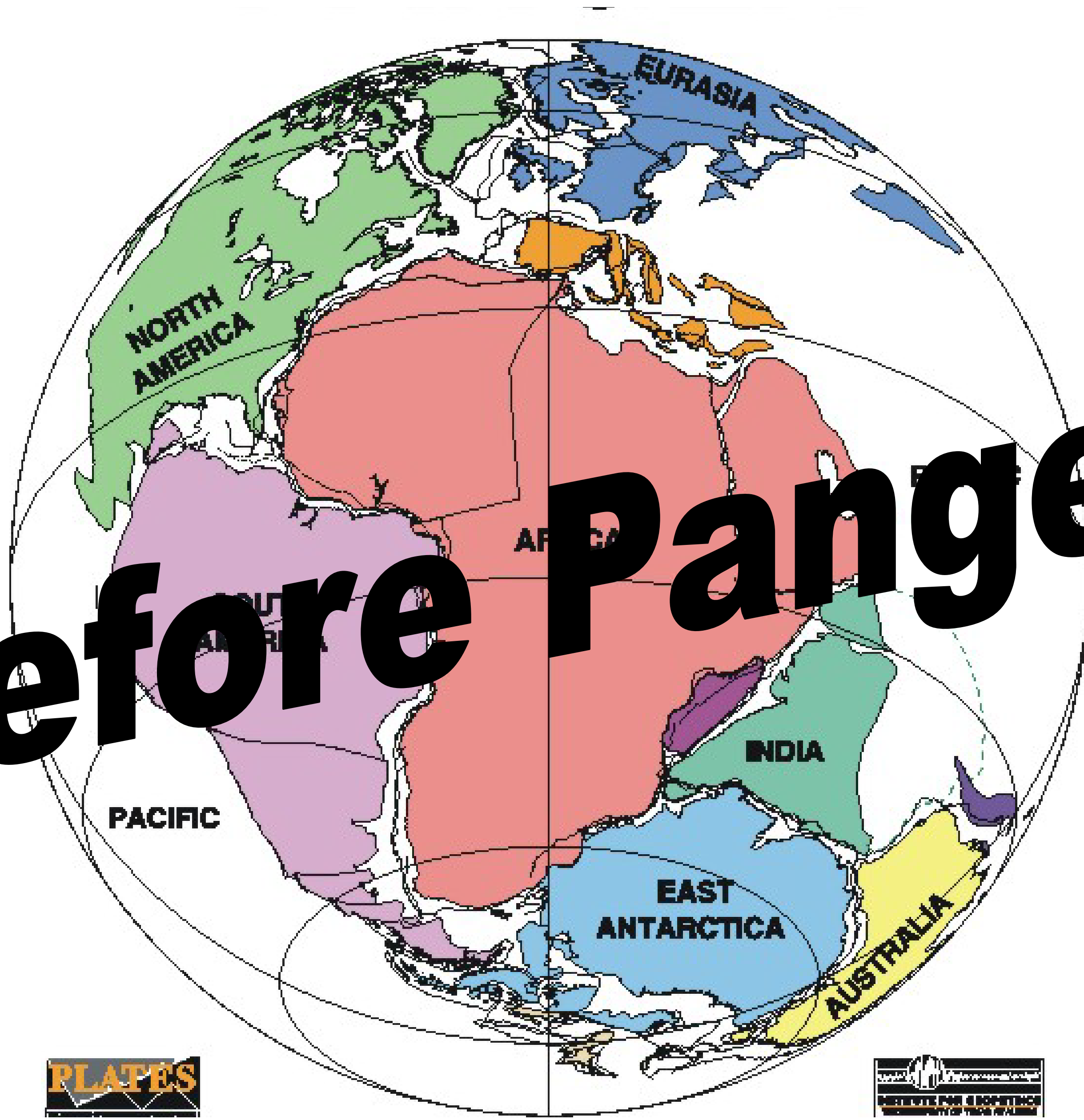
Supercontinent cycle

Plate Reconstruction

Supercontinent cycle

from an exploration point of view
and
Conceptualization of earth's evolution history

