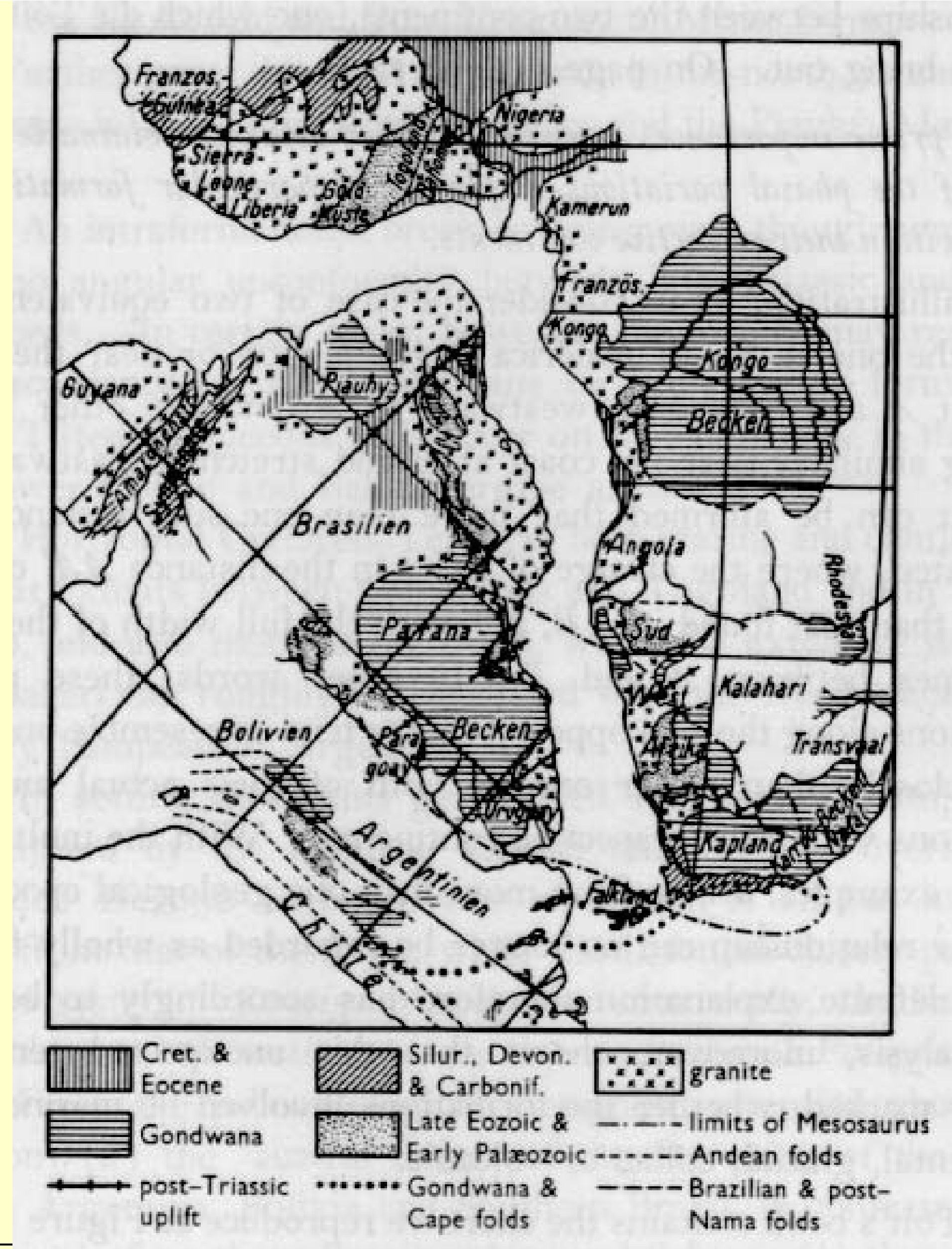


**First noted by Francis Bacon in 1620**

Fig. 1. The fit of the southern continents at the 500-fathom contour, except Antarctica, fitted at the 1,000-metre contour. Apart from Ceylon, which has been fitted by inspection, the map is an ornamented tracing of computer output. The Antarctic coast includes ice boundaries, some of which lie above water deeper than 1,000 metres. Lambert equal area projection centred at 5° S, 35° E.

A. WEGENER (1880-1930)



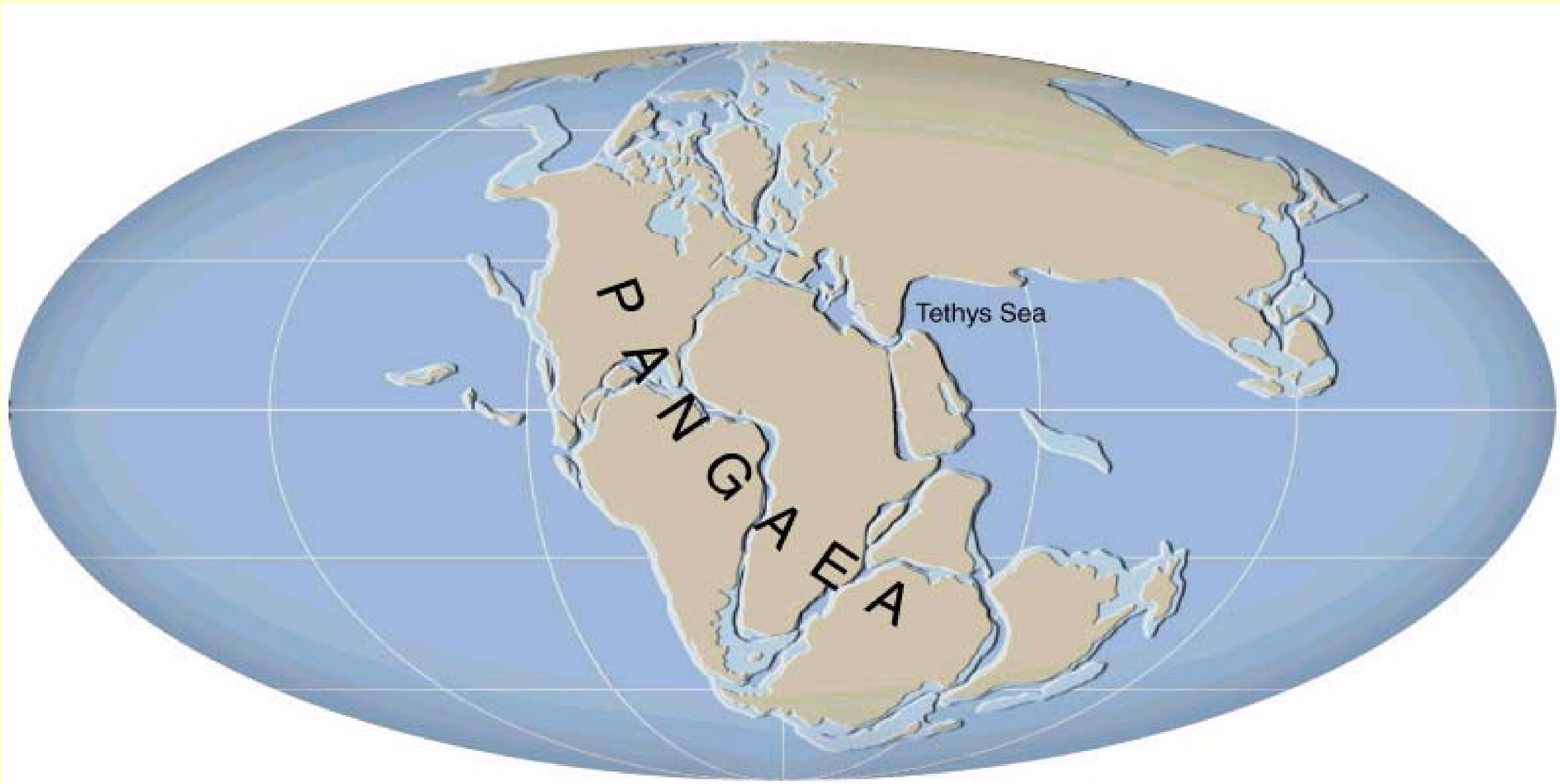



**ALFRED WEGENER PROPOSED THEORY OF CONTINENTAL DRIFT IN HIS BOOK *The Origin of the Continents and Oceans* IN 1915** →

# CONTINENTAL DRIFT

Proposed by A. Wegener in 1915

- A supercontinent, **PANGAEA**, started to break up about 200 million years ago and continents "drifted" into their current positions.



# EVIDENCE 1: Fit of Continental Shorelines

- Similarities between continents was noted by early proponents of the theory of continental drift.
- Opponents suggested that shorelines are shaped by erosional and depositional processes, and therefore are continually being modified.
- More realistic approach is to fit the continents together along the continental slope: at about 900 m depth.

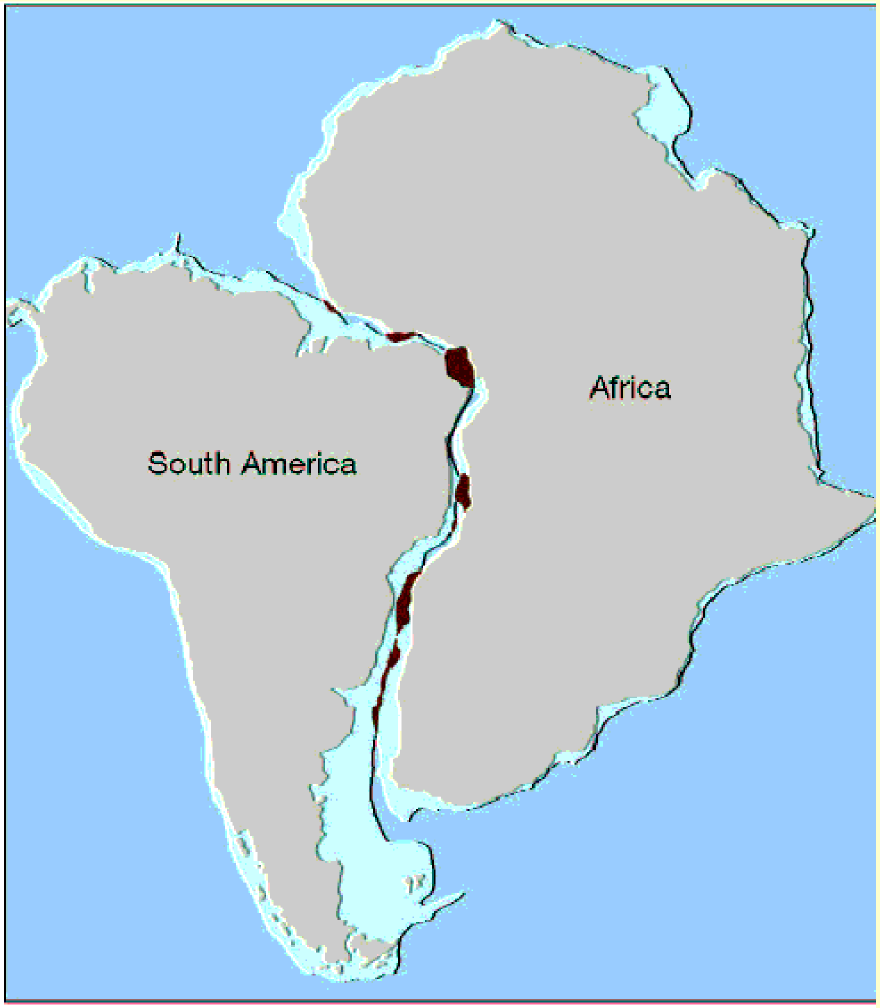



**Figure 19.3** This shows the best fit of South America and Africa along the continental slope at a depth of about 900 metres. The areas where continental blocks overlap appear in brown.
(After A. G. Smith, "Continental Drift." In *Understanding the Earth*, edited by I. G. Gass)

# EVIDENCE 2: Fossils

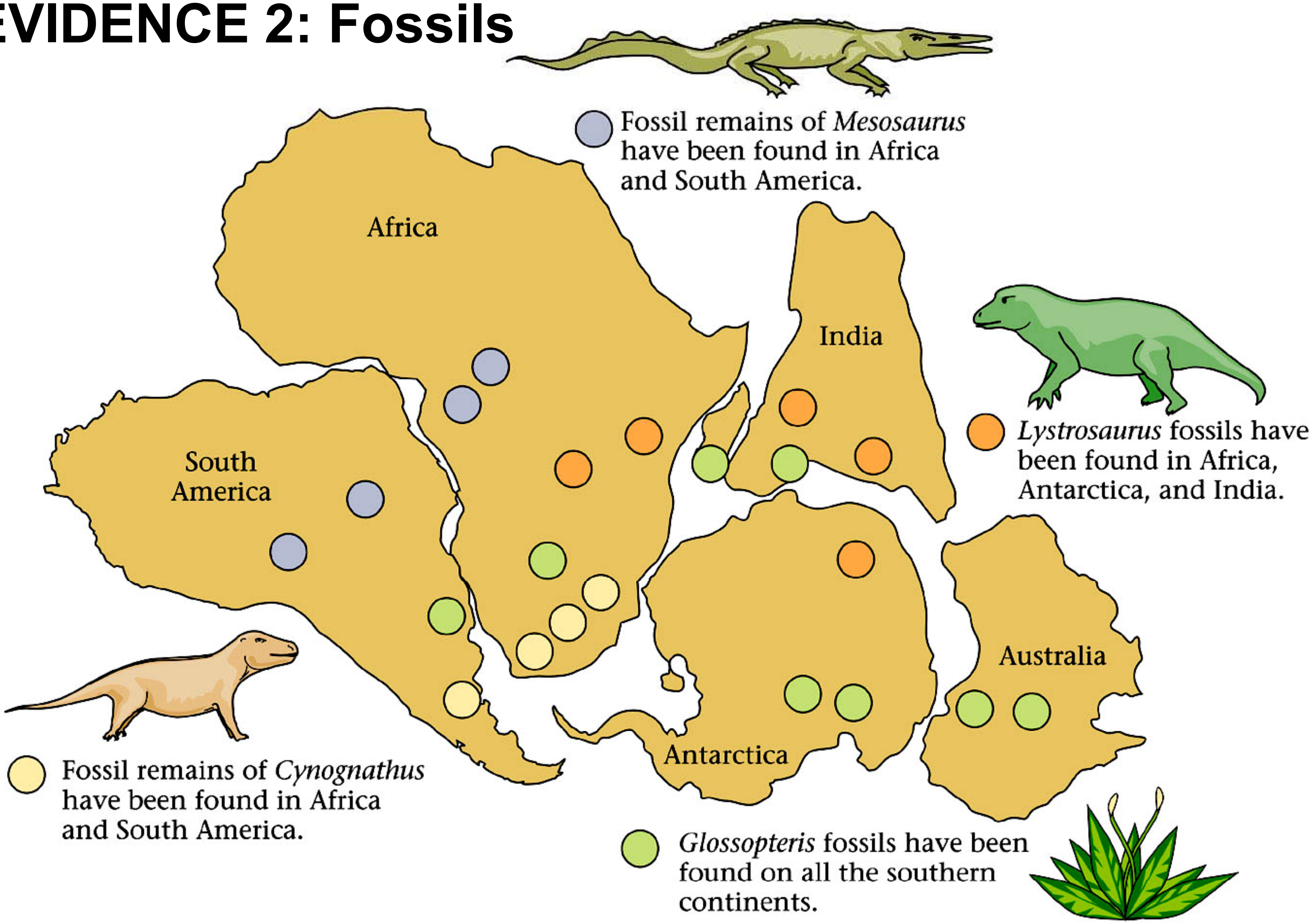
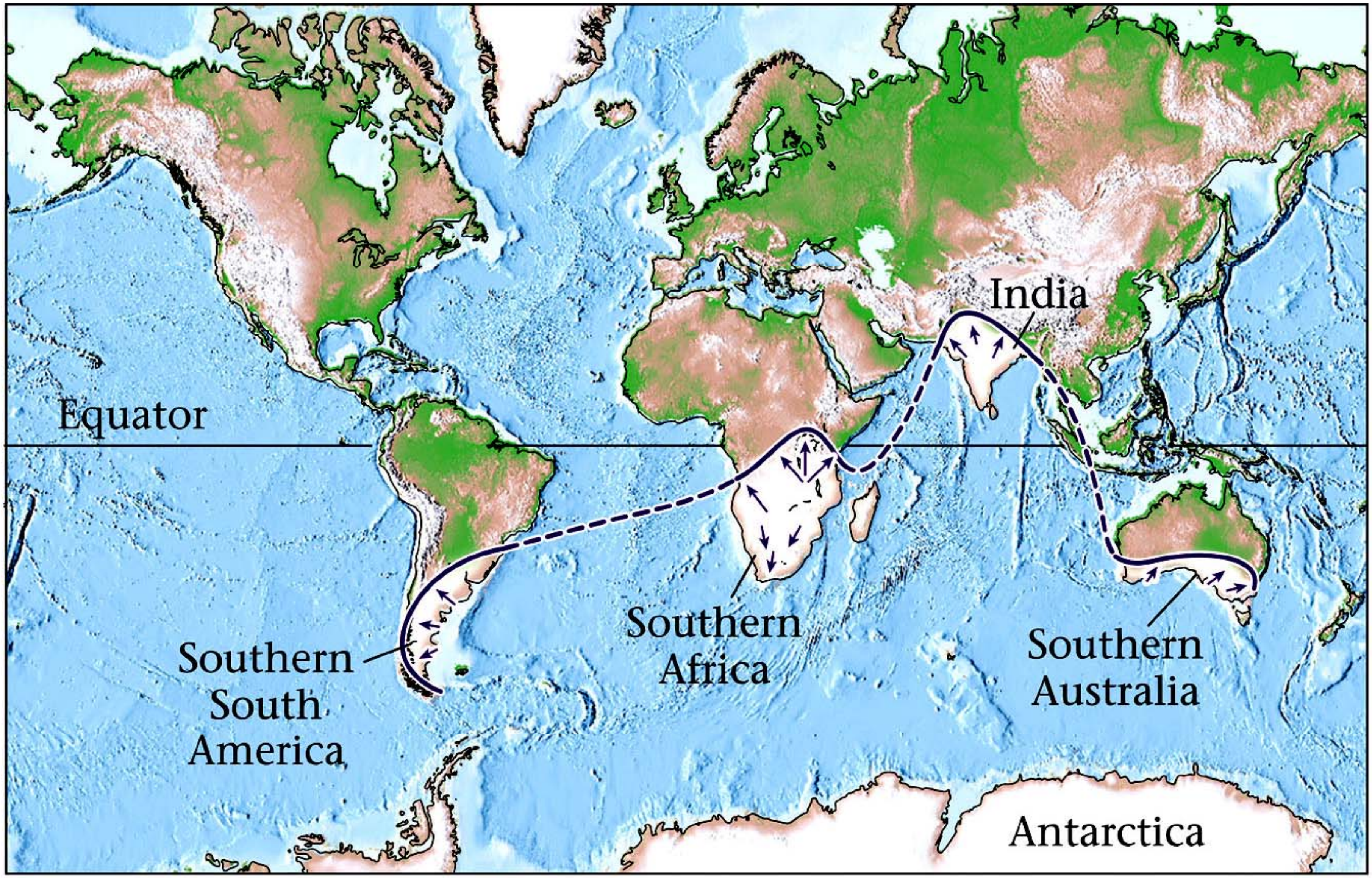


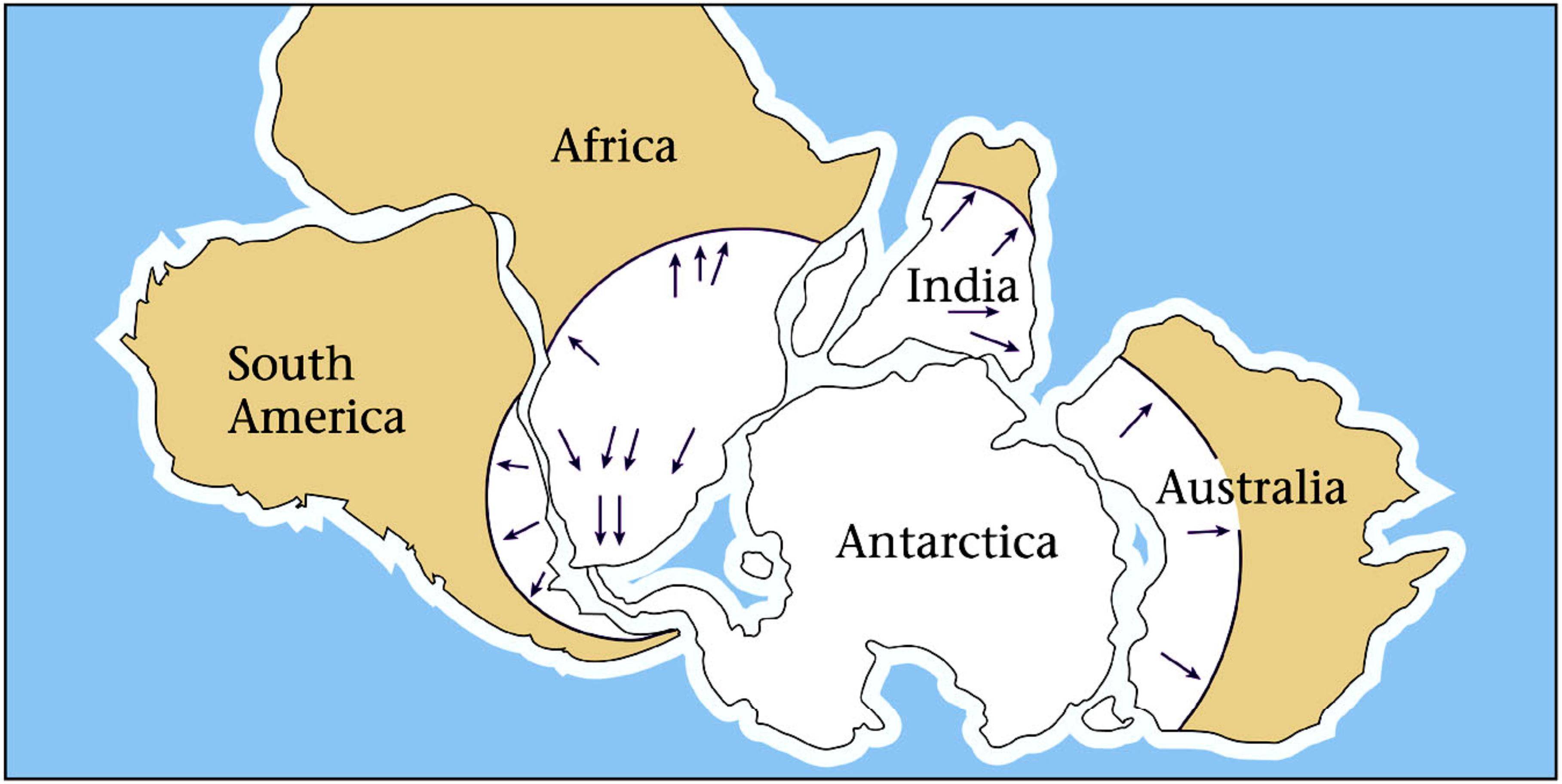

FIGURE 3.5

*Earth: Portrait of a Planet*, 2nd Edition




**EVIDENCE 3 : DISTRIBUTION OF LATE PALEOZOIC GLACIAL DEPOSITS ON PRESENT CONTINENTS**

# GLACIATION OF PANGAEA BEFORE SUPERCONTINENT BROKE UP




(b)

FIGURE 3.3

*Earth: Portrait of a Planet*, 2nd Edition

# EVIDENCE 4 : DISTINCTIVE AREAS OF ROCK ASSEMBLAGES

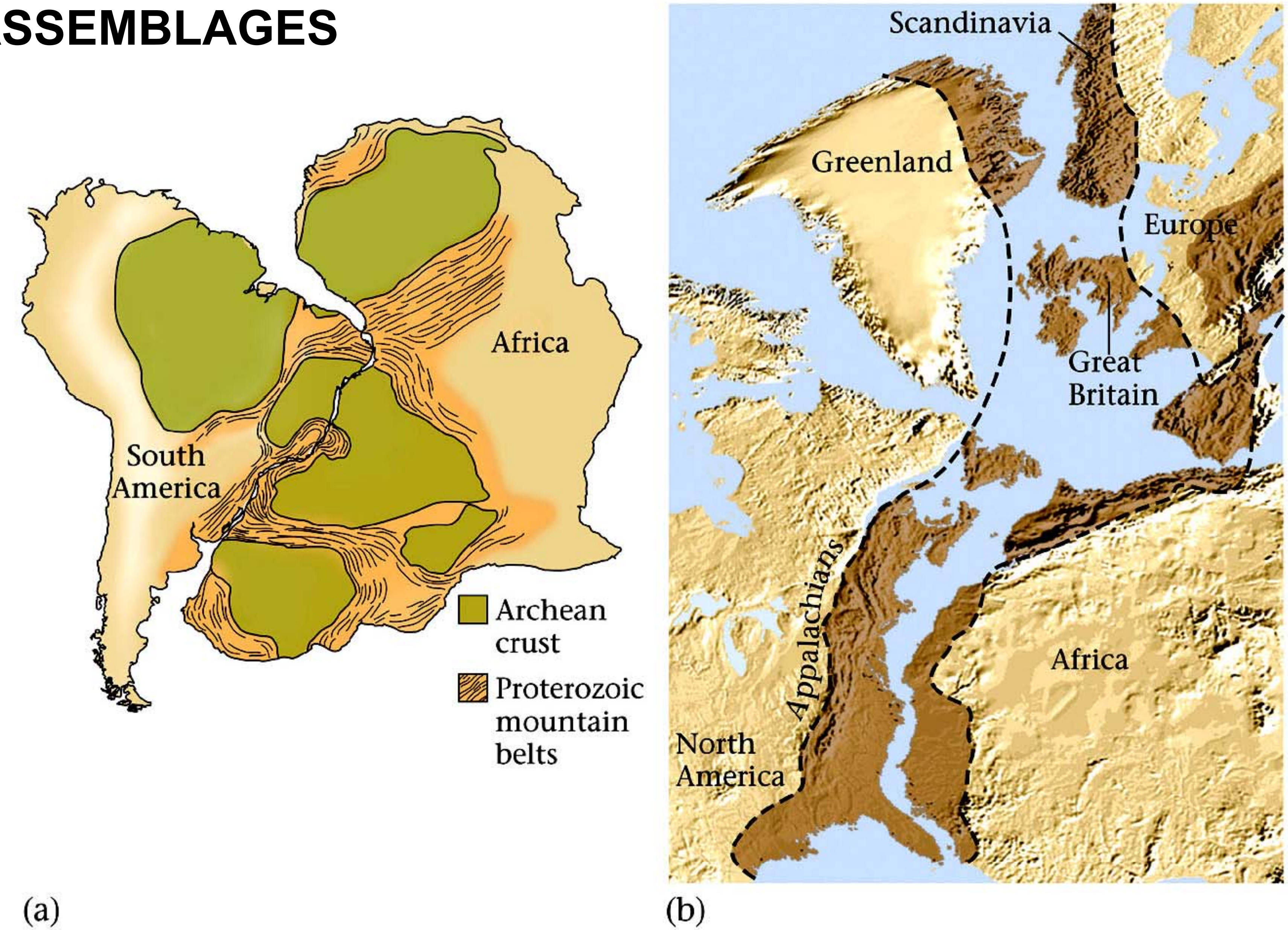
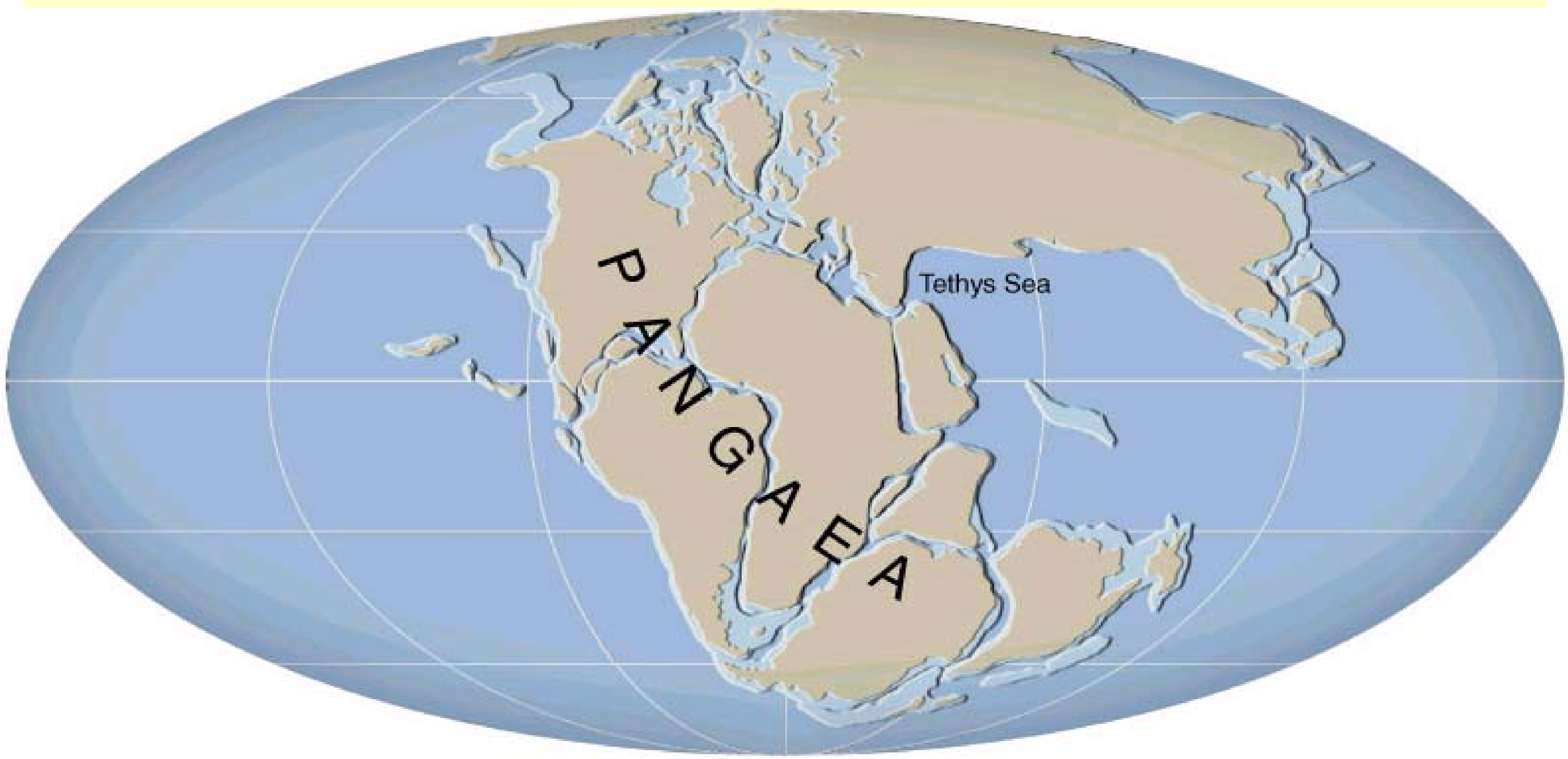



FIGURE 3.6

# CONTINENTAL DRIFT

## Rejected by Geologists in 1920’s, 1930’s and 1940’s

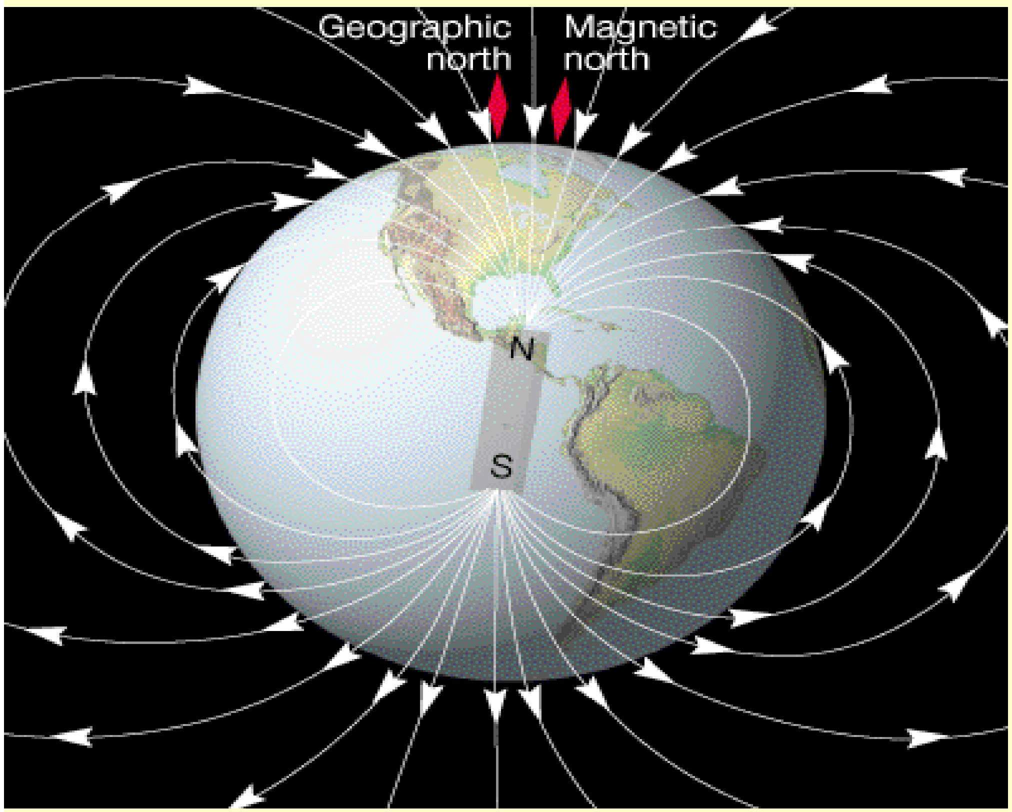
- A supercontinent, Pangaea, started to break up about 200 million years ago and continents “drifted” into their current positions – dismissed as “**utter nonsense**”.

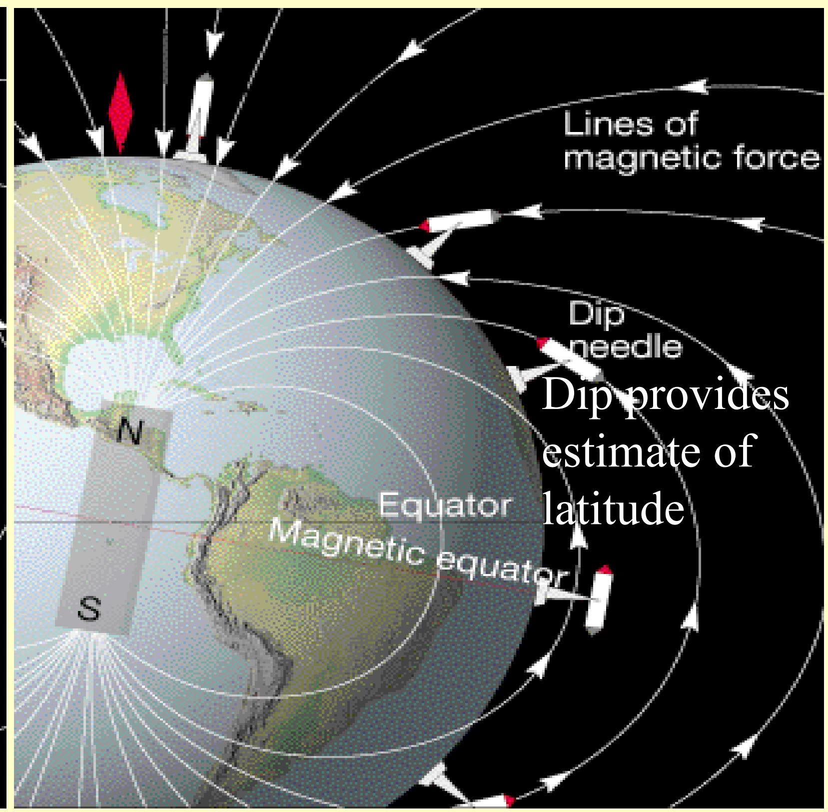


# Developing the evidence 1 : Paleomagnetism (1950s)

- When lava cools below about 580 C (Curie point), the iron-bearing minerals are magnetized and align their N pole with magnetic north. Preserved as fossil magnetism.

- Earth's magnetic field consists of lines of force like those a giant bar magnet would produce if placed at the center of Earth



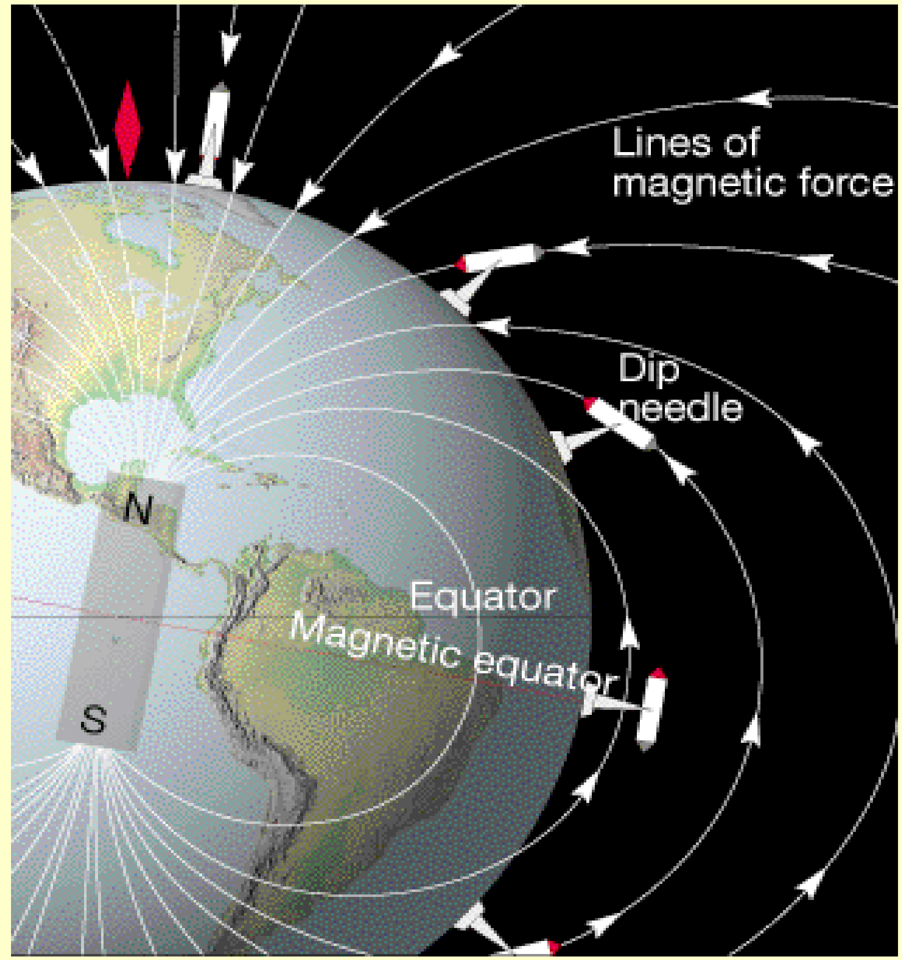



# Determining Latitude by Paleomagnetism

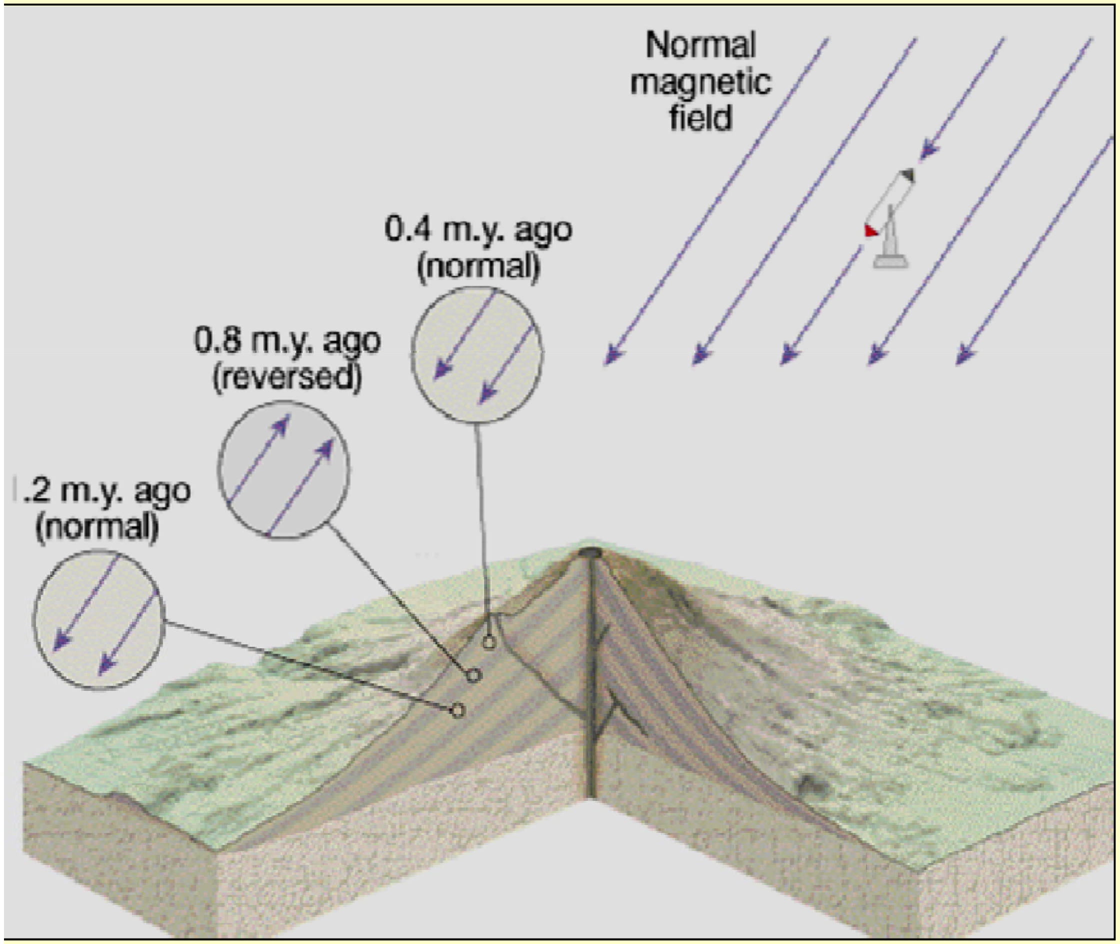
Earth's magnetic field causes a dip needle (compass oriented in a vertical plane) to align with the lines of magnetic force.

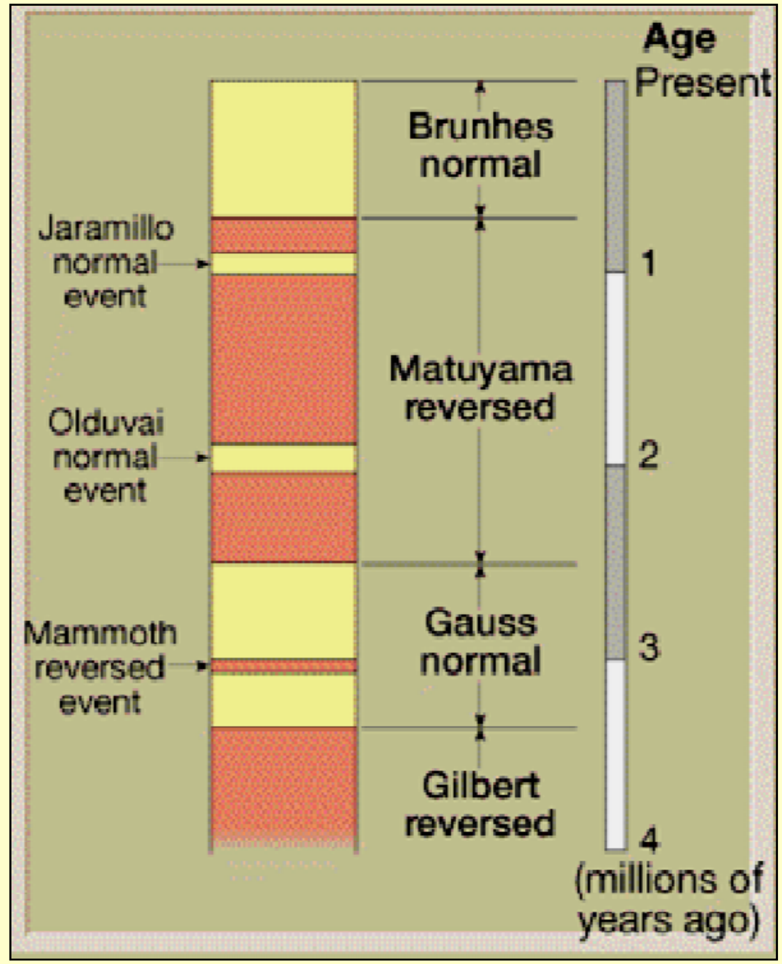
The dip angle decreases uniformly from 90 degrees at the magnetic poles to 0 degrees at the magnetic equator.

Consequently, the distance to the magnetic poles can be determined from the dip angle



# Geomagnetic Reversals



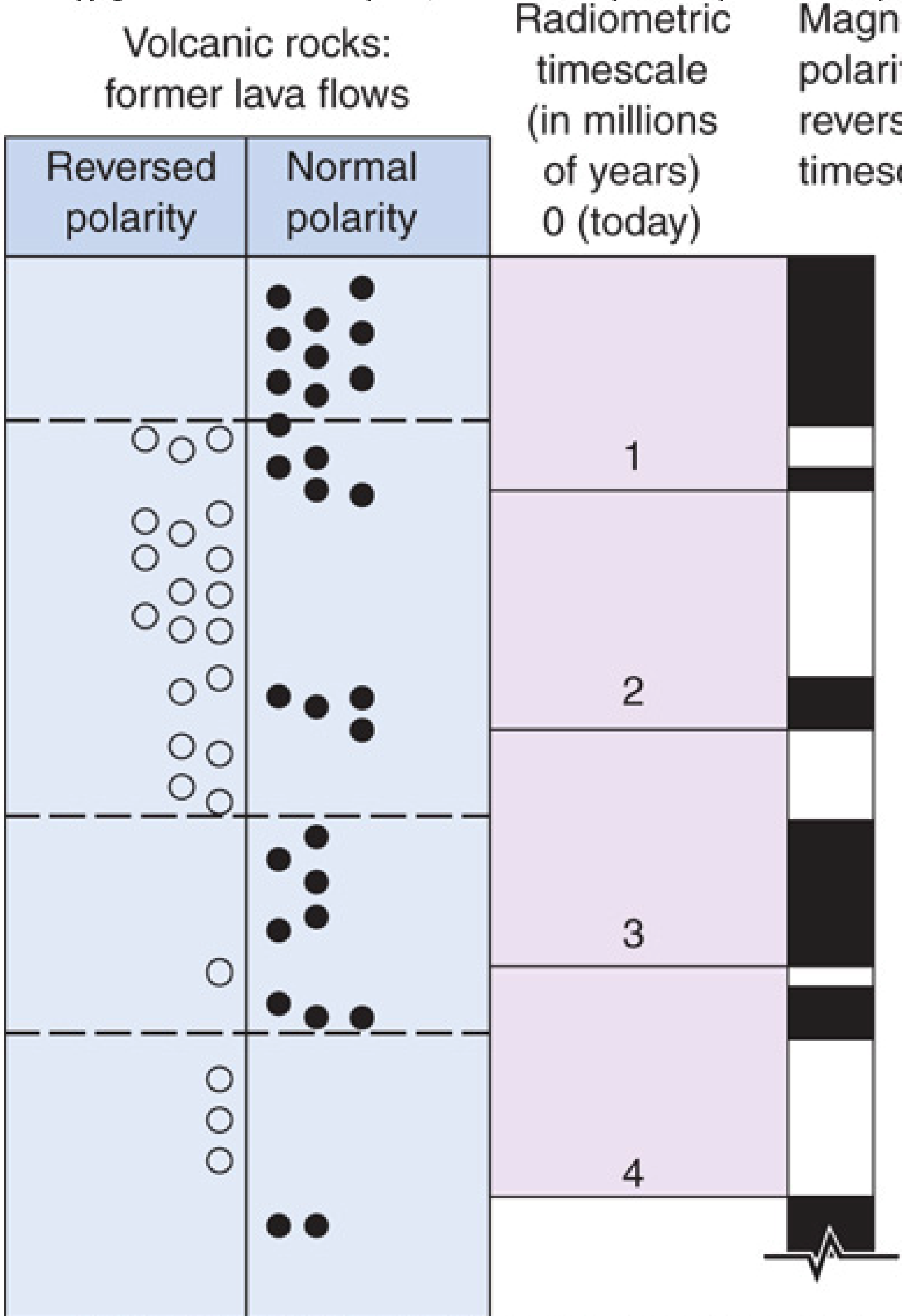




Polarity of lava flows from various locations and ages were used to establish a time scale for reversals. How fast does the “flip” occur? What are the consequences for life?:

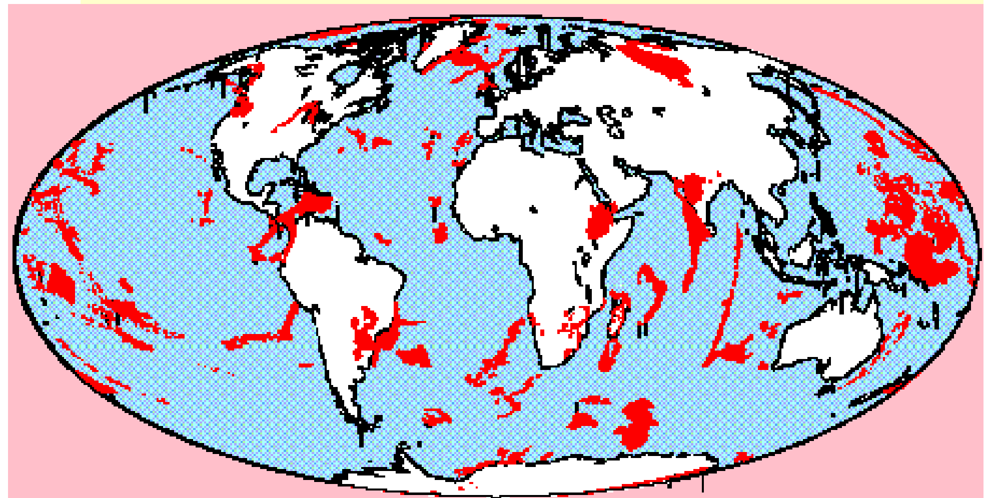
http://www.geomag.bgs. ac.uk/reversals.html;

http://gsc.nrcan.gc.ca/geomag/field/reversals_e.php

# PORTION OF MAGNETIC POLARITY TIMESCALE

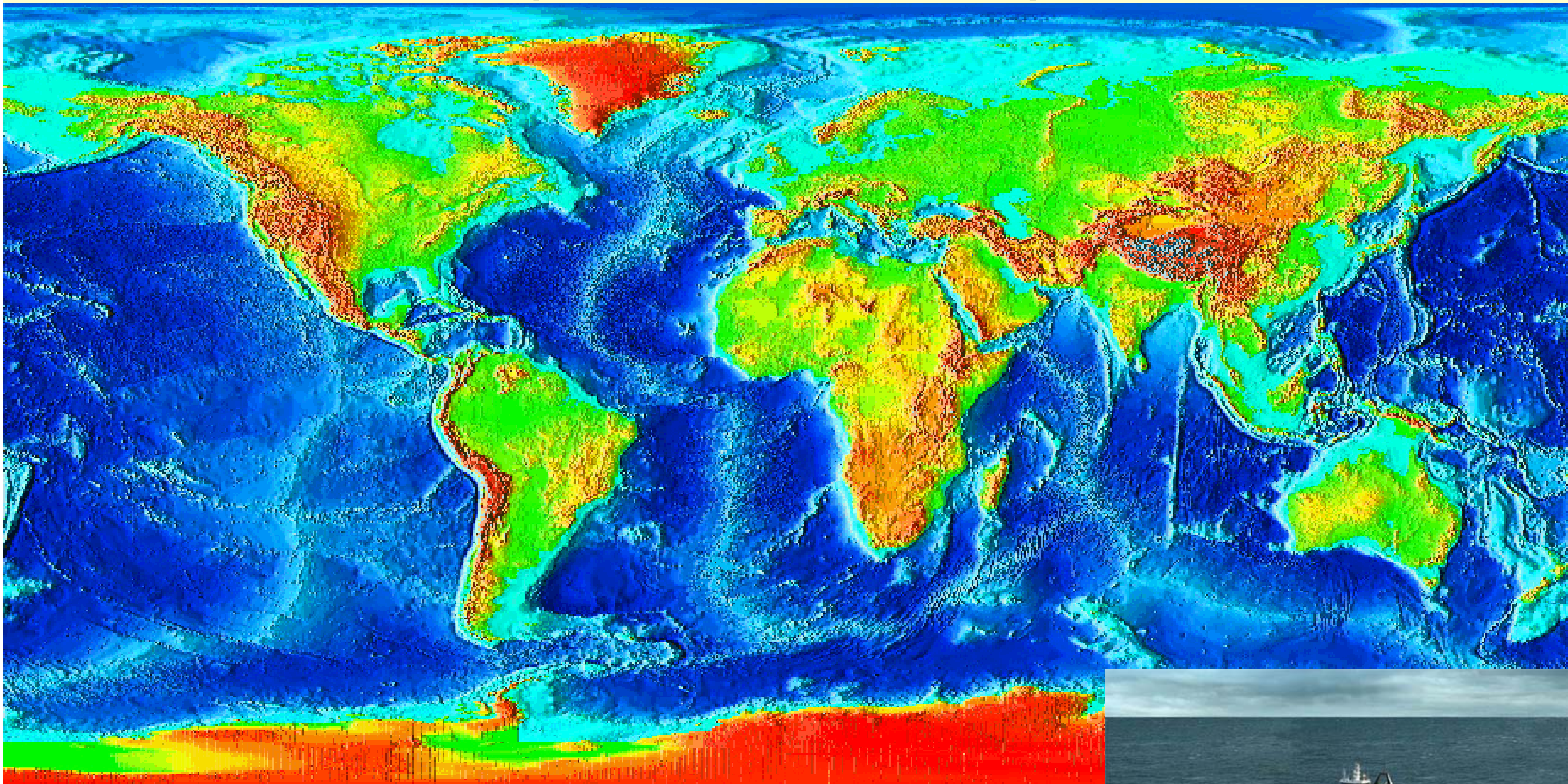


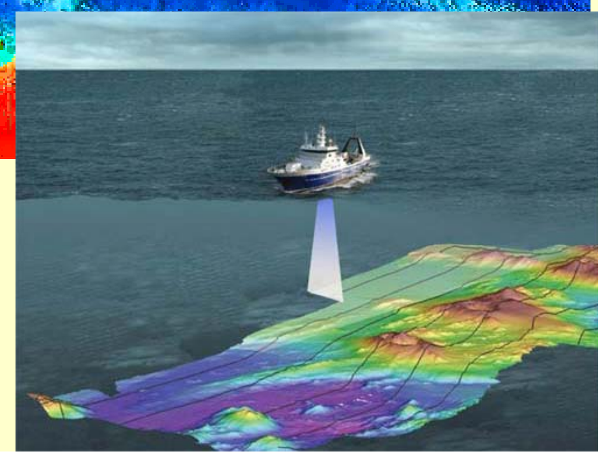


Location of extensive areas of volcanic rocks

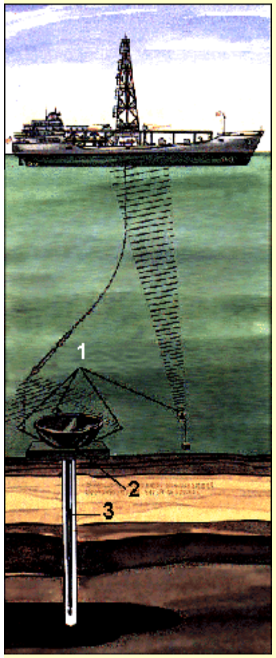
# Developing the Evidence II – Mapping the Sea Floor (1950s and 1960s)



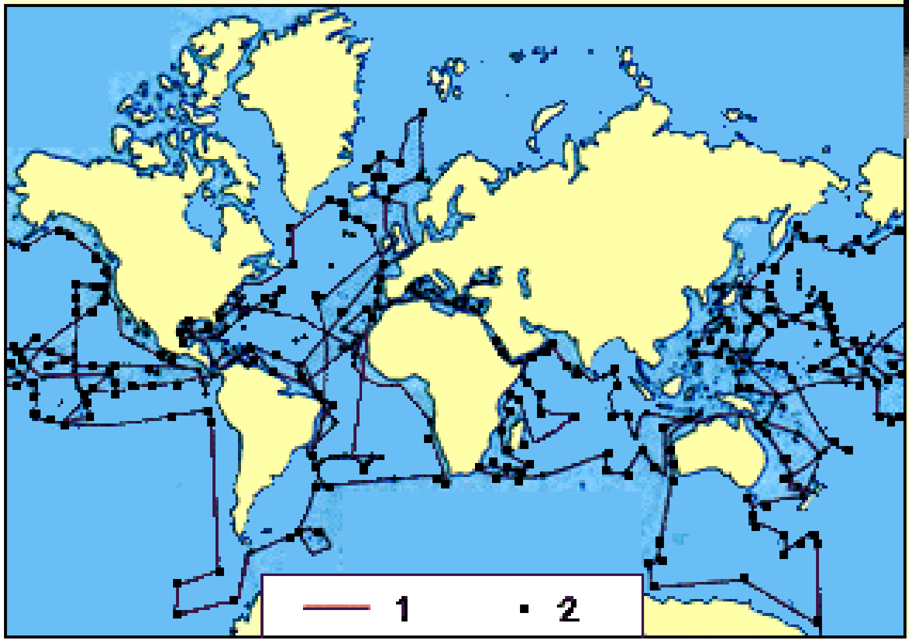


**Landforms and Morphology, Depths, Magnetic Surveys, Sea Floor Materials and Sub-Surface Structure**

# Drilling the Sea Floor (1950s through the 1990's)

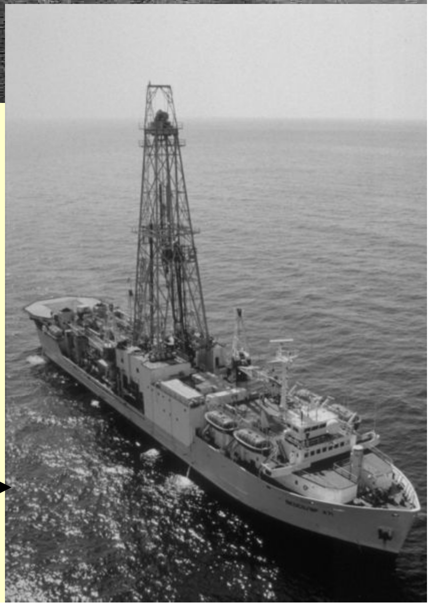



**Voyages of *Glomar Challenger* (1968 – 1975) and location of ocean floor drill holes**

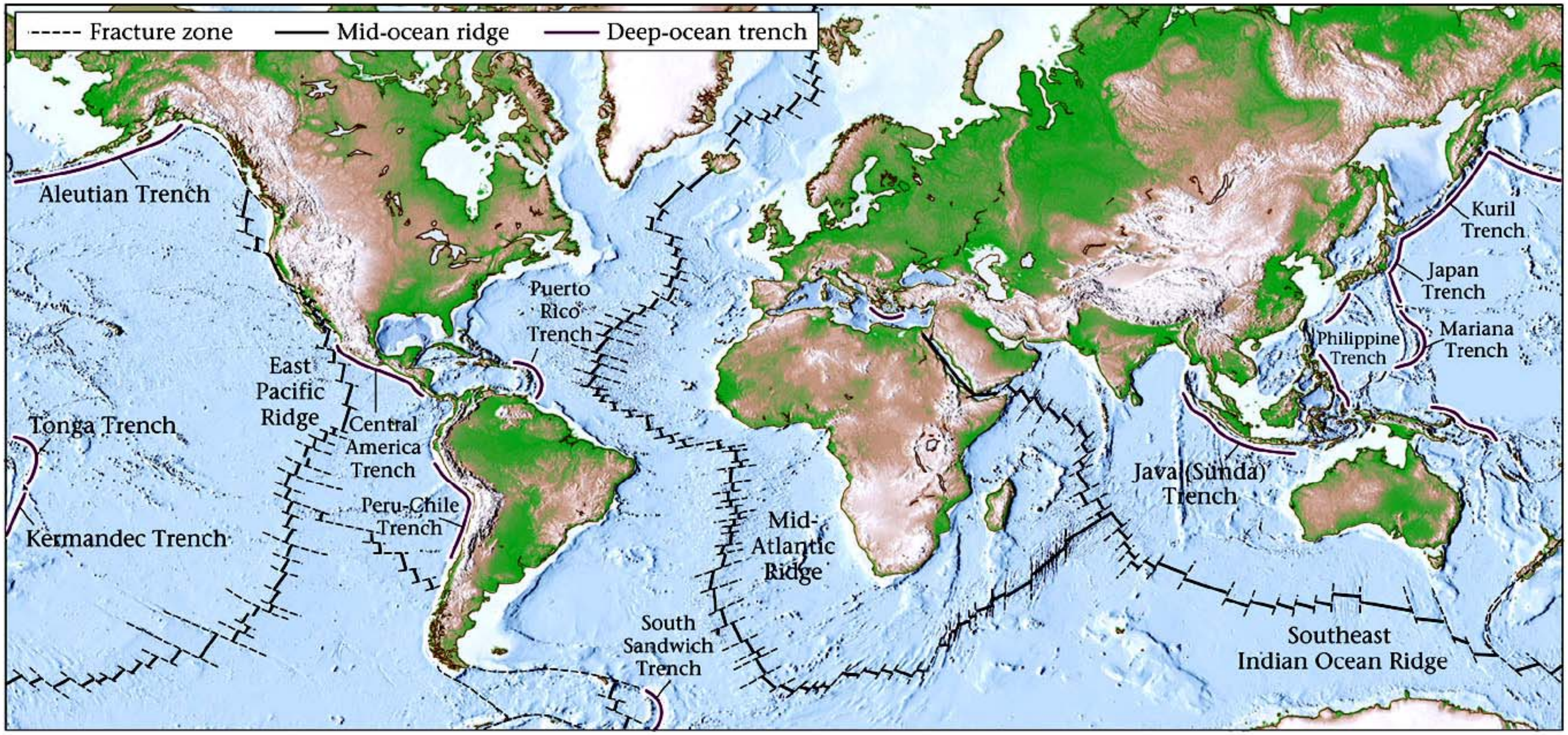




***Joides Resolution* carries this work on**



# MORPHOLOGY OF OCEAN FLOORS (MID-OCEAN RIDGES, FRACTURE ZONES, AND DEEP-OCEAN TRENCHES)




OCEAN FLOOR MAPPING BY BATHYMETRIC SURVEYS IN THE 1950s and 1960s (DEEP SEA MARINE GEOLOGY)

FIGURE 3.19

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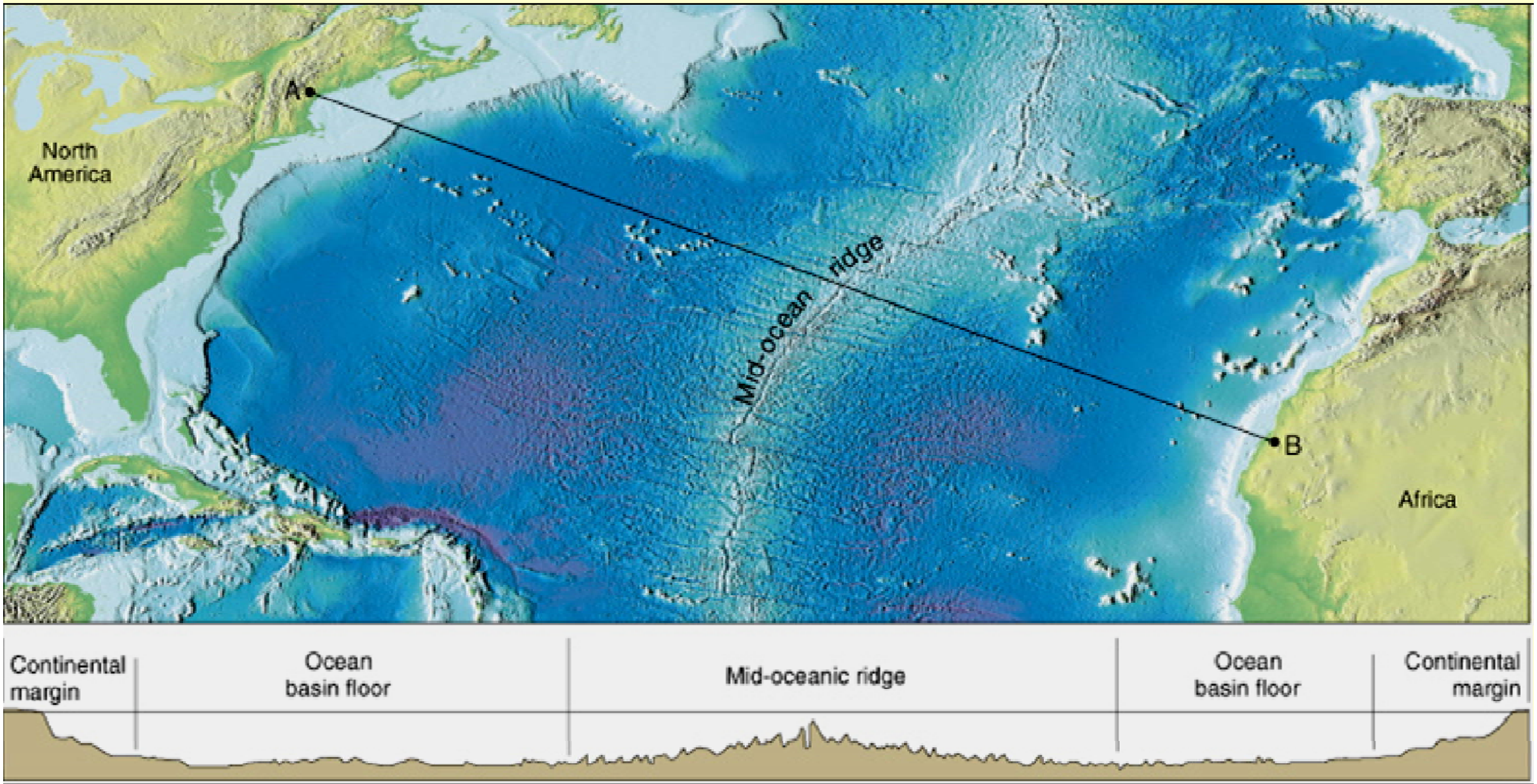
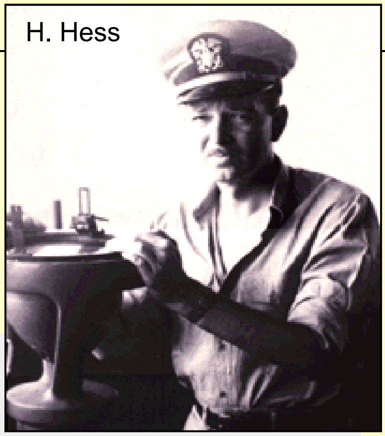
# Sea Floor Spreading – Development of a Paradigm

Post-WW II information about the sea floor

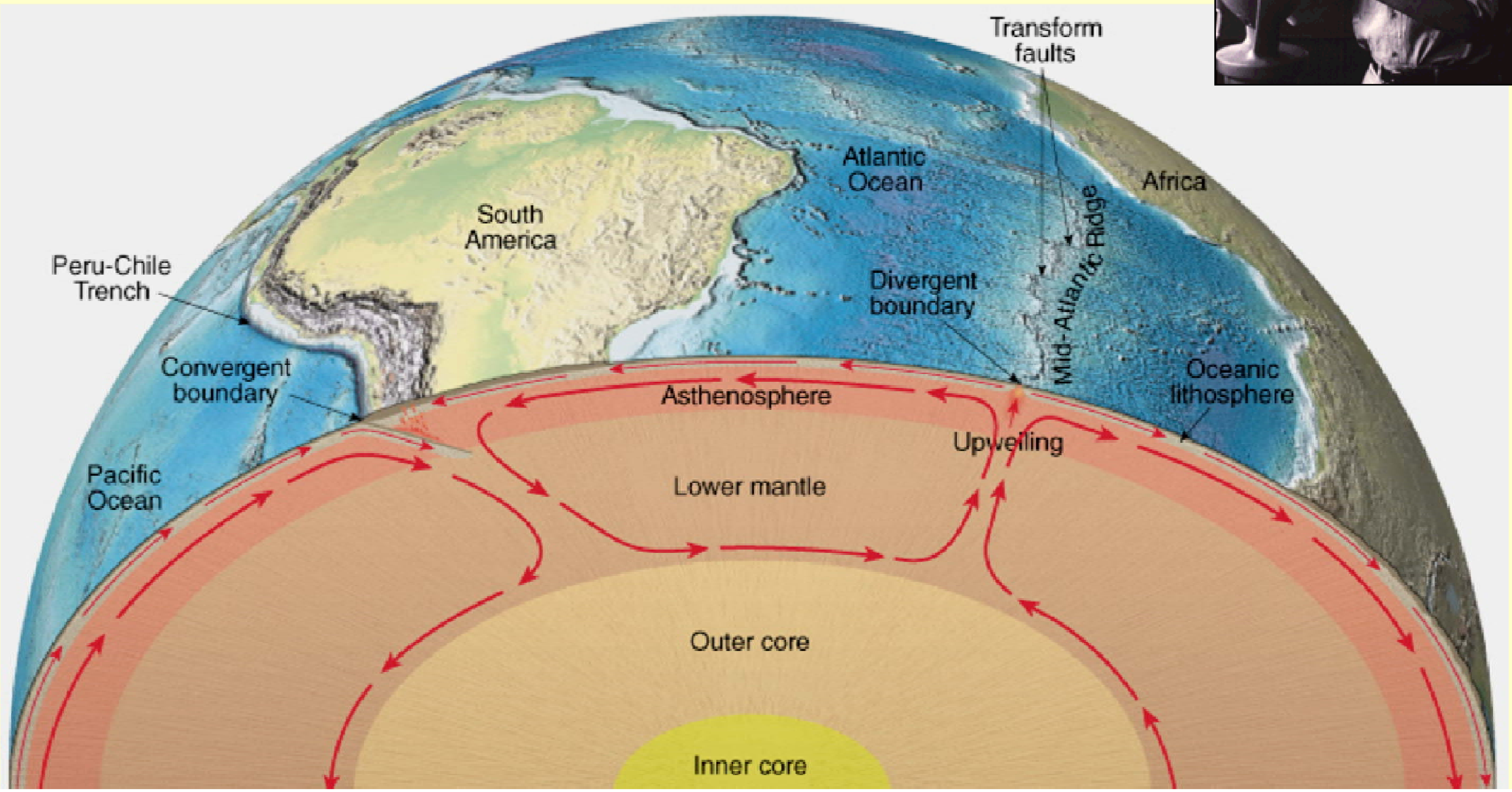



- Note symmetry around mid-ocean ridge
- No dredged sea floor samples were > 160 M y old

# Sea Floor Spreading: Harry Hess's Theory (1960 and 1962)




- Ocean ridges are along zones of upwelling mantle
- Upwelling mantle spreads laterally, splitting/dragging crust
- Ocean trenches are zones where mantle plume plunges, dragging crust back into mantle



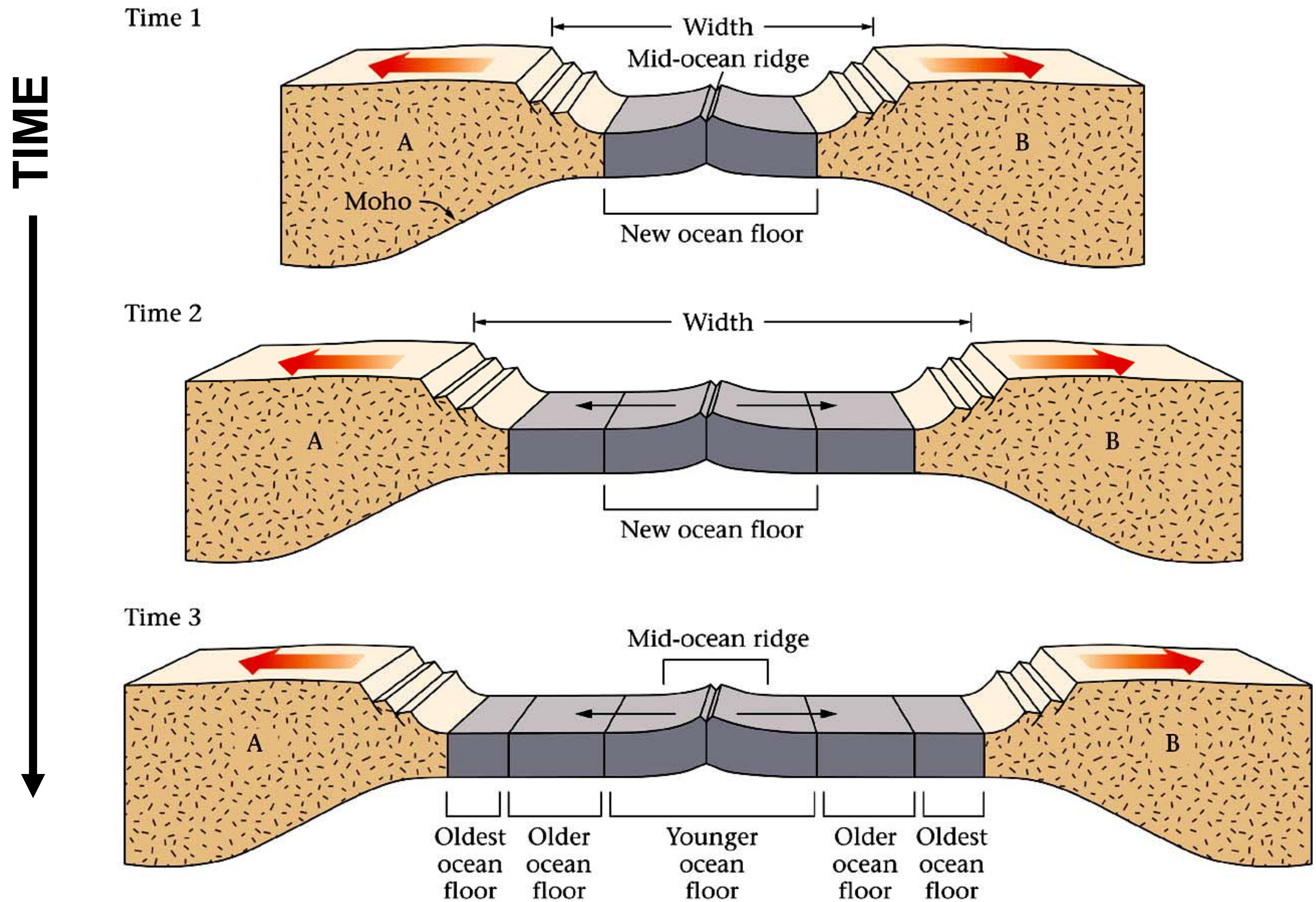



FIGURE 4.7

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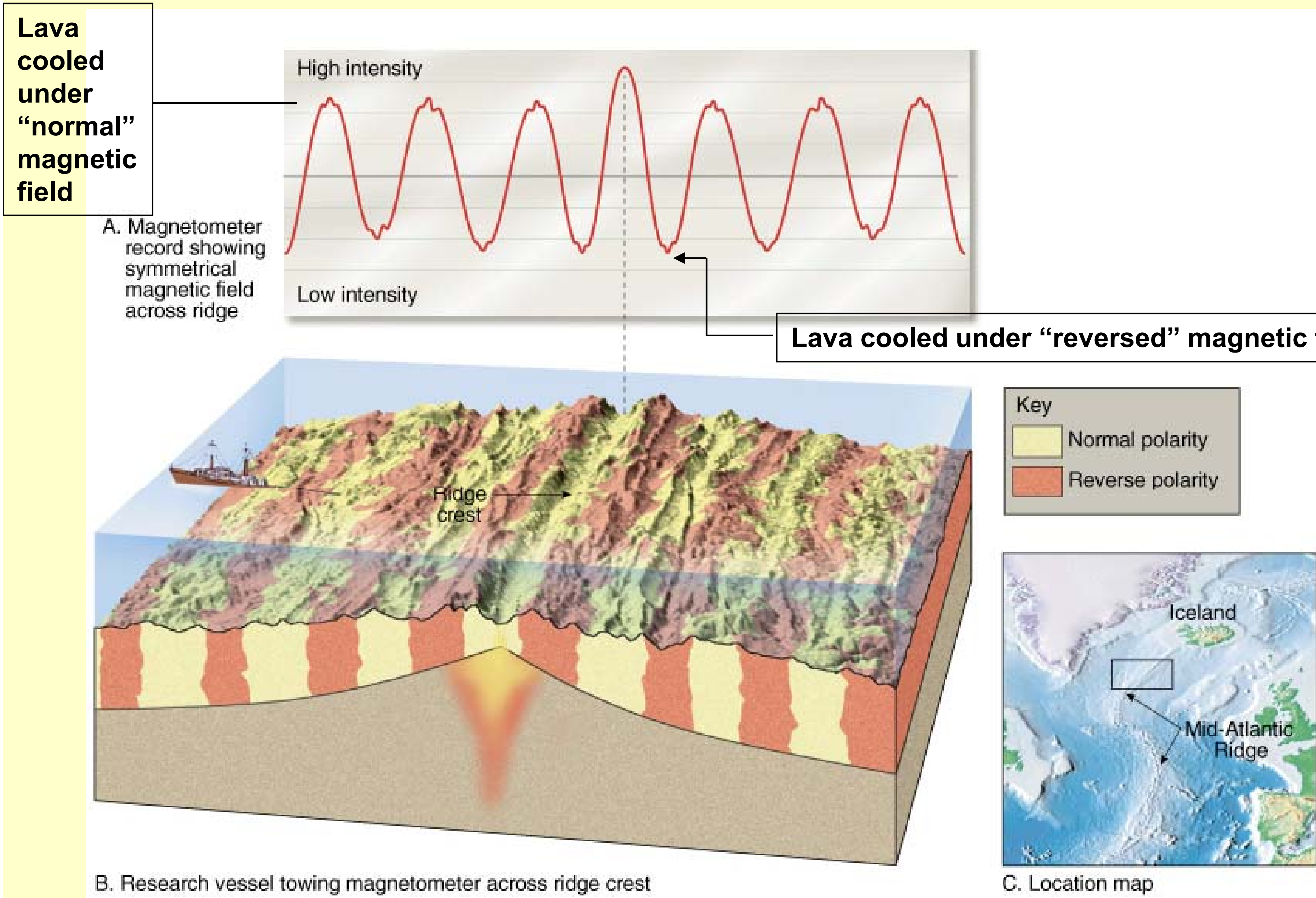
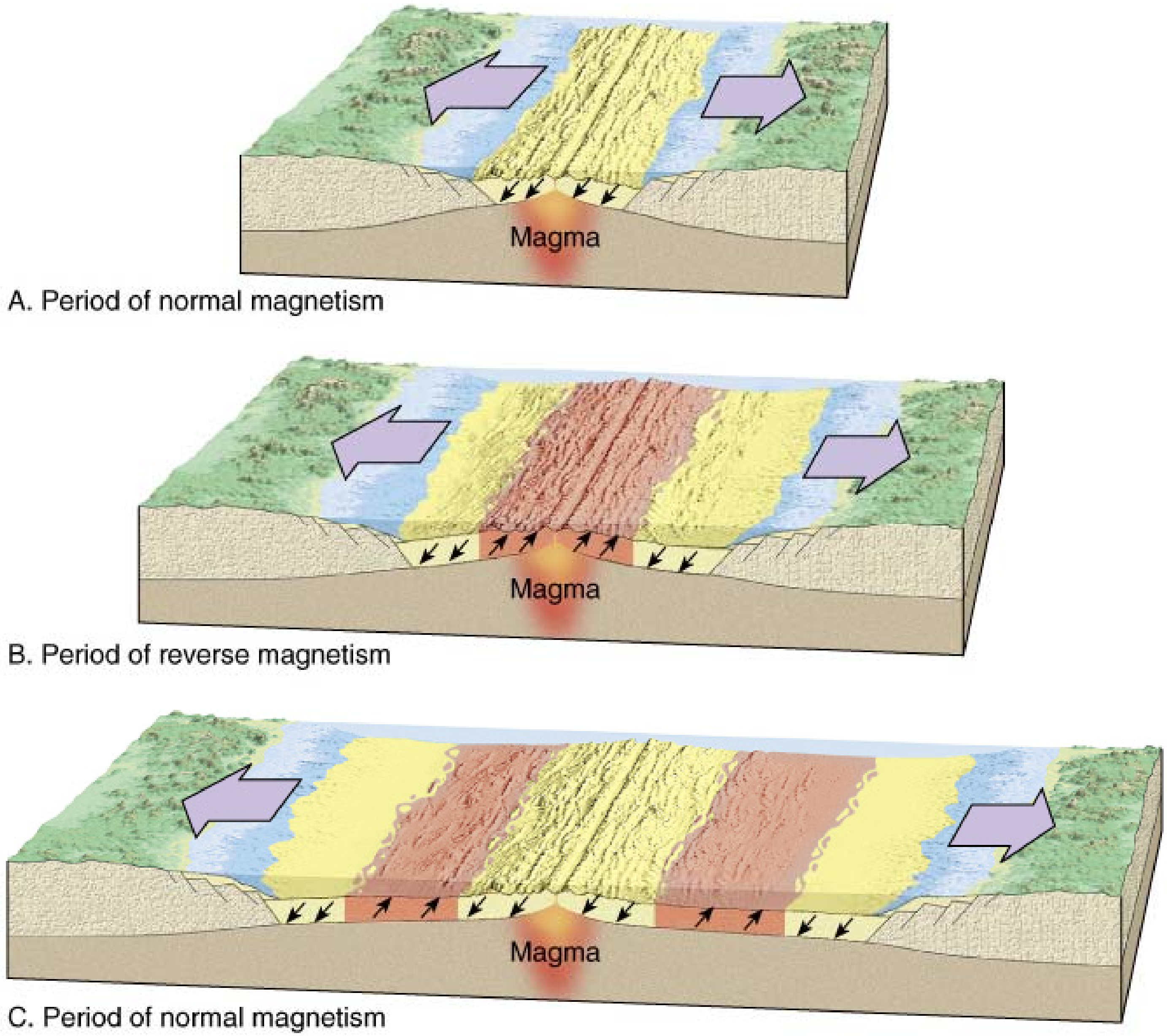
# Geomagnetic Reversals in the Ocean Floor



# Verification of sea floor spreading model (1960's) - a mechanism for continental drift




Vine and Matthews (1963) of Cambridge University (UK) combined concepts of sea floor spreading from Hess with recent observations of magnetism pattern near mid-ocean ridges

MAGNETIC STRIPES

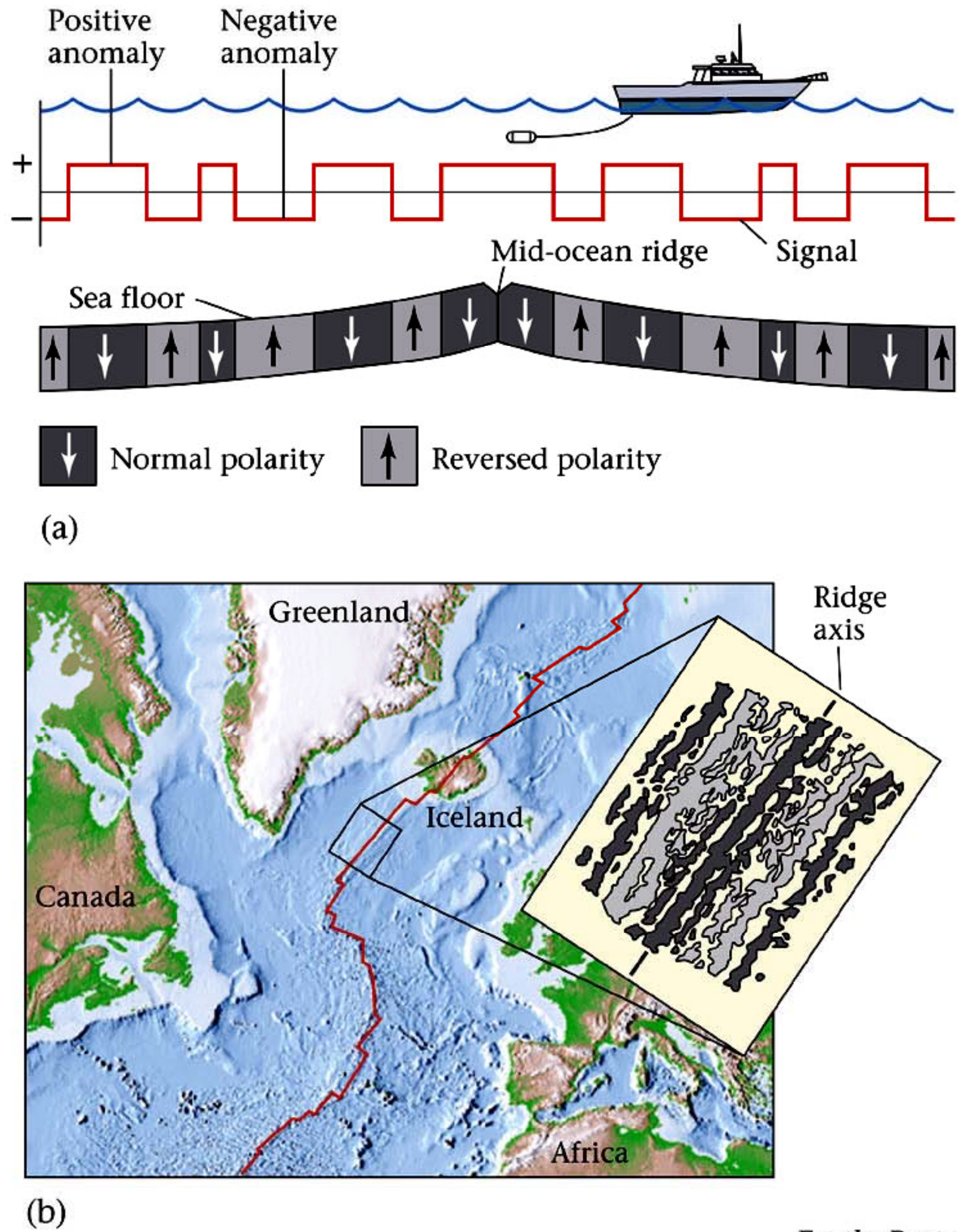
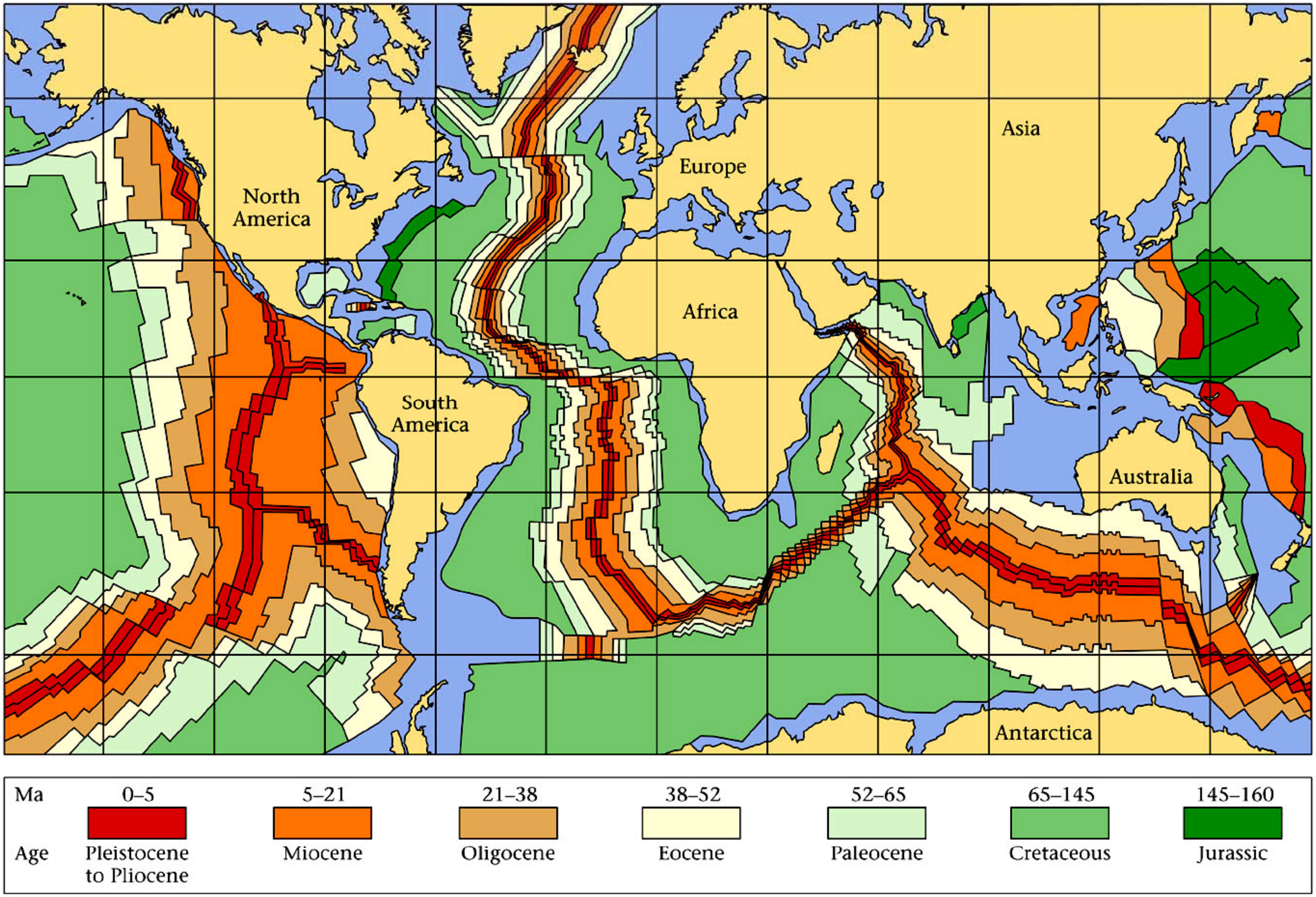


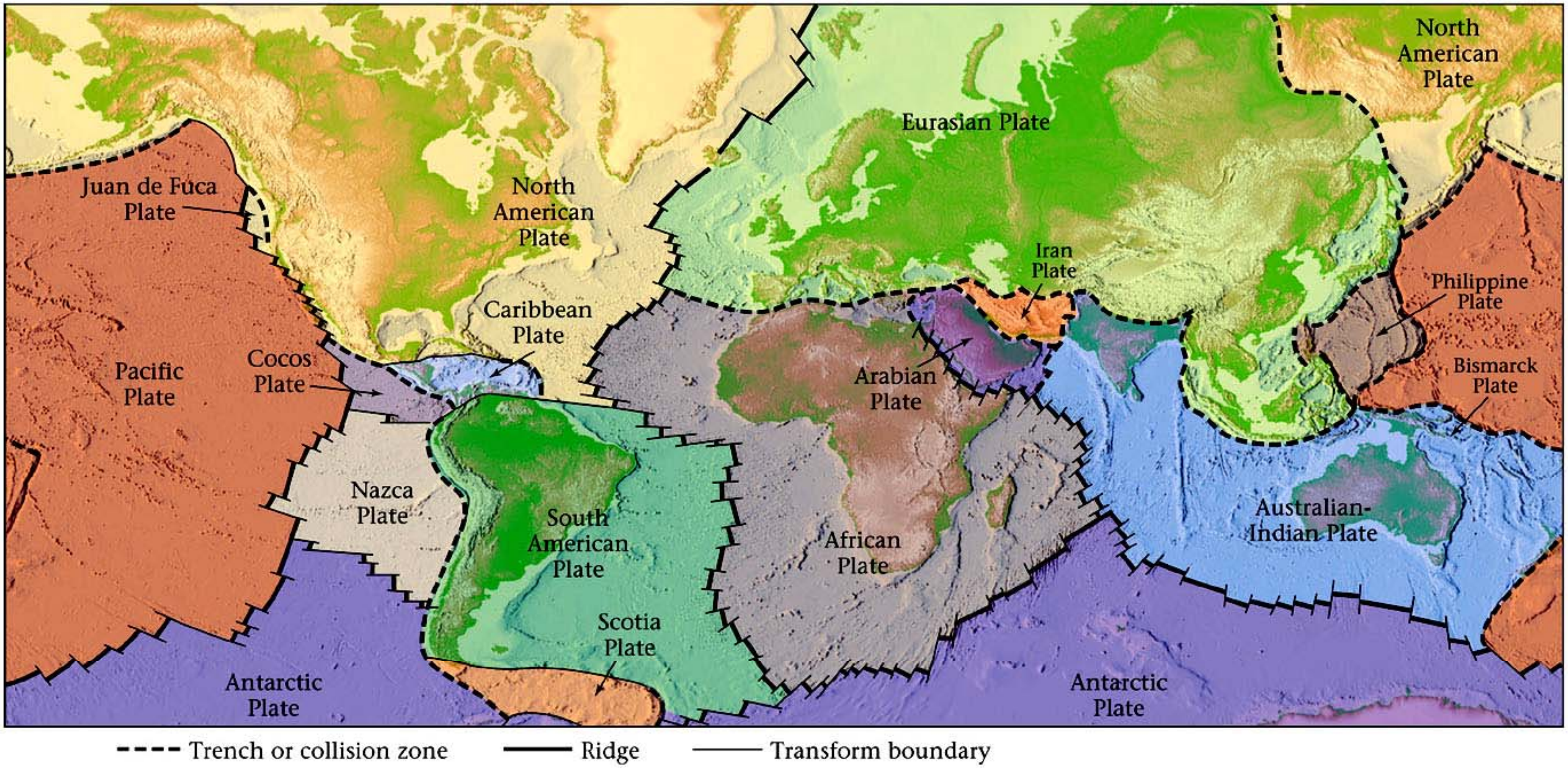

FIGURE 3.29




# AGE OF THE SEA FLOOR

*Earth: Portrait of a Planet*, 2nd Edition

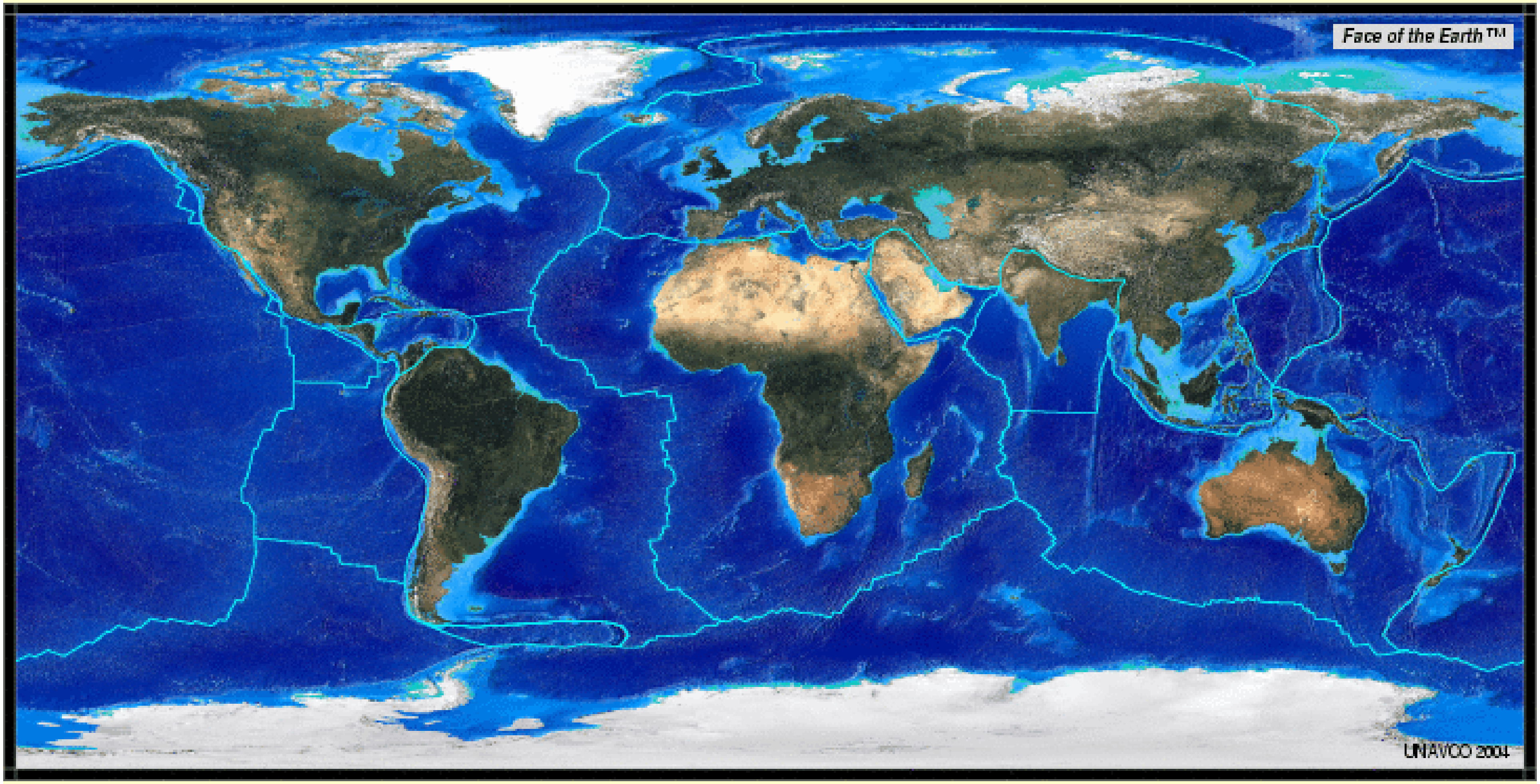
# PLATE TECTONICS THEORY PROPOSED BY W.J. MORGAN (USA) IN 1968 AND FORMALISED BY X. LE PICHON (FRANCE) ALSO IN 1968