Before Pangea



THE SUPERCONTINENT CYCLE

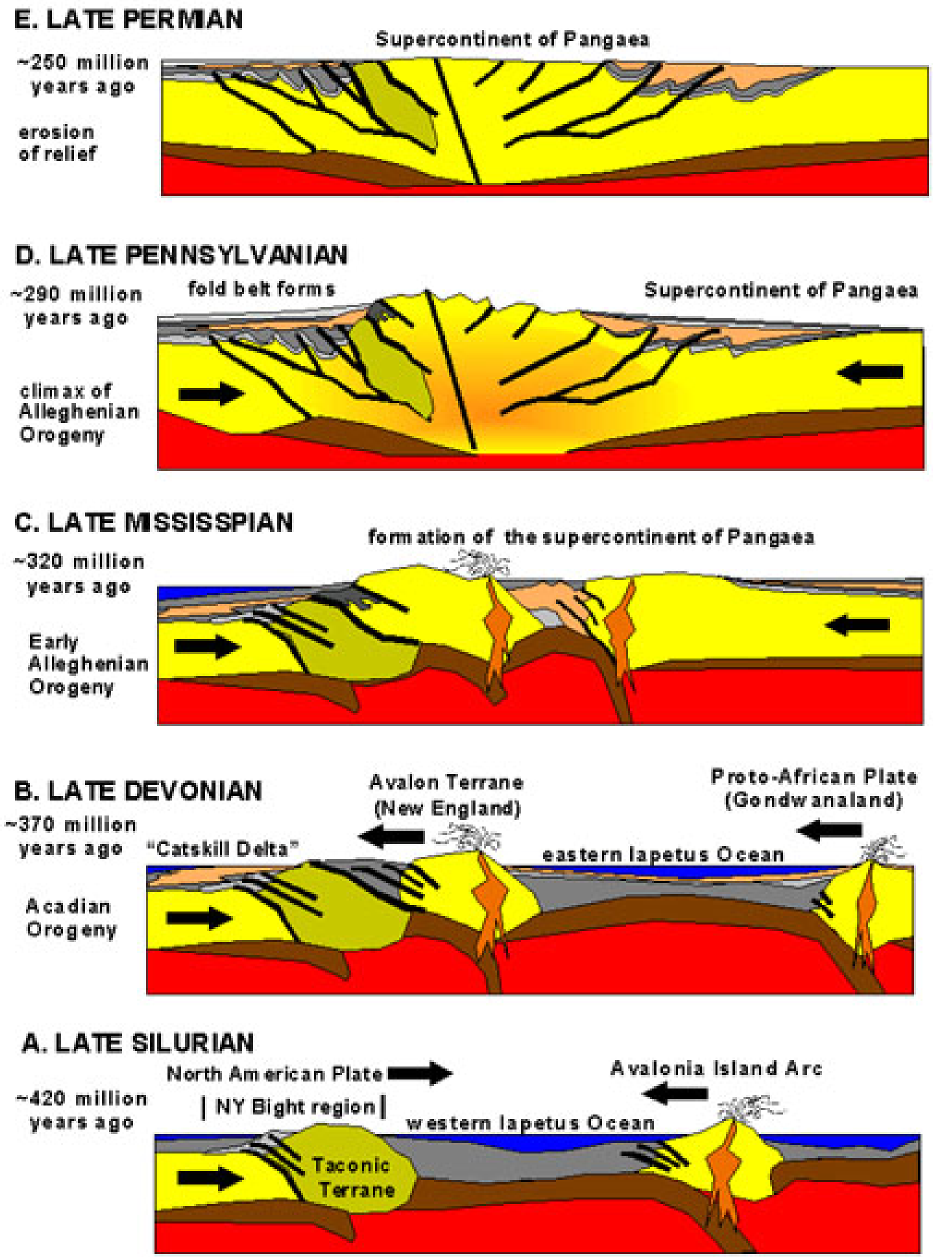
While Wegener's view that continental drift happens ultimately proved correct, his view that drift *only* happened after the breakup of Pangaea was just part of the story.

Tuzo Wilson, a Canadian geophysicist, noted that formation of the Appalachian-Caledonide Orogen involved closure of an ocean.


CANADA
WASHINGTON
MONTANA
NORTH DAKOTA
MINNESOTA
SOUTH DAKOTA
WISCONSIN
MICHIGAN
OREGON
IDAHO
WYOMING
ROCKY MOUNTAINS
CASCADE RANGE
SIERRA NEVADA
GREAT PLAINS
NEBRASKA
IOWA
NEW YORK
PENNSYLVANIA
OHIO
ILLINOIS
INDIANA
GREAT BASIN
NEVADA
UTAH
COLORADO
KANSAS
MISSOURI
KENTUCKY
WEST VIRGINIA
VIRGINIA
CALIFORNIA
OKLAHOMA
TENNESSEE
NORTH CAROLINA
APPALACHIAN MOUNTAINS
ARIZONA
NEW MEXICO
ARKANSAS
MISSISSIPPI
ALABAMA
GEORGIA
SOUTH CAROLINA
TEXAS
LOUISIANA
FLORIDA
MAINE
Nova Scotia
Vancouver
Seattle
Portland
Sacramento
San Francisco
Los Angeles
San Diego
Salt Lake City
Denver
Minneapolis
Milwaukee
Chicago
Detroit
Cleveland
Toronto
OTTAWA
Montréal
Québec
Boston
New York
Philadelphia
Baltimore
WASHINGTON, DC
Pittsburgh
Indianapolis
St-Louis
Kansas City
Memphis
Atlanta
Dallas
Austin
Houston
San Antonio
New Orleans
Miami
Calgary
Regina
Winnipeg
PACIFIC OCEAN
ATLANTIC OCEAN
Gulf of Mexico
MEXICO
Ciudad Juárez
Monterrey
Culiacán
Guadalajara
CIUDAD DE MEXICO
Acapulco
Mérida
Cancún
THE BAHAMAS
TROPIC OF CANCER
LA HABANA
CUBA
Santiago de Cuba
HAITI
DOMINICAN REPUBLIC
PUERTO RICO
JAMAICA
Greater Antilles
BELIZE
GUATEMALA
HONDURAS
EL SALVADOR
NICARAGUA
CARIBBEAN SEA
Alaska at 25%
ALASKA
Anchorage
Bering Sea
Gulf of Alaska
PACIFIC OCEAN
Hawaii
Honolulu
PACIFIC OCEAN
HAWAII
UNITED STATES OF AMERICA
GEOATLAS - © 2000 Graphi-Ogre

Physical Features of the United States

Appalachian Plateau
Pennsylvania Salient
Appalachian Piedmont
Atlantic Coastal Plain
N
25 km


E. LATE PERMIAN
~250 million years ago
erosion of relief
Supercontinent of Pangaea
D. LATE PENNSYLVANIAN
~290 million years ago
climax of Alleghenian Orogeny
fold belt forms
Supercontinent of Pangaea
C. LATE MISSISSPIAN
~320 million years ago
Early Alleghenian Orogeny
formation of the supercontinent of Pangaea
B. LATE DEVONIAN
~370 million years ago
Acadian Orogeny
"Catskill Delta"
Avalon Terrane (New England)
Proto-African Plate (Gondwanaland)
eastern Iapetus Ocean
A. LATE SILURIAN
~420 million years ago
North American Plate
| NY Bight region |
western Iapetus Ocean
Avalonia Island Arc
Taconic Terrane

Thus, there must have been another ocean (not the Atlantic) on the east side of North America *before* the formation of Pangaea.

Wilson envisioned a cycle of tectonic activity in which an ocean basin:

- **opens by rifting,**
- **grows by seafloor spreading,**
- **closes by subduction, and disappears during collision and supercontinent formation**

And, further, that more than one such cycle has happened during Earth history. The successive stages of:

- **rifting,**
- **seafloor spreading,**
- **convergence,**
- **collision,**
- **rifting,**

recorded in a single mountain range came to be called the *Wilson cycle.*

Because of the *Wilson cycle*, we cannot find oceanic lithosphere older than about 200 Ma on Earth-

it has all been subducted.