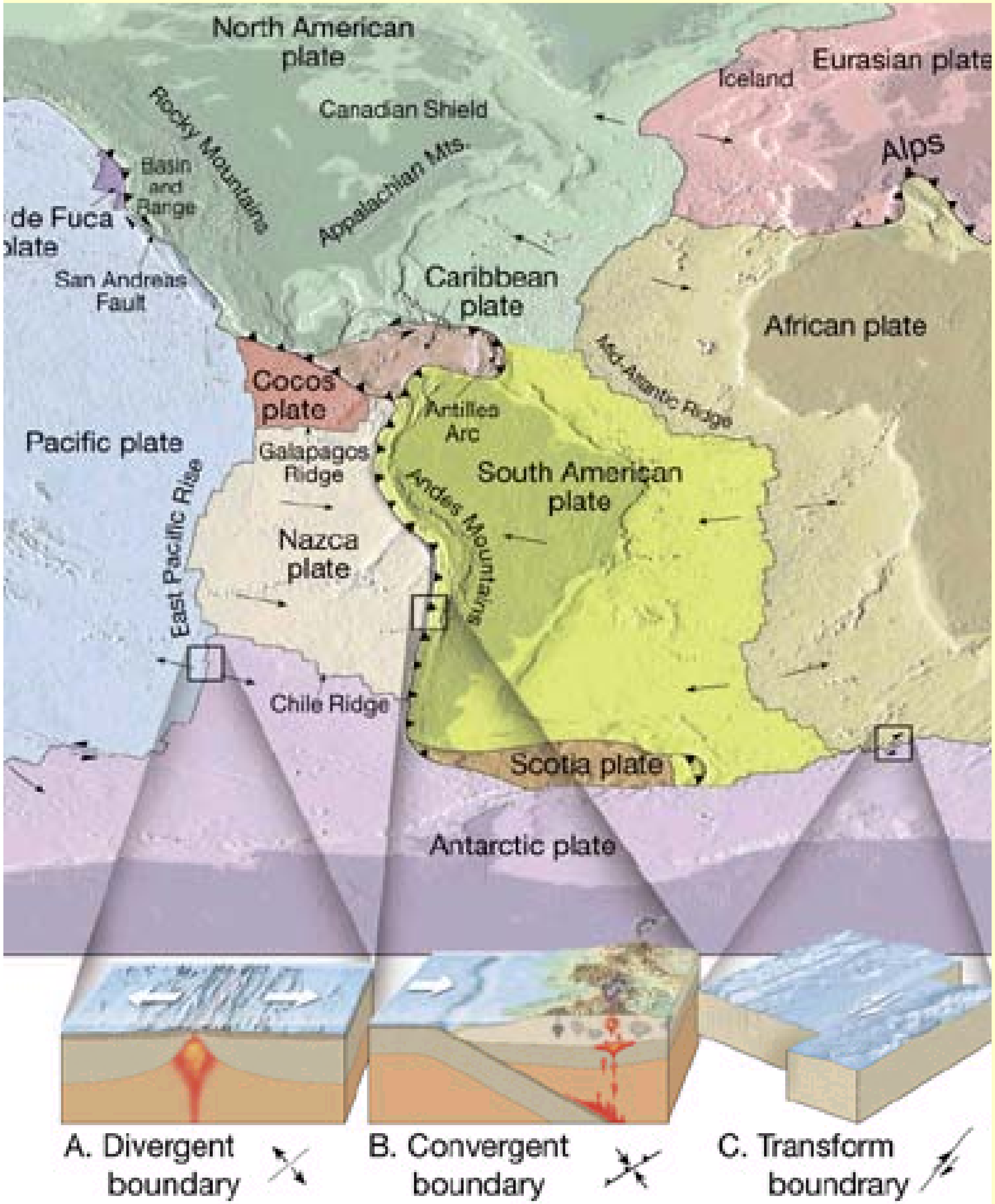

**NOTE MOST PLATES CONSIST OF OCEANIC CRUST AND CONTINENTAL CRUST**

FIGURE 4.3

# NOTE MOST PLATES CONSIST OF OCEANIC CRUST AND CONTINENTAL CRUST

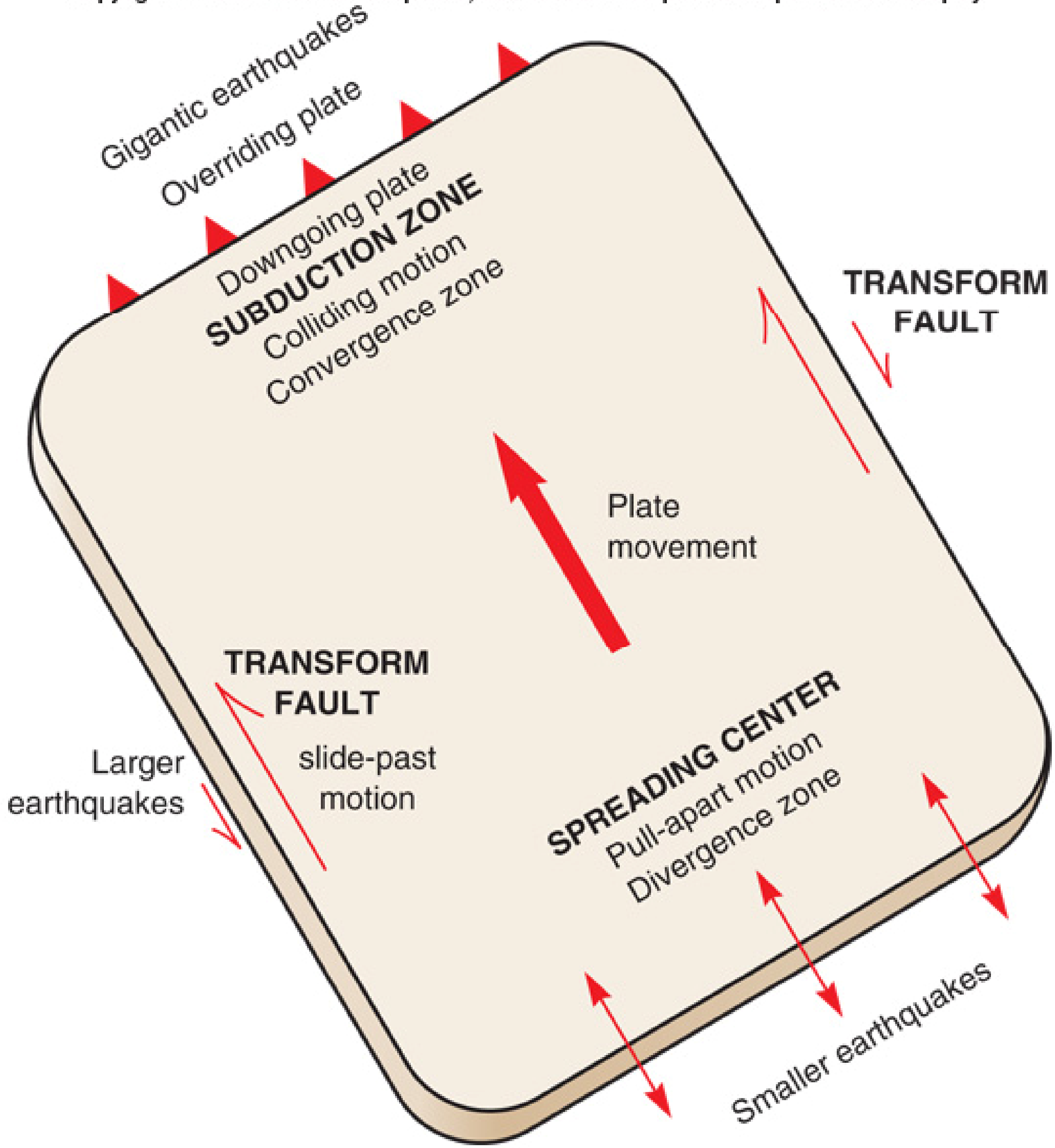



# AS PLATES MOVE SO DO THE CONTINENTS

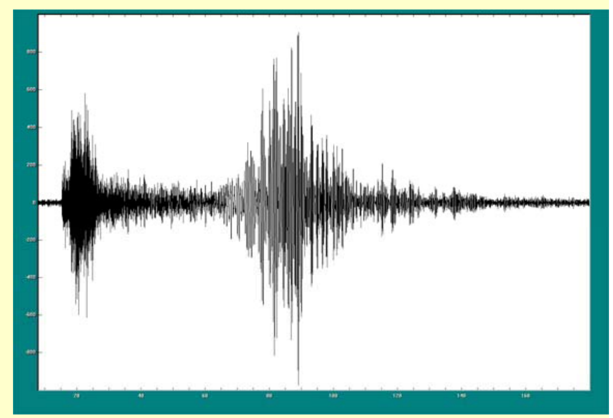



# PLATE BOUNDARIES

1. **DIVERGENT** Plate Boundaries (constructive margin)
2. **CONVERGENT** Plate Boundaries (destructive margin)
3. **TRANSFORM** Fault Boundaries (neutral margin)



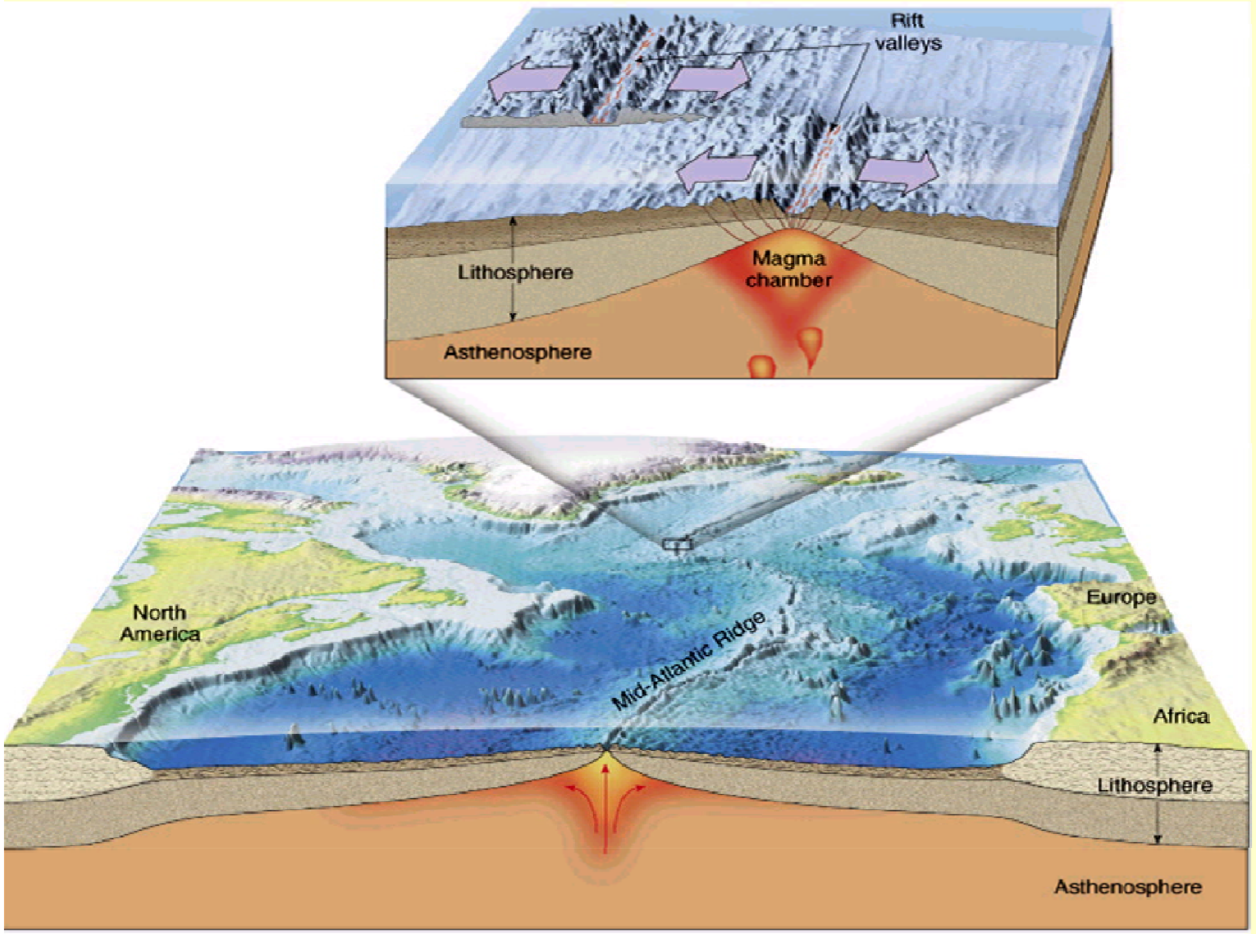

# RELATION BETWEEN PLATE BOUNDARIES AND EARTHQUAKE CHARACTERISTICS



*Seismogram of 2004 Great Sumatra Earthquake (A MegaThrust Event)*

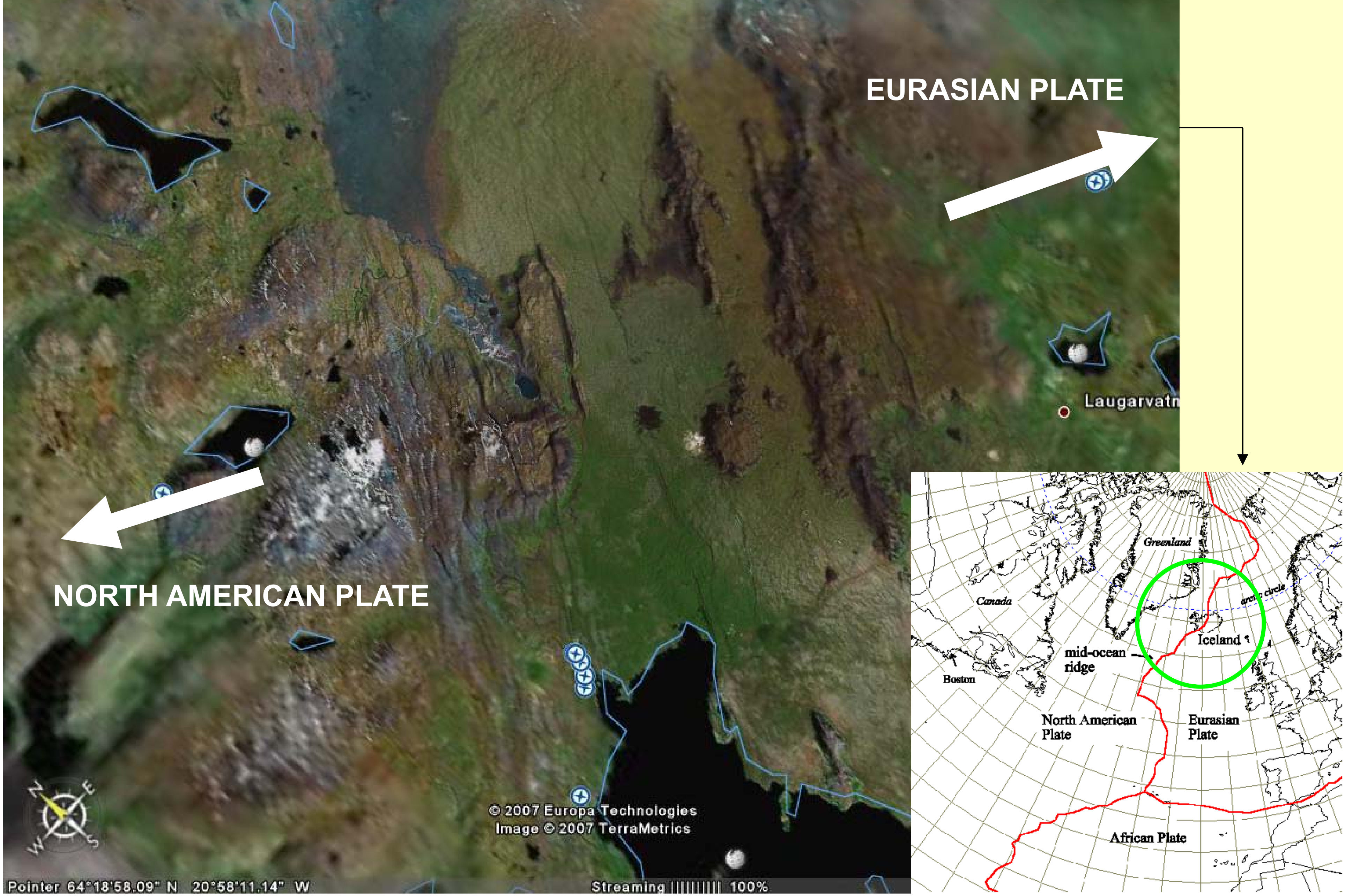
# 1. DIVERGENT PLATE BOUNDARIES: Oceanic Ridges and Sea Floor Spreading

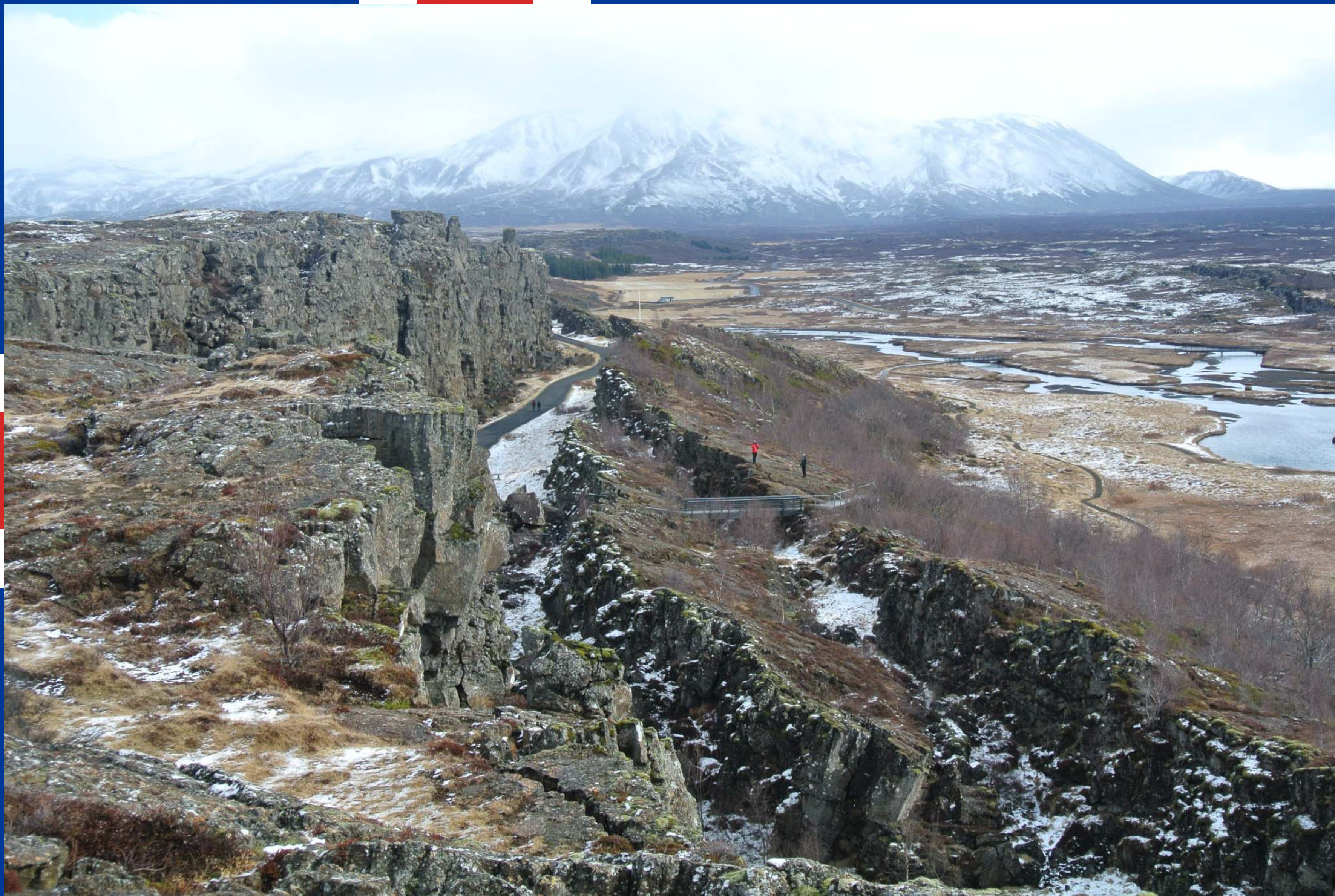
•Most common divergent boundary is an OCEANIC RIDGE
•Oceanic ridges form a >70,000 km long surface feature on the ocean floor
•Crests usually 2-3 km higher then adjacent ocean basin



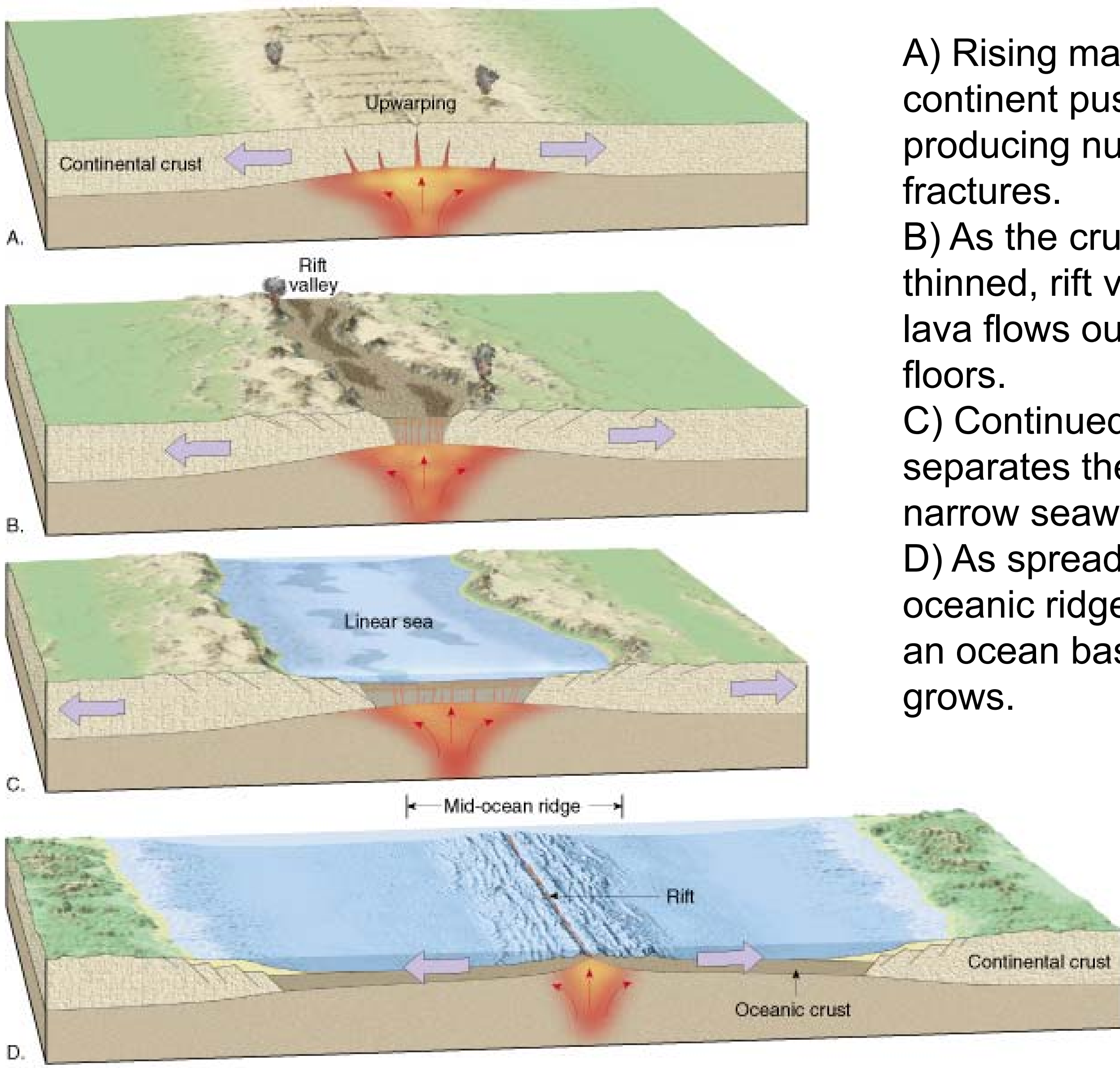

- Along the axis often deep down-faulted structures called rift valleys
- Sea floor spreading (2 - 15 cm/year) pushes ocean crust laterally and generates new crust symmetrically
- Slow process but recycles oceanic crust in 200 M y

# SPREADING OF MID-ATLANTIC RIDGE IN ICELAND; PLATE BOUNDARY ON GOOGLE EARTH





# DIVERGENT BOUNDARIES: Continental Rifts




A) Rising magma beneath a continent pushes the crust up, producing numerous cracks and fractures.
B) As the crust is stretched and thinned, rift valleys develop, and lava flows out onto the valley floors.
C) Continued spreading further separates the continent until a narrow seaway develops.
D) As spreading continues, an oceanic ridge system forms, and an ocean basin develops and grows.

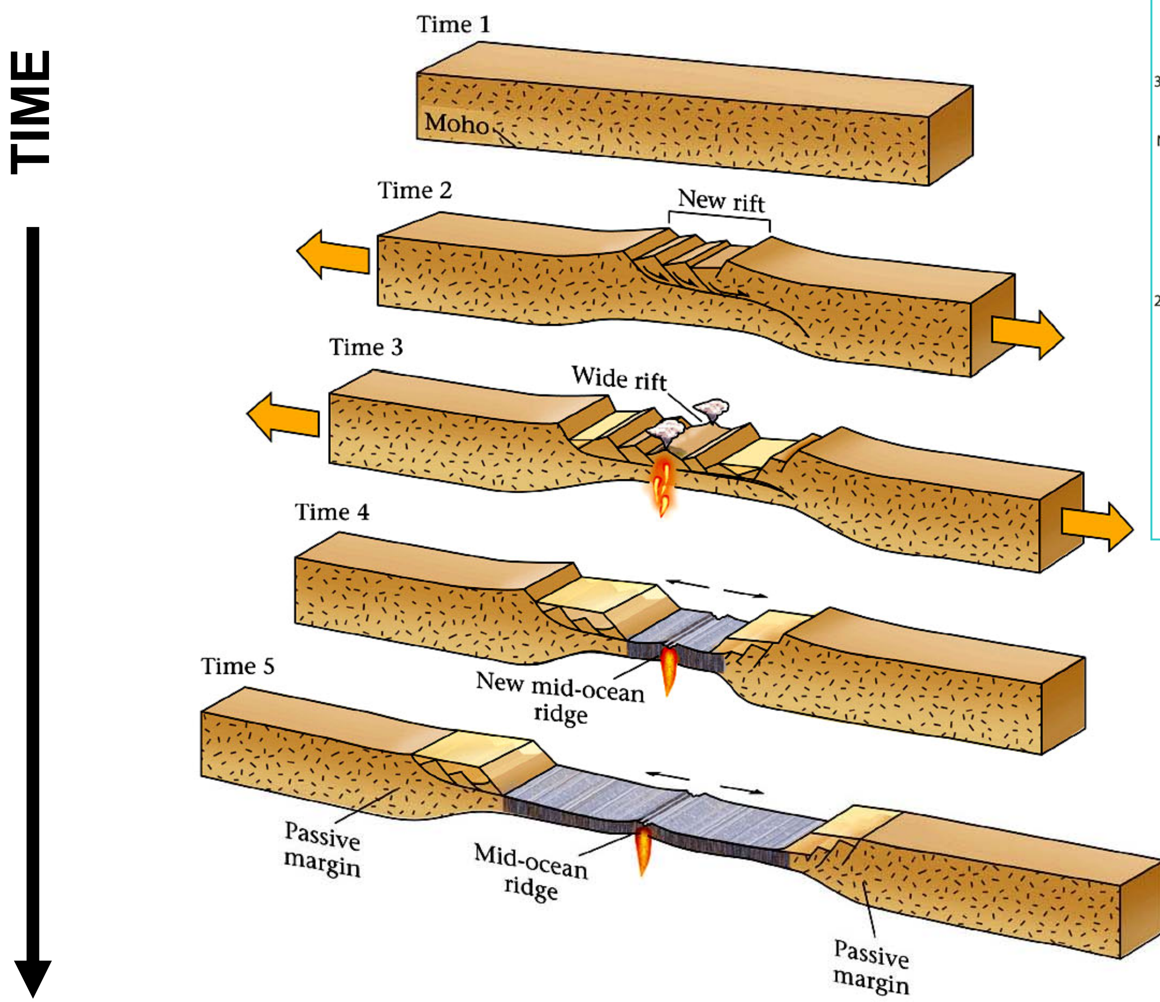
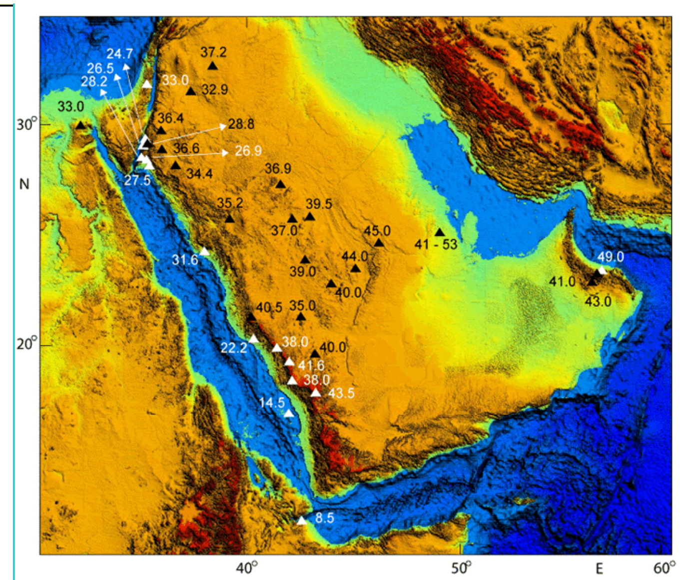



FIGURE 4.24

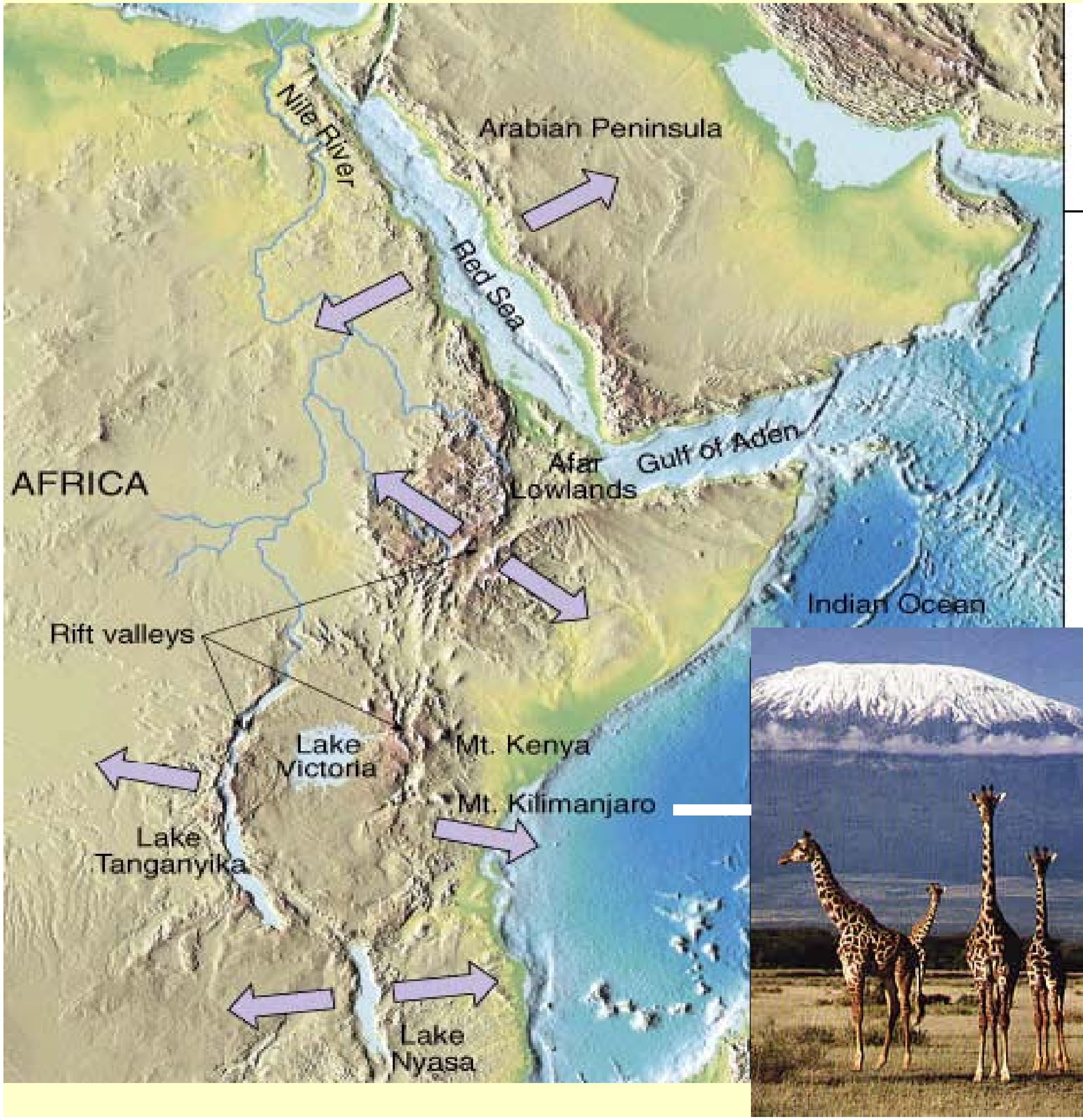
*Earth: Portrait of a Planet*, 2nd Edition

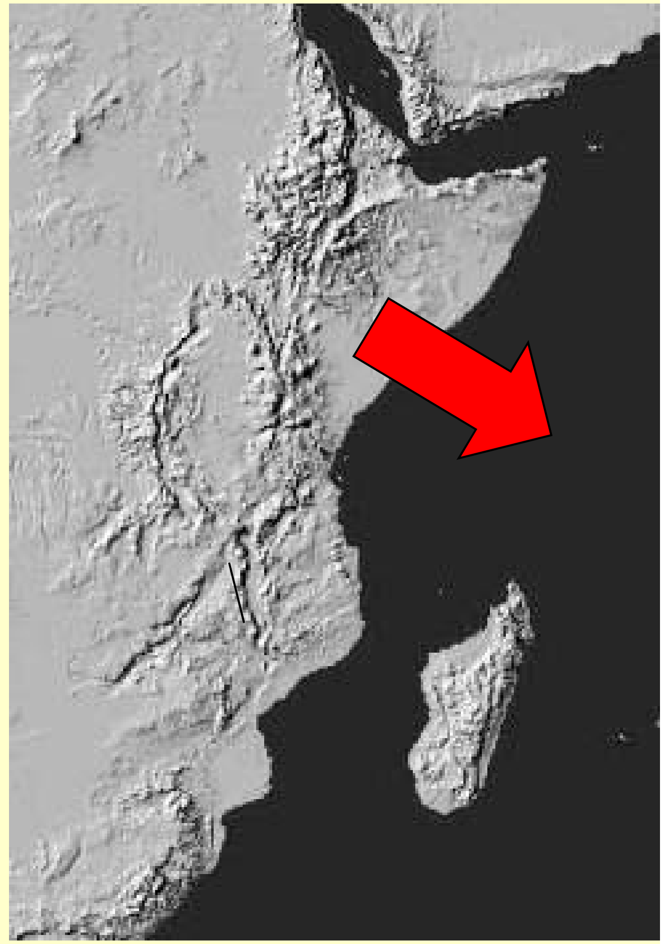

# CONTINENTAL RIFTING

**RED SEA**

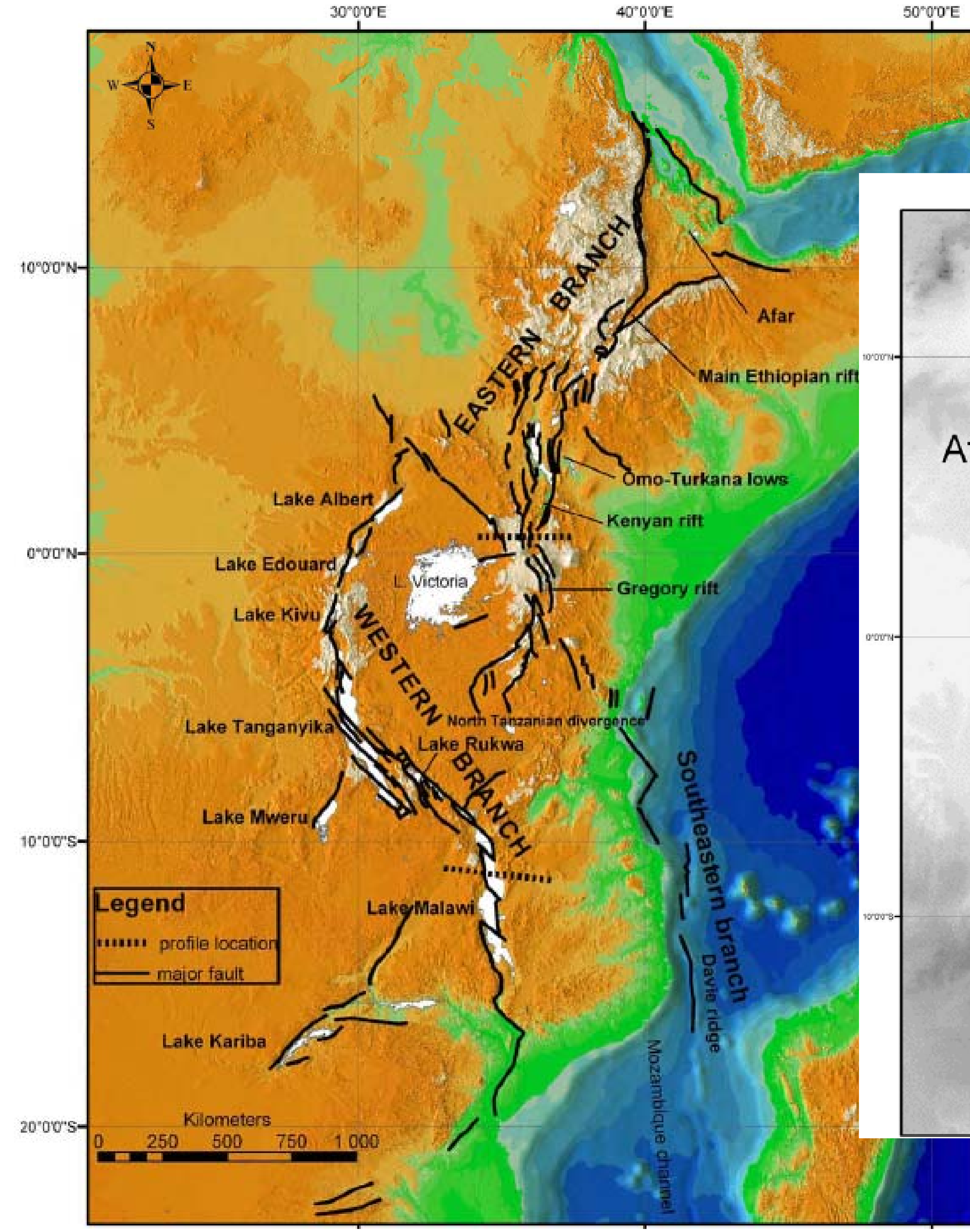
# DIVERGENT BOUNDARIES: Continental Rifts