Very old continental crust, however, can remain because it's too buoyant to be subducted; that's why we can still find Archean rocks on continents.

Eventually, geologists realized that *Wilson cycles* were part of a global succession of events leading to:

- **formation of a supercontinent,**
- **breakup of a supercontinent,**
- **dispersal of continents, and**
- **reassembly of continents into a new supercontinent.**

This succession of events has come to be known as the *supercontinent cycle* (Figure 14.24).

At various times in the past, continental movements and collisions have produced supercontinents, which lasted for tens of millions of years before eventually rifting apart.

The geologic record shows that a supercontinent, *Pangaea*, had formed by the end of the Paleozoic (-250 Ma), only to disperse in the Mesozoic.

Similarly, a supercontinent formed at the end of the Precambrian (1.1 Ga, called *Rodinia*),

only to disperse at about 900 Ma to form a new supercontinent, Panotia,

which itself broke up about 600 Ma (i.e., at the beginning of the Paleozoic).

And there is growing evidence that supercontinents also formed even earlier in Earth history.

Thus, it seems that supercontinents have formed, broken up, formed, and broken up at roughly 200-500 m.y. intervals.

Modeling suggests that the supercontinent cycle may be related to long-term convection patterns in the mantle.

In these models, relative motion between plates at any given time-the "details" of plate kinematics-is determined by ridge-push and slab-pull forces.

But over long periods of time (about 200-500 m.y.), continents tend to accumulate over a zone of major mantle downwelling to form a supercontinent (Figure 14.18).

However, supercontinents don't last forever;

once a supercontinent forms, the thermal structure of the mantle beneath it changes.

This change happens because a supercontinent acts like a giant insulator that does not allow heat to escape from the mantle.

Over 80% of the Earth's internal heat escapes at mid-ocean ridges, where seawater circulating through the hot crust and upper mantle cools the lithosphere much like a coolant cools an automobile engine;

however, within the area of a supercontinent, there are no ridges, so heat cannot easily be lost.

As a consequence, the mantle beneath the supercontinent eventually heats up, and can no longer be a region of downwelling.

When this happens, a new downwelling zone develops elsewhere, and hot asthenosphere must begin to upwell beneath the supercontinent.

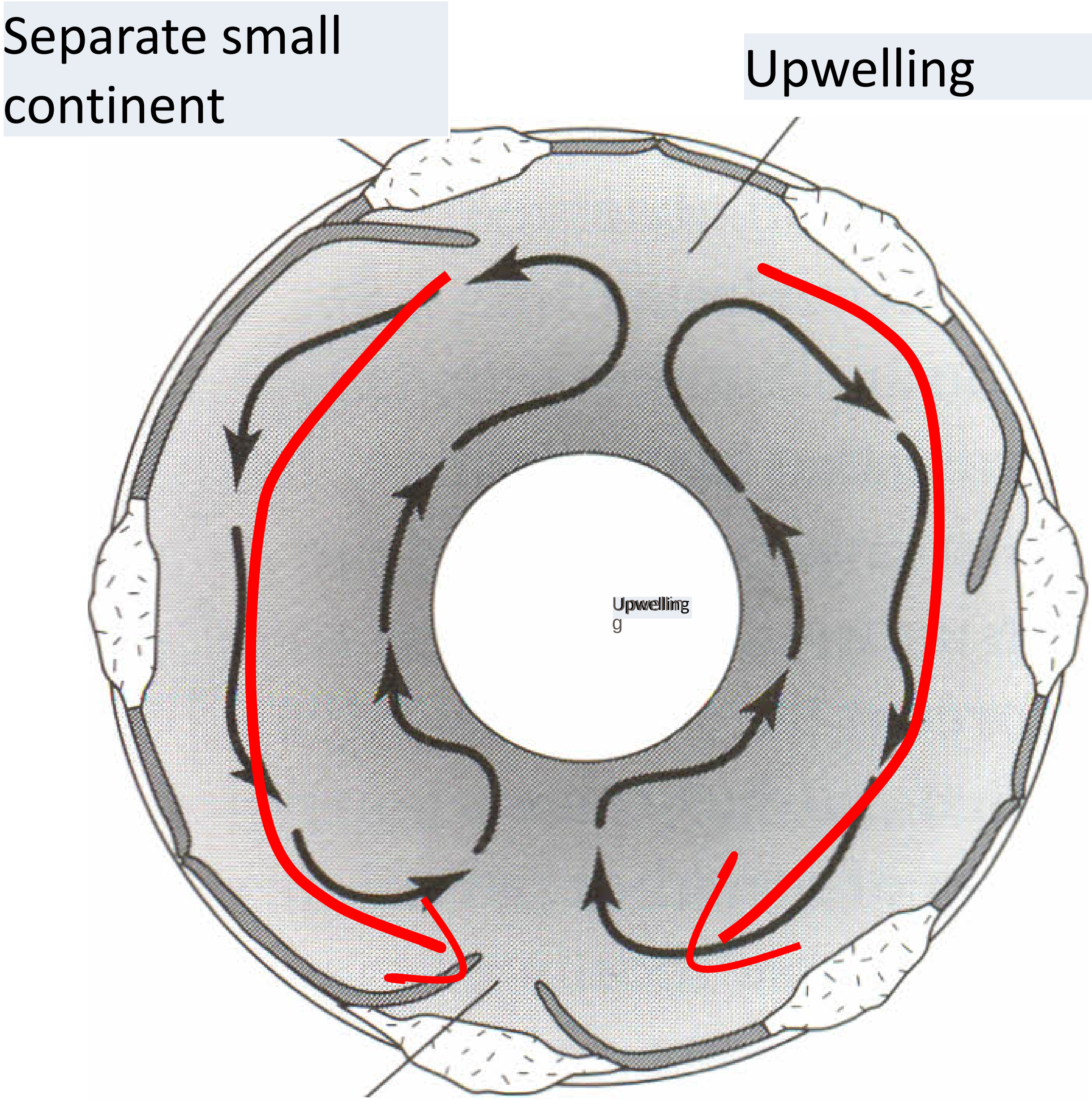
Upwelling causes the continental lithosphere of the supercontinent to heat up and weaken.

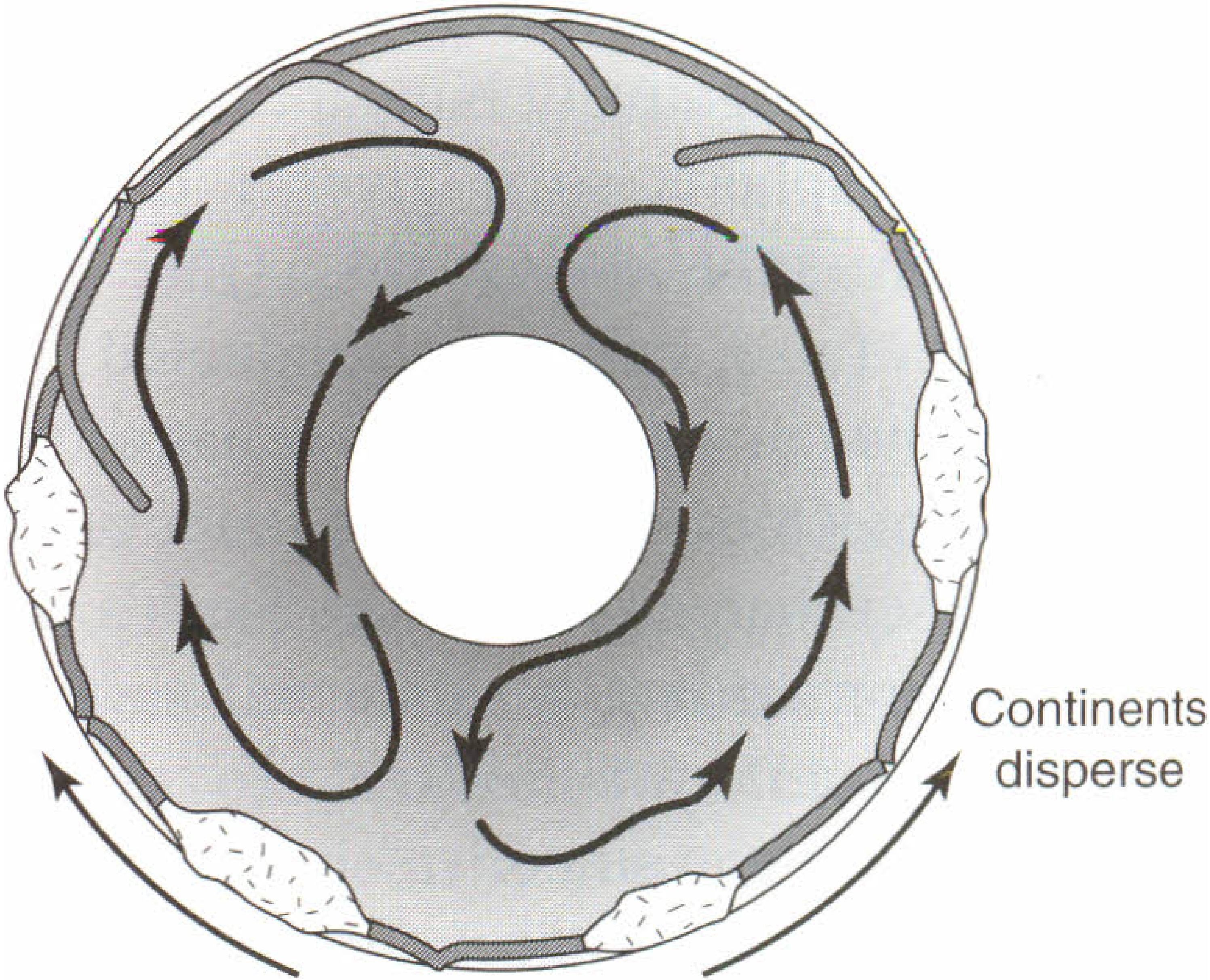
Ultimately, the supercontinent rifts apart into smaller continents separated by new oceans.