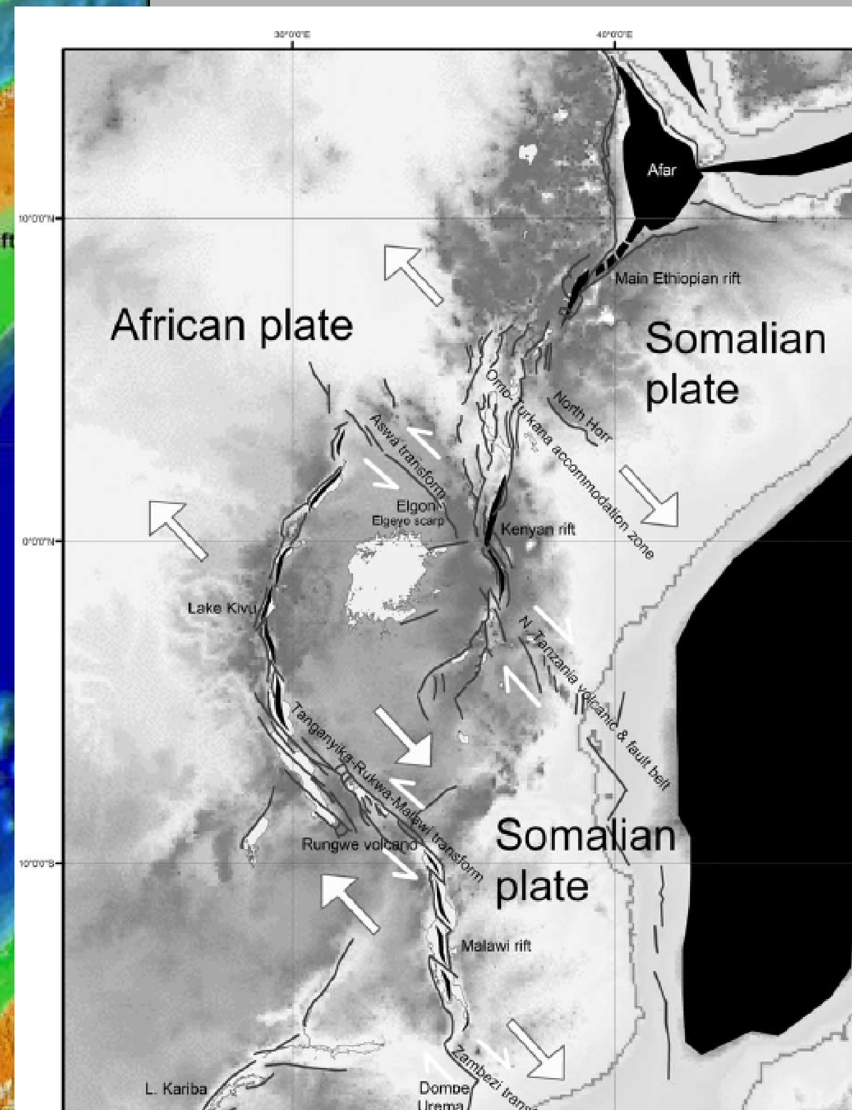


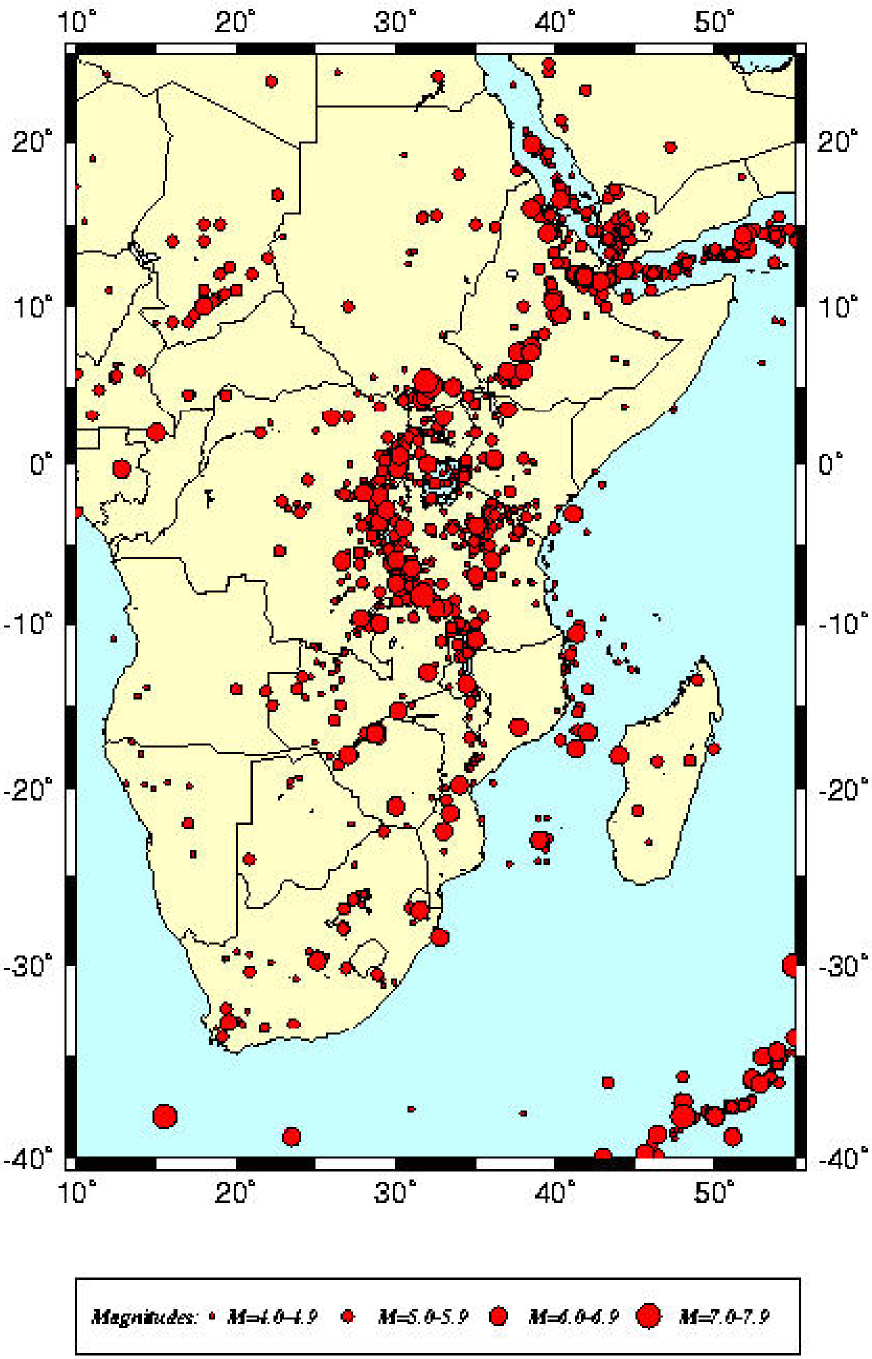

## EAST AFRICAN RIFT



# EAST AFRICAN RIFT SYSTEM



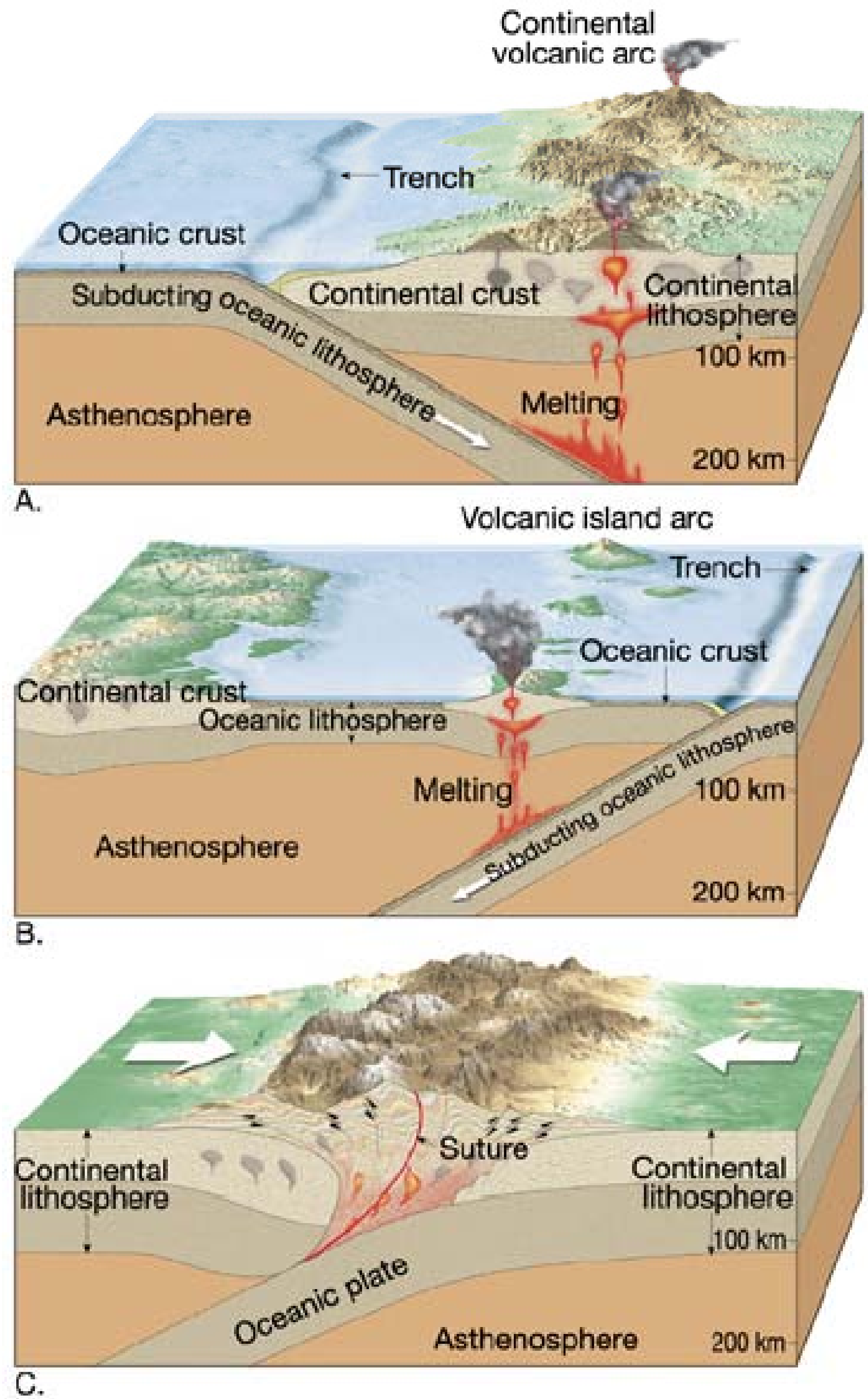






# EARTHQUAKES ALONG THE EAST AFRICAN RIFT


# 2. CONVERGENT PLATE BOUNDARIES

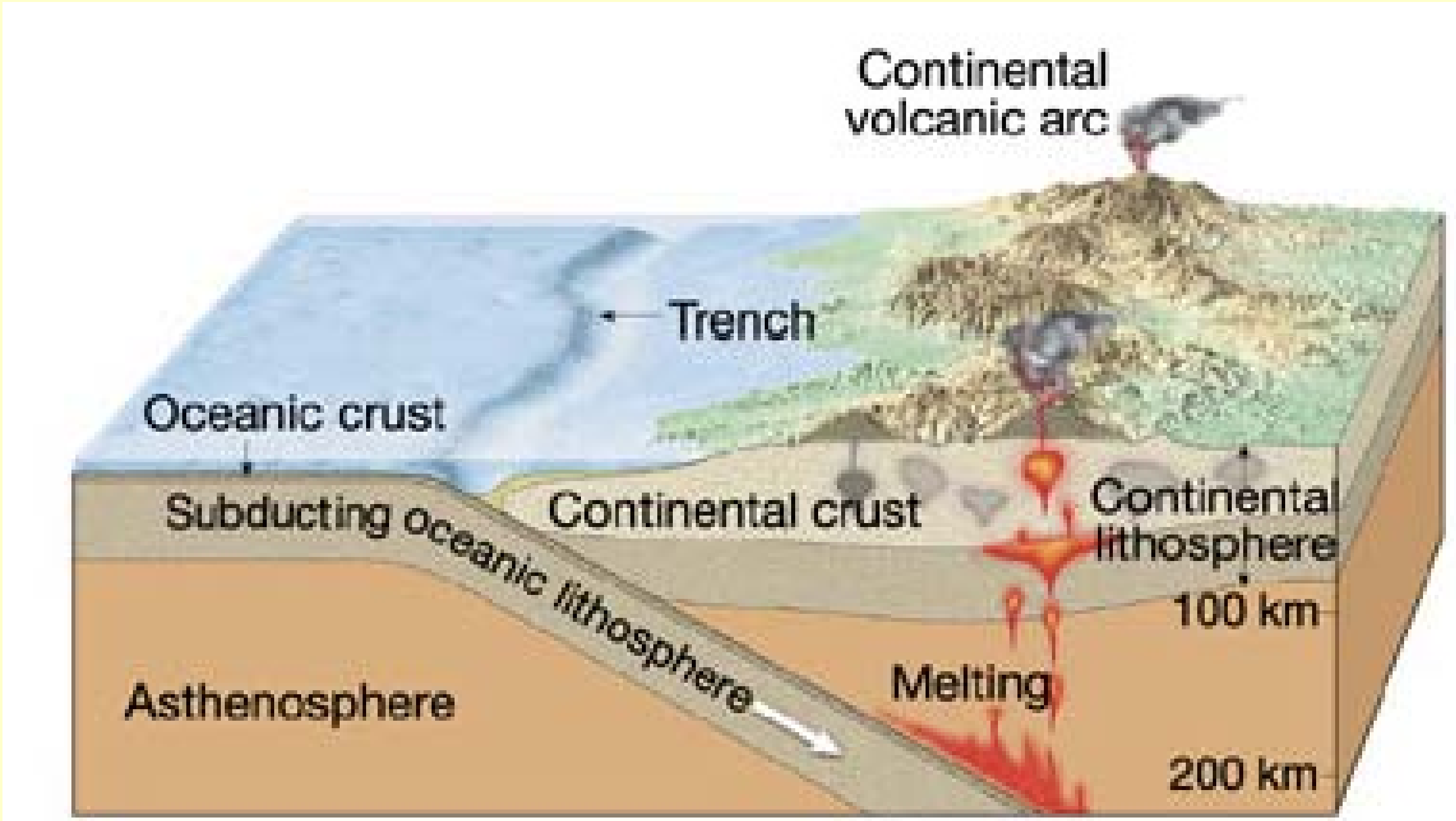
- Convergent boundaries are characterized by deformation, volcanism, mountain building, metamorphism, seismicity and important mineral deposits
- Convergent margins can be one of three types ;
  - **oceanic : continental (A)**
  - **oceanic : oceanic (B)**
  - **continental : continental (C)**



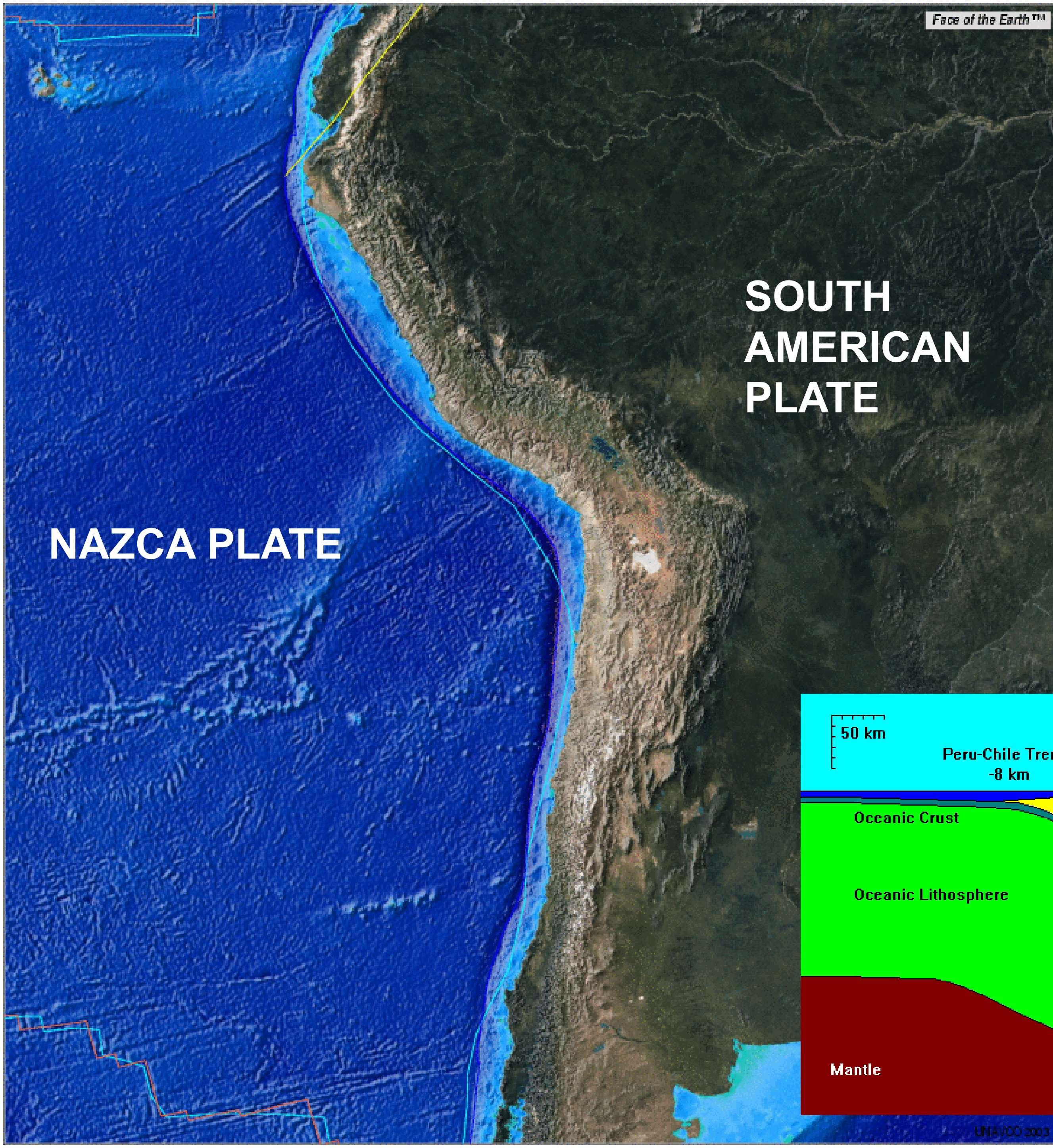
# (A) Oceanic - Continental Plate Boundaries

**Why is the oceanic plate always subducted ?**

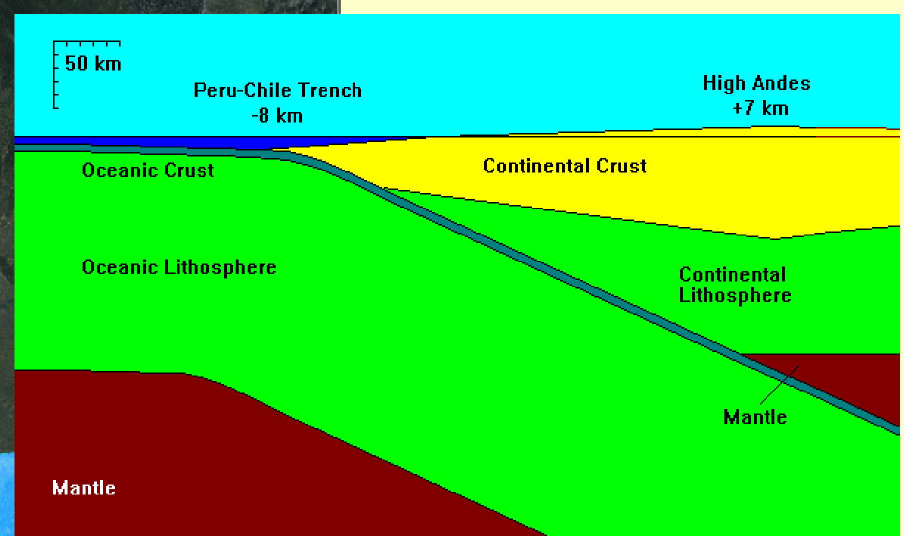
**Why not the continental plate ?**

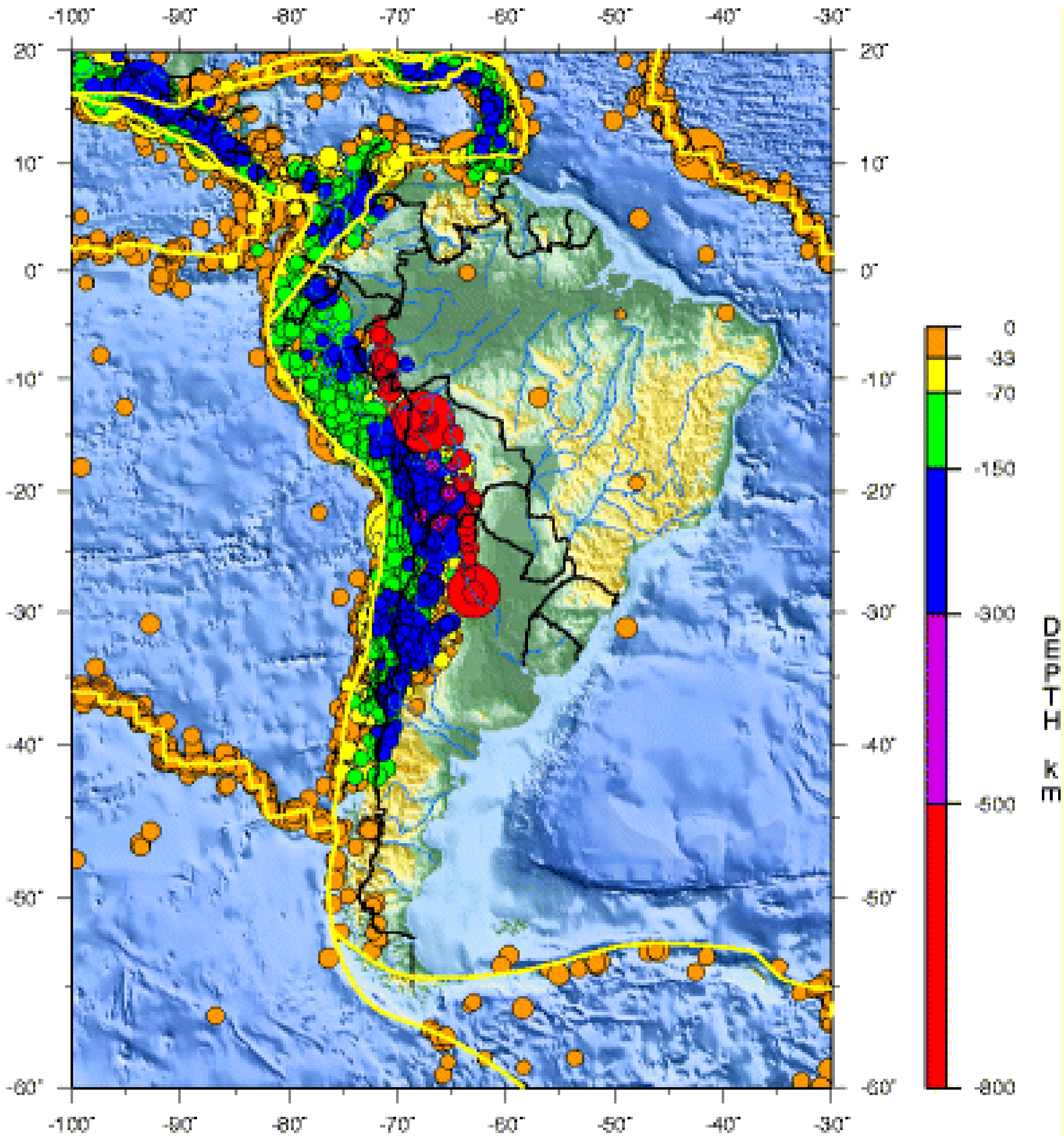



When oceanic plate is subducted beneath continental plate, an andesitic (see igneous rocks, later) volcanic mountain range is formed on the continent as a result of rising magma.




**ANDEAN SUBDUCTION ZONE :** NAZCA PLATE IS SUBDUCTING BENEATH SOUTH AMERICAN PLATE ; NOTE PERU-CHILE TRENCH



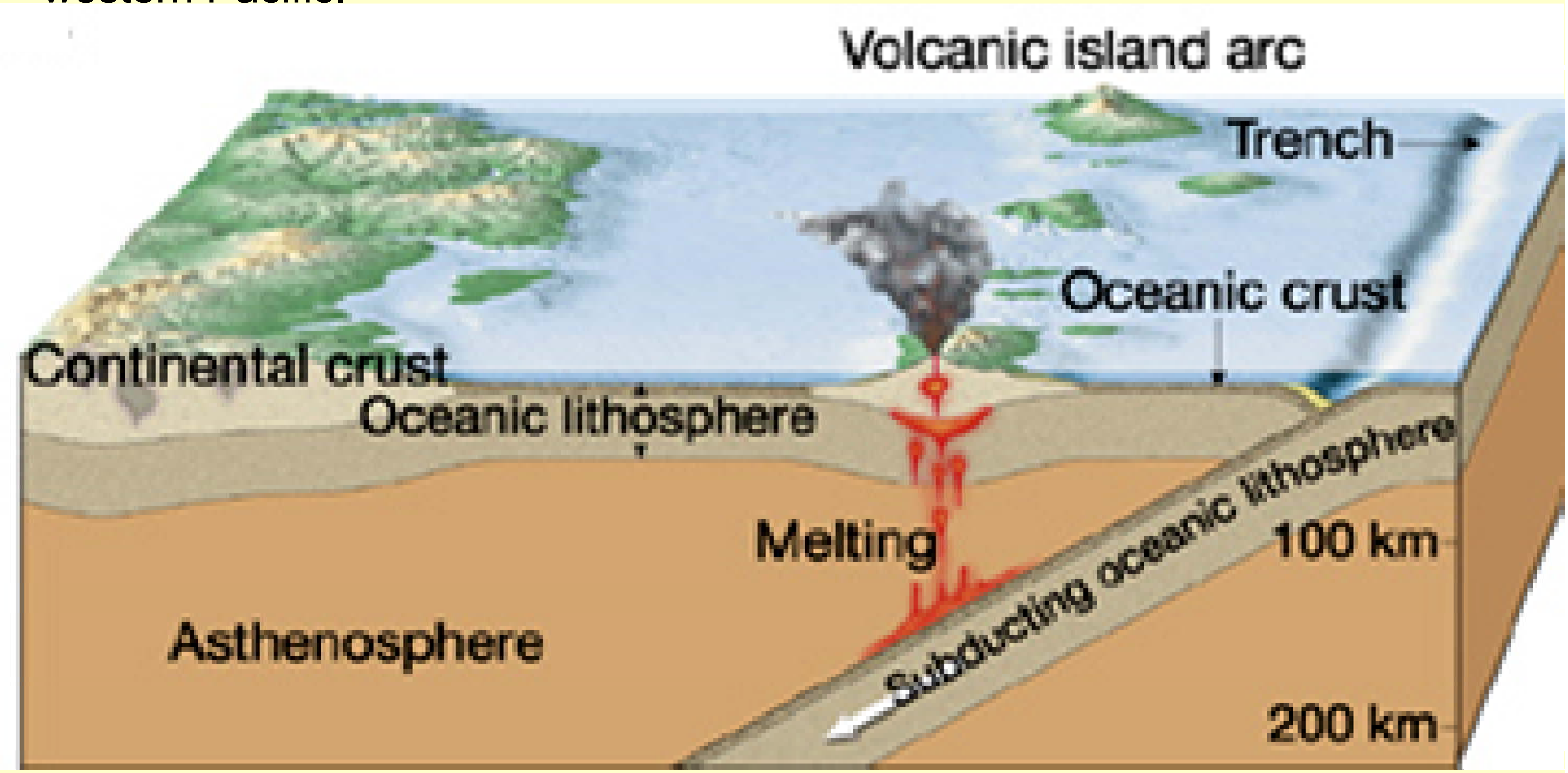


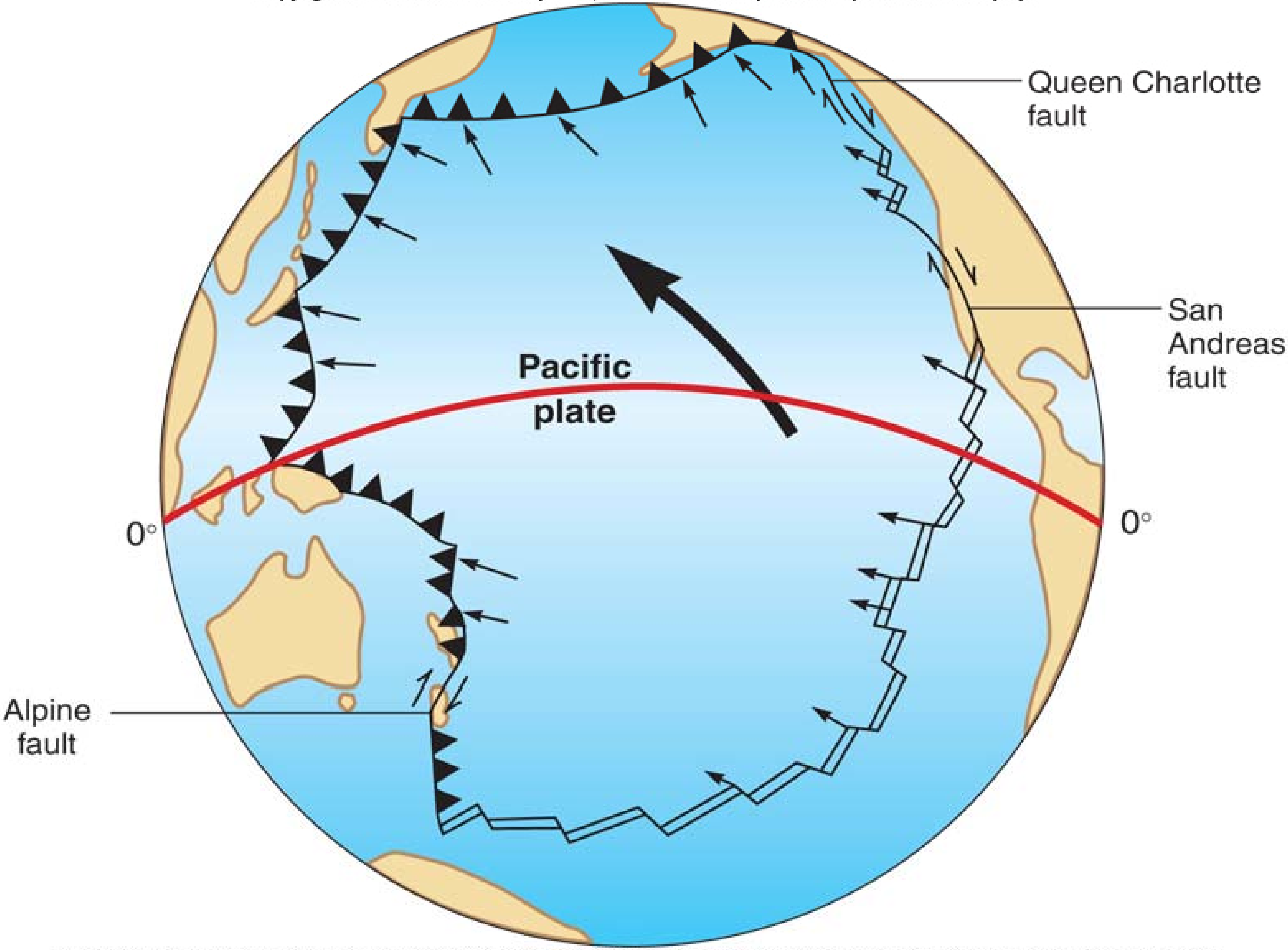

Seismicity of South America, 1990 - 2000

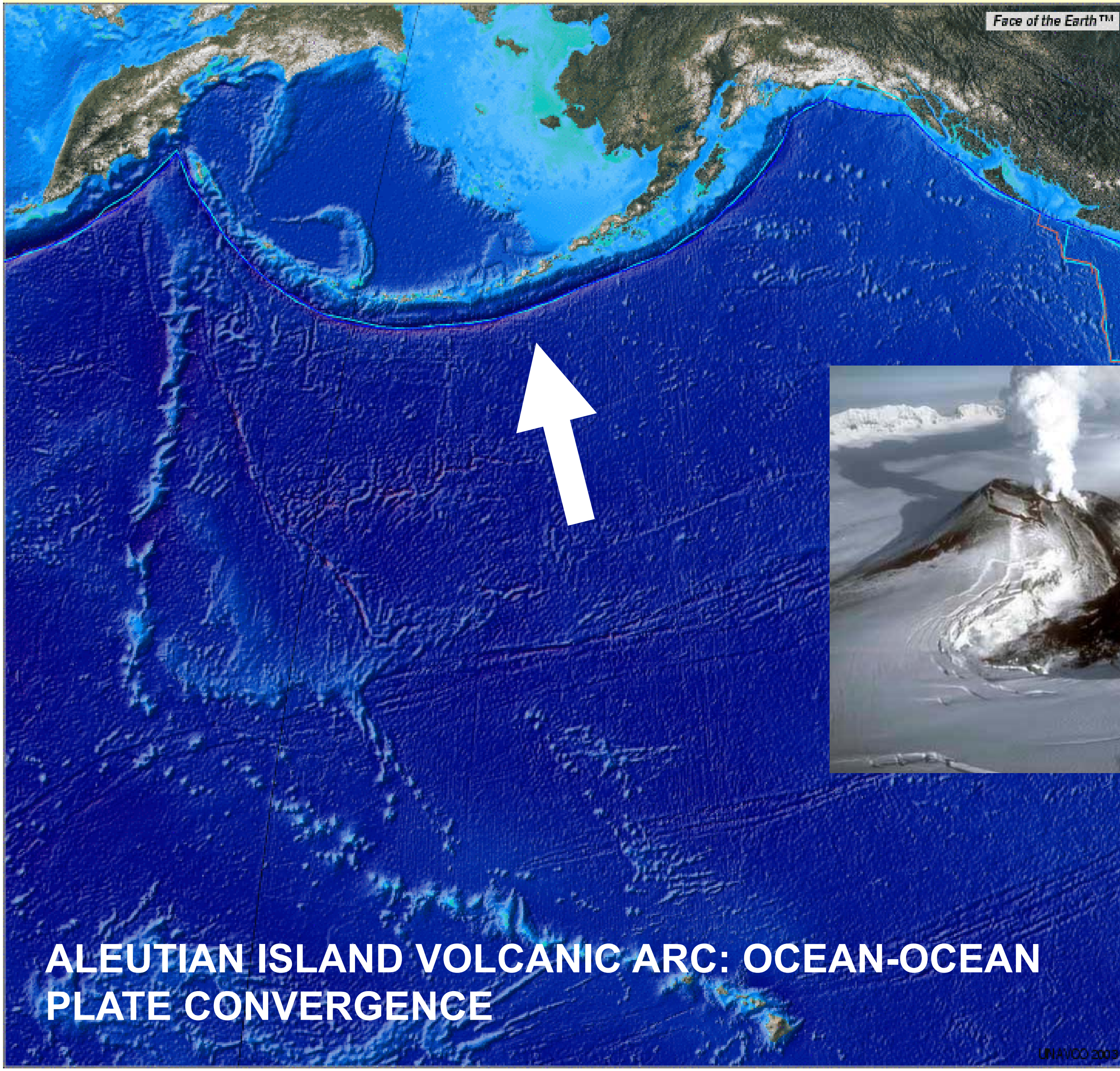
# EARTHQUAKES OF SOUTH AMERICA – CONVERGENT PLATE BOUNDARY

# (B) Oceanic - Oceanic Plate Boundaries

An oceanic trench forms where one oceanic plate is subducted beneath another. On the non-subducted plate, a volcanic island arc forms from the rising magma generated from the subducted plate. Distance to volcanic island arc depends on the angle of dip of the subducting plate. Most are in western Pacific.

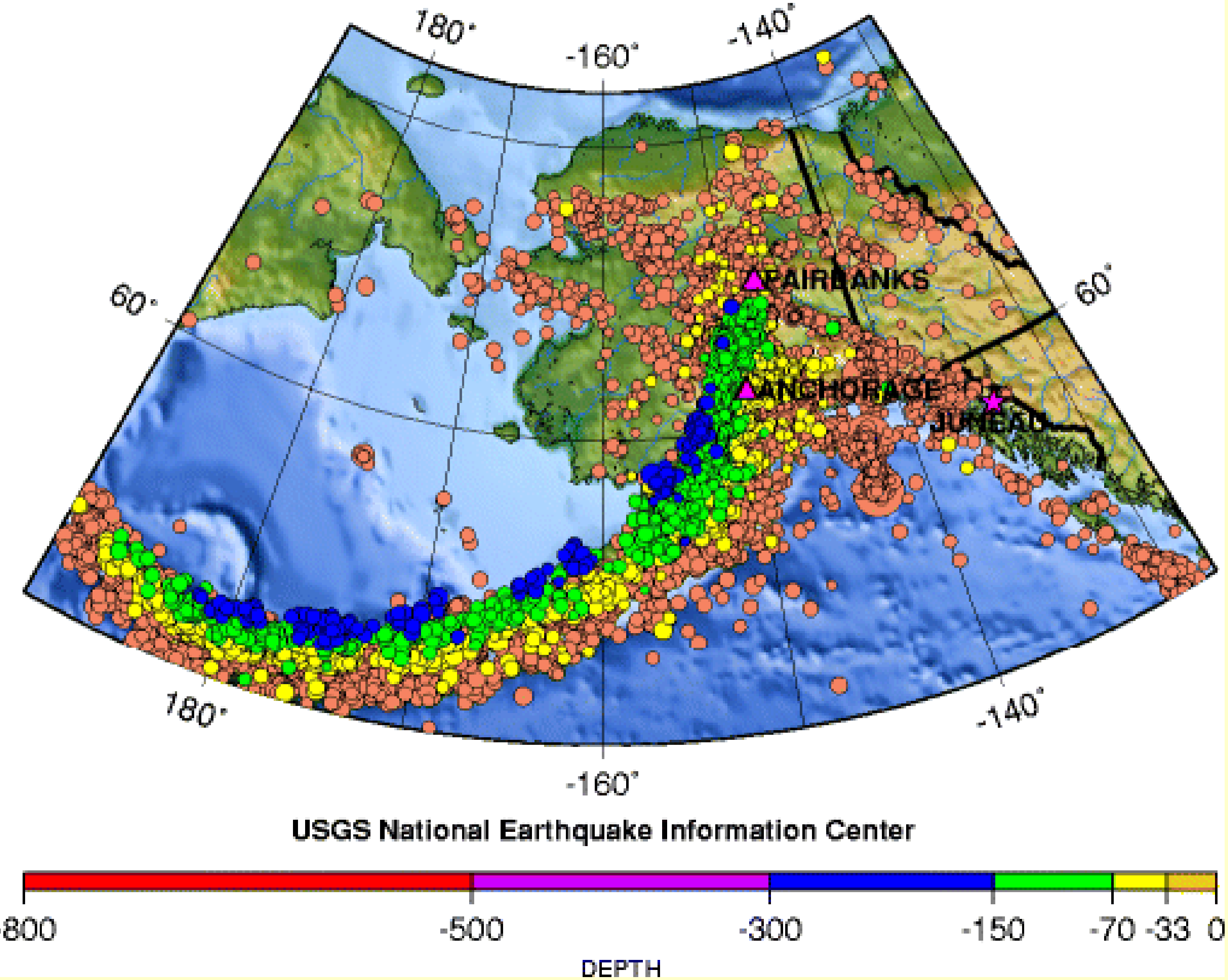



Queen Charlotte fault
San Andreas fault
Pacific plate
0°
0°
Alpine fault

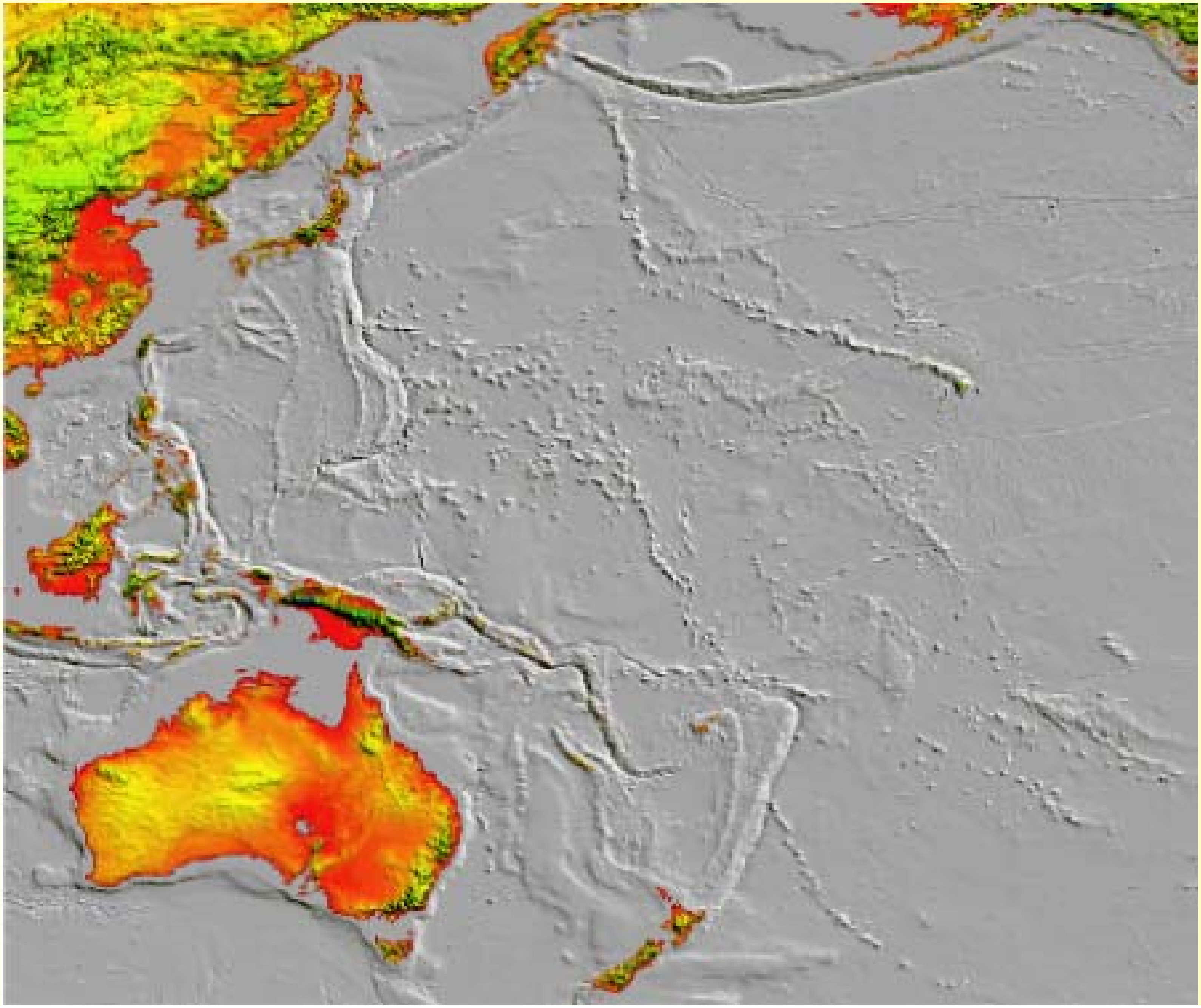

Face of the Earth™
ALEUTIAN ISLAND VOLCANIC ARC: OCEAN-OCEAN PLATE CONVERGENCE
UNAVCO 2003

# 1990 - 2001

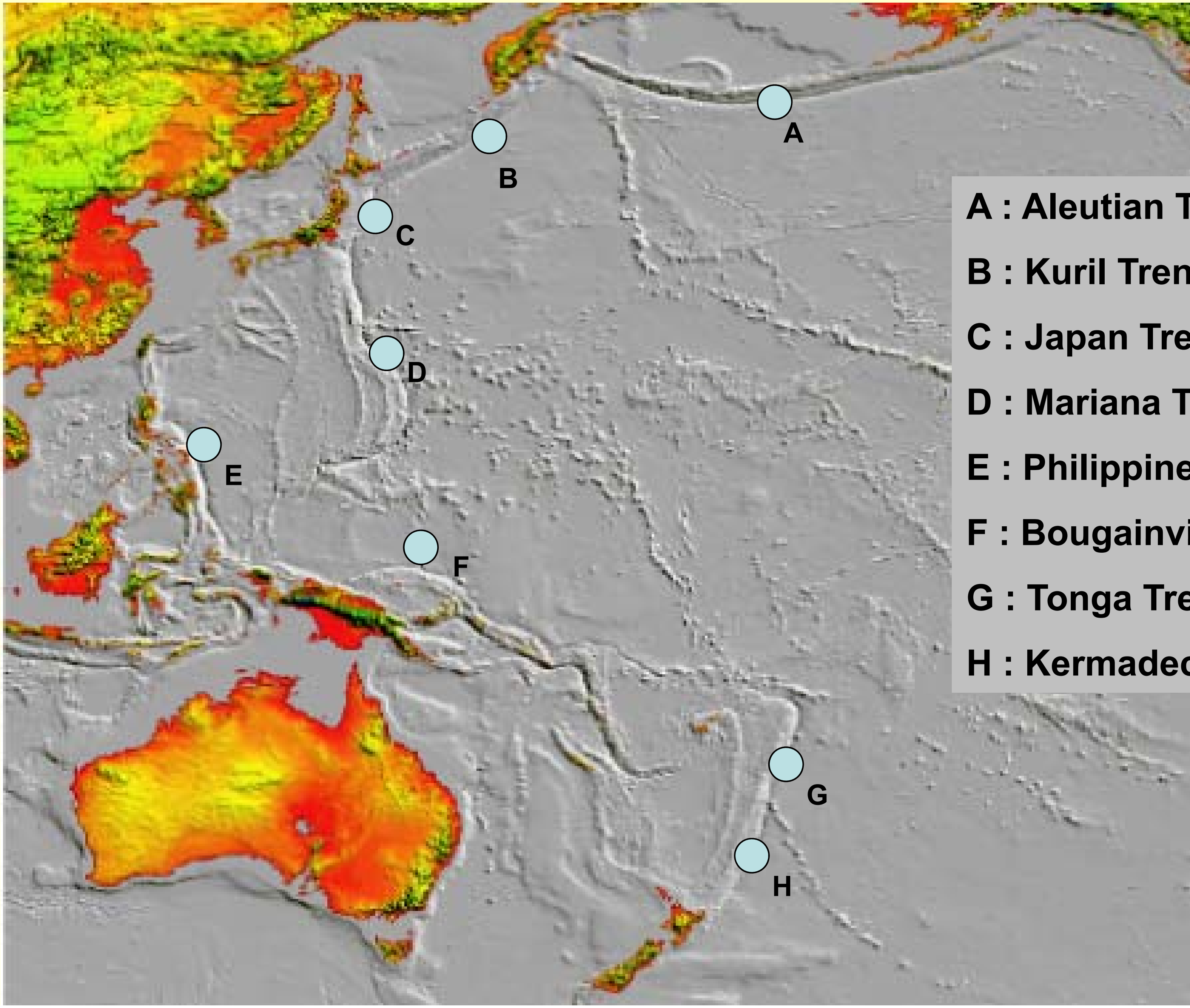
# Seismicity of Alaska



# TRENCHES OF THE WESTERN PACIFIC : CONVERGENCE OF OCEANIC CRUST



# TRENCHES OF THE WESTERN PACIFIC : CONVERGENCE OF OCEANIC CRUST




A : Aleutian Trench

B : Kuril Trench

C : Japan Trench

D : Mariana Trench

E : Philippine Trench

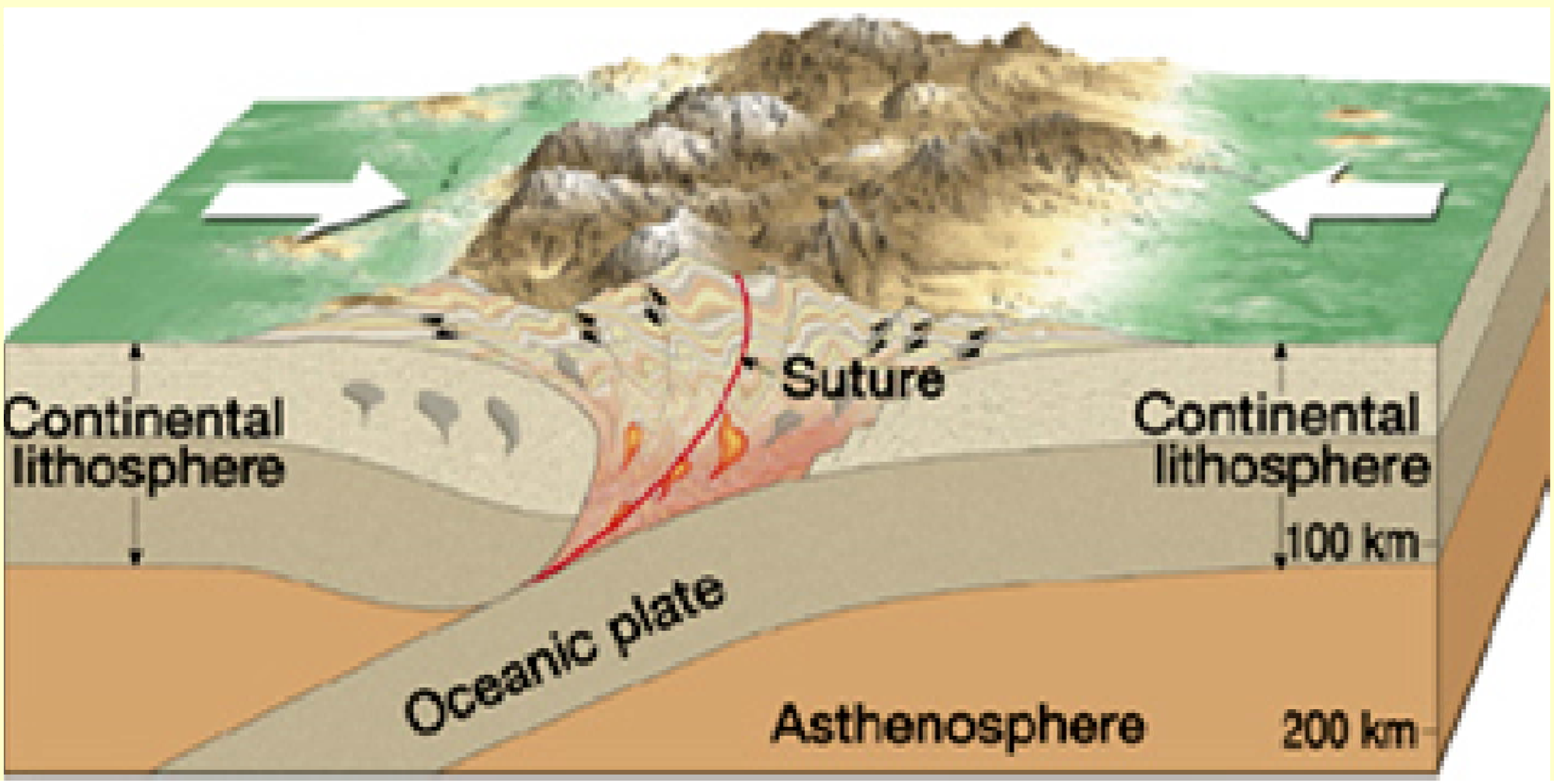
F : Bougainville Trench

G : Tonga Trench

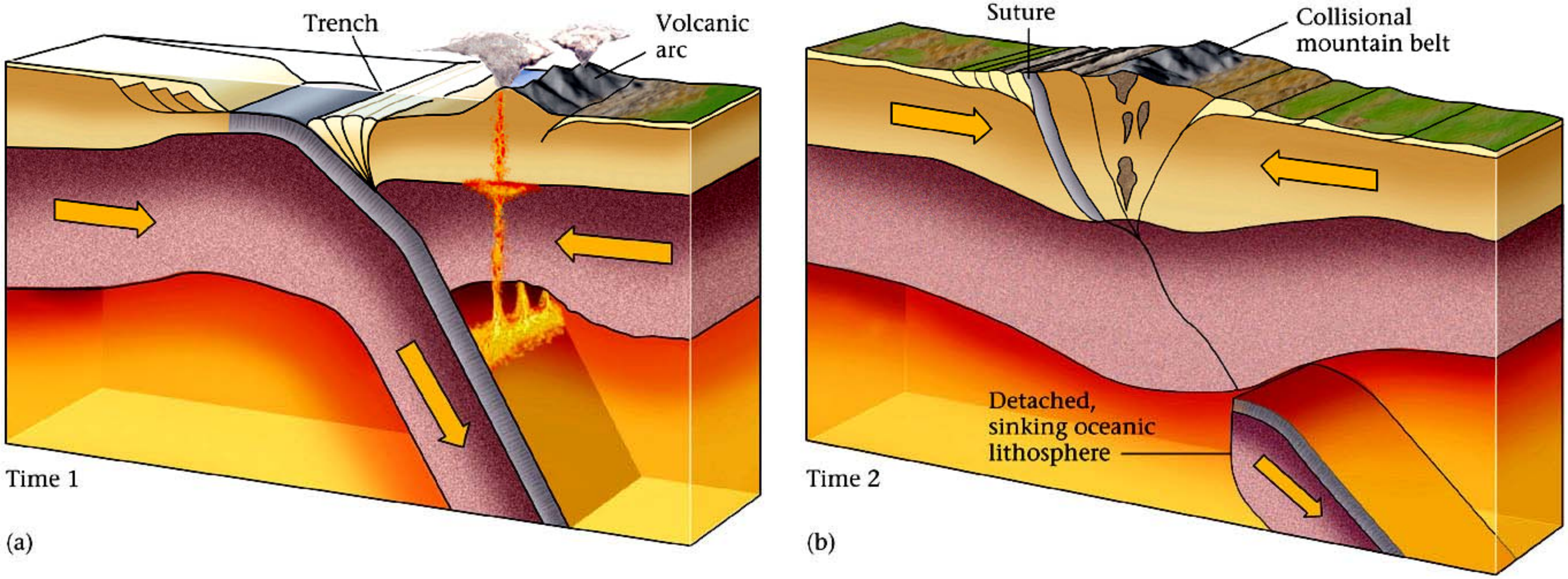
H : Kermadec Trench

## (C) CONTINENT – CONTINENT PLATE BOUNDARIES CONTINENTAL COLLISION

When two continental plates converge, neither is subducted because of their great thickness and low and equal densities. As the two continental plates collide, a mountain range is formed in the interior of a new and larger continent.