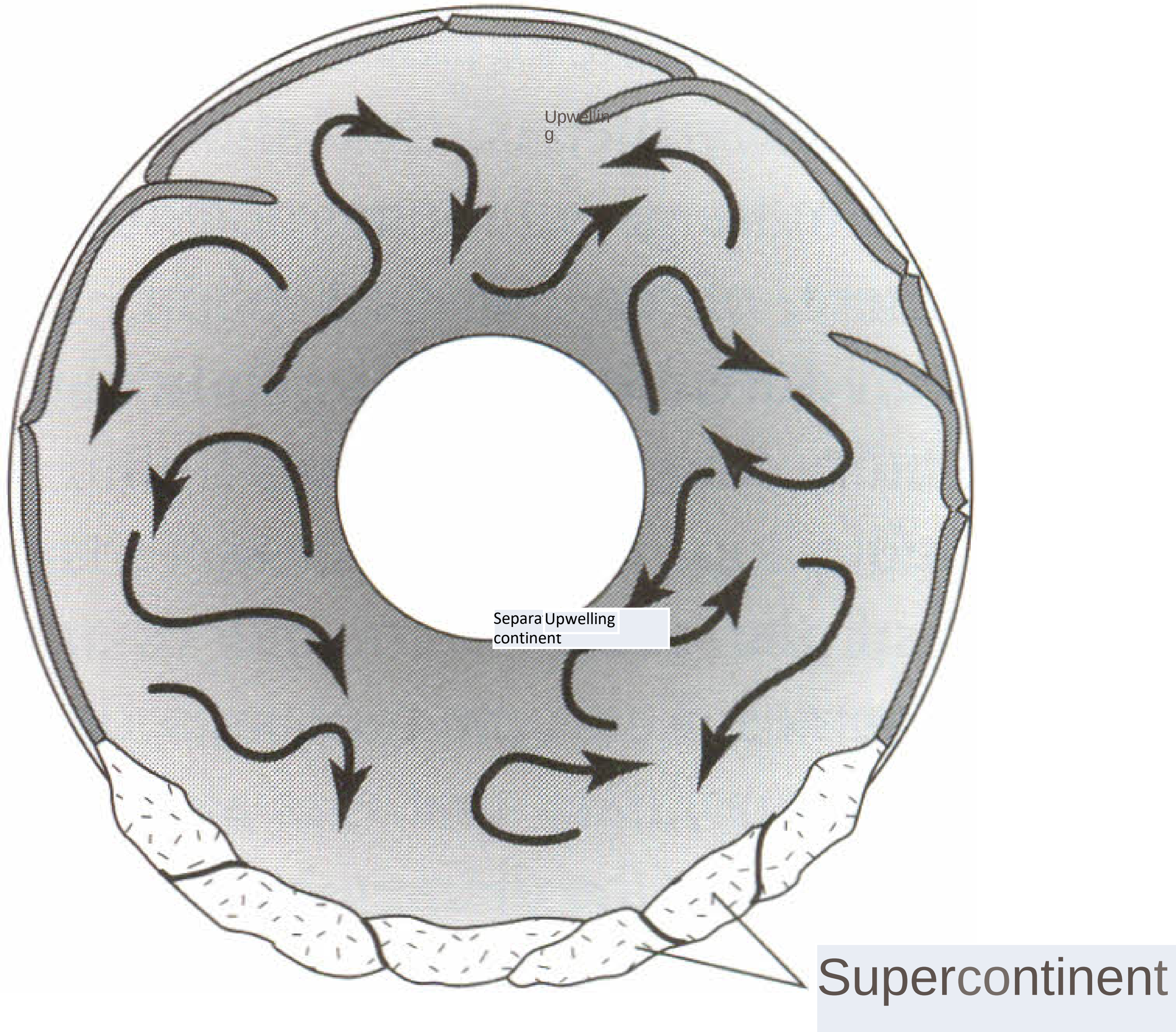
If the supercontinent-cycle model works, then we can say that Earth is currently in the dispersal stage of the cycle.

During the next 200 million years, the assembly stage will begin and the floors of the Atlantic and Pacific Oceans will be subducted.

After a series of collisions, the continents will once again coalesce to form a new supercontinent.


Separate small continent
Upwelling
Upwelling


Continents
disperse


Upwellin
g
Separa Upwelling
continent
Supercontinent

SUPERCONTINENTS

Supercontinents result when separate continental plates collide with each other in a general process known as <u>suturing</u>.

Pangea — the youngest of Earth's supercontinents — was preceded by an older supercontinent generally known as *Rodinia* (Russian for "motherland").

It had grown out an earlier cycle of continental suturing at about 1.3 billion years (Ga) and

entered a time of rifting, and fragmentation starting between ca. 800 and 550 Ma.

Those and other fragments collided to became *Pangea (around 250 Ma)*.

NEOPROTEROZOIC RIFTING

R
O
D
I
N
I
A

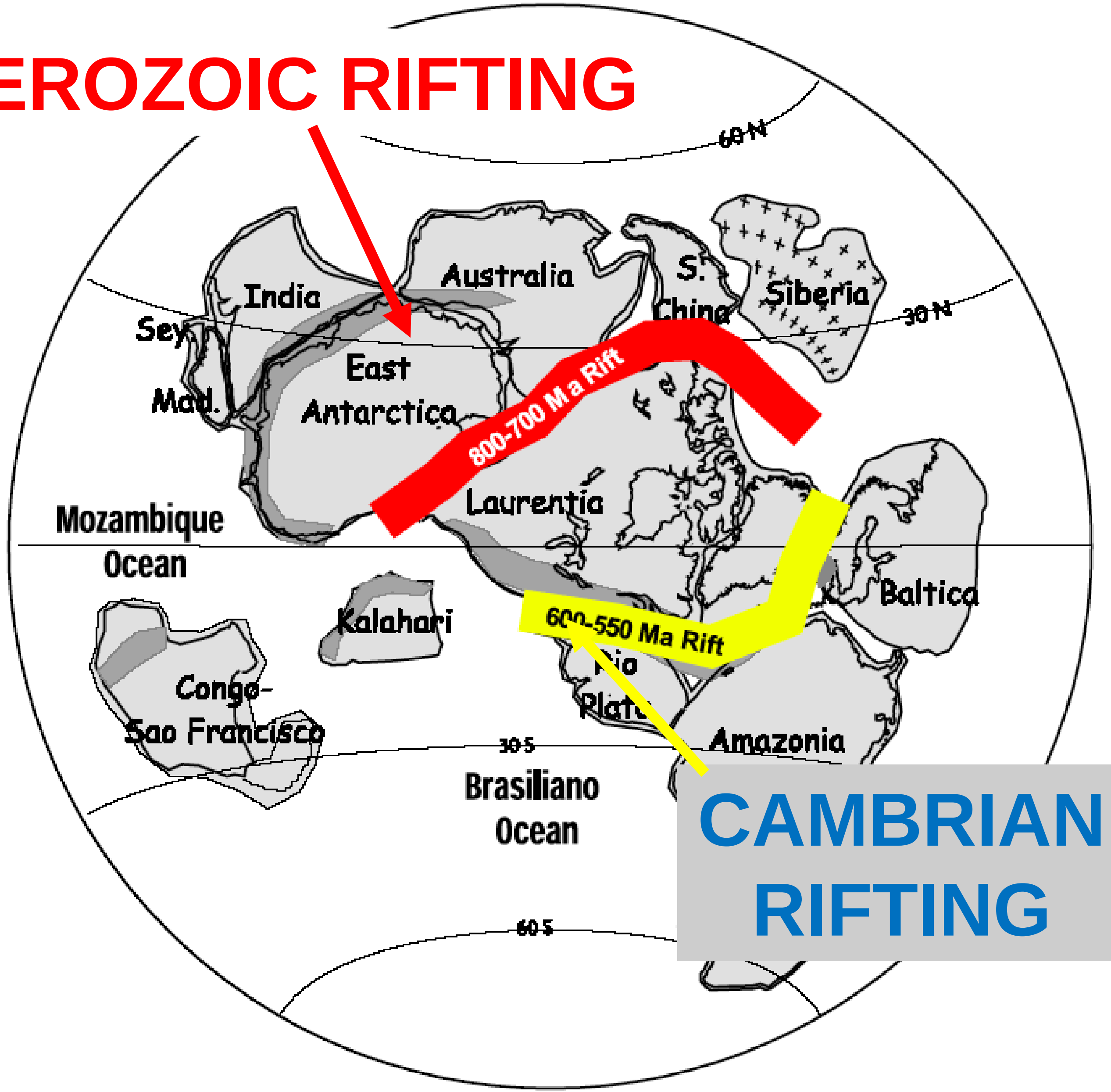
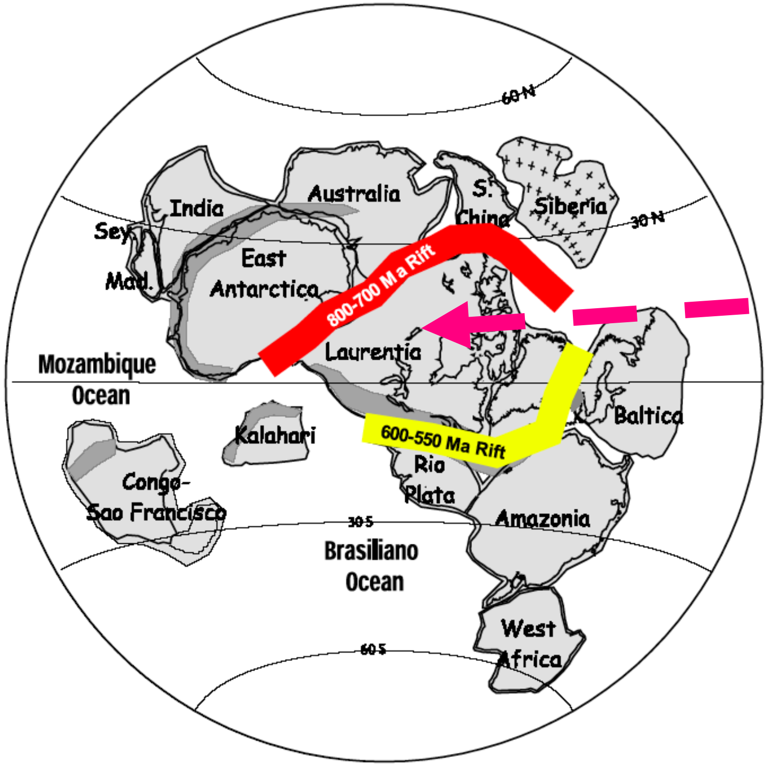