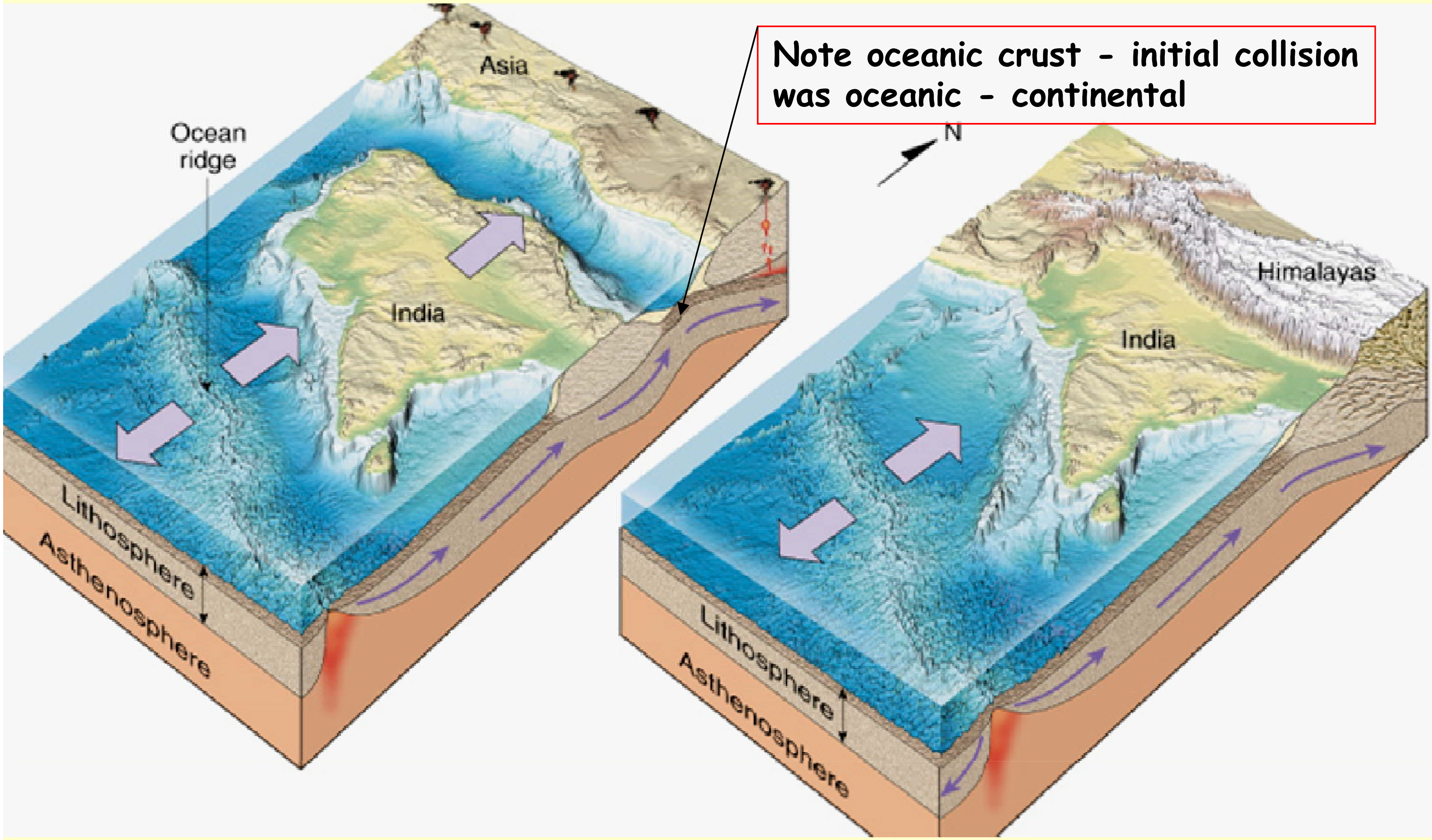
# DEVELOPMENT OF A CONTINENTAL COLLISION



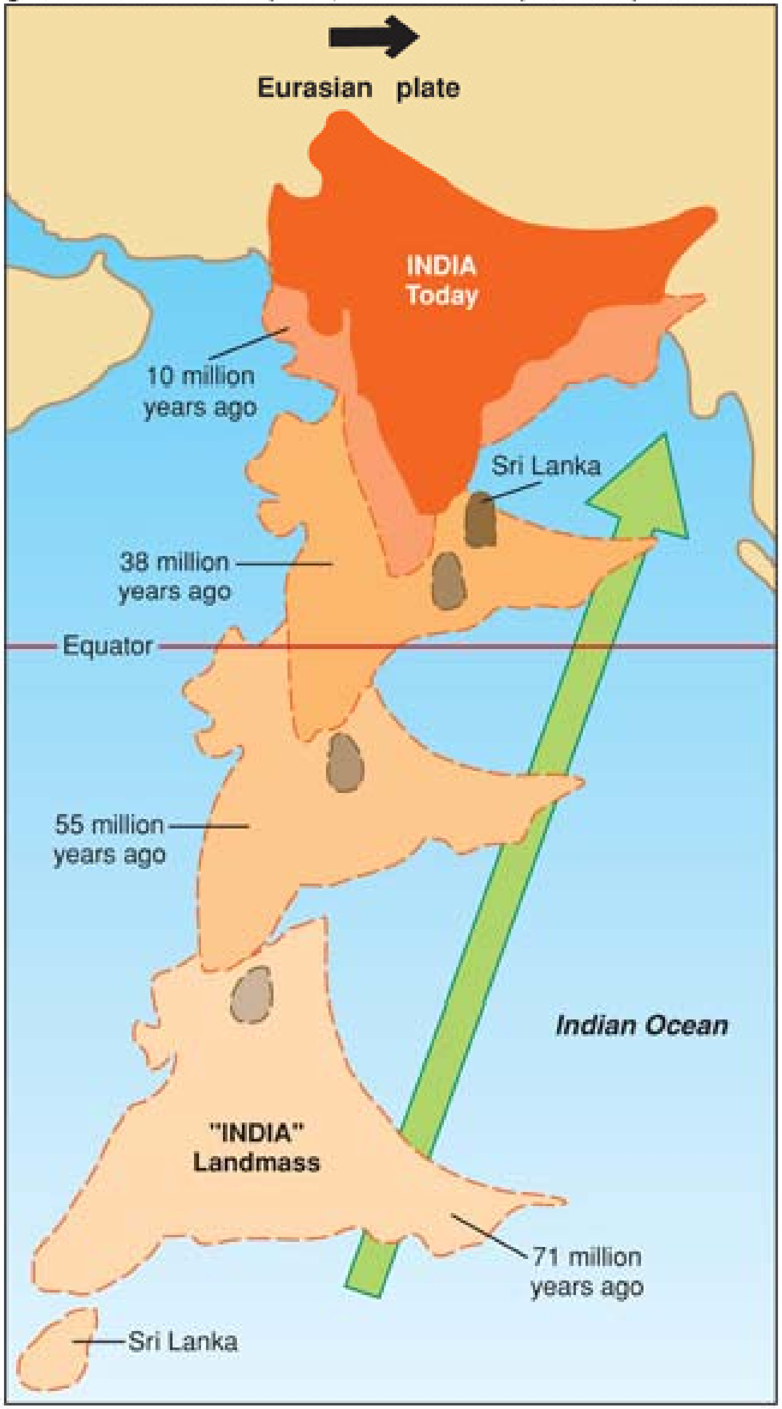

Before collision an oceanic plate is consumed by subduction and sinks into the mantle

FIGURE 4.27

# Continent – Continent Plate Boundaries
# The example of the India – Asia Collision




Note oceanic crust - initial collision was oceanic - continental

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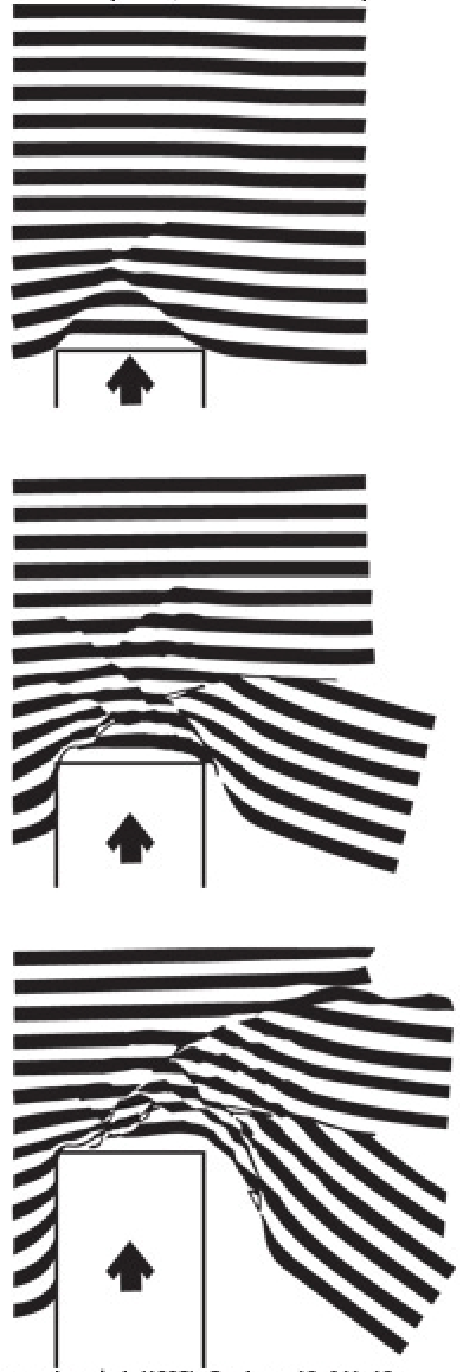
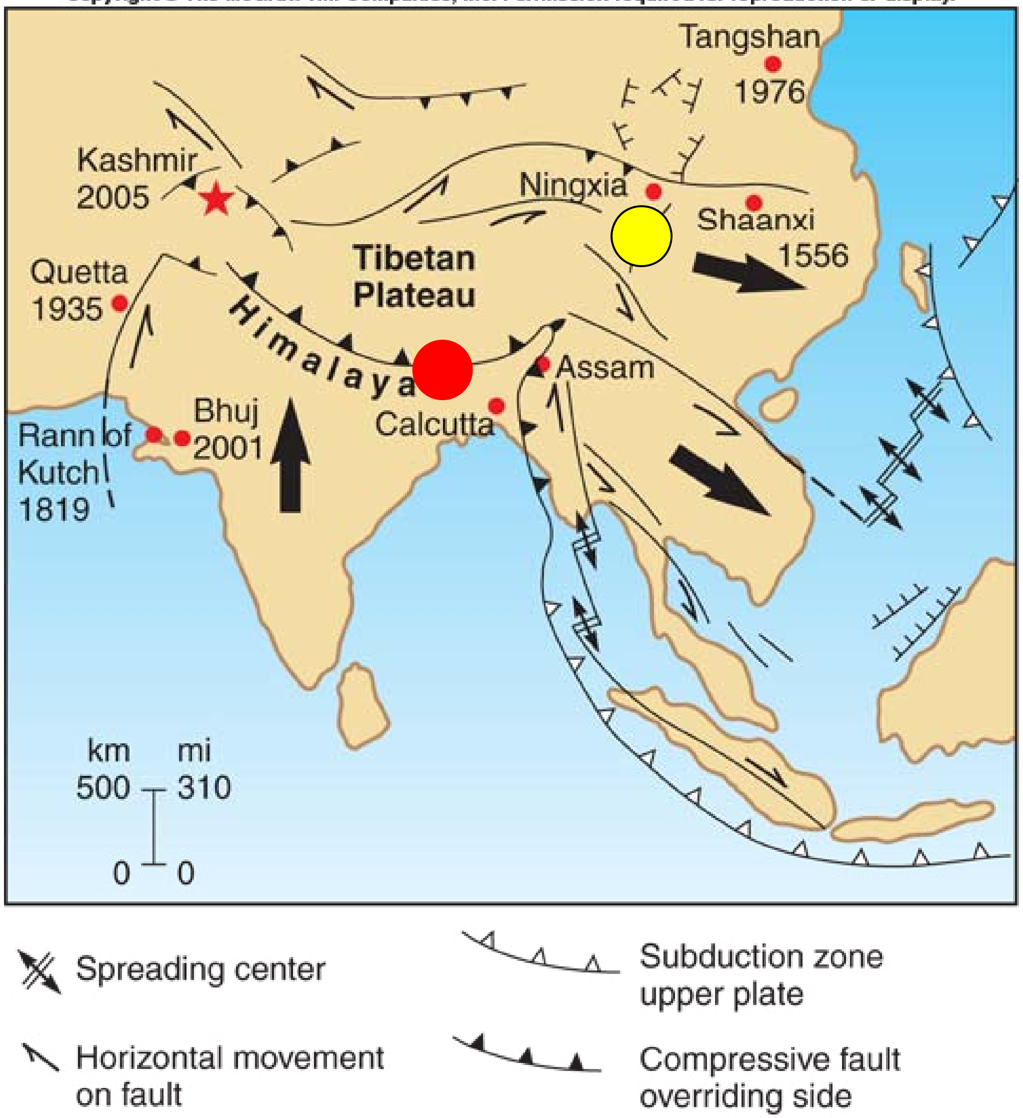
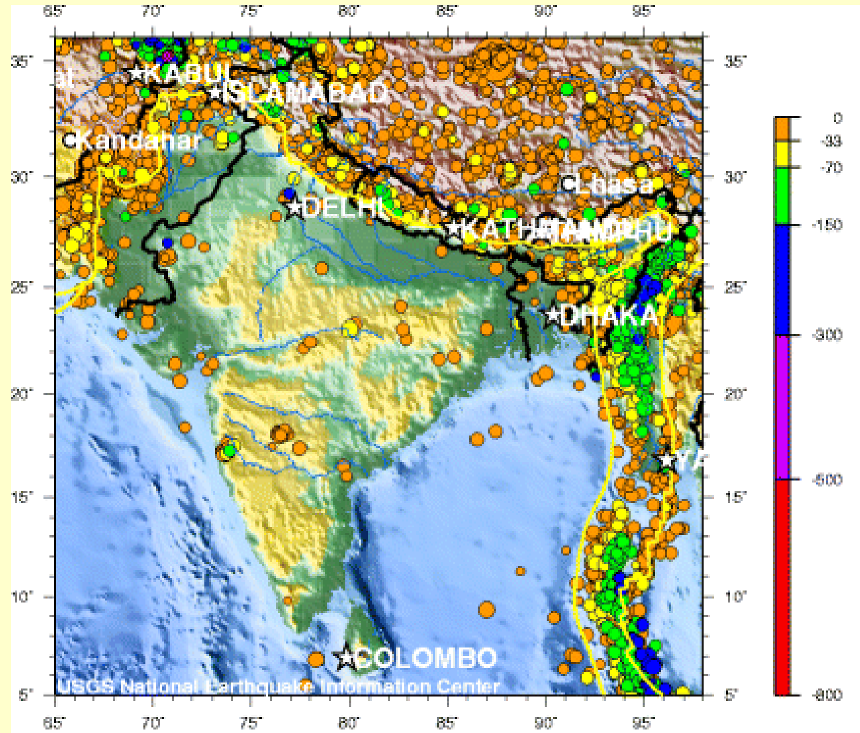


P. Tapponier, et al. (1982). Geology, 10, 611–16

# EARTHQUAKES AND THE INDIA-ASIA CONTINENTAL COLLISION





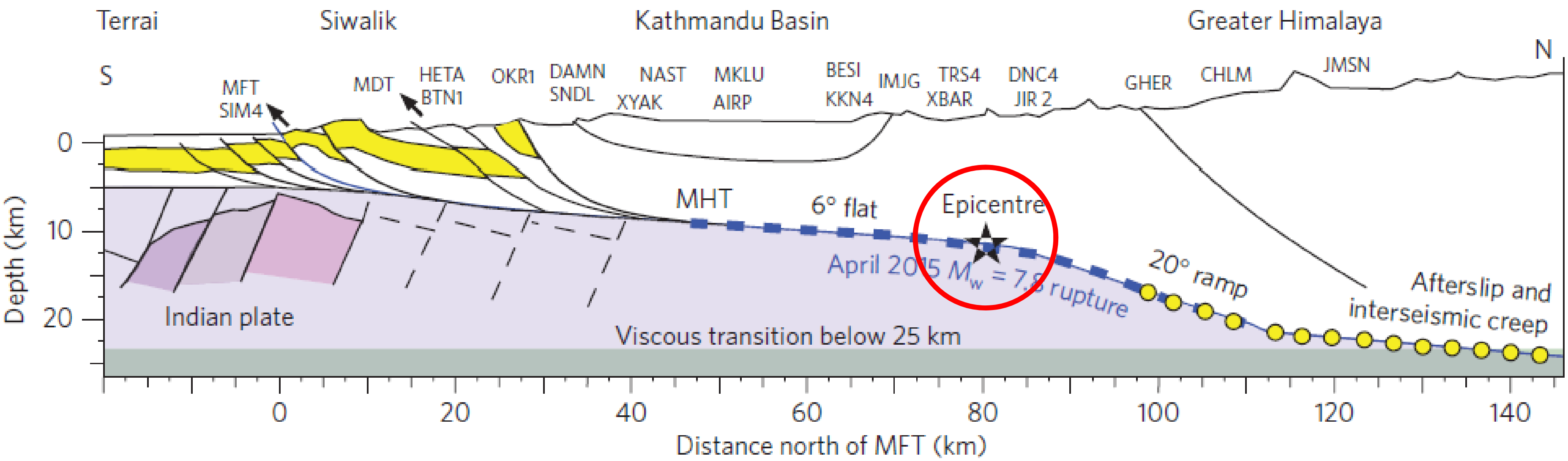



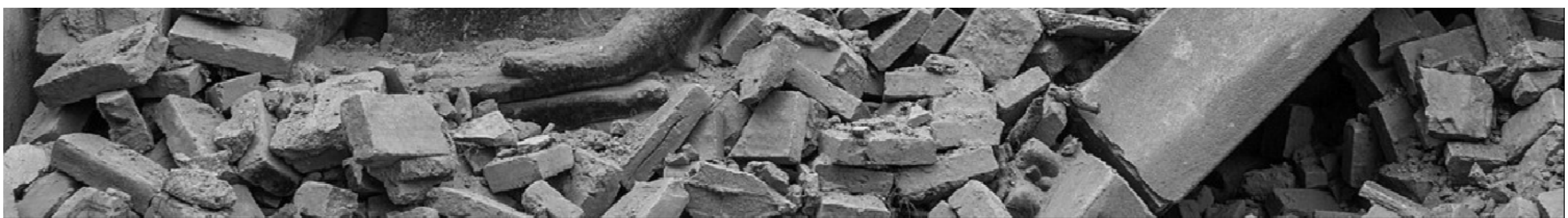

Seismicity of India, 1990 - 2000

80°
85°
90°
95°
100°
105°
110°
40°
35°
30°
25°
20°
阿拉善地块
塔里木盆地
阿尔金断裂带
11mm/a
2mm/a
河西走廊
和田
~18mm/a
柴达木-祁连块体
鄂尔多斯
地块
海原断裂带
六盘山
东昆仑断裂带
~20mm/a
2014-02-12
$M_w$7.1
1997-11-08
$M_w$7.6
2001-11-14
$M_w$7.8
11mm/a
西昆仑
2008-03-21
$M_w$7.1
~32mm/a
~30mm/a
2010-04-14
$M_w$6.9
巴颜喀拉块体
喀喇昆仑断裂
甘孜-玉树断裂
羌塘块体
鲜水河断裂
~15mm/a
4mm/a
2008-05-12
$M_w$7.9
拉萨块体
嘉黎断裂
2014-11-25
$M_w$6.0
2013-04-20
$M_w$6.6
大凉山断裂
雅鲁藏布江断裂
~10/15mm/a
~20mm/a
Kathmandou
川滇菱形块体
小江断裂带
华南地块
亚东
2014-08-03
$M_w$6.2
喜马拉雅山前推覆构造带
DAUKITHRUST
Yunnan
2014-10-107
$M_w$6.2
~40mm/a
红河断裂
加尔各答
实皆断裂
5mm/a
河内
印度板块
密支那-西盟
块体
0
500km

# NEPAL EARTHQUAKE [M7.8; APRIL, 25, 2015] – 9,000 deaths

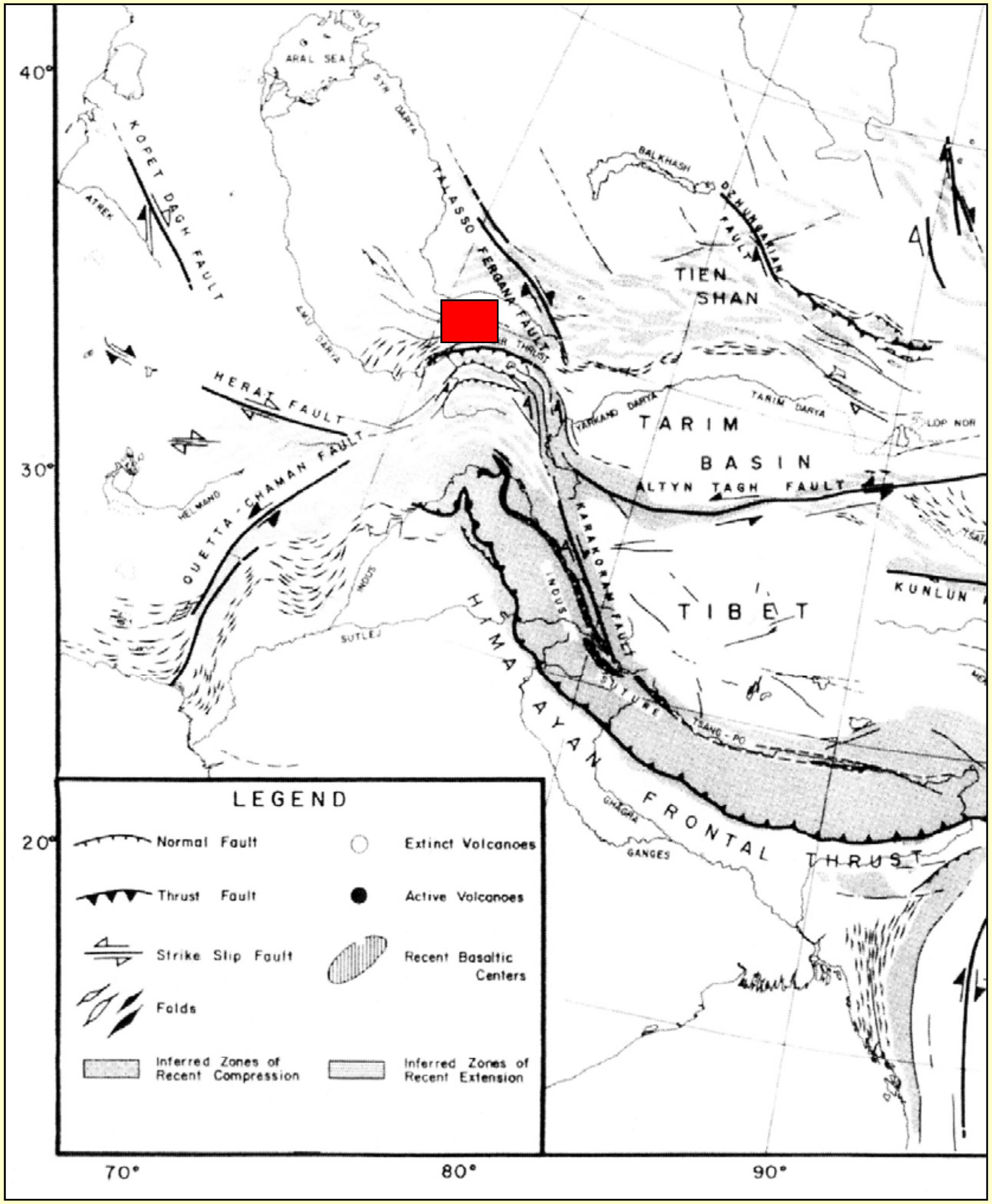

DEPTH – 13 km [PLATE BOUNDARY IN INDIA-EURASIA CONTINENTAL COLLISIONAL ZONE]



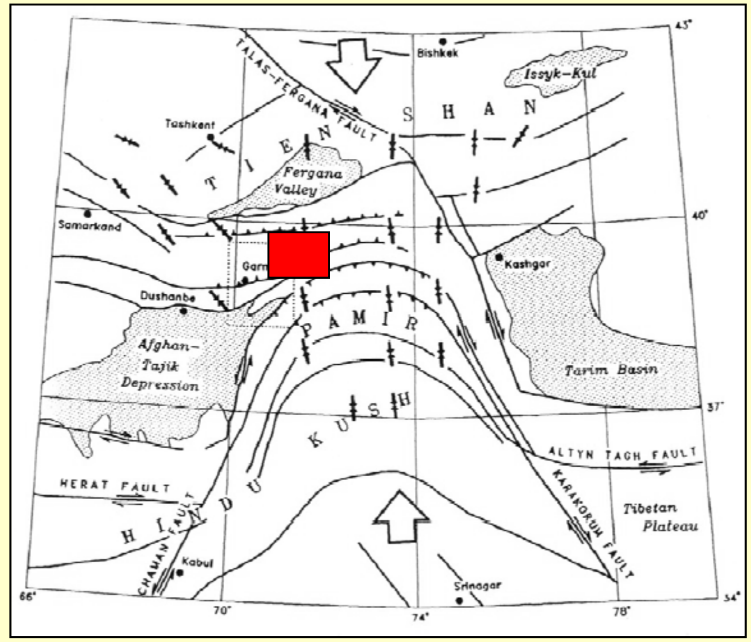



X- section of Himalayan thrust after Mencin et al. (2016)

(After Molnar and Tapponnier, 1975)




(After Lukk et al., 1995)

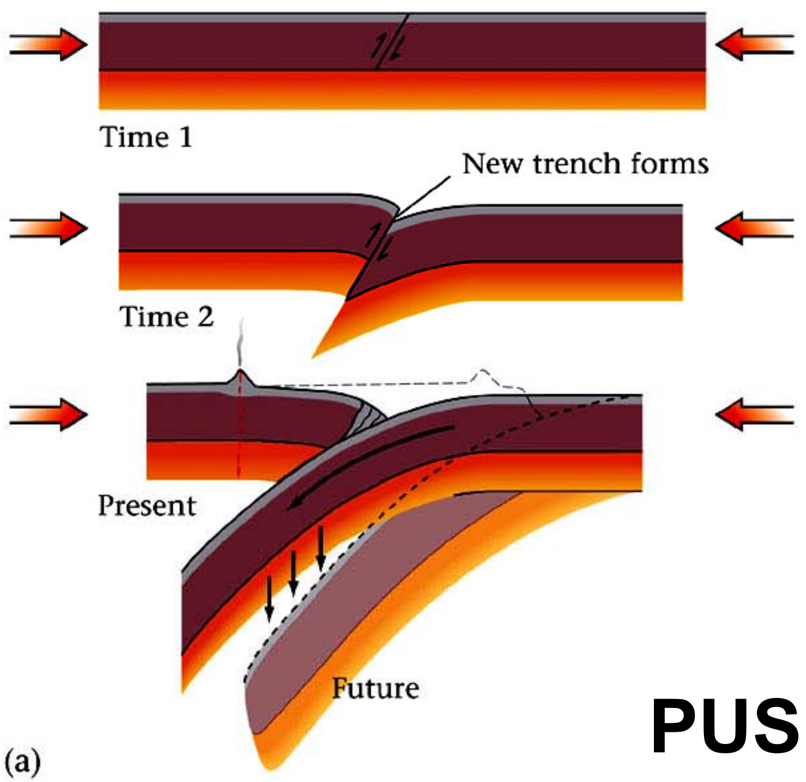


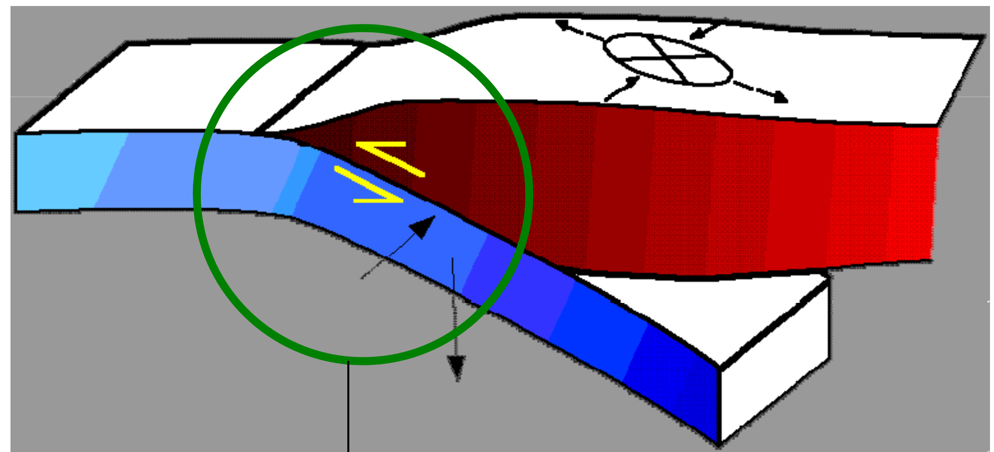

# LOCATION OF KHAIT AREA IN CONTINENTAL COLLISION ZONE (PAMIR SALIENT)

# CLOSE-UP LOOK AT CONTINENT-CONTINENT COLLISION

View of on-rushing (2.5 cm/yr) Peter the Great Range (being pushed by the Indian Plate towards me), Surkhob River, Tajikistan at the leading edge of the Pamir Indentation (I am standing on the Eurasian Plate)

# MECHANICS OF SUBDUCTION

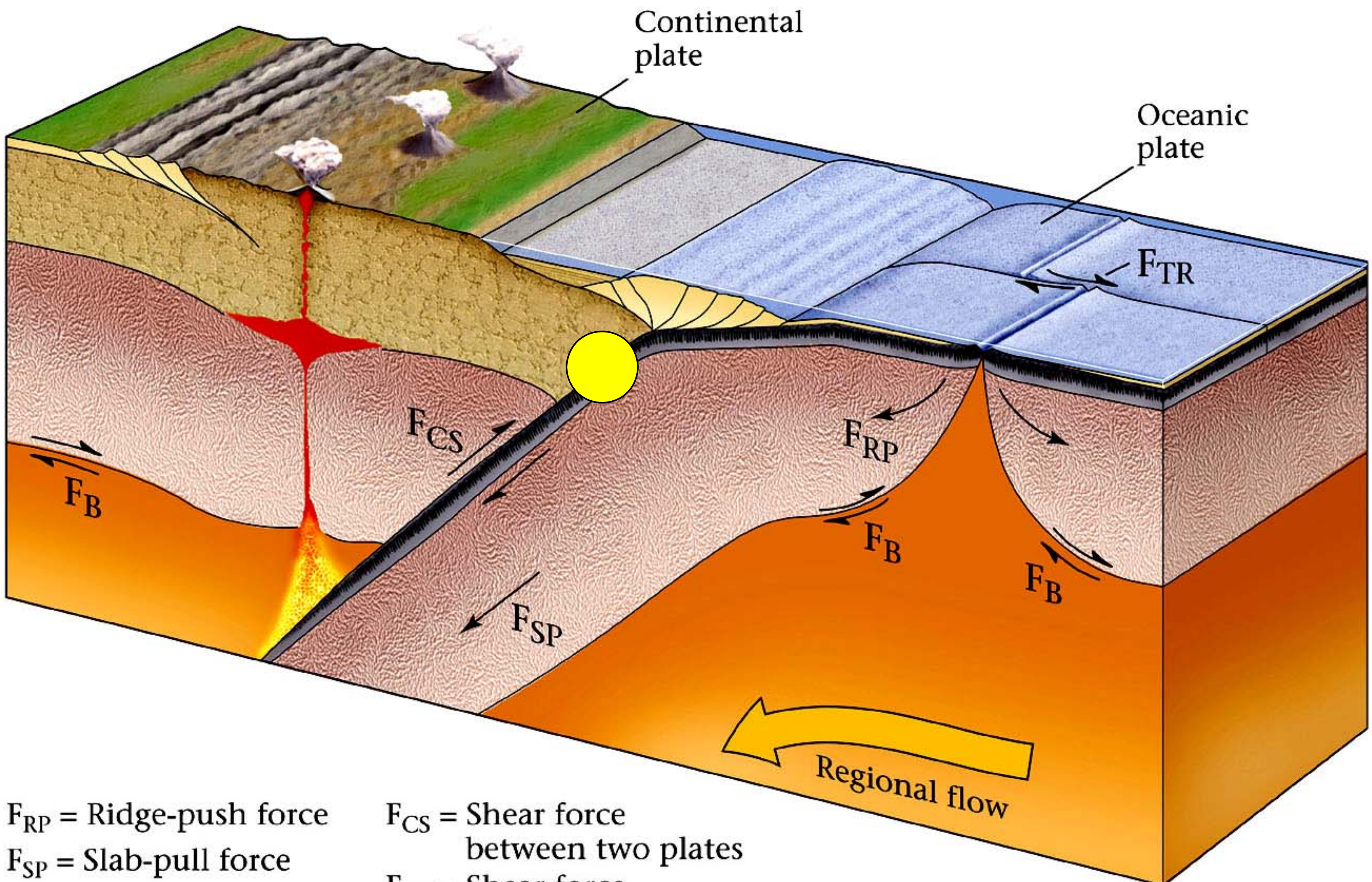



## PUSH, PULL, RESISTANCE, STICK, SLIP

FIGURE 4.13

*Earth: Portrait of a Planet*, 2nd Edition




$F_{RP}$ = Ridge-push force

$F_{SP}$ = Slab-pull force

$F_B$ = Shear force at the base of the plate

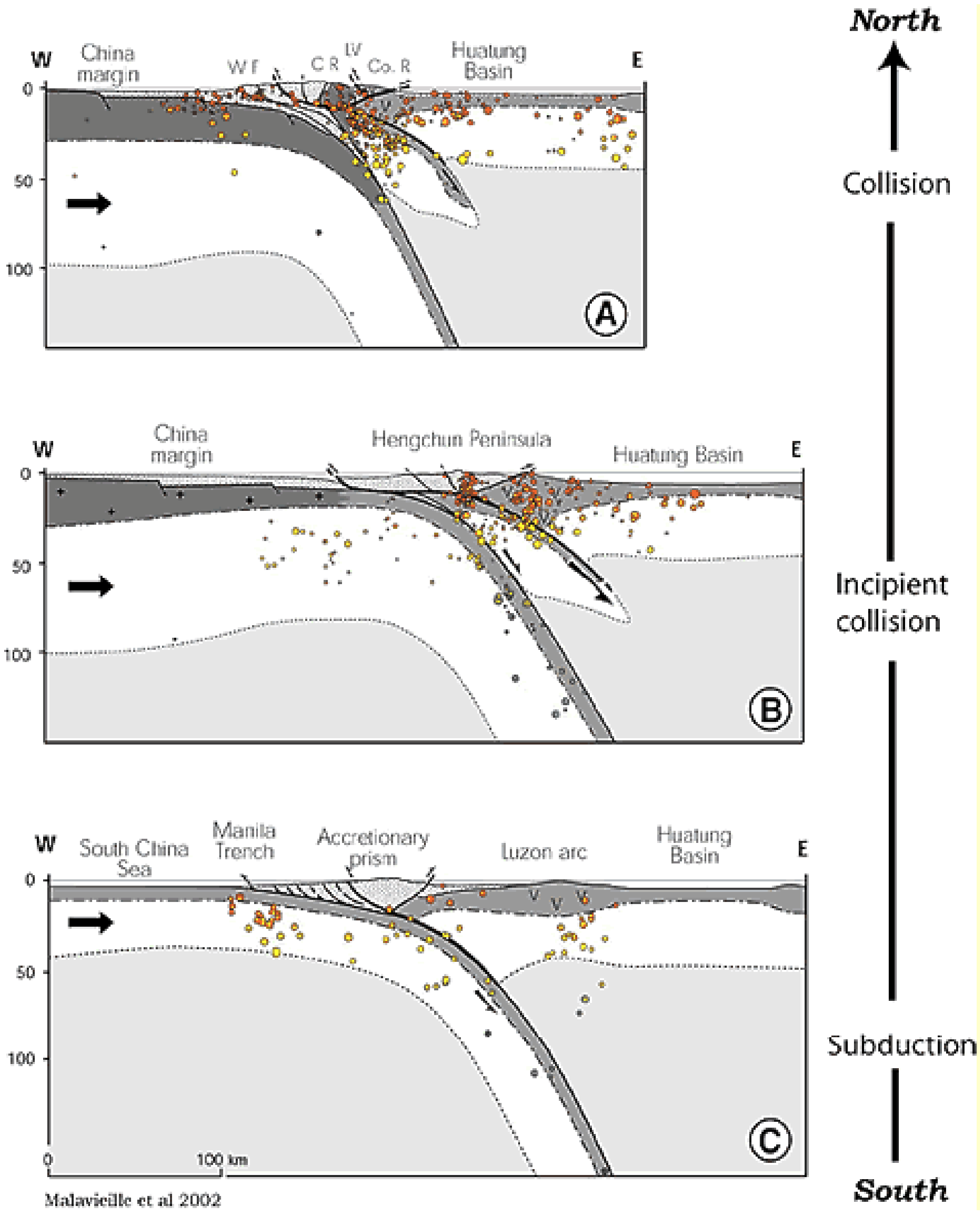
$F_{CS}$ = Shear force between two plates

$F_{TR}$ = Shear force along a transform fault

(c)

FIGURE 4.29

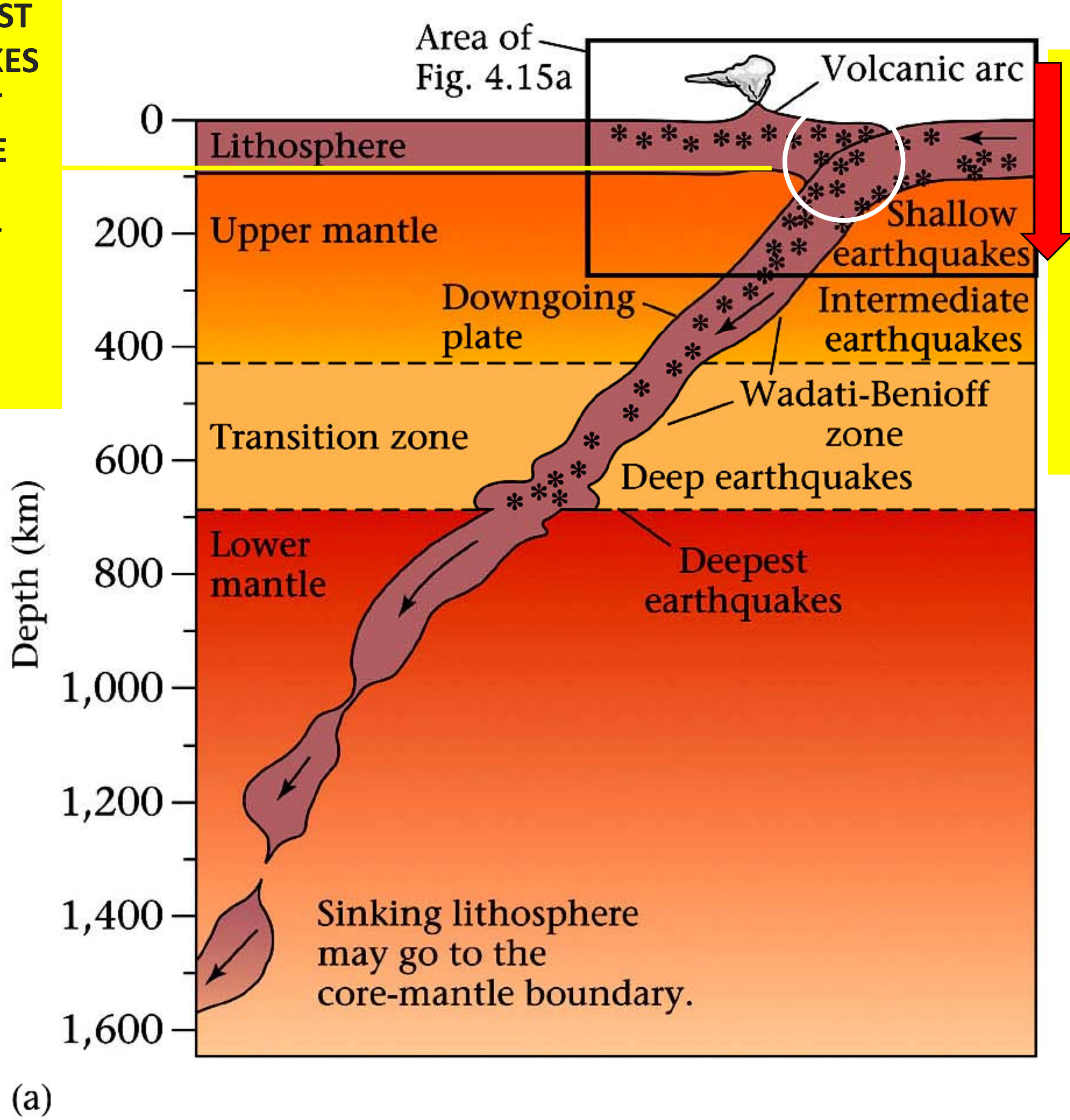
*Earth: Portrait of a Planet*, 2nd Edition




**SUBDUCTION – COLLISION TRANSITION (AREA OF PHILIPPINES - TAIWAN)**

# SUBDUCTION EARTHQUAKES

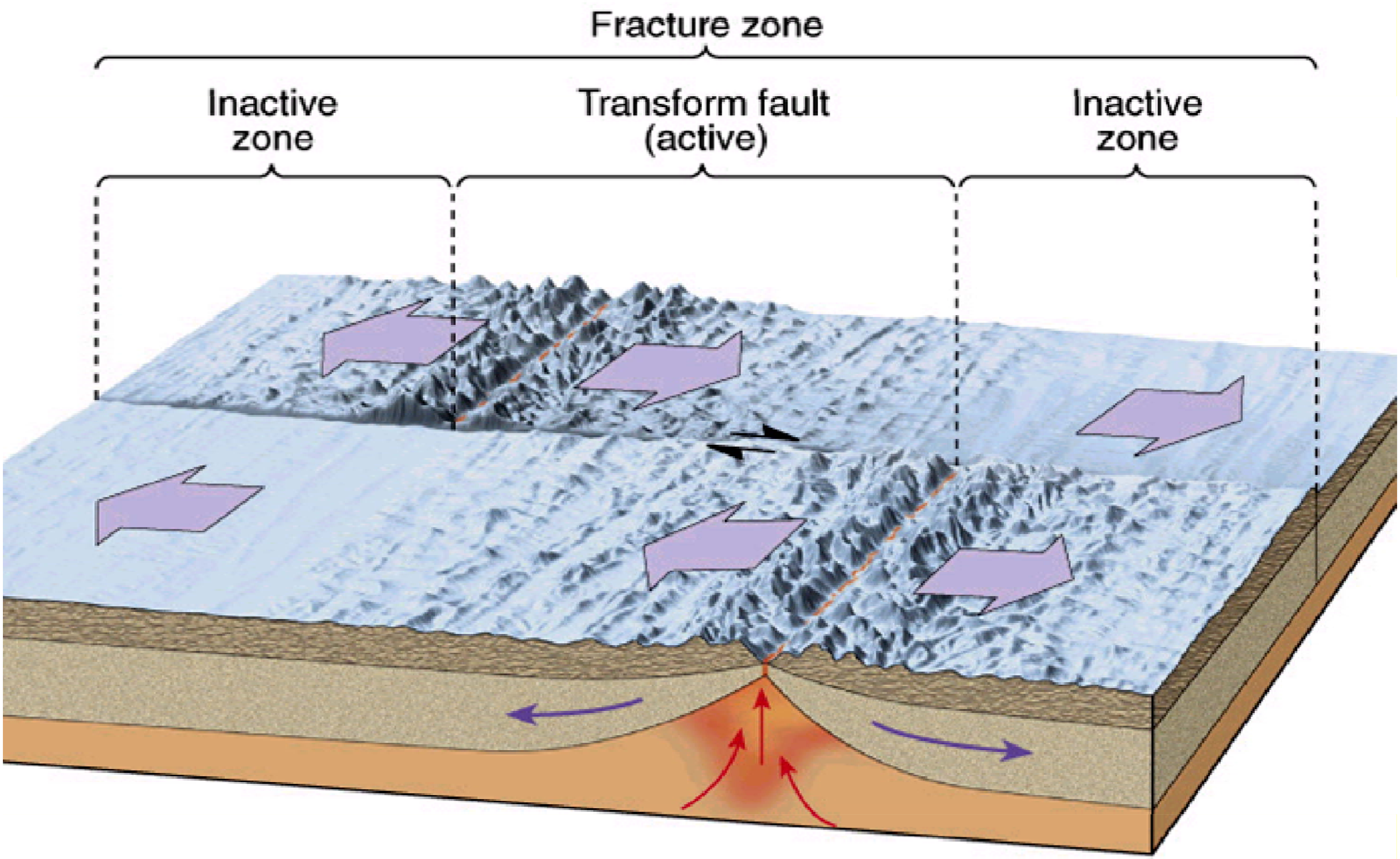
MEGATHRUST EARTHQUAKES OCCUR AT INTERFACE BETWEEN PLATES AT SHALLOW DEPTHS (< 50 km)




COMPRESSION IN SUBDUCTING PLATE DUE TO RESISTANCE OF DENSER MATERIAL AT DEPTH

FIGURE 4.14

# 3. TRANSFORM FAULT BOUNDARIES




A transform boundary offsetting segments of a divergent boundary (oceanic ridge).

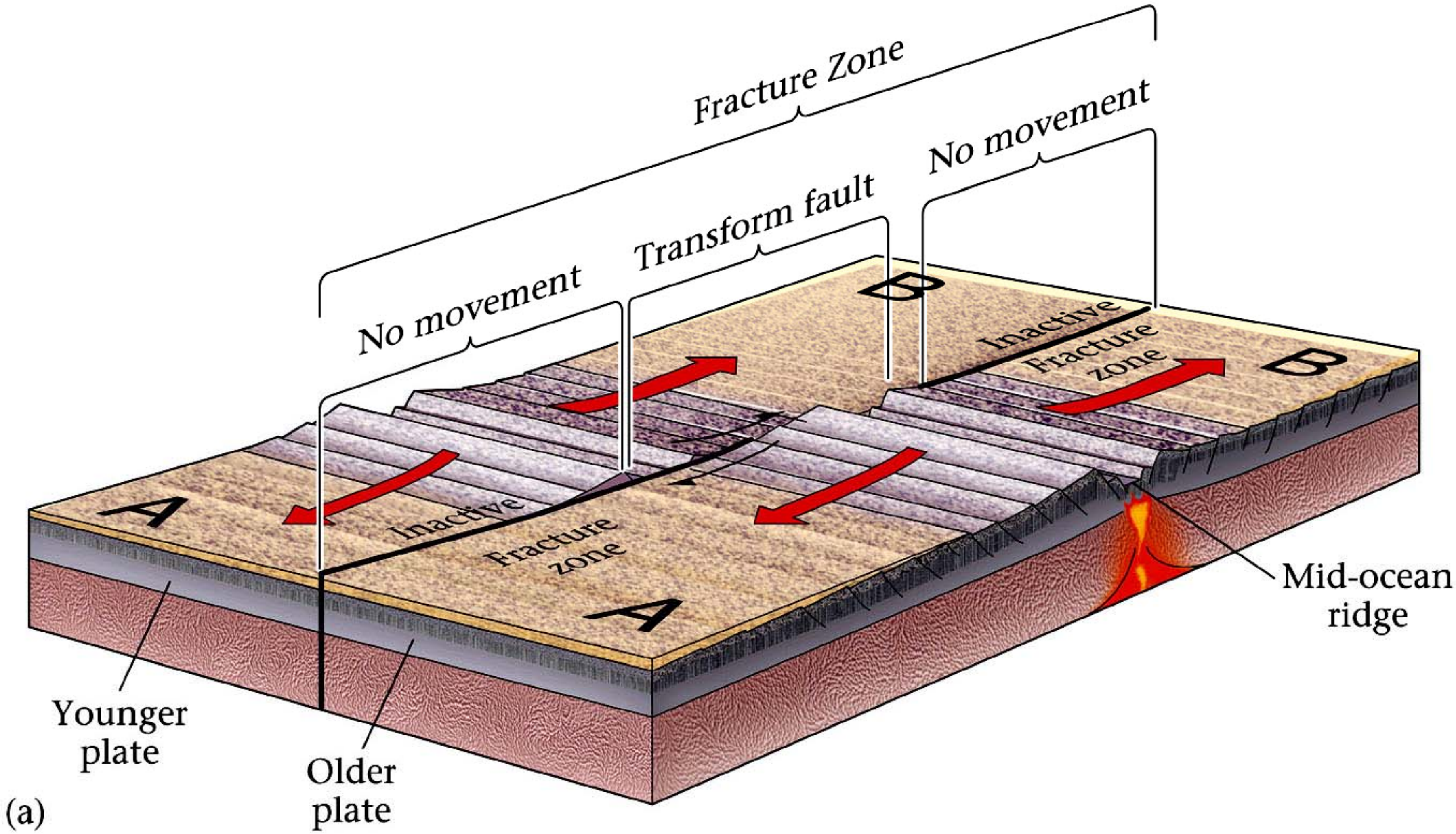
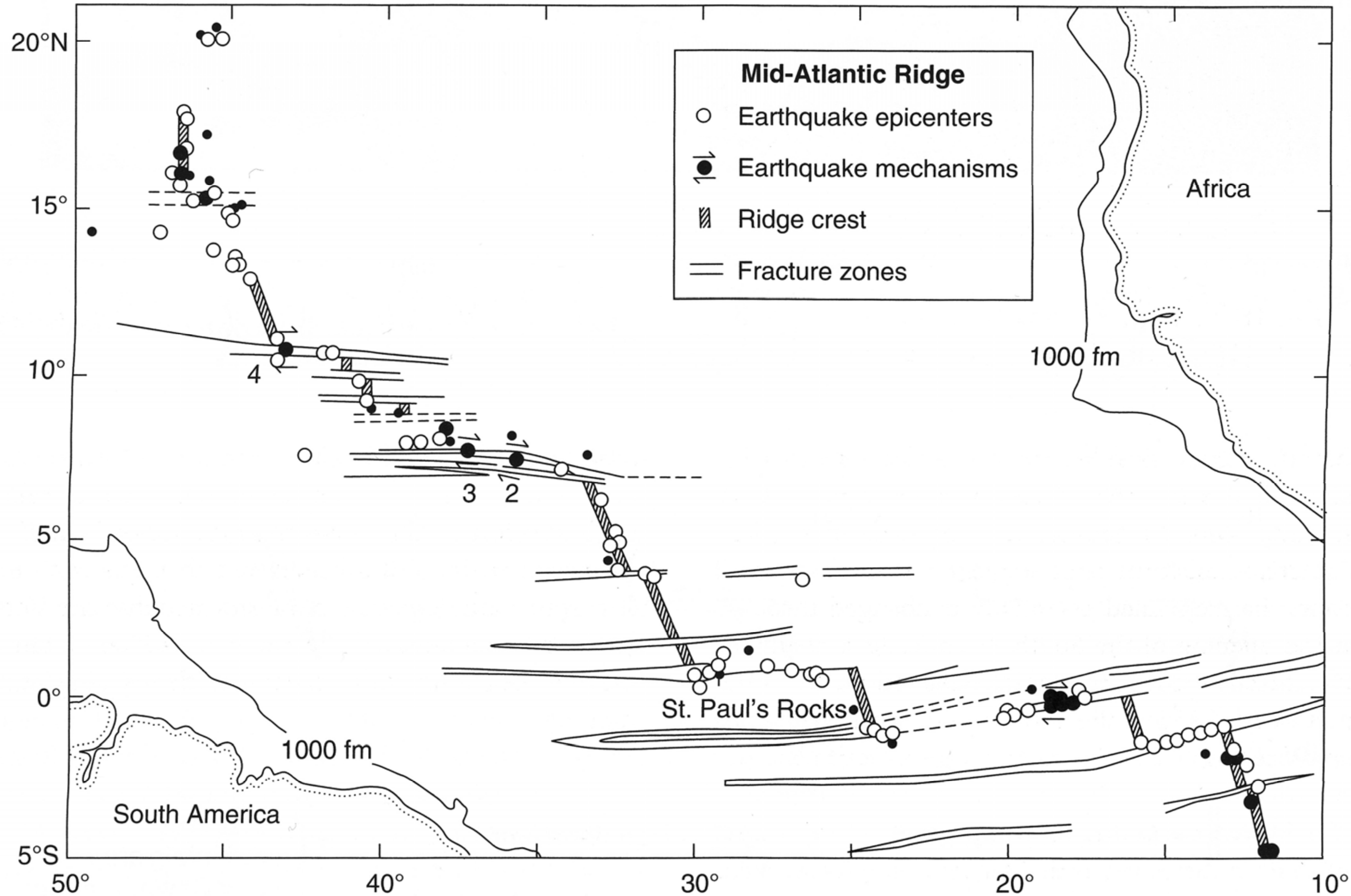

Fracture Zone
No movement
Transform fault
No movement
B
B
A
A
Inactive
Fracture
zone
Inactive
Fracture
zone
Mid-ocean
ridge
Younger
plate
Older
plate
(a)

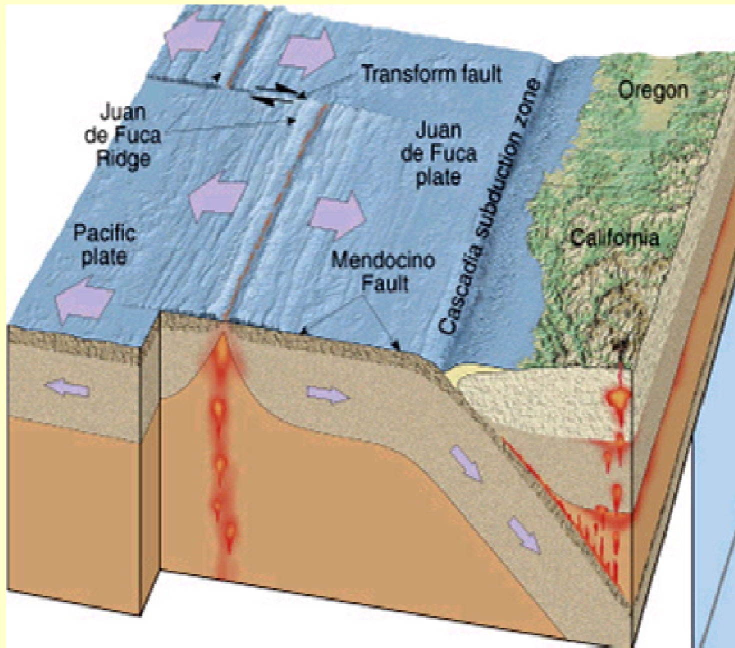
FIGURE 4.17

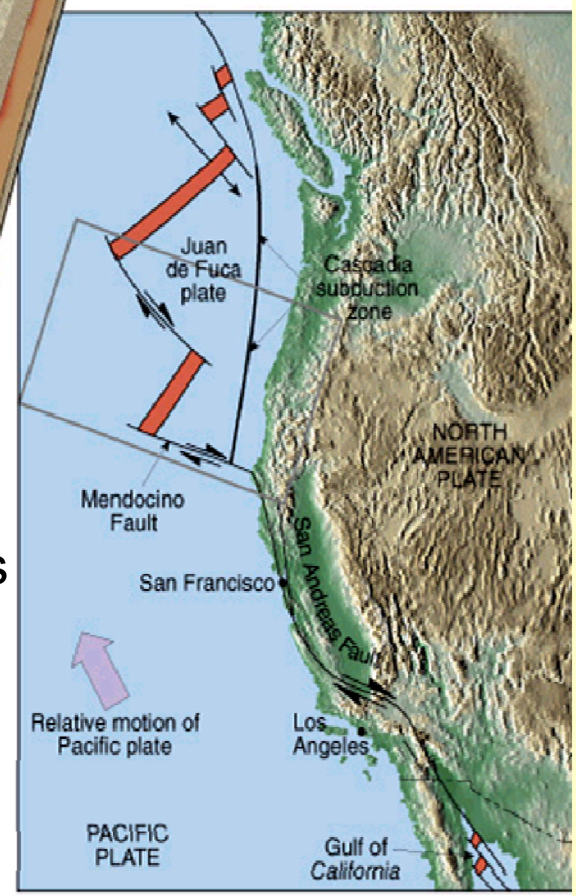



EARTHQUAKES ALONG THE SPREADING MID-ATLANTIC RIDGE

# Transform Fault Boundaries

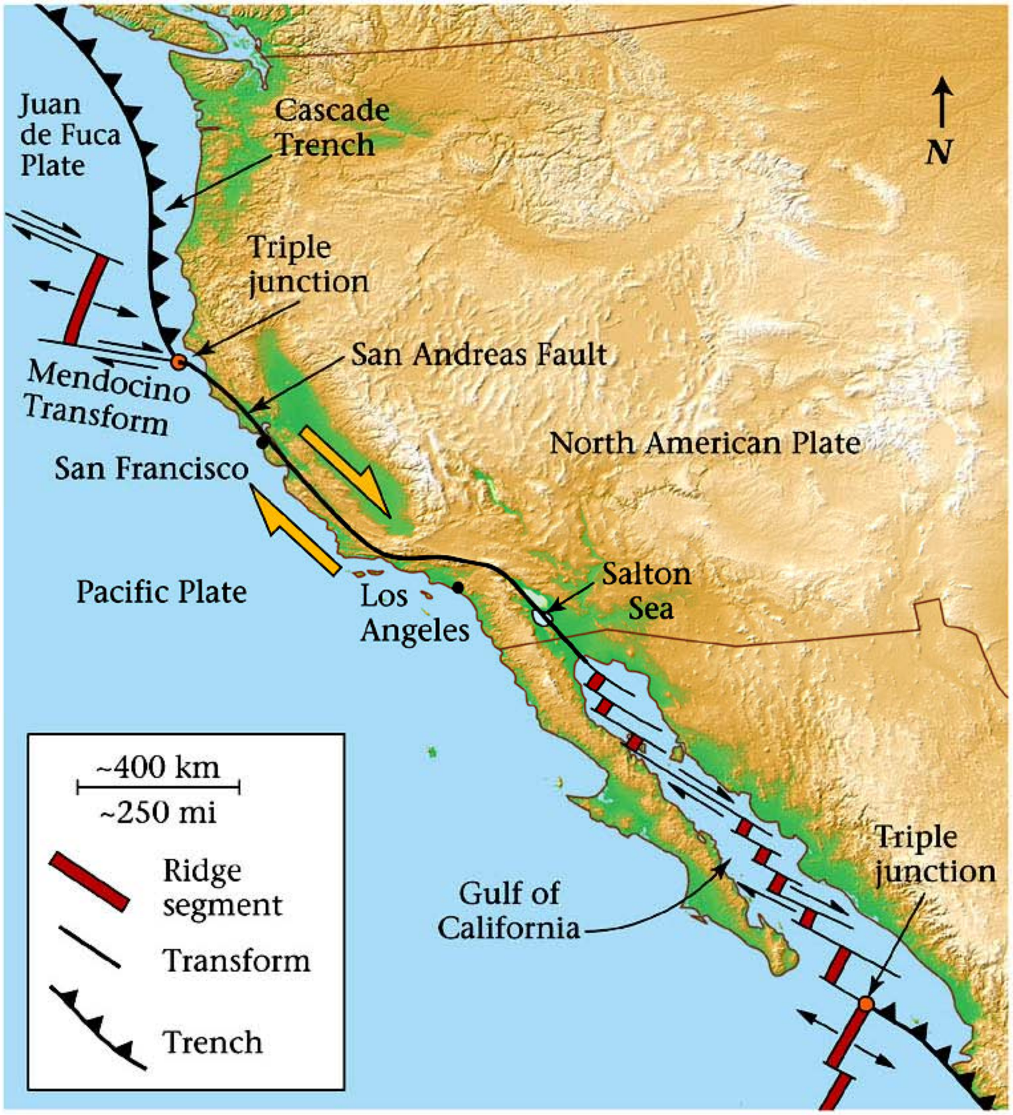
- Mendocino transform fault connects a divergent boundary to a subduction zone



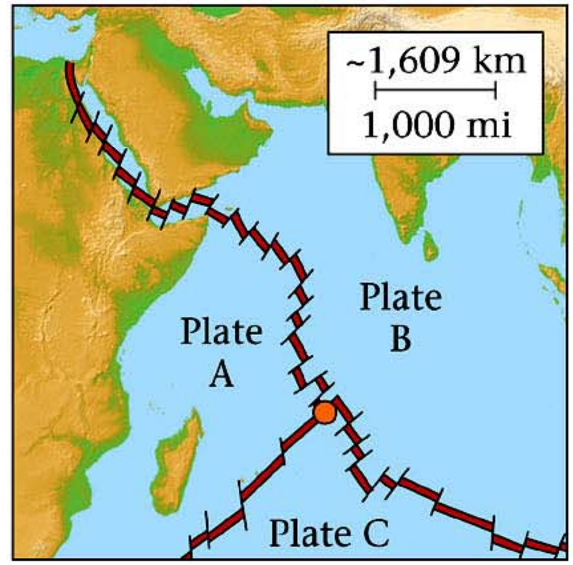




- San Andreas fault, separating the Pacific plate from the North American plate, connects spreading centres in the Gulf of California and the Juan de Fuca and Pacific plates.

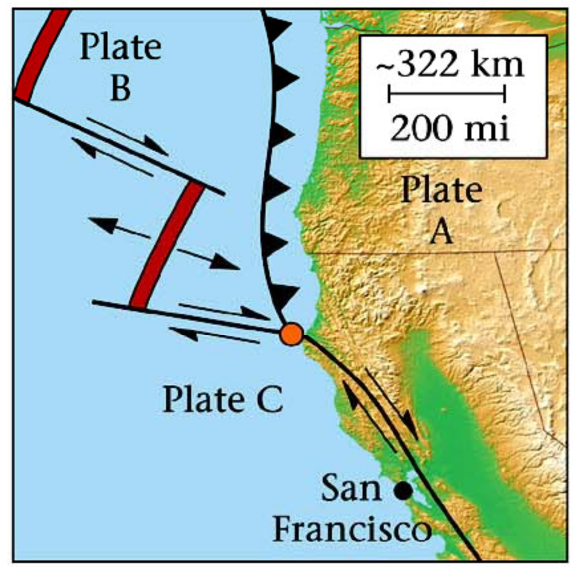
# TRIPLE JUNCTIONS




(a)




(a)




(b)

FIGURES 4.19 and 4.20

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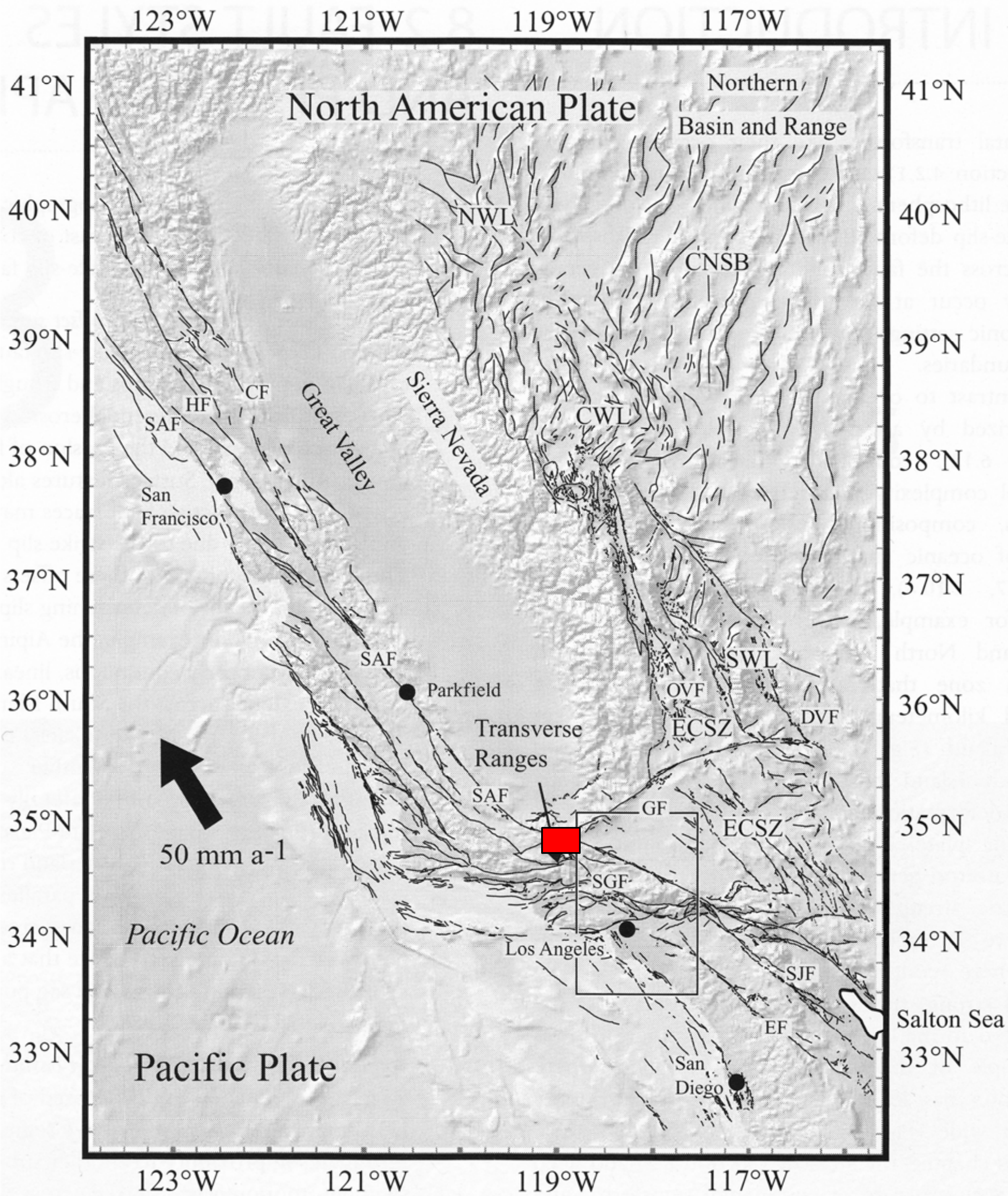
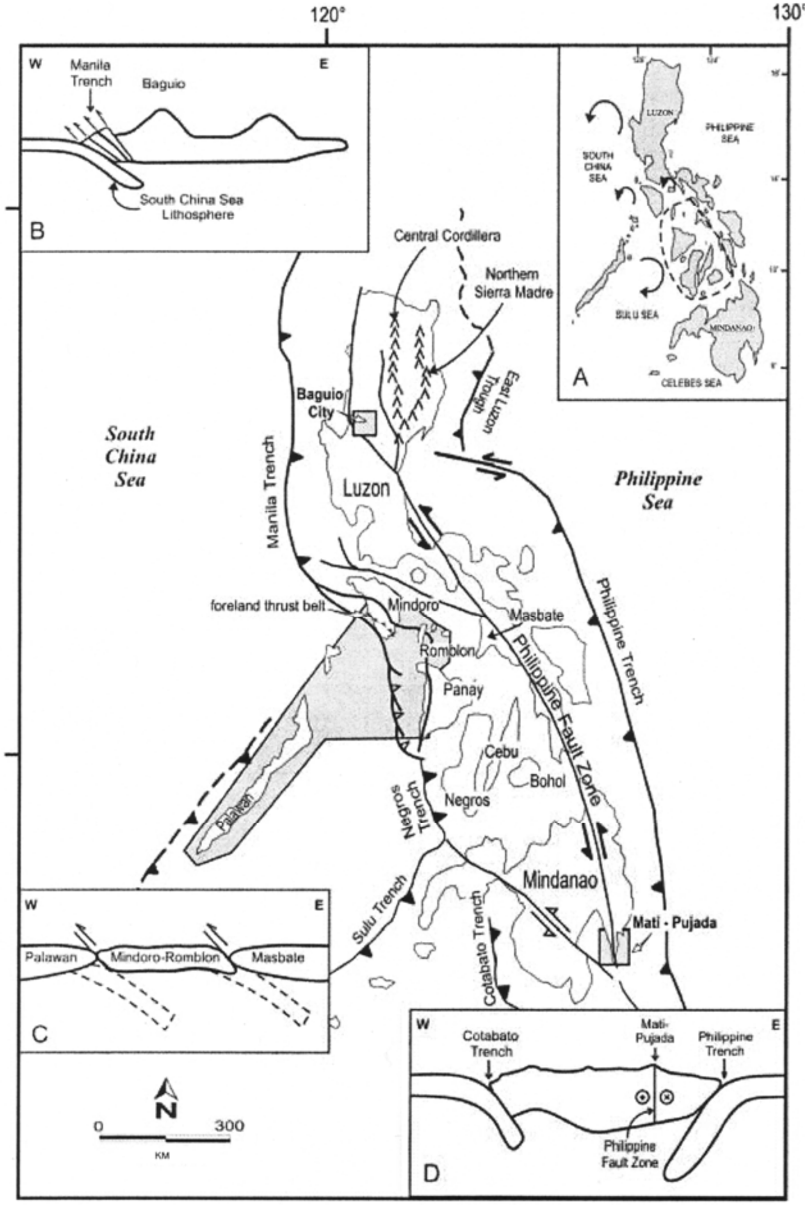
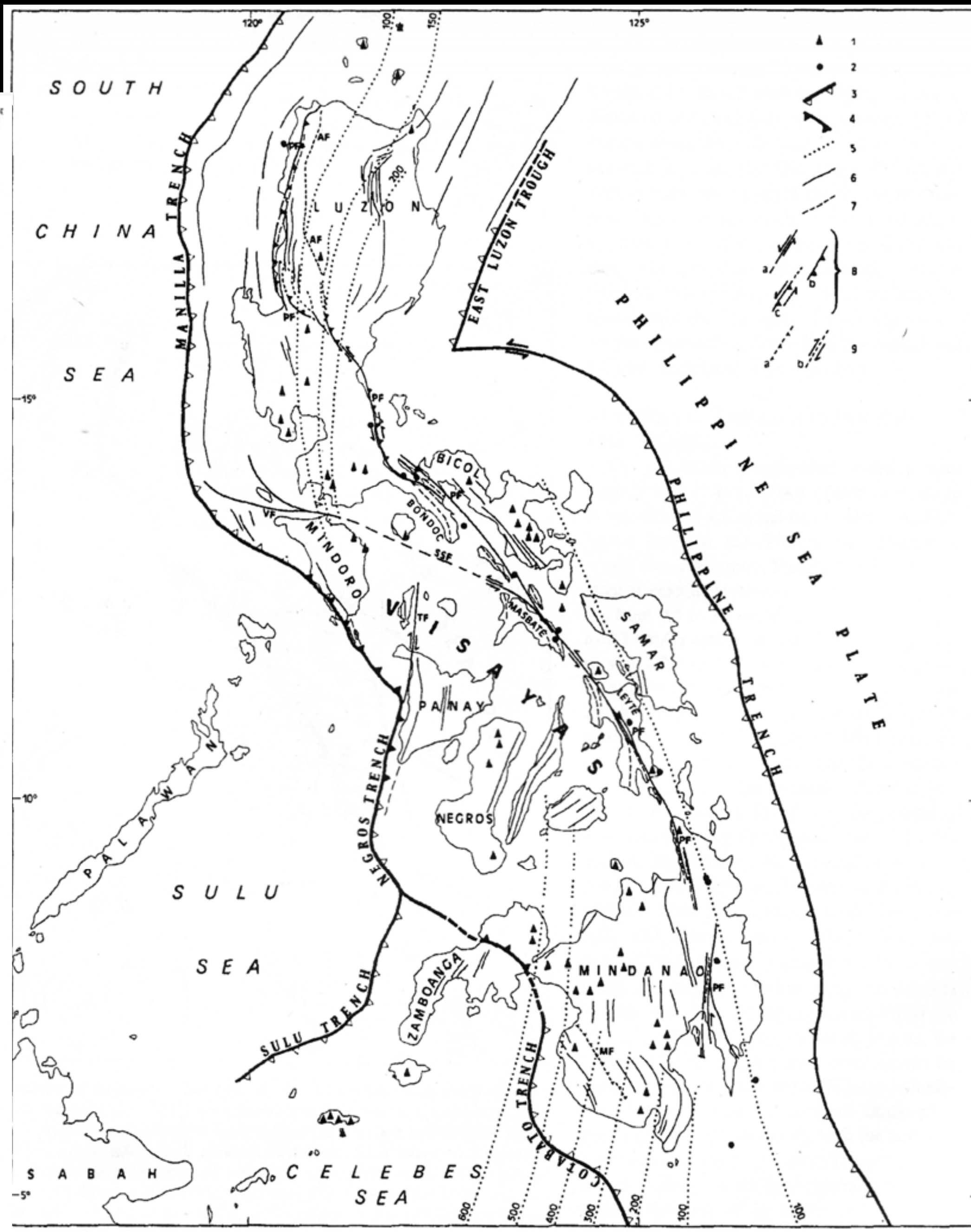


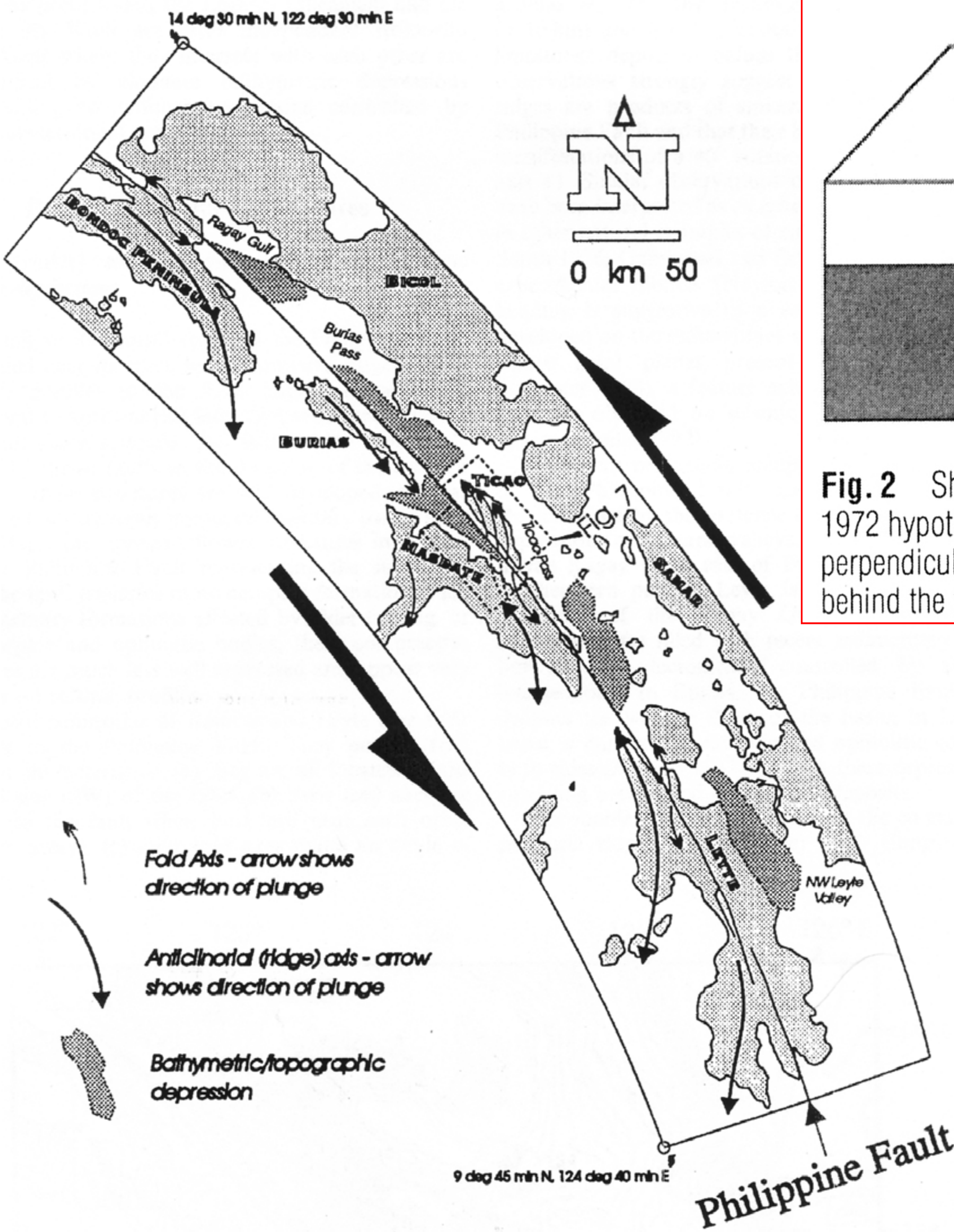
123°W
121°W
119°W
117°W
41°N
40°N
39°N
38°N
37°N
36°N
35°N
34°N
33°N
North American Plate
Northern
Basin and Range
NWL
CNSB
CWL
Great Valley
Sierra Nevada
HF
CF
SAF
San Francisco
Parkfield
Transverse Ranges
SWL
OVF
ECSZ
DVF
GF
SGF
50 mm a-1
Pacific Ocean
Los Angeles
SJF
EF
Salton Sea
San Diego
Pacific Plate


©2010 Google
Eye alt 4.75 km
631 m

# PHILIPPINE FAULT – A TRANSFORM FAULT IN THE SOUTHWEST PACIFIC





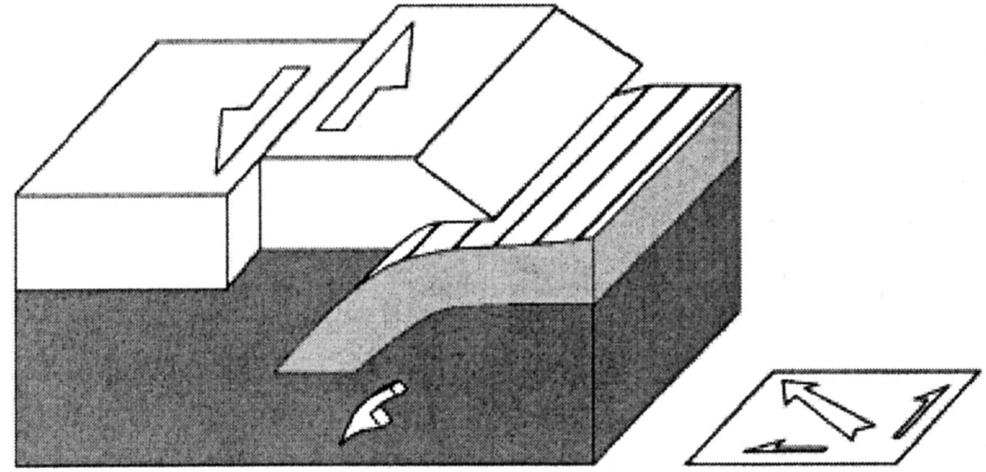



**Fig. 2** Shear partitioning at the lithospheric scale drawn from Fitch's 1972 hypothesis. Oblique convergence is decomposed into a component perpendicular to a trench and another parallel to a strike–slip fault located behind the trench.

# THE PHILIPPINE FAULT IN THE CENTRAL PHILIPPINES

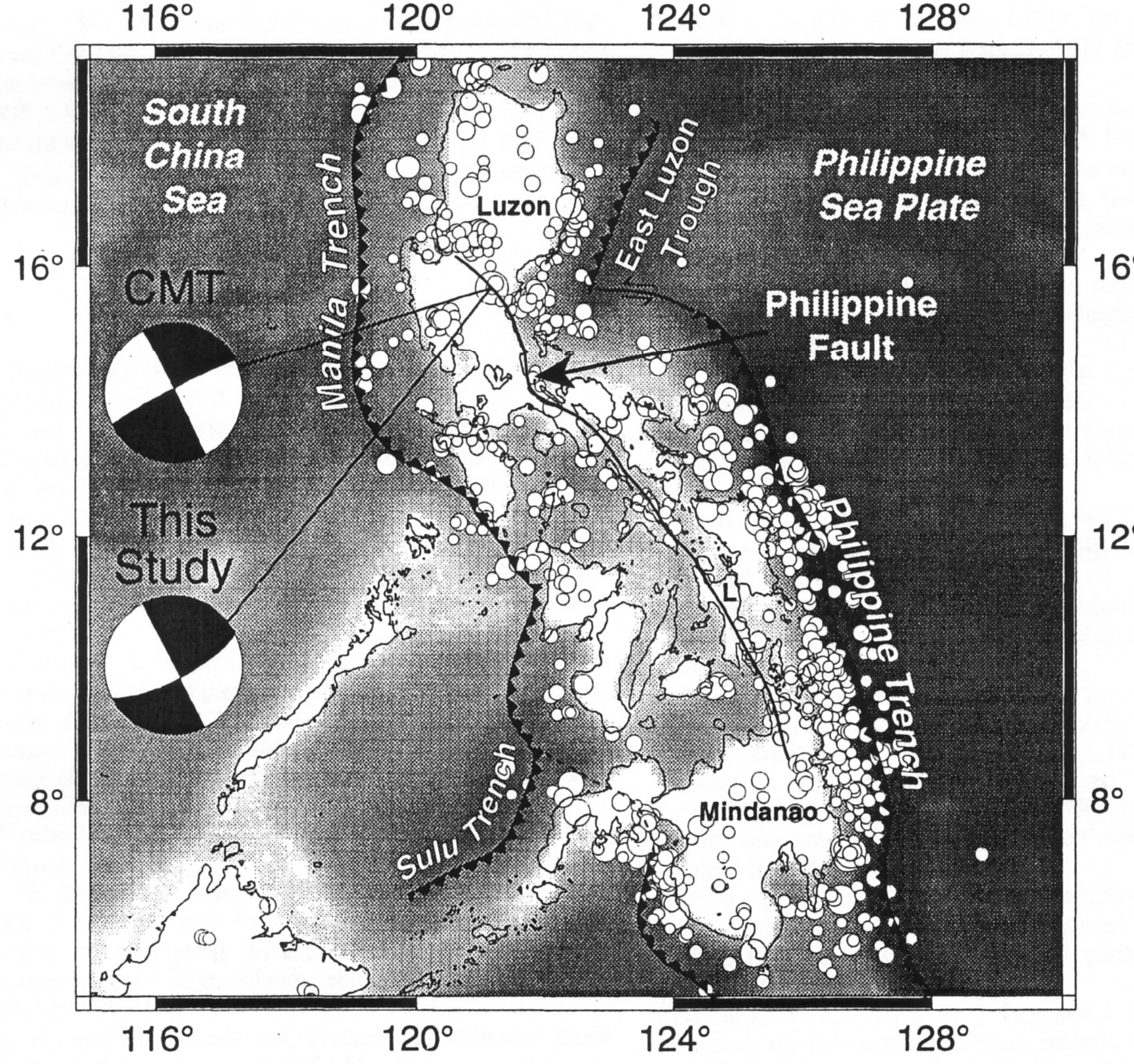
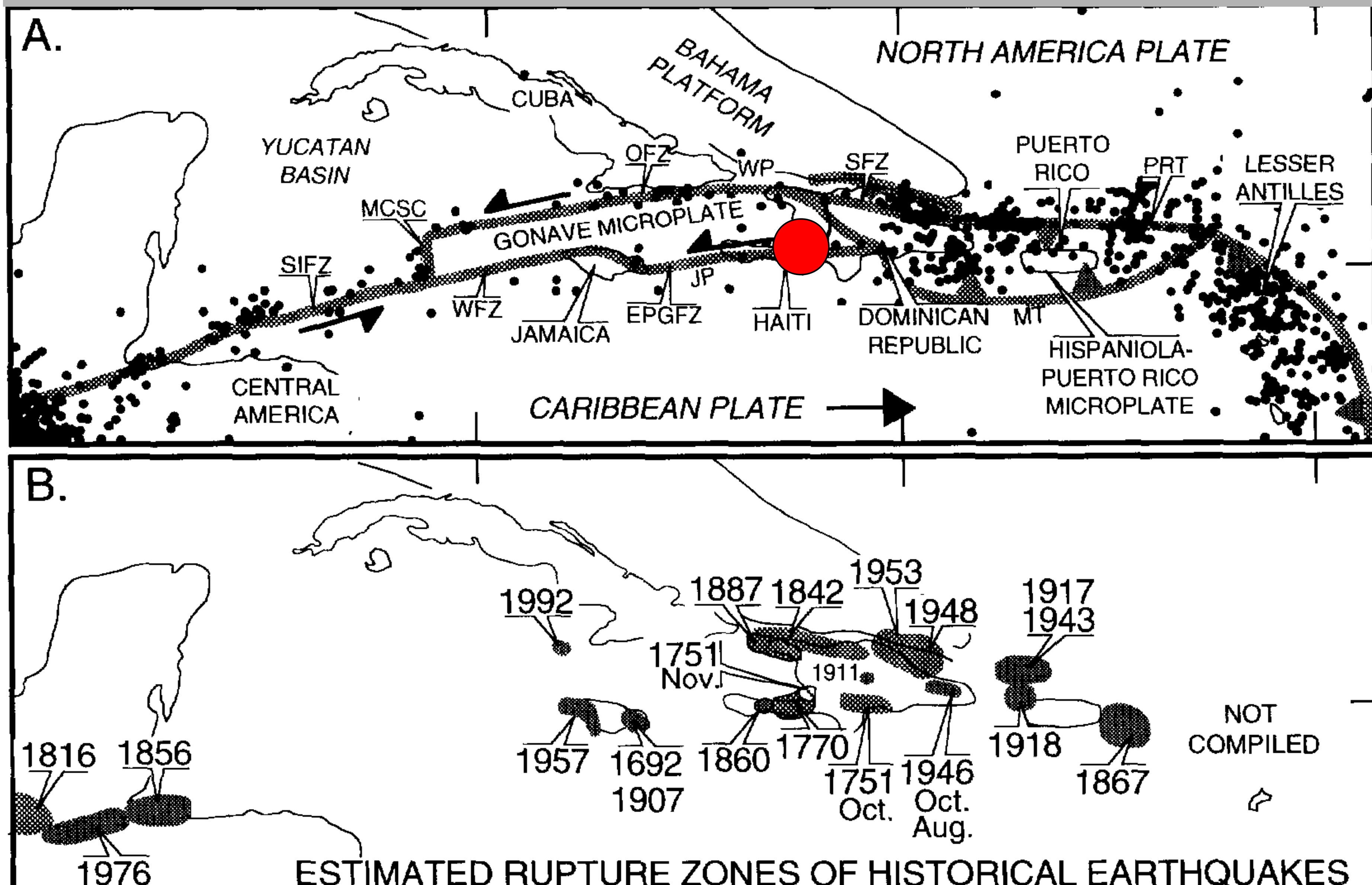
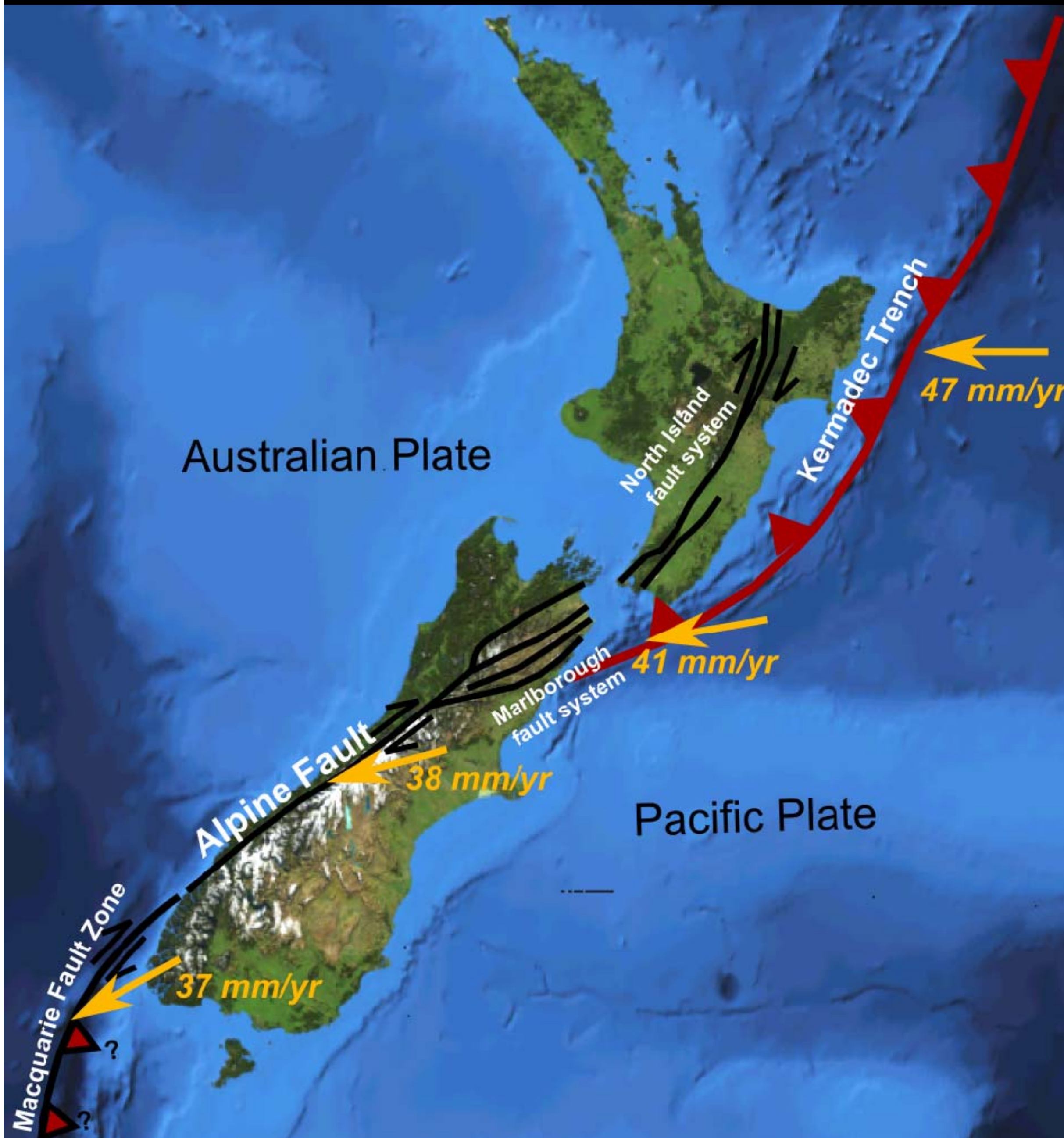



**Figure 2.** Map showing the regional tectonic setting of the July 16, 1990, Luzon ($M_w = 7.7$) earthquake. The best double-couple solutions from the CMT inversion and the surface wave inversions of this study are shown and indicate the mainshock epicenter. The NEIC locations of earthquakes from 1960 to 1994 with $m_b > 5.0$ and depths <35 km are shown with increasing symbol size proportional to the magnitude. The mainshock occurred on the northern segment of the Philippine fault (solid line) with its epicenter given by the largest symbol on the fault trace. The island of Leyte is indicated by the L.