Fig. 1. The 'traditional' model of Rodinia adopted from Dalziel (1997) and Torsvik et al. (1996). The model posits two rifting events, the present-day western margin of Laurentia sometime between 800 and 700 Ma, and a second along the present-day eastern Laurentia between 600 and 550 Ma.

As Rodinia was being rifted apart at ca 750 Ma — along what is now the western margin of North America — some of its fragments were coming together 100 million years later in a collisional belt across what is now eastern Africa.

Therefore, Pangea was already starting to form while Rodinia was breaking up!



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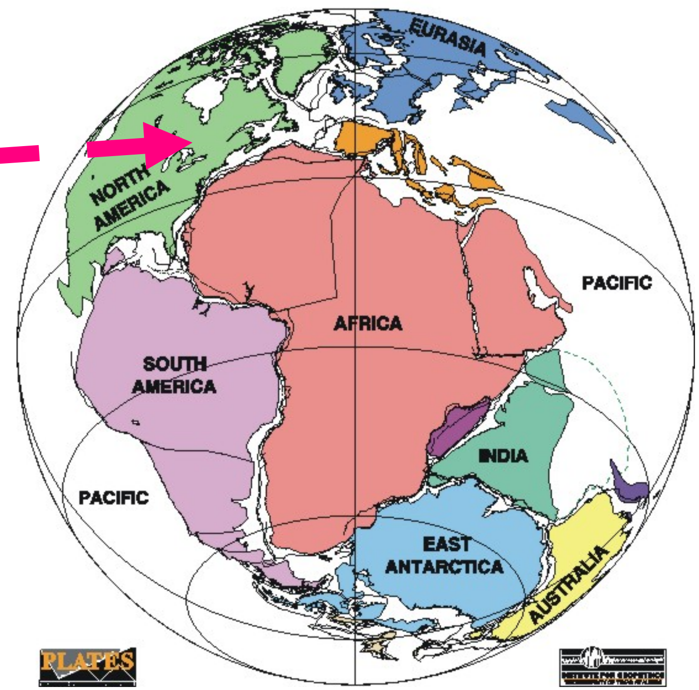
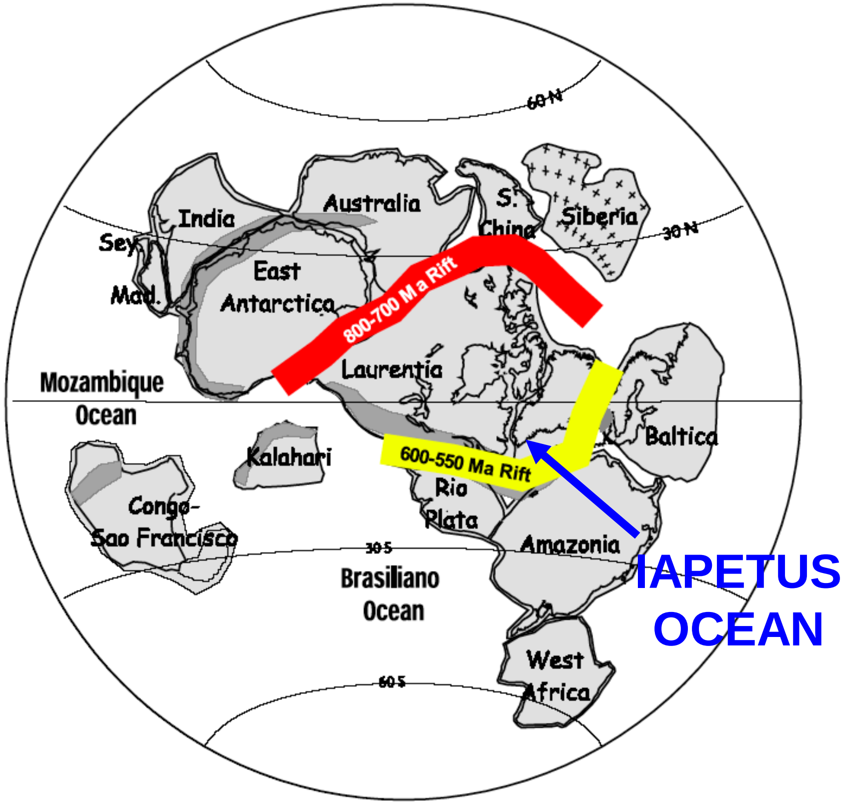
PANGEA