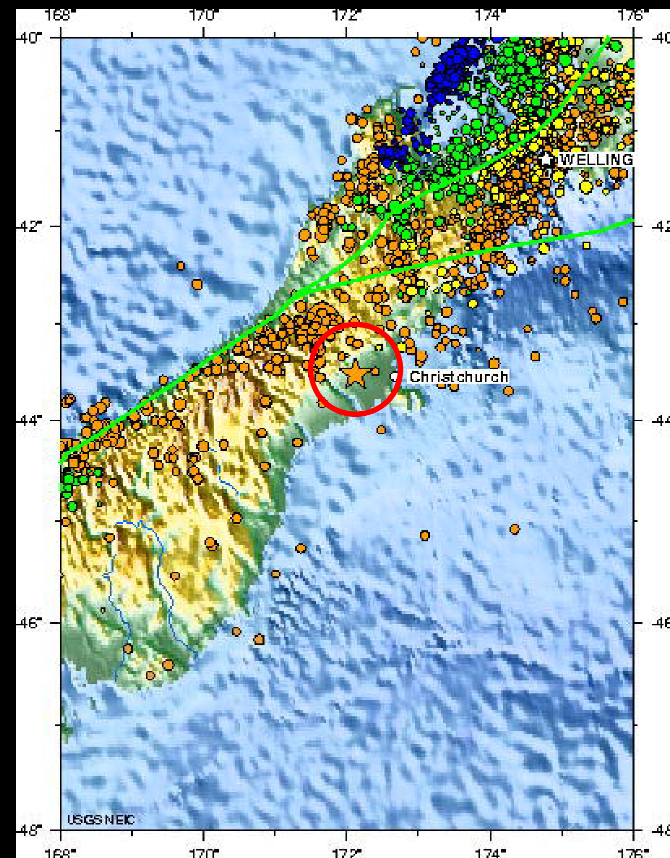


A.
NORTH AMERICA PLATE
BAHAMA PLATFORM
CUBA
YUCATAN BASIN
OFZ
WP
SFZ
PUERTO RICO
PRT
LESSER ANTILLES
MCSC
GONAVE MICROPLATE
SIFZ
WFZ
JAMAICA
EPGFZ
JP
HAITI
DOMINICAN REPUBLIC
MT
HISPANIOLA-PUERTO RICO MICROPLATE
CENTRAL AMERICA
CARIBBEAN PLATE
20
B.
1992
1887
1842
1953
1948
1917
1943
1751 Nov.
1911
1957
1692
1907
1860
1770
1751 Oct.
1946 Oct. Aug.
1918
1867
NOT COMPILED
1816
1856
1976
20
ESTIMATED RUPTURE ZONES OF HISTORICAL EARTHQUAKES

# ALPINE FAULT: A TRANSFORM FAULT RUNNING THROUGH THE SOUTH ISLAND, NEW ZEALAND




M7.0 September 2010 NZ Earthquake

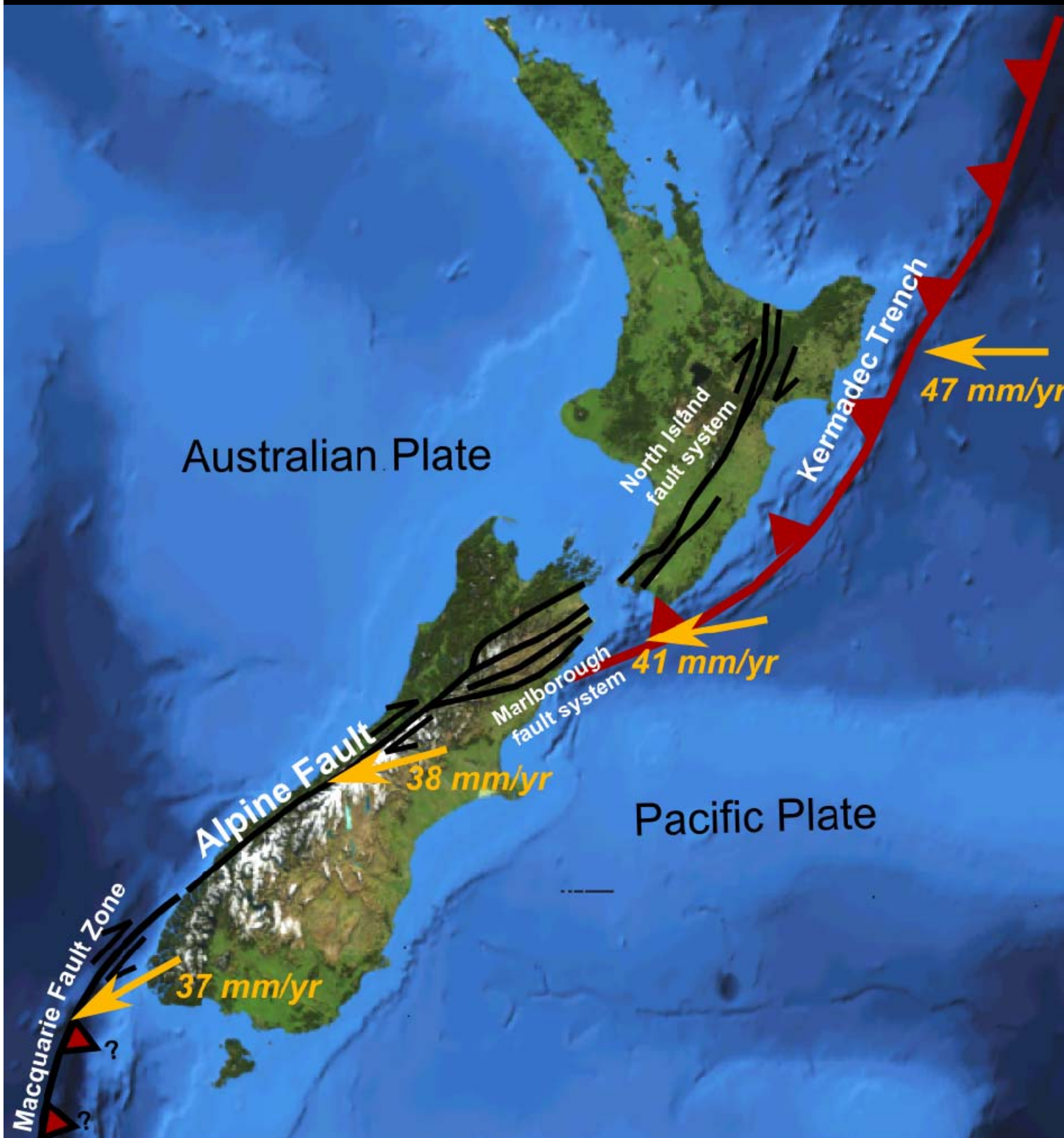


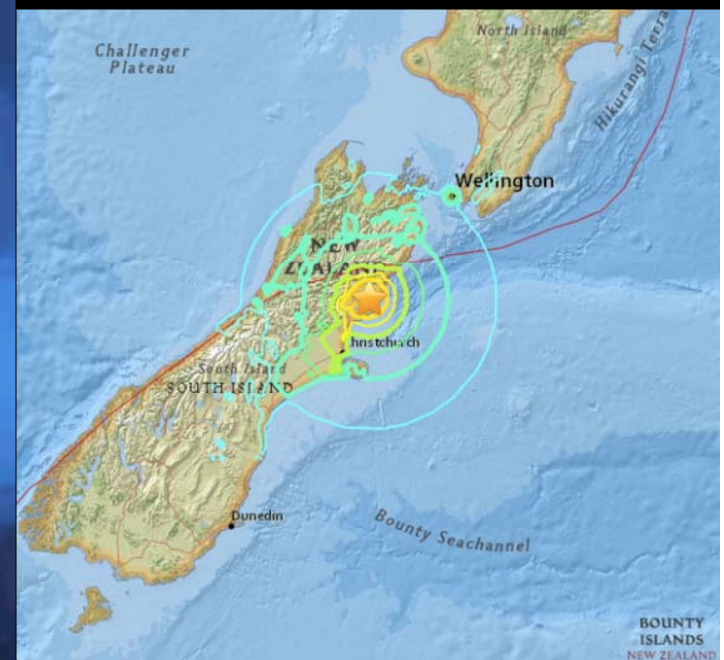

SOUTH ISLAND OF NEW ZEALAND

2010 09 03 16:35:46 UTC 43.53S 172.12E Depth: 5.0 km, Magnitude: 7.0

Seismicity 1990 to Present

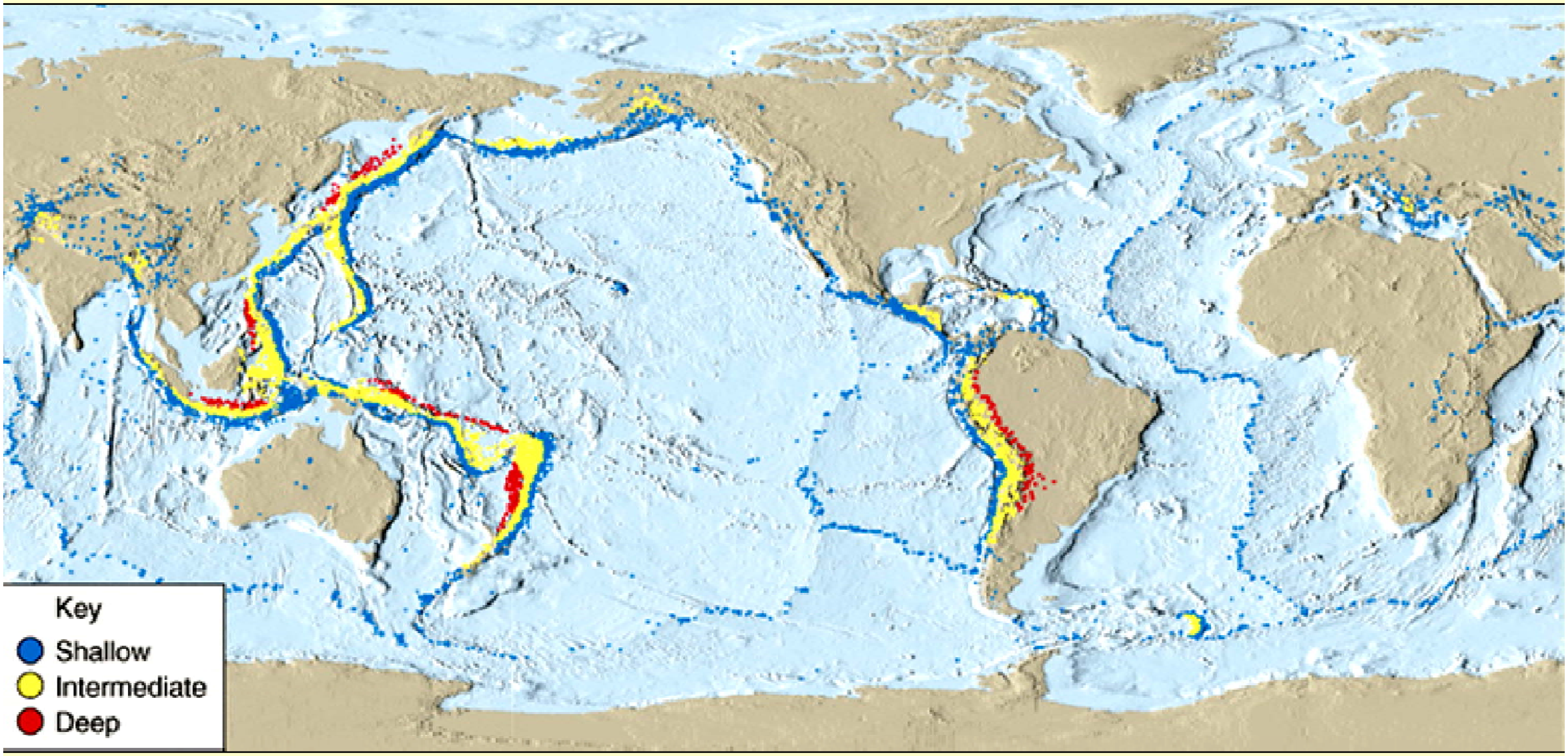
# ALPINE FAULT: A TRANSFORM FAULT RUNNING THROUGH THE SOUTH ISLAND, NEW ZEALAND



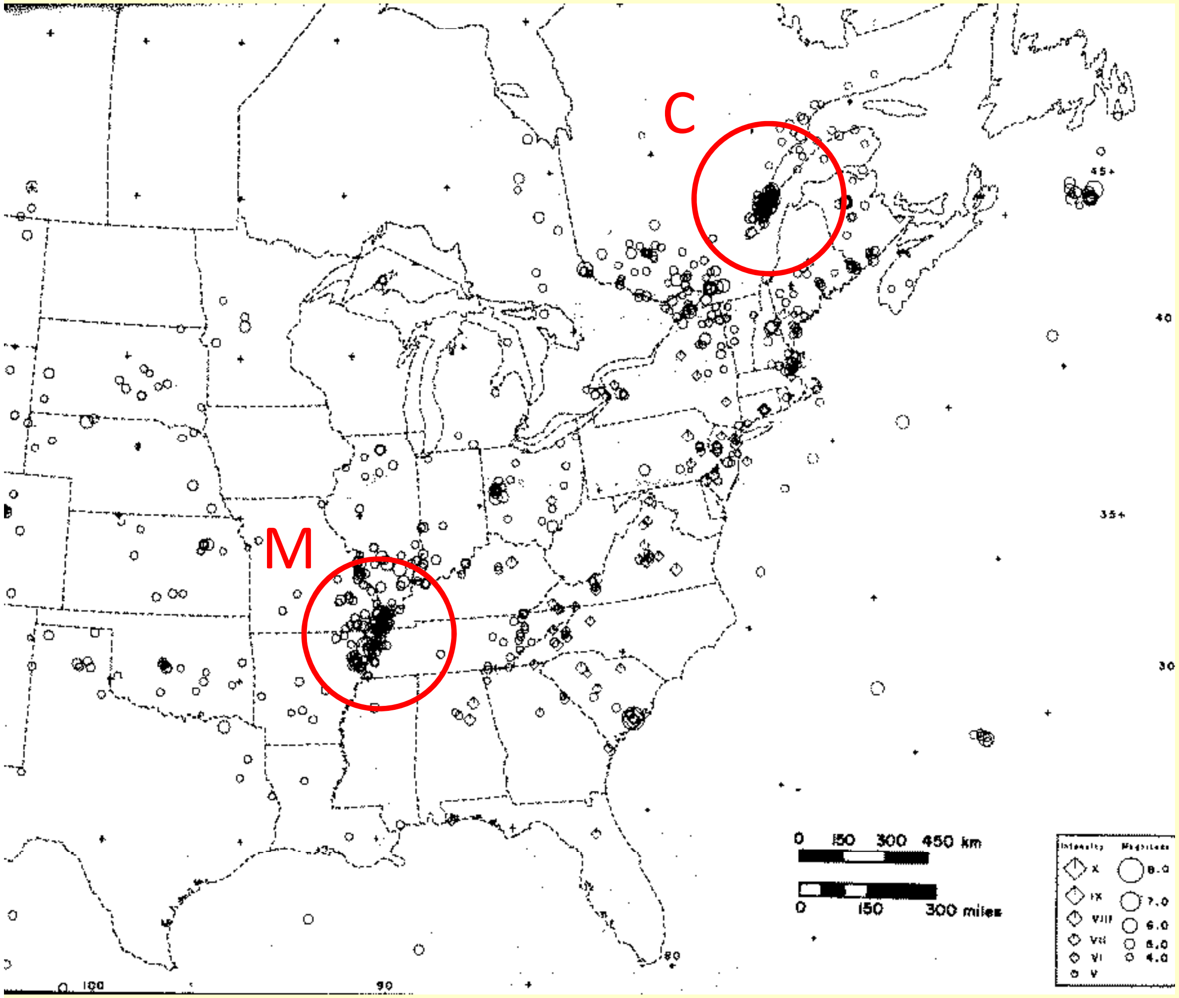




M7.8 November 2016 NZ Earthquake

# PLATE TECTONICS & EARTHQUAKES



# THE PROBLEM OF INTRA-PLATE EARTHQUAKES




- EARTHQUAKES THAT OCCUR AWAY FROM PLATE BOUNDARIES
- LONG RECURRENCE INTERVAL
- POSSIBLE CAUSES ARE STRESS CONCENTRATIONS, HIGH HEAT FLOW WEAKENED CRUST

**EXAMPLES ARE 1811-1812 NEW MADRID EARTHQUAKES (M) AND 1663 CHARLEVOIX (NEW FRANCE) (C) EARTHQUAKE**

# DIRECTION OF PLATE MOVEMENTS AND RELATIVE PLATE VELOCITIES

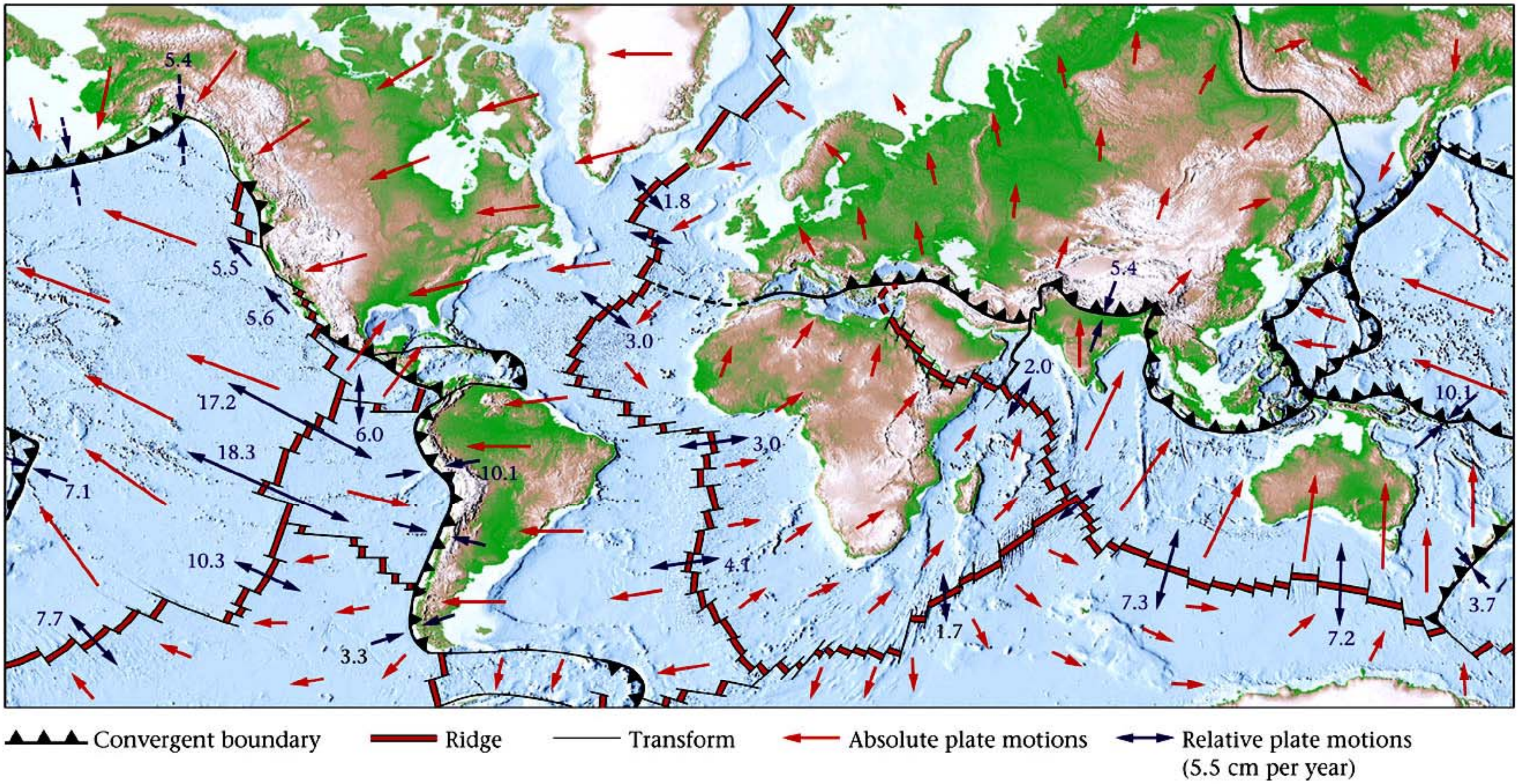



FIGURE 4.30

*Earth: Portrait of a Planet*, 2nd Edition

# GPS USED TO MEASURE ABSOLUTE PLATE MOTIONS ON THE SURFACE OF THE EARTH

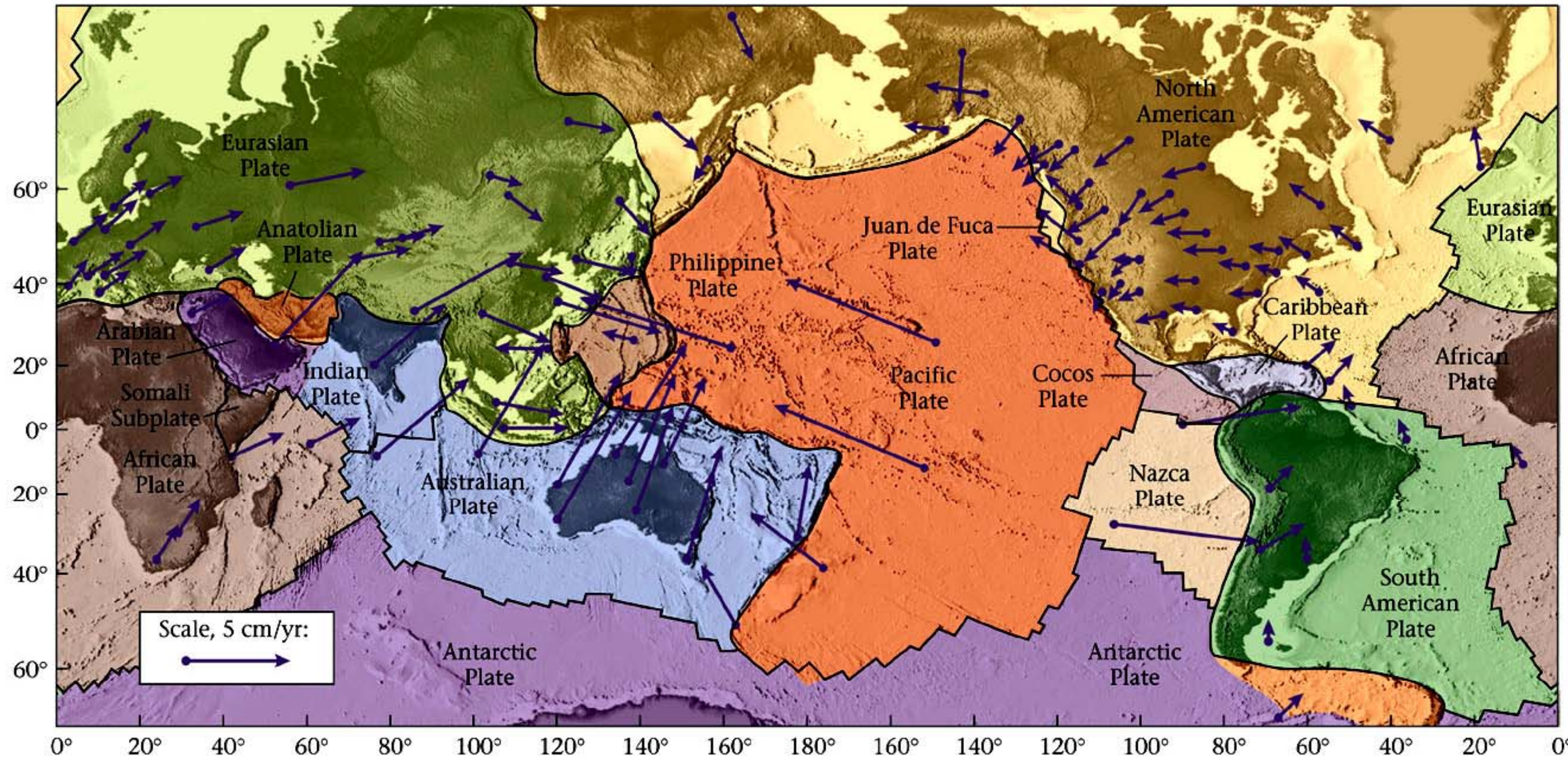
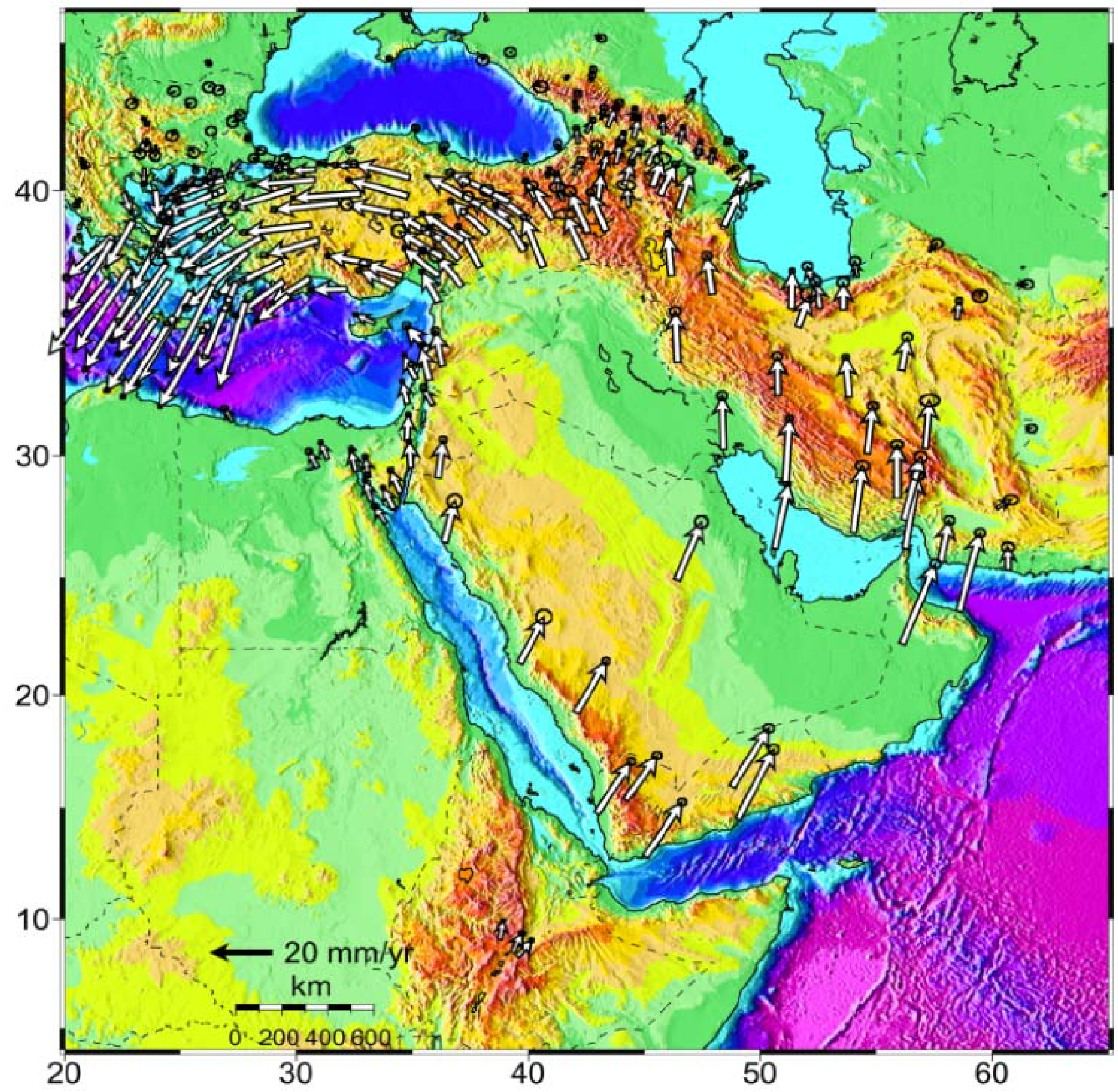
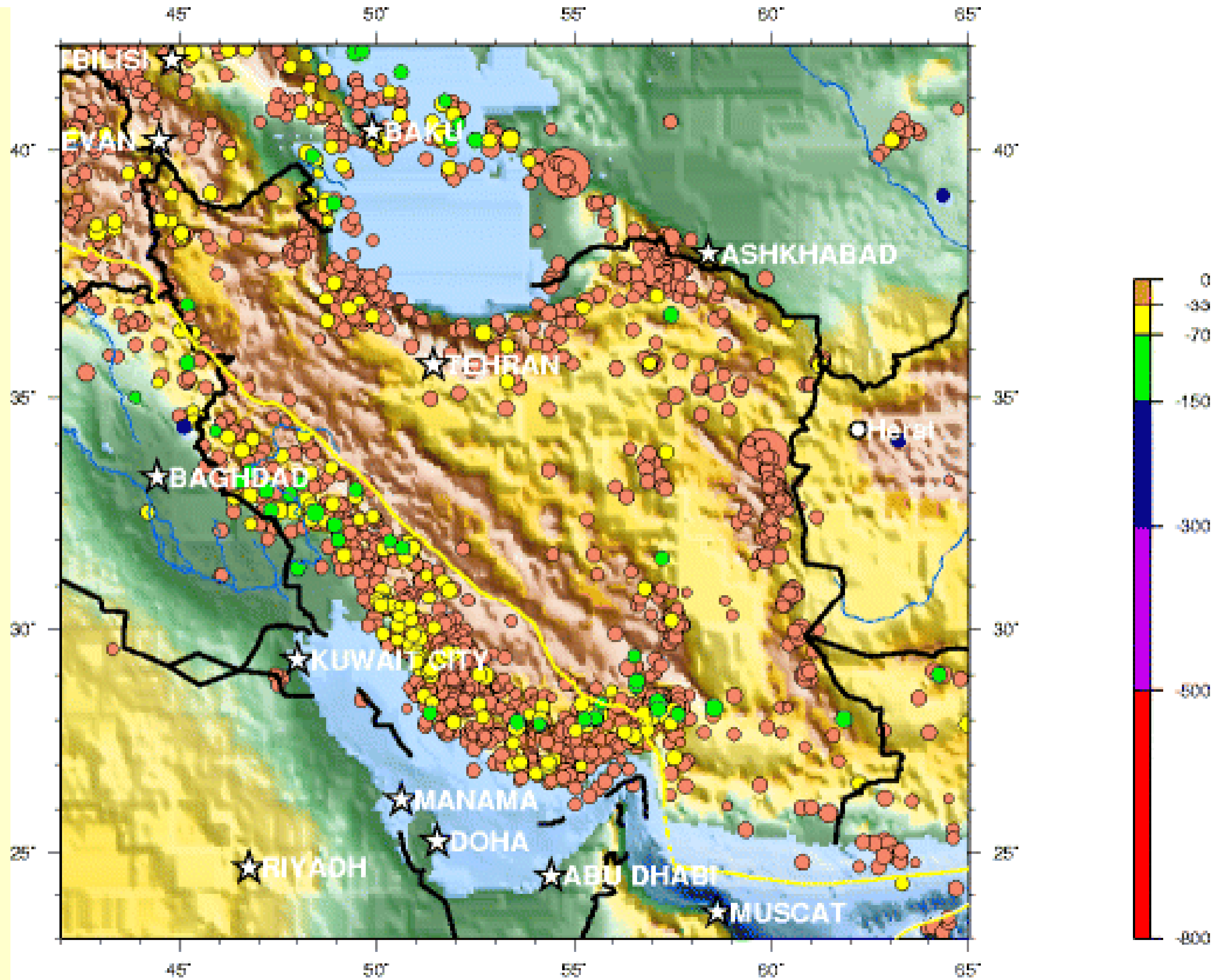



FIGURE 4.31

*Earth: Portrait of a Planet*, 2nd Edition

# Global Positioning System (GPS) Data



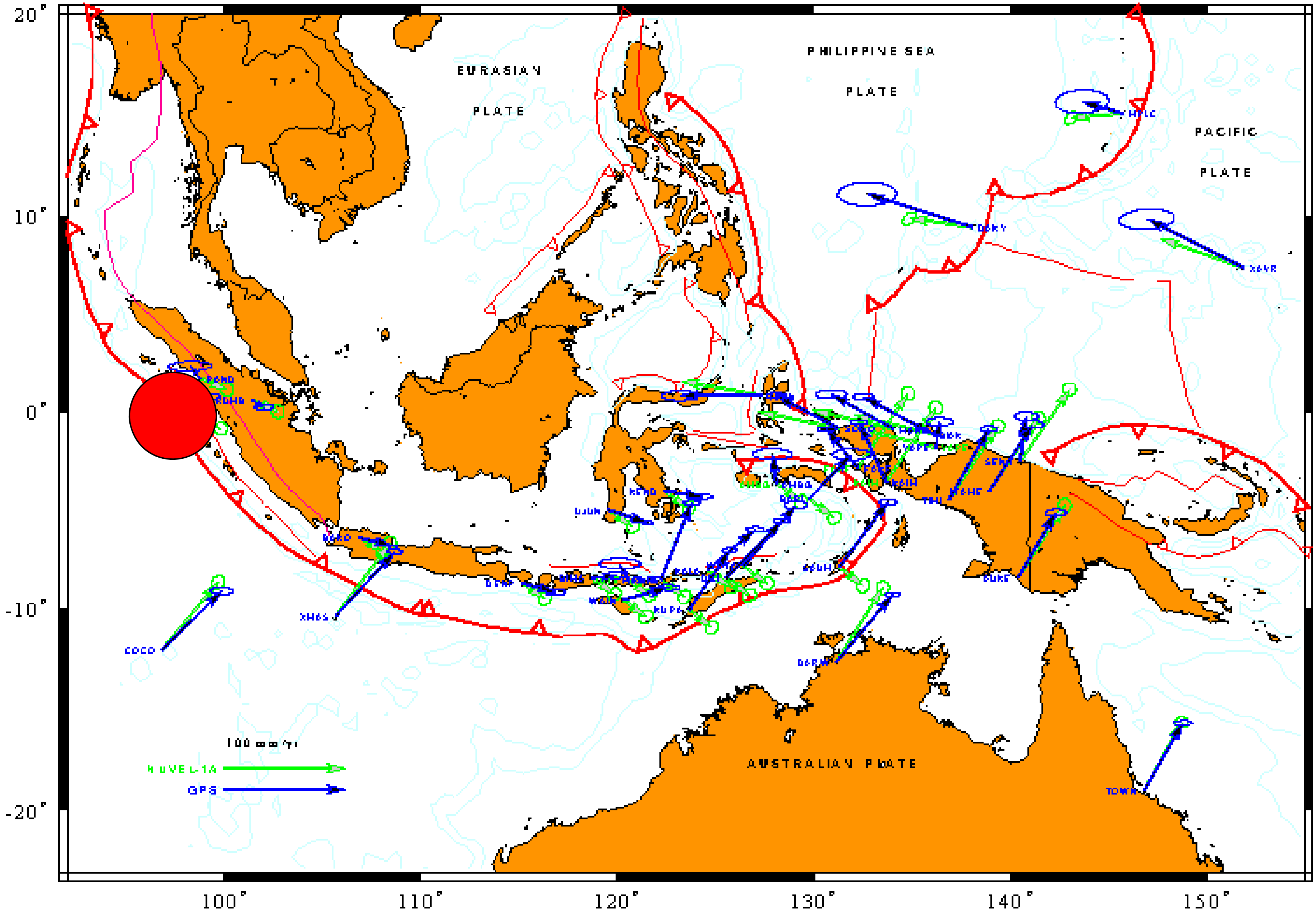

**Seismicity of Iran, 1990 - 2000**

# TABLE 3.1

Table 3.1

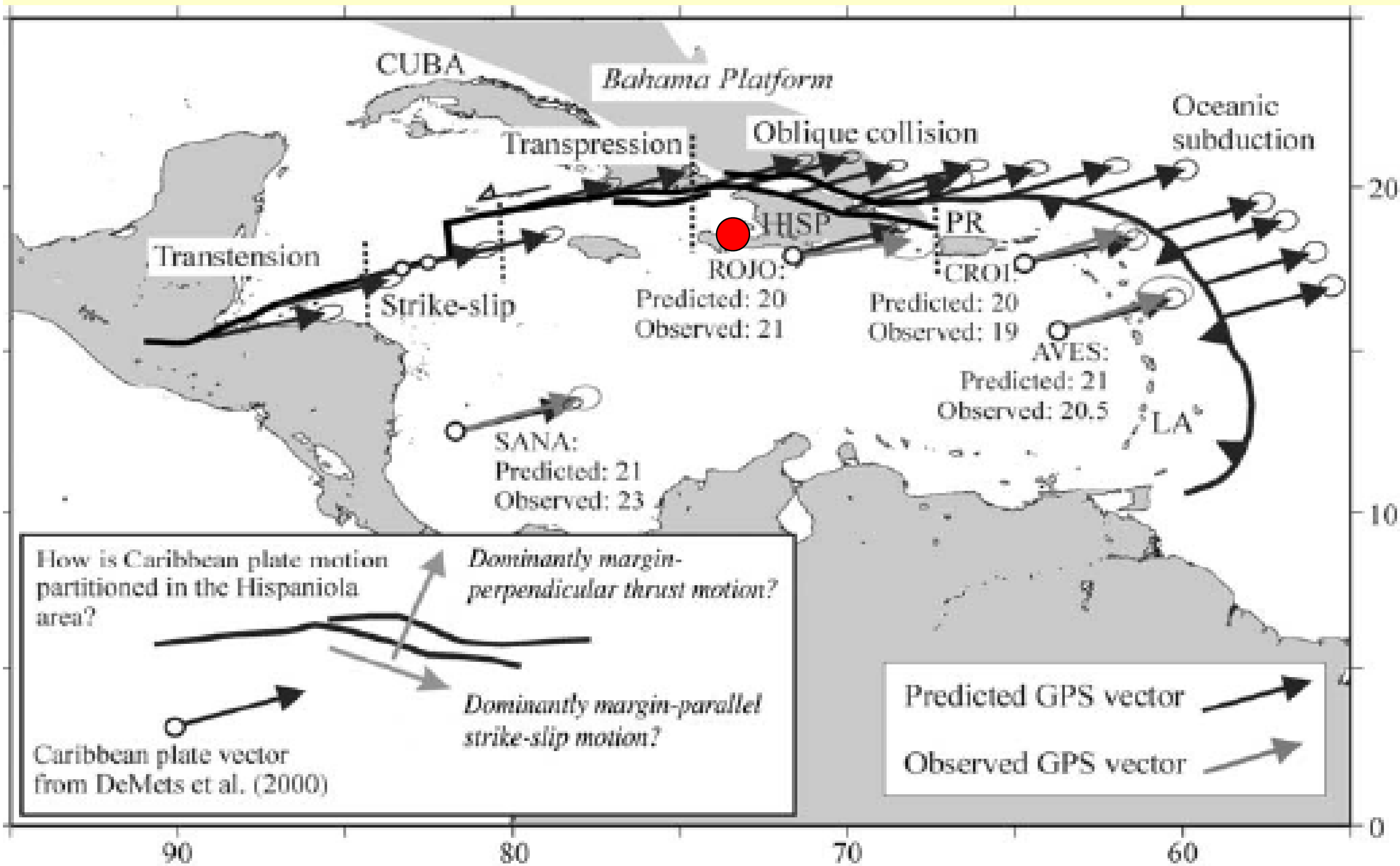
## Earthquake Fatalities in Iran, 1962–2005

| Fatalities | Date | Location |
|---|---|---|
| 612 | 22 Feb 2005 | Zarand |
| 41,000 | 26 Dec 2003 | Bam |
| 50,000 | 21 Jun 1990 | Rudbar-Tarom |
| 3,000 | 28 Jul 1981 | Kerman |
| 3,000 | 11 Jun 1981 | Golbas |
| 25,000 | 16 Sep 1978 | Tabas-e-Golshan |
| 5,000 | 24 Nov 1976 | Northwest |
| 5,044 | 10 Apr 1972 | Fars |
| 12,000 | 31 Aug 1968 | Khorasan |
| 12,225 | 1 Sep 1962 | Buyin-Zara |
| 156,881 | Total deaths | |

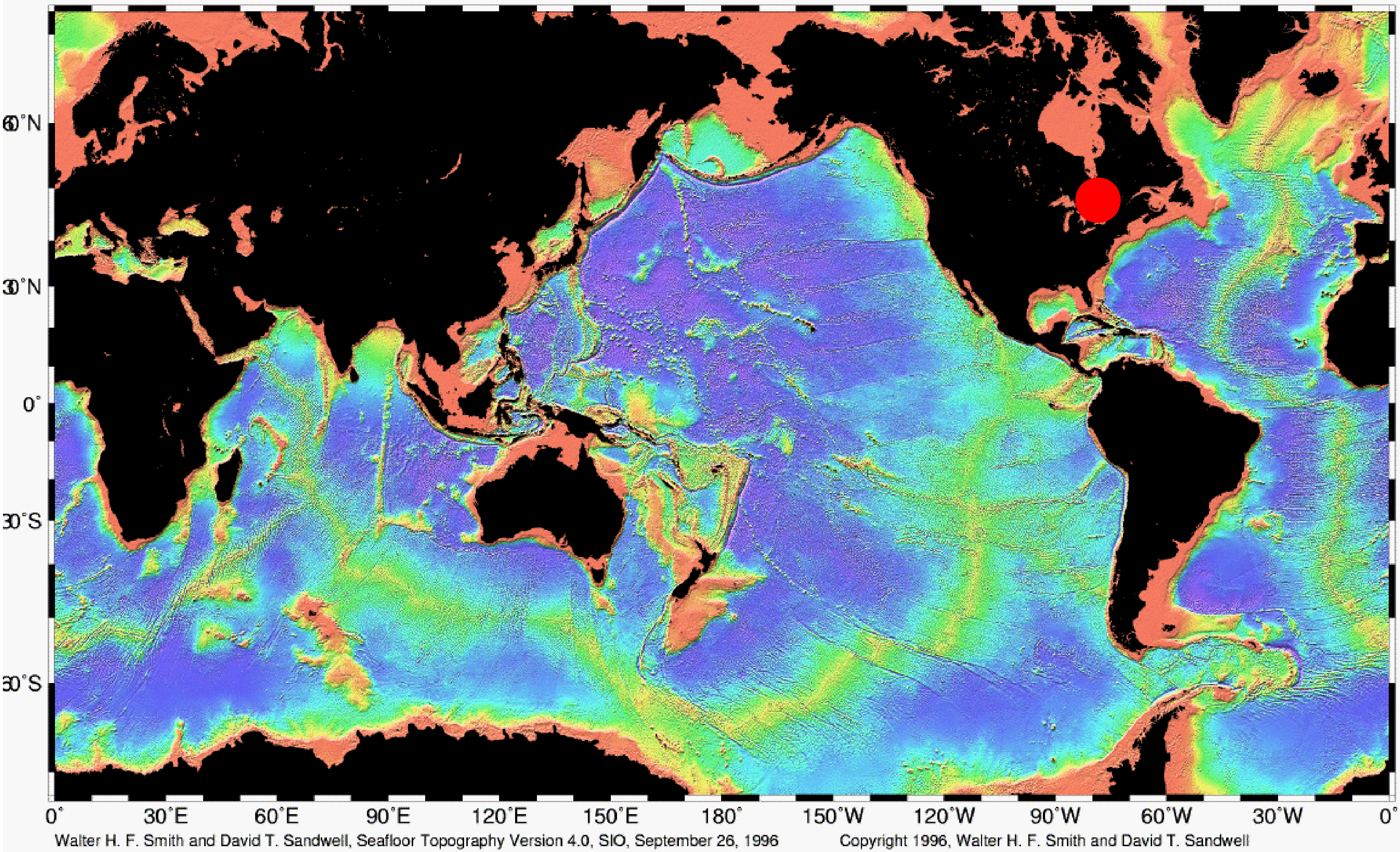



Southeast Asia - 1989.1994 ITRF93N Reference Frame - 95% confidence ellipses

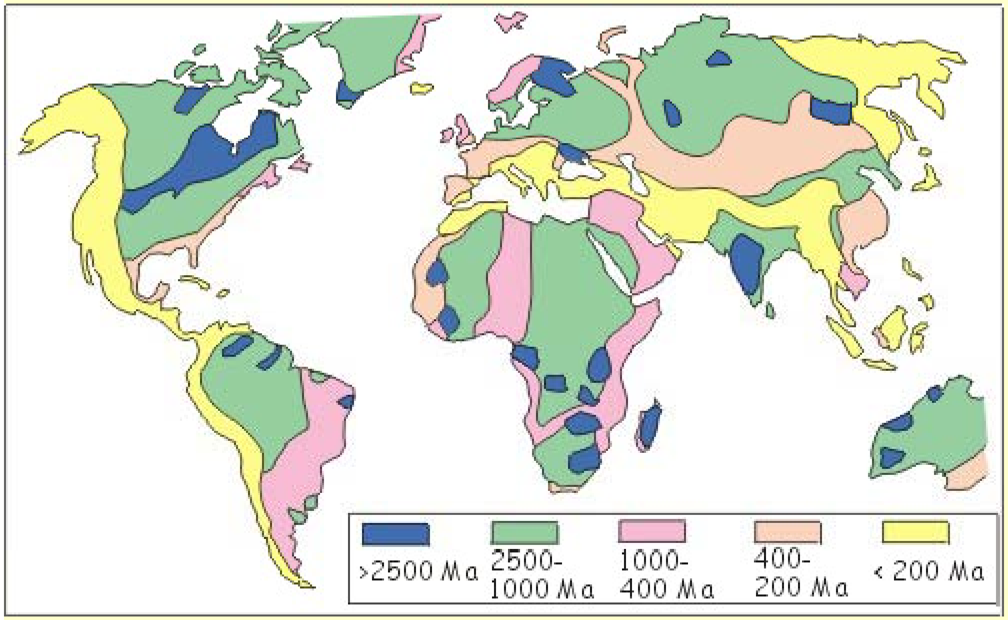
# PLATE MOTIONS IN SOUTHWEST PACIFIC

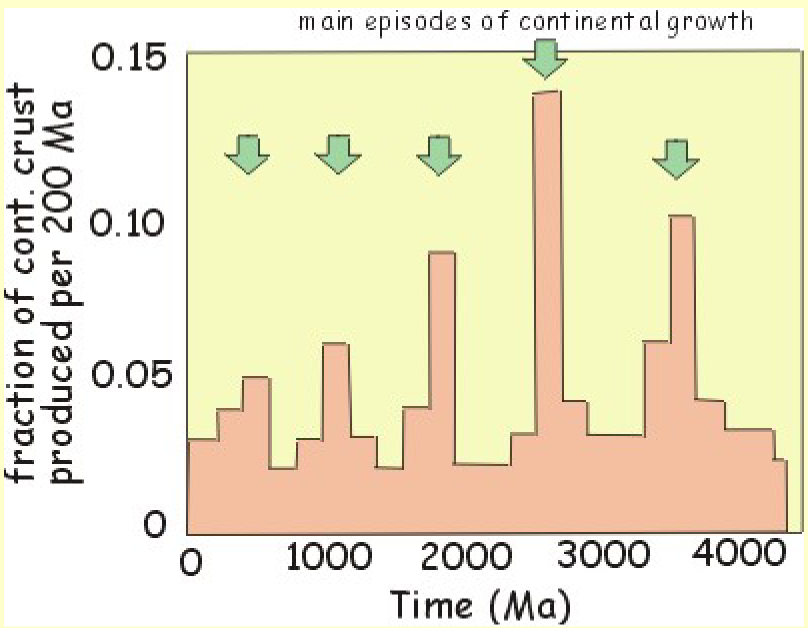



**VECTORS OF PLATE MOVEMENT IN THE CARIBBEAN REGION OBTAINED FROM GPS MEASUREMENTS**




**WHAT ABOUT THE CONTINENTAL CRUST ???**



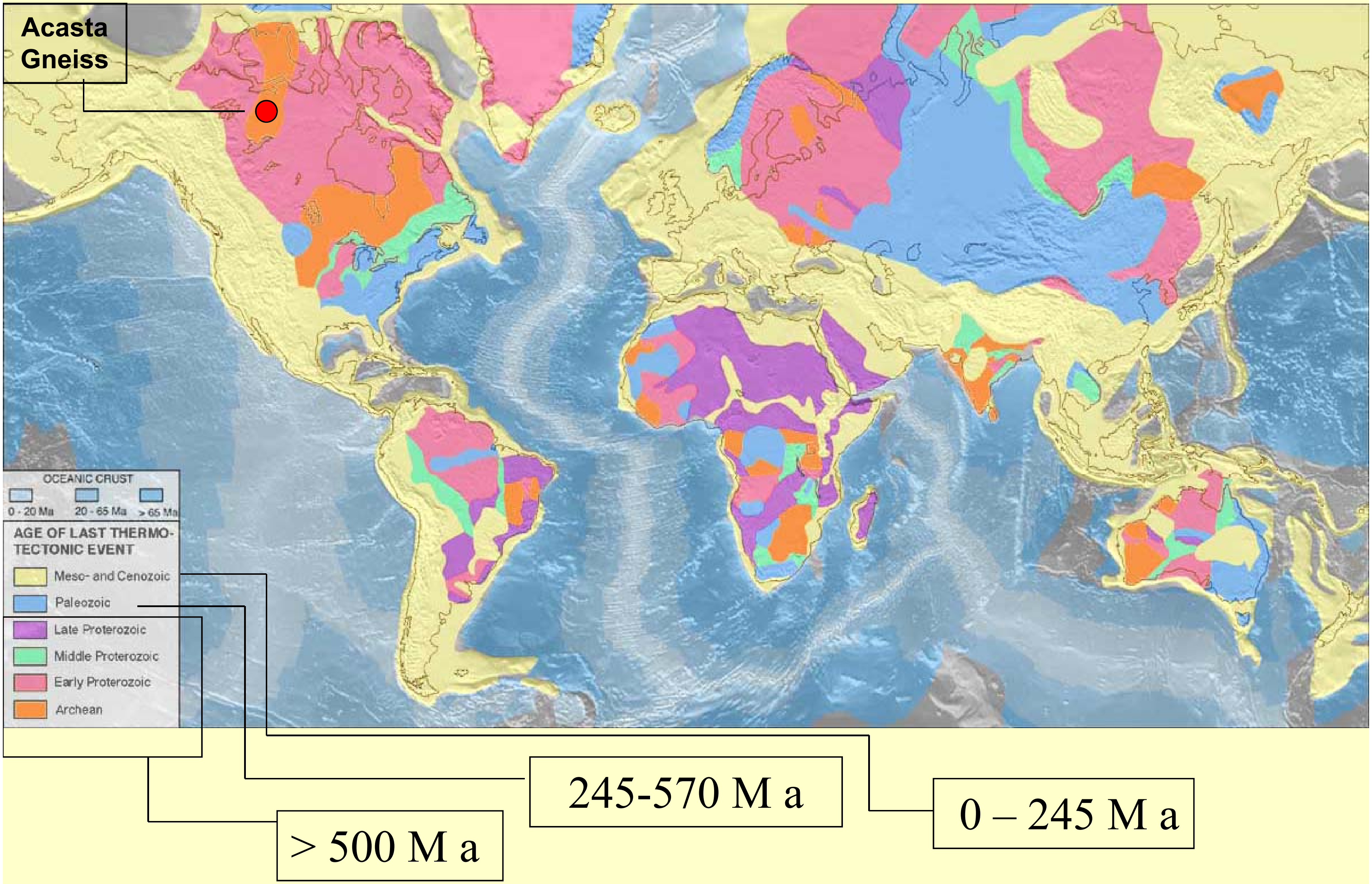



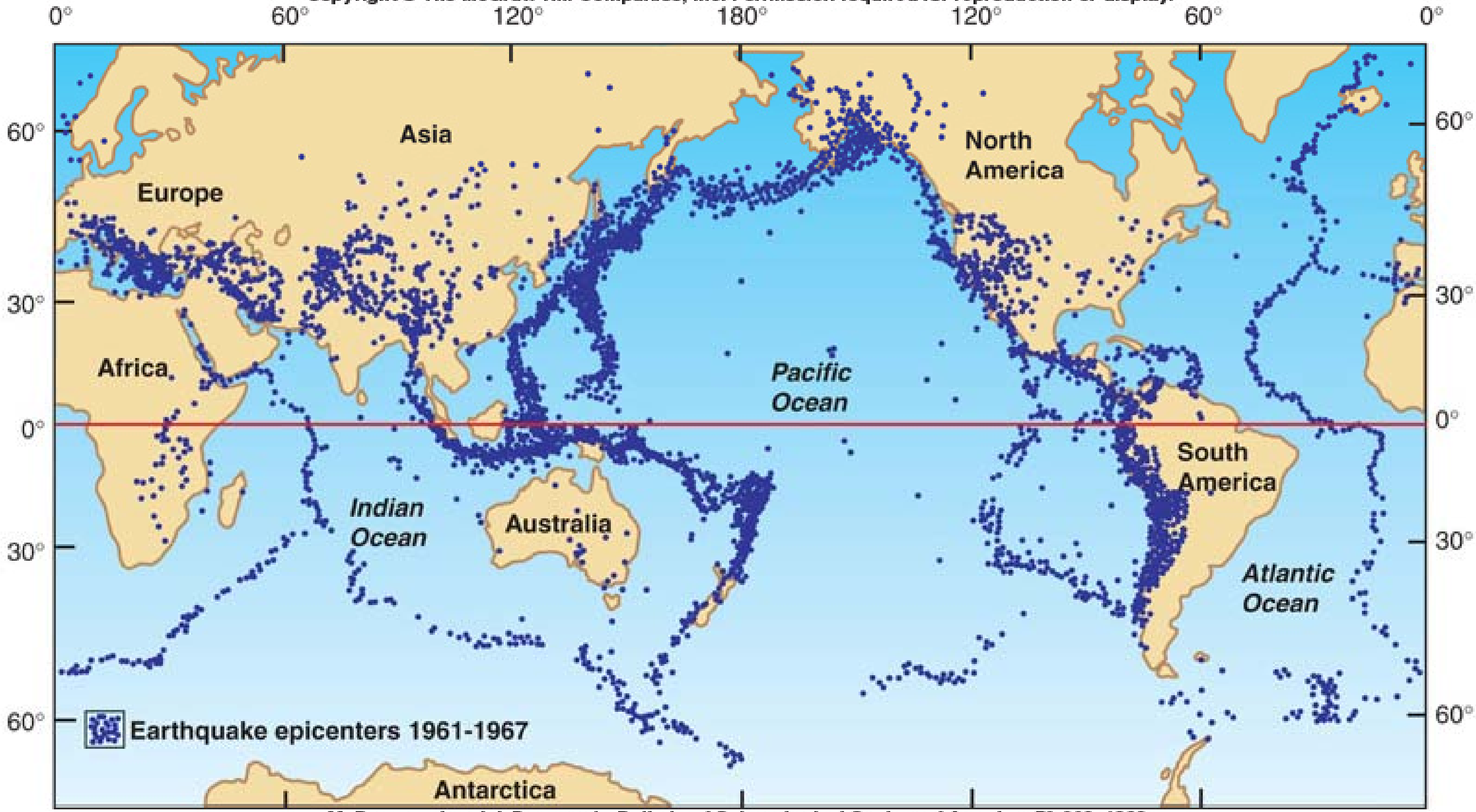

## FEATURES OF THE CONTINENTAL CRUST

- 40 % of the Earth's surface
- Lighter than oceanic crust
- Floats like a raft on the mantle
- Made up of very different ages
- Oldest rock is Acasta Gneiss, NWT, Canada (4.1 Ga)

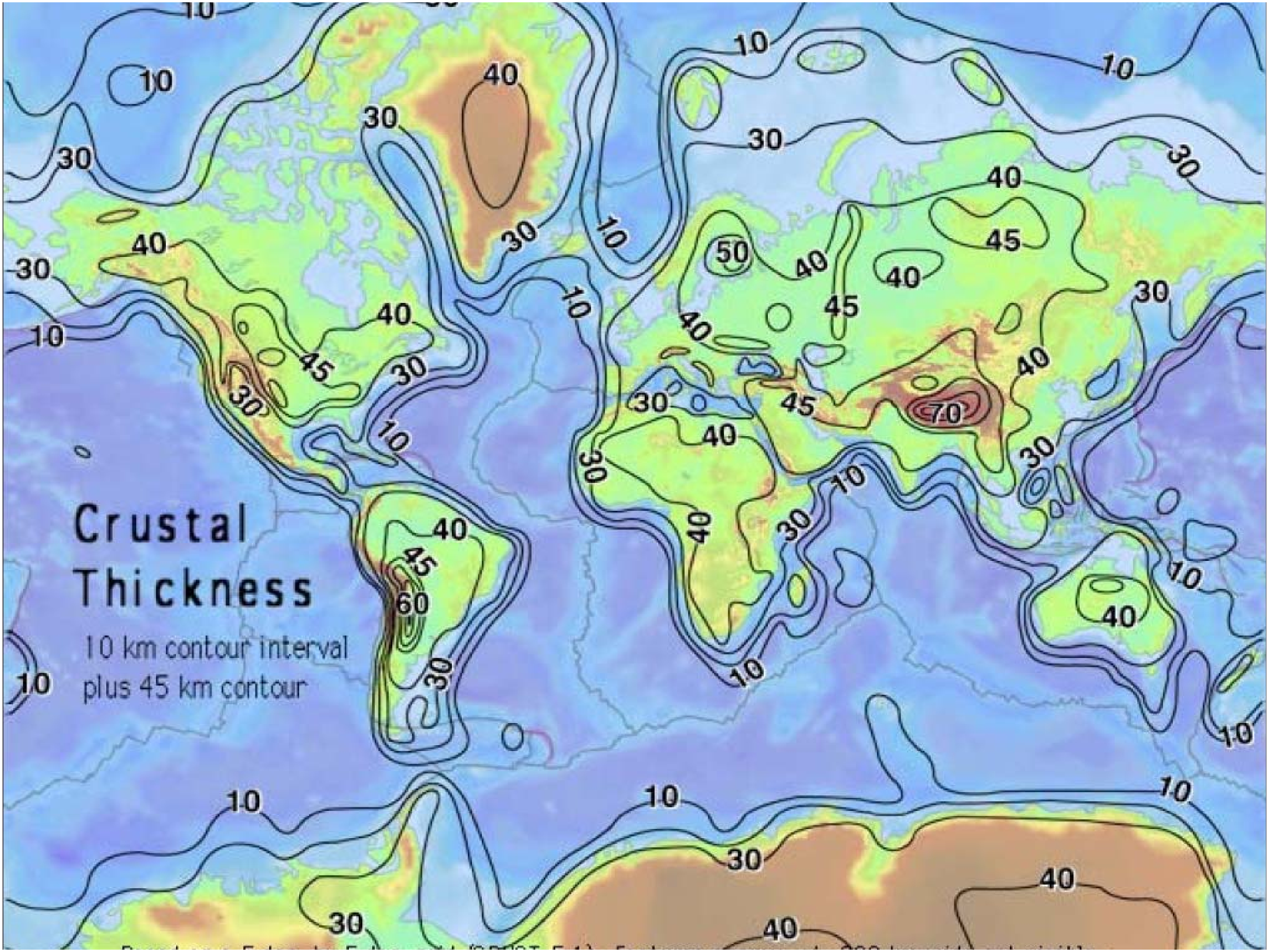
- Formed in an episodic pattern in geologic time
- Thickest (~90 km) beneath the highest mountains
- Thinnest (~20 km) in rift valley areas
- New crust forms at flood basalt centres and subduction zones

# USGS MAP OF THE AGE OF THE LAST FORMATIVE THERMO-TECTONIC EVENT






M. Barazangi and J. Dorman, in Bulletin of Seismological Society of America, 59:369, 1969.


Crustal
Thickness
10 km contour interval
plus 45 km contour

# POSTSCRIPT ON PANGAEA



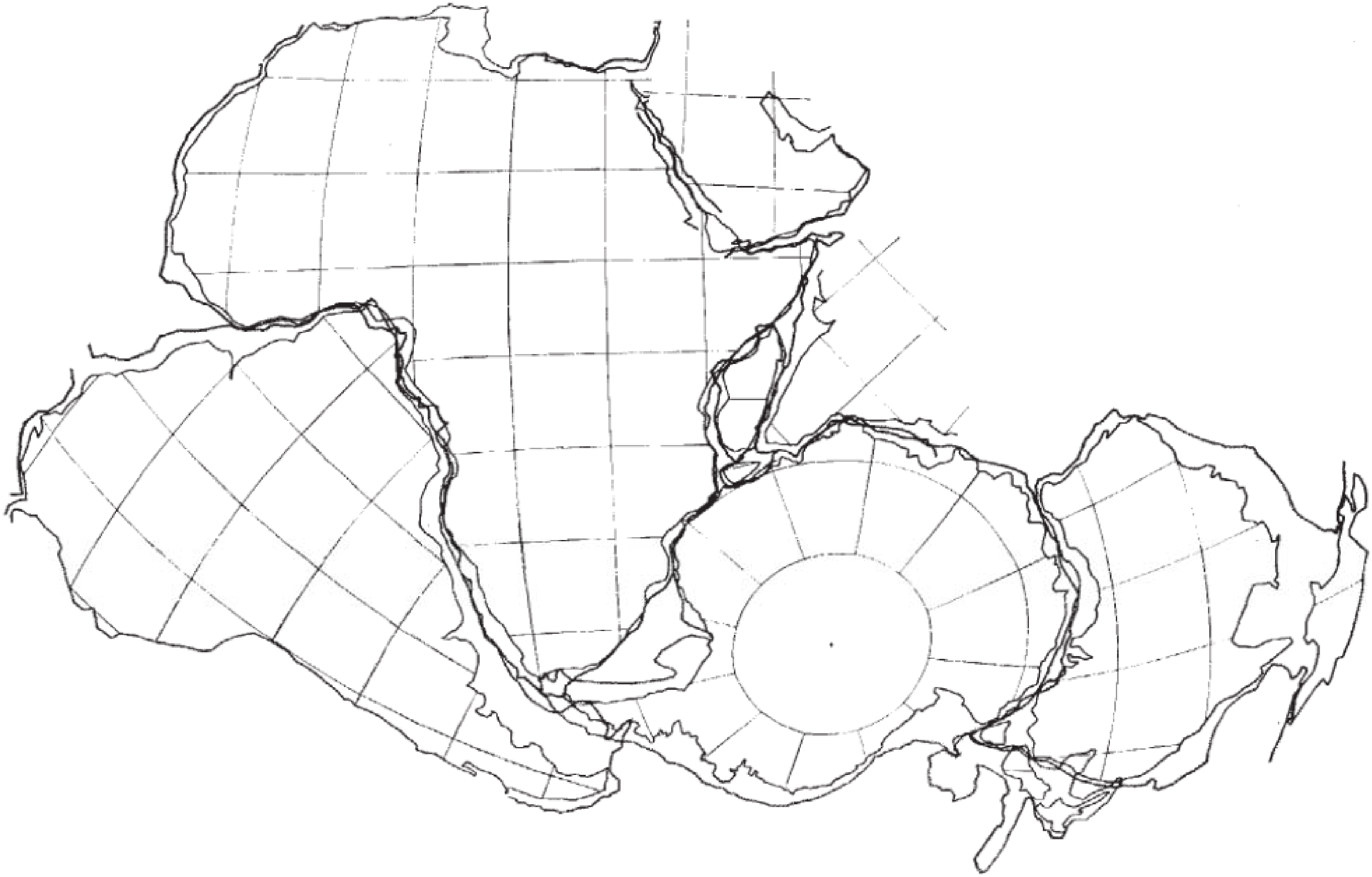
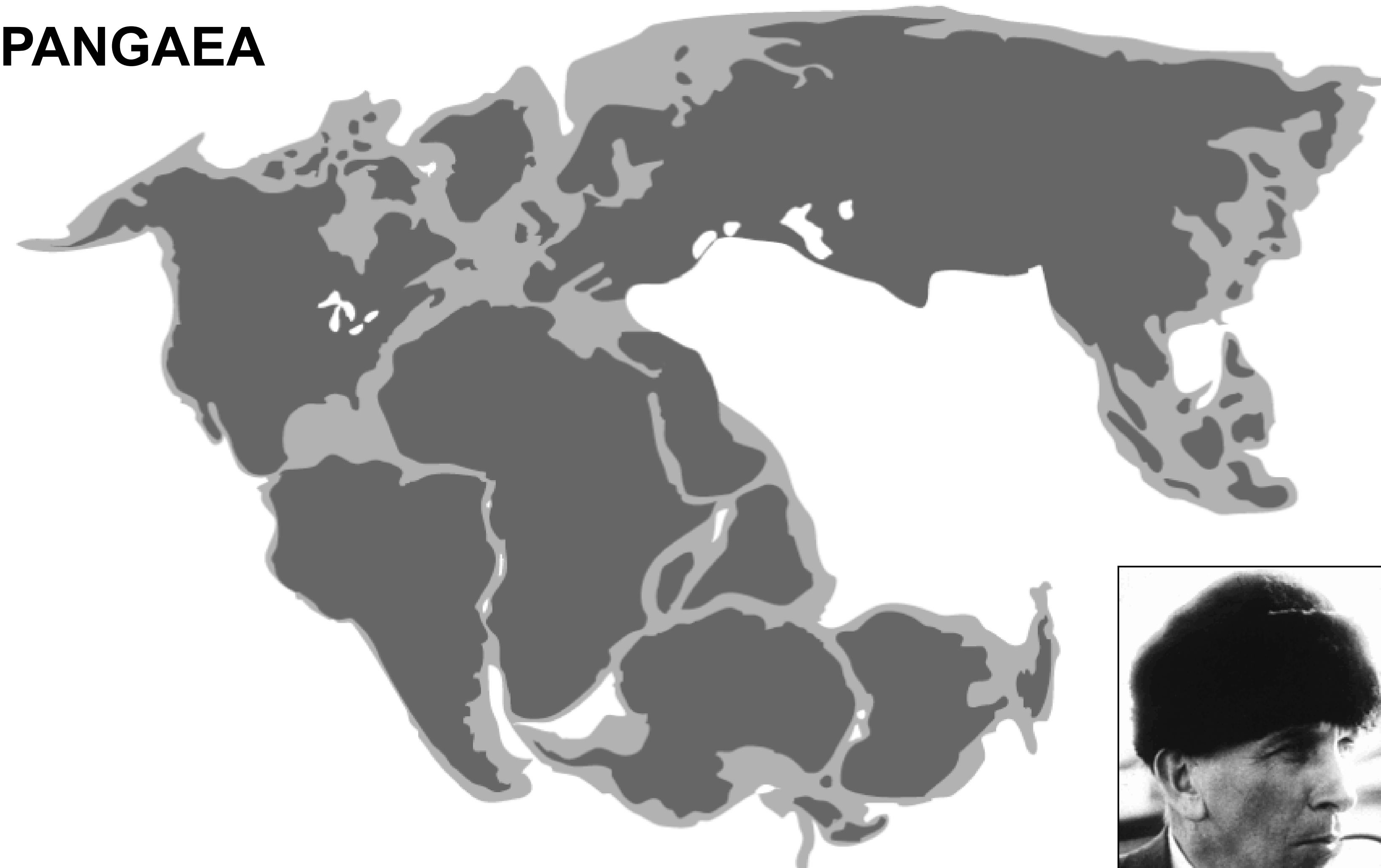
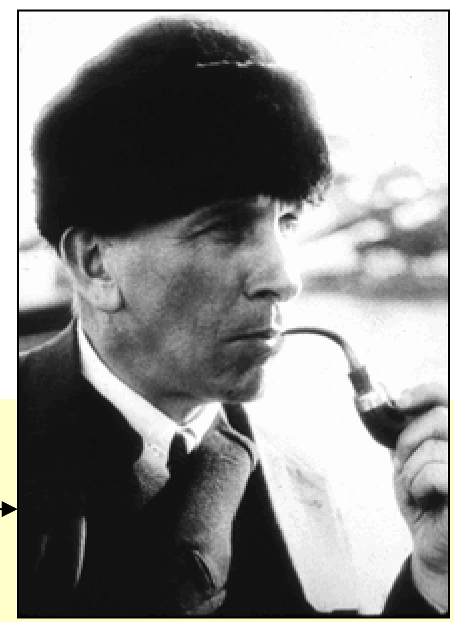


Fig. 1. The fit of the southern continents at the 500-fathom contour, except Antarctica, fitted at the 1,000-metre contour. Apart from Ceylon, which has been fitted by inspection, the map is an ornamented tracing of computer output. The Antarctic coast includes ice boundaries, some of which lie above water deeper than 1,000 metres. Lambert equal area projection centred at 5° S, 35° E.

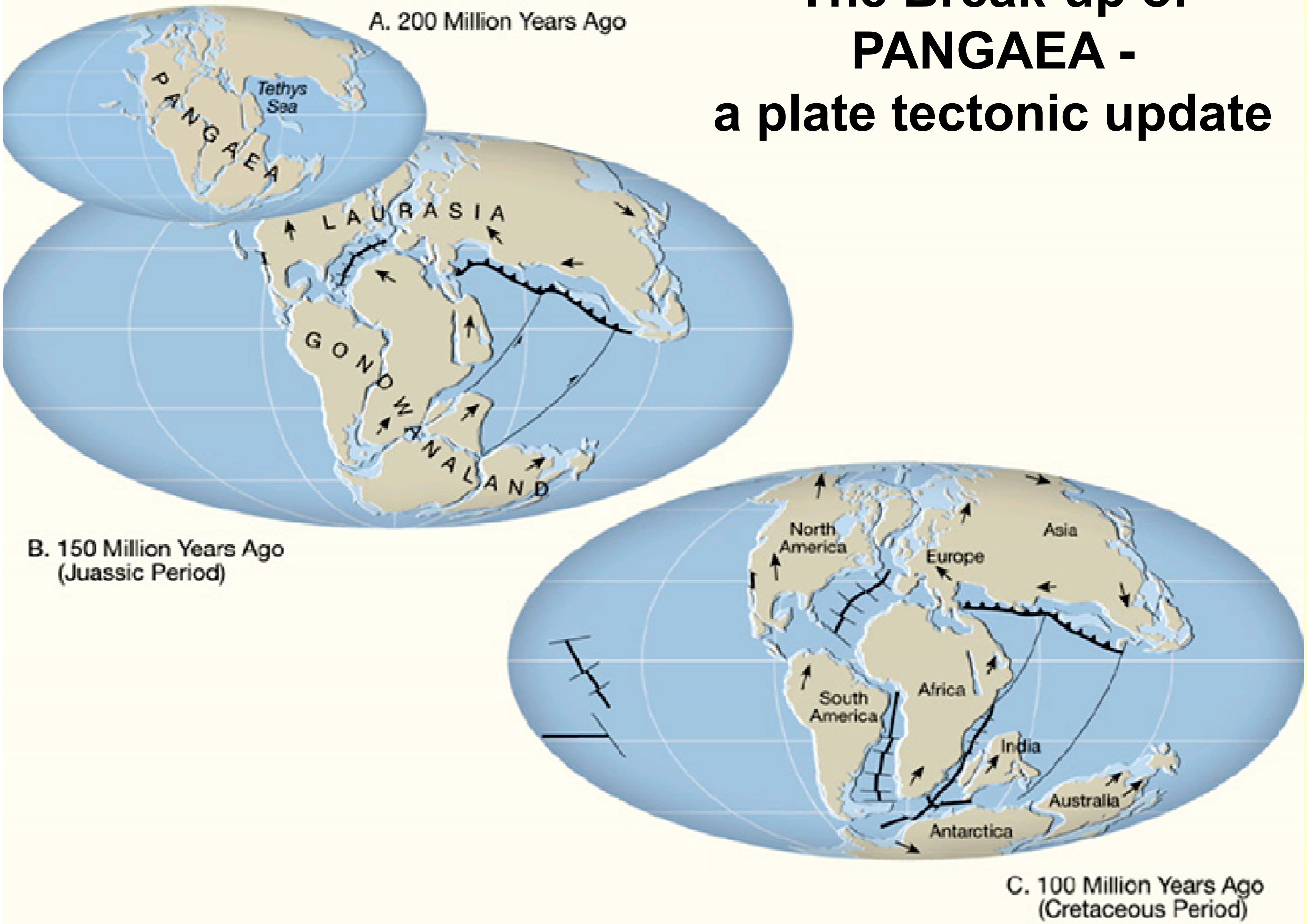
## PANGAEA



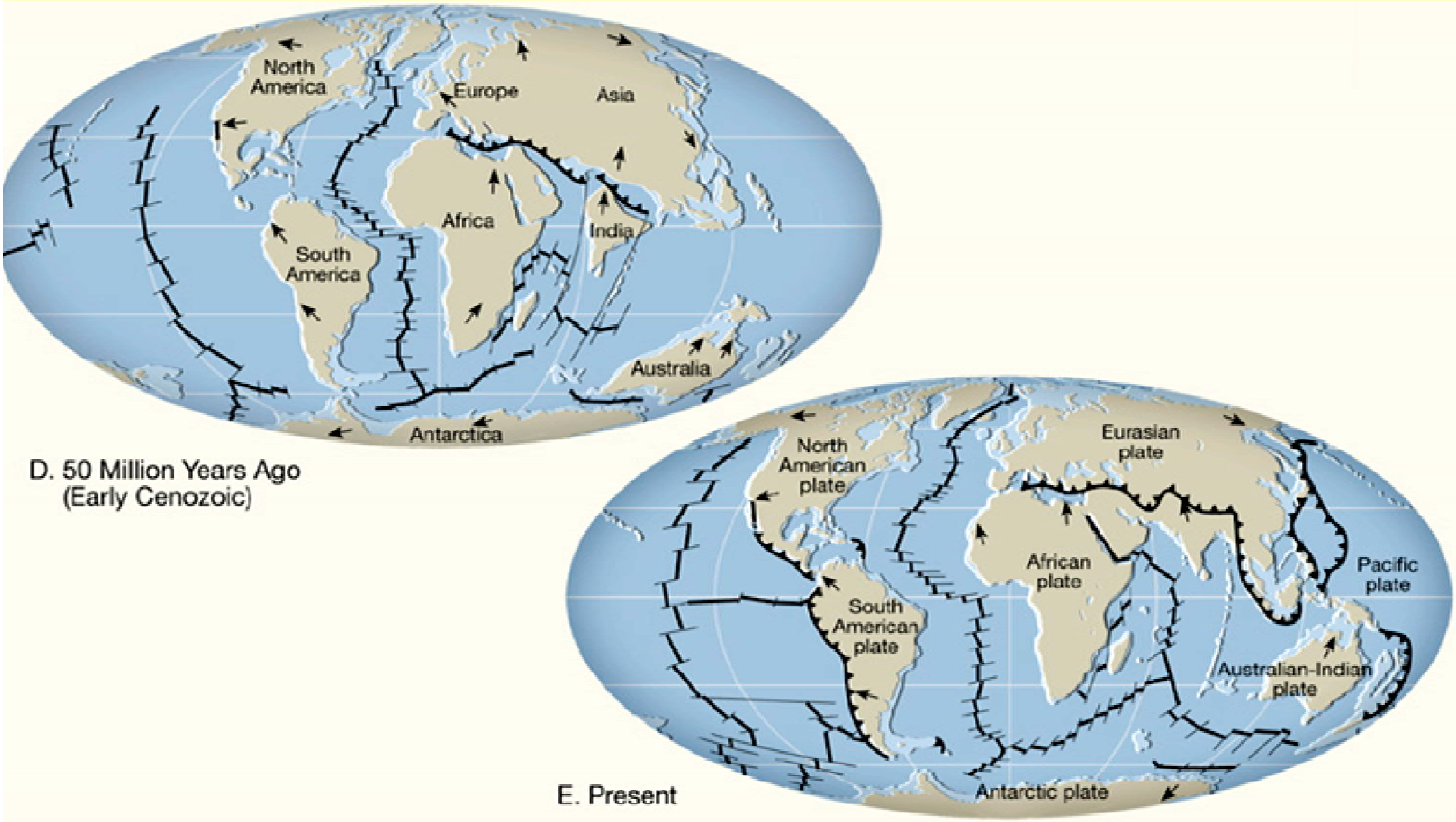
**THE FATHER OF PANGAEA – A. WEGENER**



# The Break-up of PANGAEA - a plate tectonic update

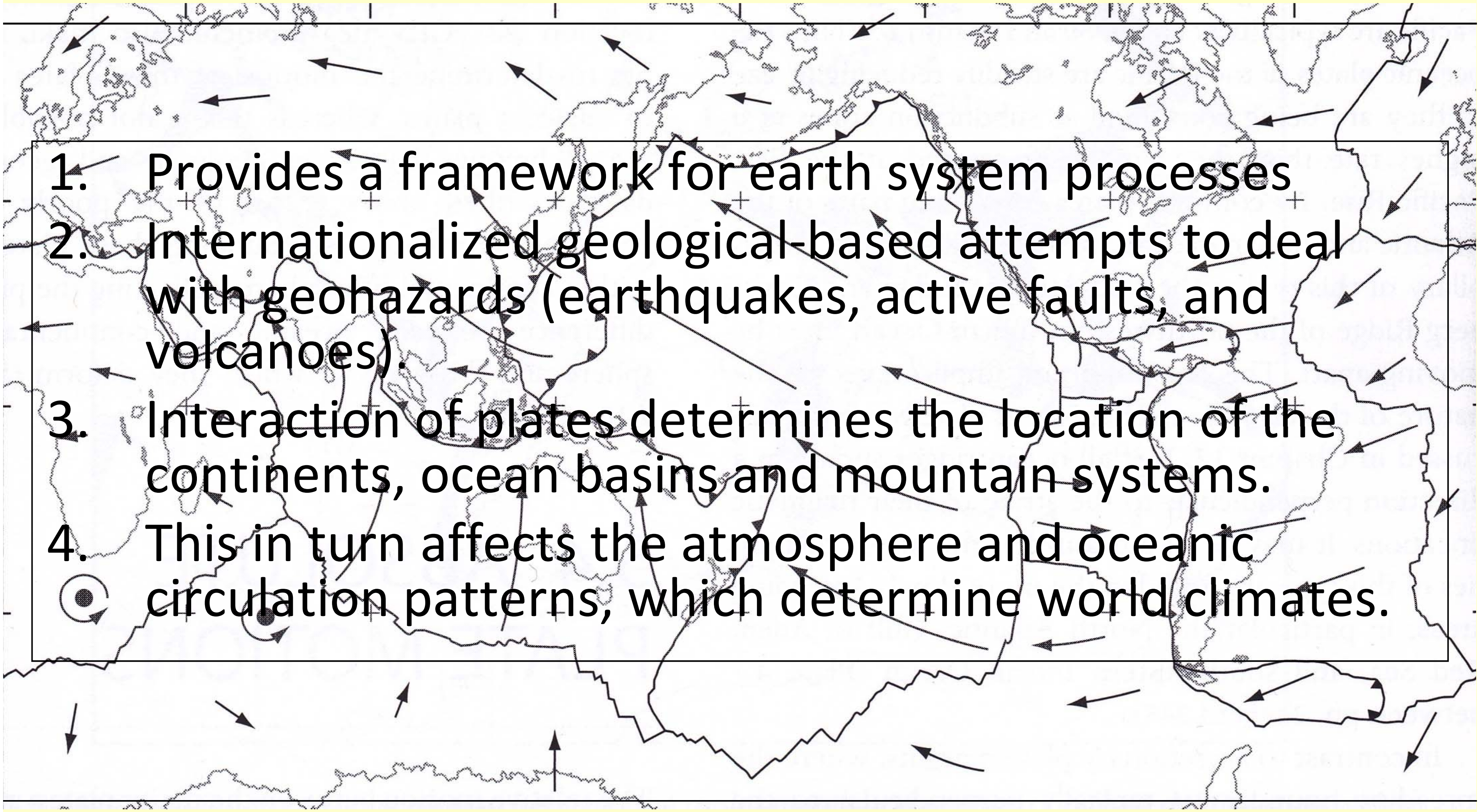


# The Break-up of PANGAEA (Continued)



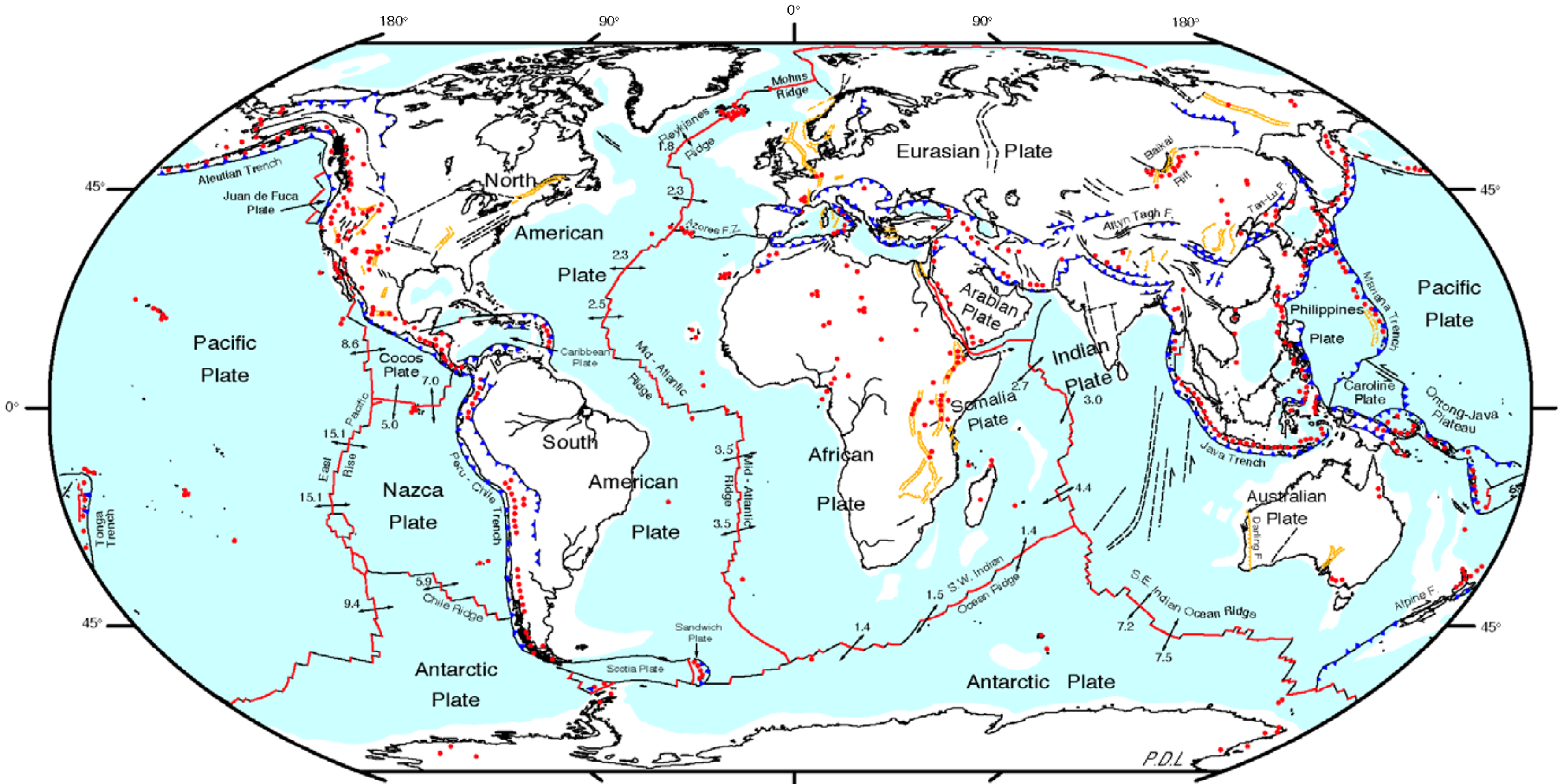

see http://www.ucmp.berkeley.edu/geology/anim2.html for an animated version
also http://www2.nature.nps.gov/geology/usgsnps/animate/pltecan.html

# Importance of Plate Tectonics Paradigm



1. Provides a framework for earth system processes
2. Internationalized geological-based attempts to deal with geohazards (earthquakes, active faults, and volcanoes).
3. Interaction of plates determines the location of the continents, ocean basins and mountain systems.
4. This in turn affects the atmosphere and oceanic circulation patterns, which determine world climates.

# PLATE BOUNDARIES, EARTHQUAKES, ACTIVE FAULTS, AND VOLCANOES




**GLOBAL TECTONIC ACTIVITY MAP OF THE EARTH**
Tectonism and Volcanism of the Last One Million Years

**DTAM - 1**

NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

Robinson Projection
Mainly oceanic crust
Mainly continental crust

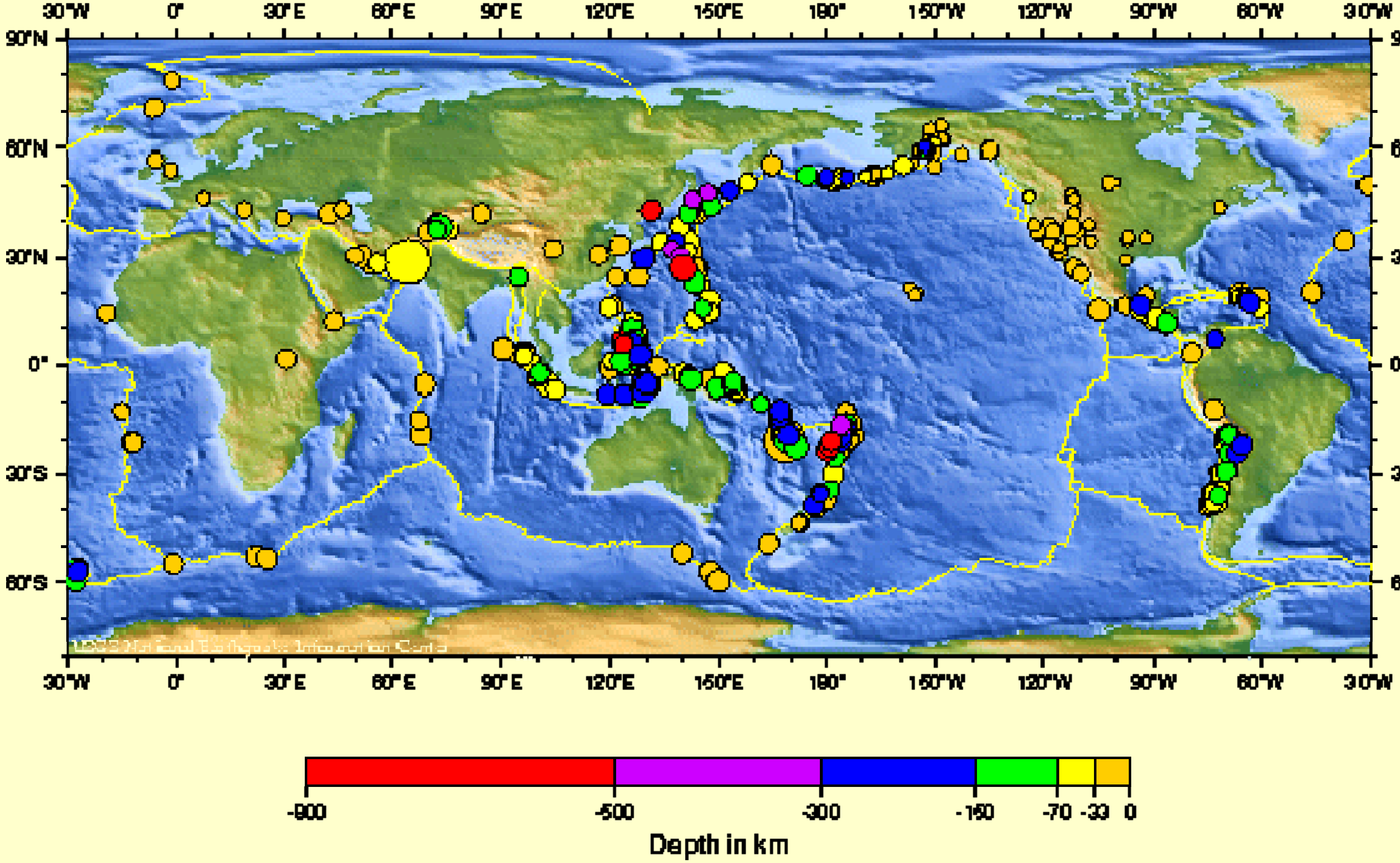
October 2002

LEGEND

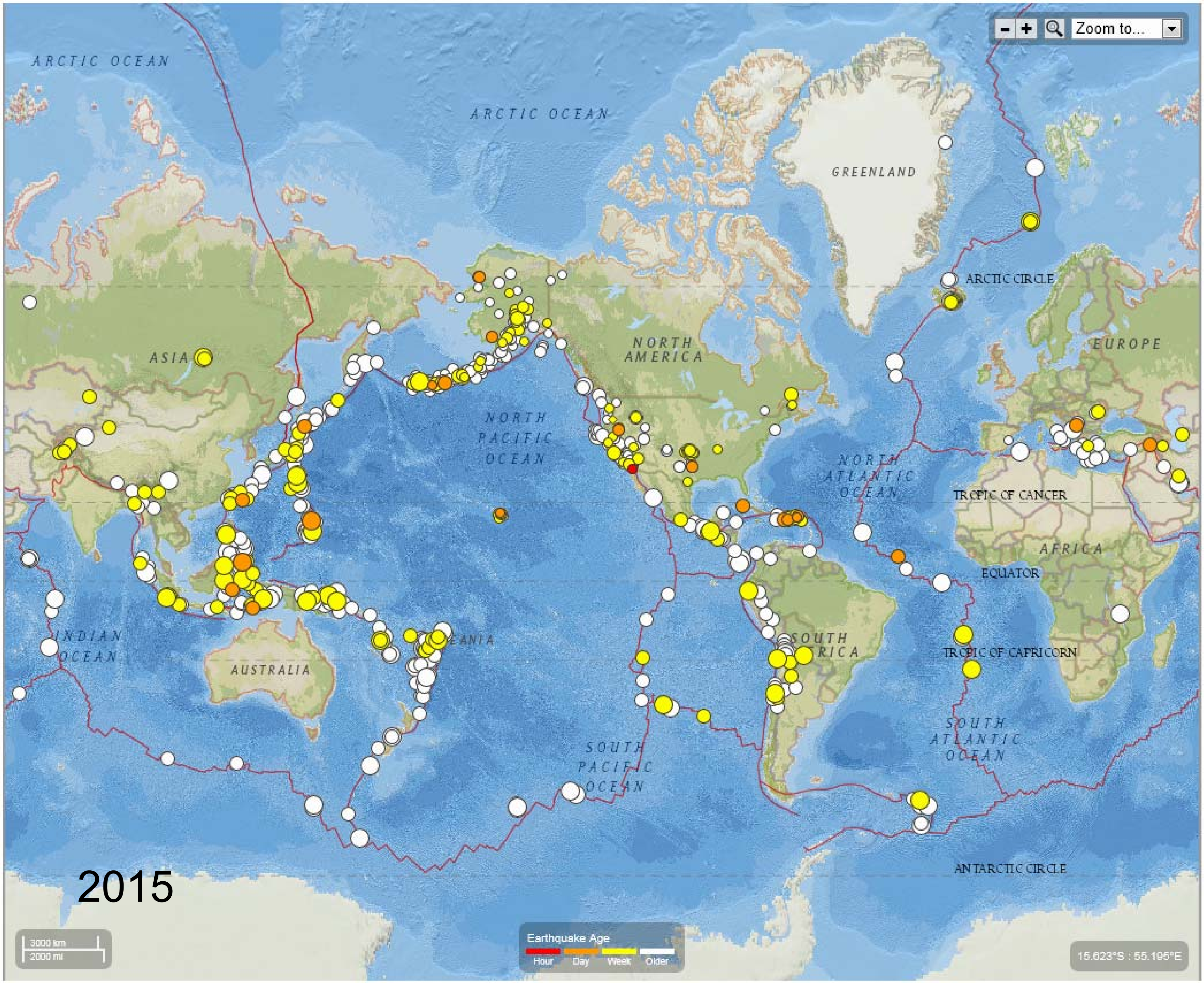
- Actively-spreading ridges and transform faults
- Total spreading rate, cm/year (1.4)
- Major active fault or fault zone; dashed where nature, location, or activity uncertain
- Normal fault or rift; hachures on downthrown side
- Reverse fault (overthrust, subduction zones); generalized; barbs on upthrown side
- Volcanic centers active within the last one million years; generalized. Minor basaltic centers and seamounts omitted.

G221.001

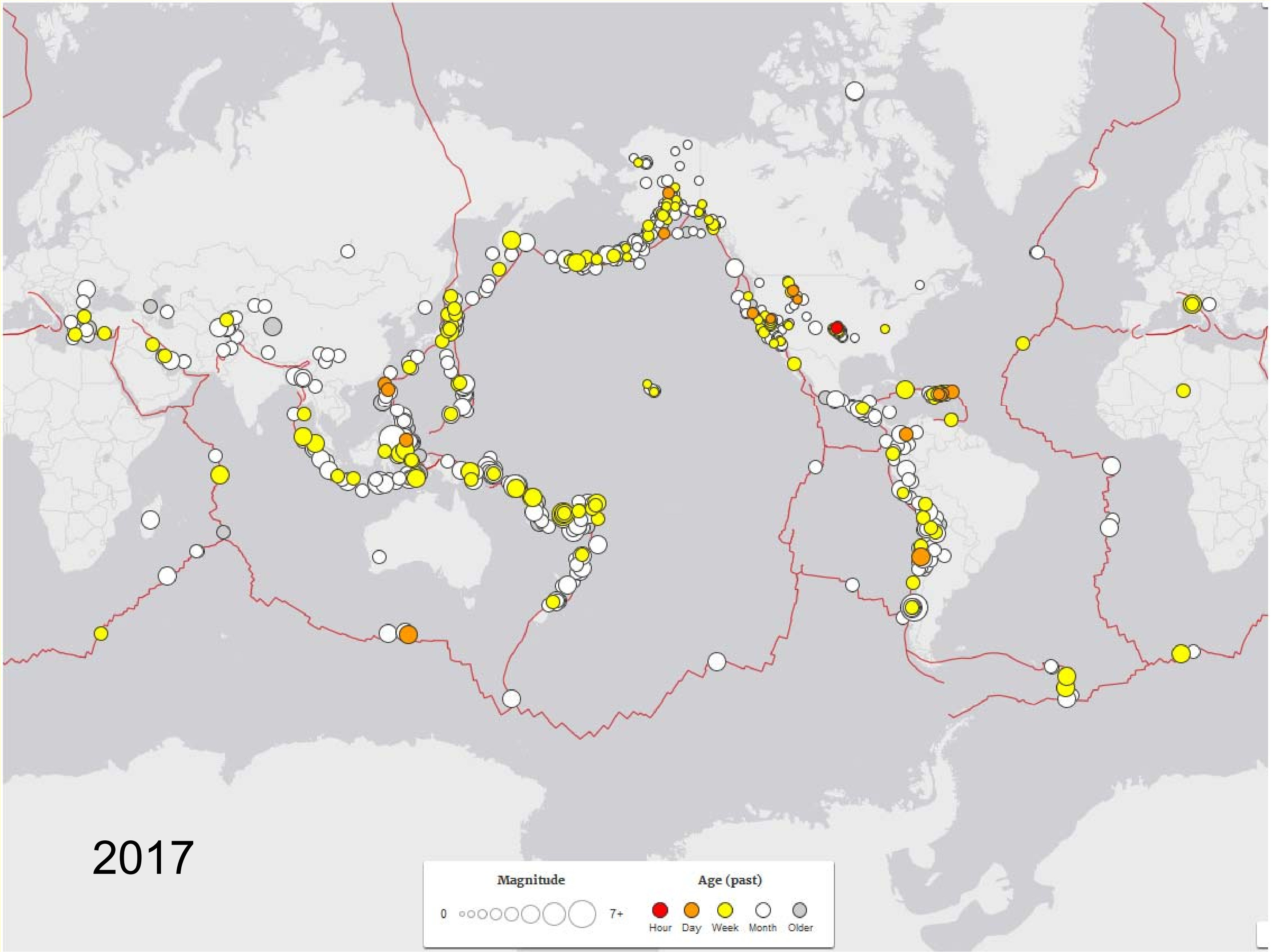
# GLOBAL DISTRIBUTION OF EARTHQUAKE EPICENTRES IN THE LAST THIRTY DAYS (as of February 1, 2011)



GLOBAL DISTRIBUTION OF EARTHQUAKE EPICENTRES IN THE LAST THIRTY DAYS (as of January 21, 2015)



GLOBAL DISTRIBUTION OF EARTHQUAKE EPICENTRES IN THE LAST THIRTY DAYS (as of January 19, 2017)



GLOBAL DISTRIBUTION OF EARTHQUAKE EPICENTRES IN THE LAST THIRTY DAYS (as of January 17, 2018)