Is there a problem here? In the Rodinia map, rifting along the eastern side of Laurentia (now North America) is said to have occurred between 600 and 550 Ma, thus forming an ocean basin. Yet in the Pangea map of ca. 220 Ma there is no open ocean along the eastern edge of North America — only a continental orogenic belt. ?????



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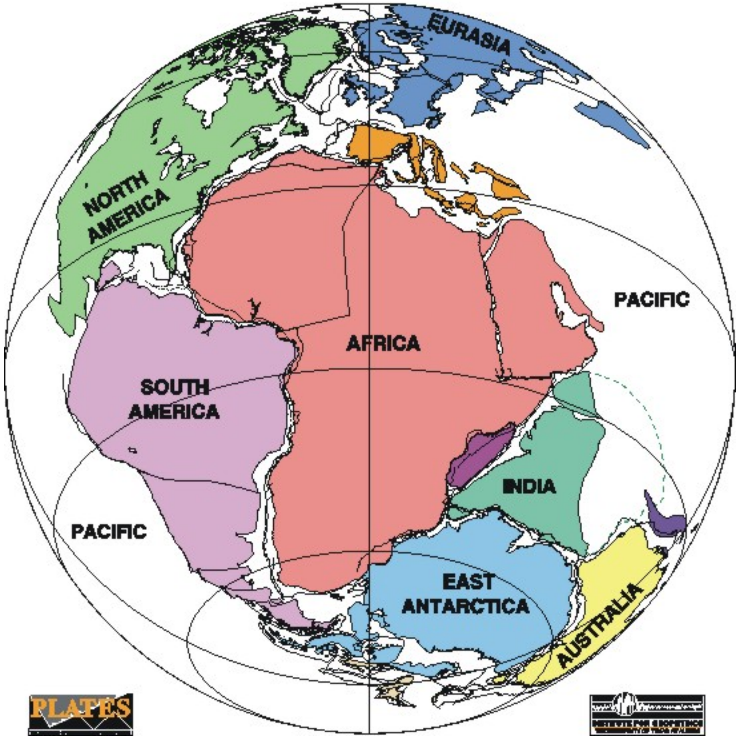
PANGEA



WAS AN EARLY OCEAN (IAPETUS) THAT OPENED BETWEEN 600 AND 500 MA, LATER CLOSED BY 220 MA? … AND THEN RE-OPENED AGAIN WITH THE BREAKUP OF PANGEA? THAT WAS A QUESTION ASKED BY J. TUZO WILSON IN 1966

The Wilson Cycle

THE WILSON CYCLE

The Making and Unmaking
of Supercontinents ....

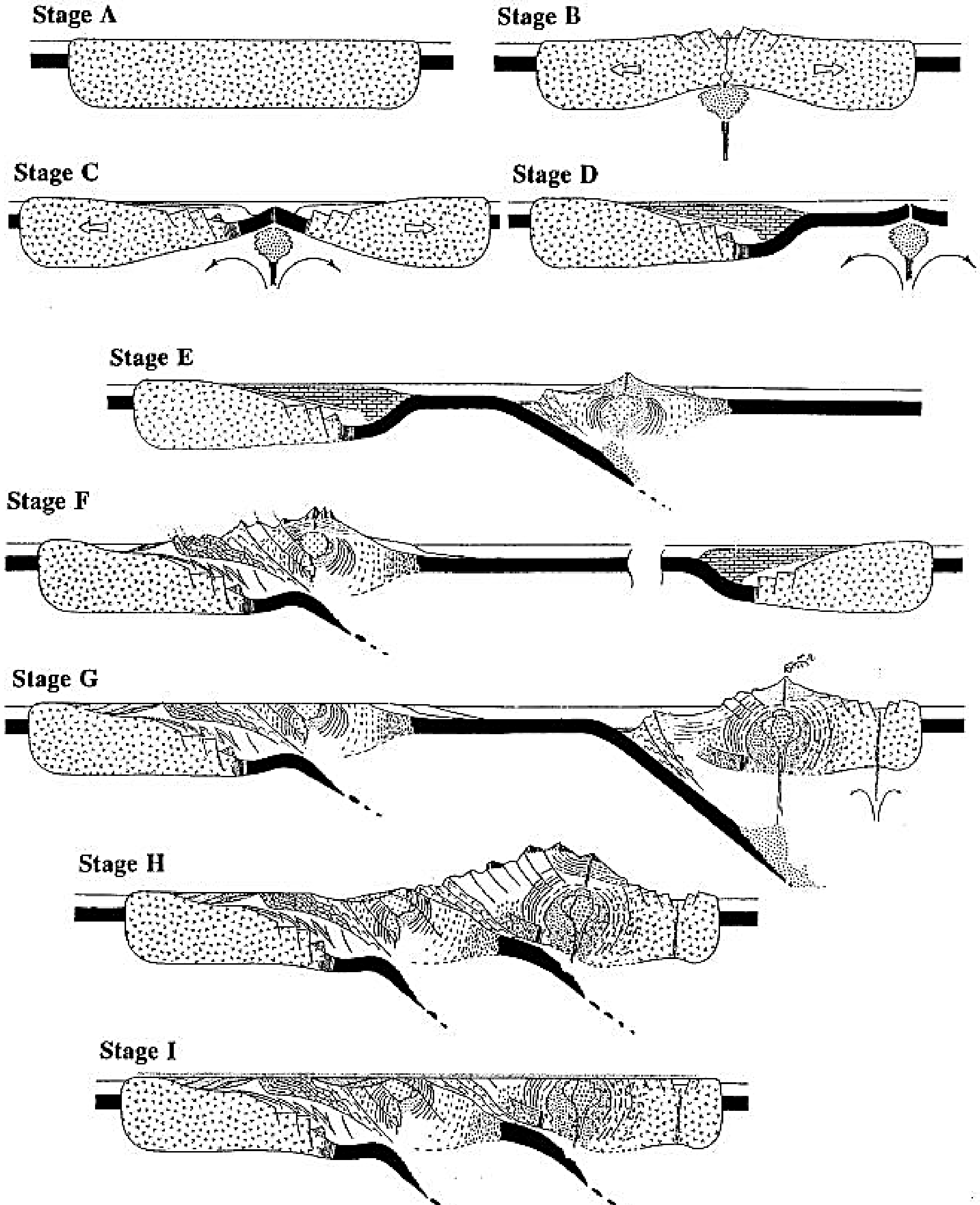
THE WILSON CYCLE

The Wilson Cycle
and Supercontinents

The geography of the Earth and its varied environments has been changing slowly but continuously for hundreds of millions of years.

The driving force for that slow change is the motion of the Earth's lithospheric plates.

A Wilson Cycle



While it seems remarkable that the continents are actually in constant motion,

what is more remarkable is the strong evidence suggesting that all continents were once joined in a single land mass that subsequently broke apart.

Not only that, but over the billions of years of the Earth's geologic history,

the union of the continents and their breakup is actually a repeating process the *Wilson* cycle that has occurred half a dozen times or more.

The Wilson cycle bears the name of the distinguished Canadian geophysicist Prof. J. Tuzo Wilson of the University of Toronto.

He made important new discoveries and interpretations that helped lead to a full-blown theory of plate tectonics.

By the time he formulated his theory, all of the parts were known:

- **continental rupture to start the opening of a new ocean basin,**
- **plate subduction to generate island arcs, and**
- **collisions to weld continents together.**

Using all of these separate lithospheric activities, Wilson forged a logical time chain of plate tectonic events, and

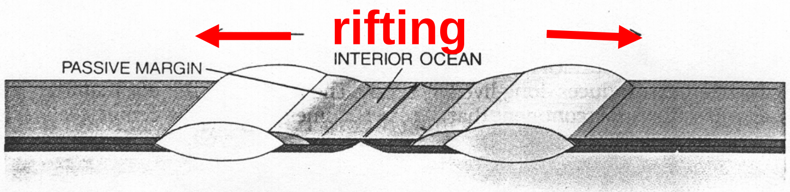
it quickly gained wide acceptance as the *Wilson cycle*.

The Wilson cycle can best be appreciated by use of a cartoonlike presentation of the essential elements of plate tectonics.

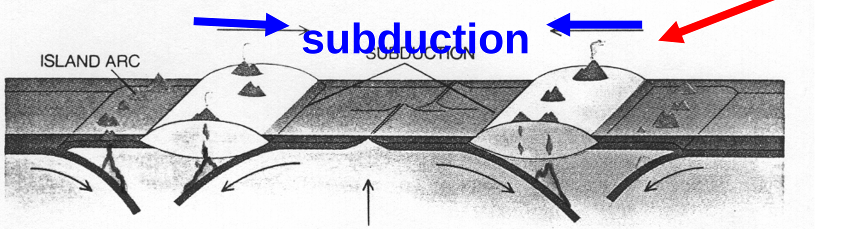
These elements are shown arranged throughout six stages and are listed with references to text diagrams and examples found on the planet today.

This ideal cycle requires some 300 to 500 my to complete.

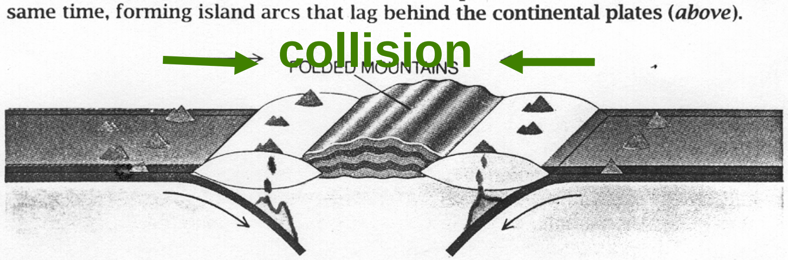
ow the Supercontinent Cycle Works



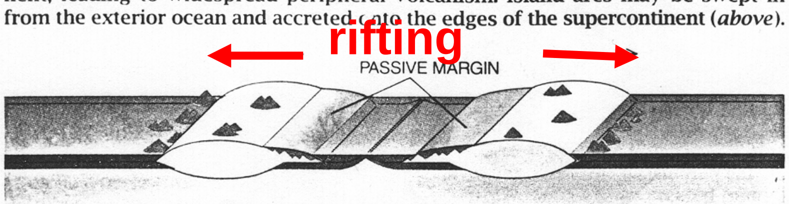
BREAKUP OF A SUPERCONTINENT results in the birth of interior oceans like the present Atlantic (*left*). Inward-facing margins of the separating continents are tectonically stable; undisturbed sediments collect along the margins, recording this period of relative placidity (*above*). Passive margin sediments continue to collect until the continents reach their maximum dispersal.



MAXIMUM DISPERSAL of the continents occurs when the interior oceans are about 200 million years old. Then the oldest parts of the interior oceans begin to sink, or subduct, into the earth (*left*). Subduction generates magma that fuels volcanoes in the overlying continent. Subduction can take place in the exterior ocean at the same time, forming island arcs that lag behind the continental plates (*above*).



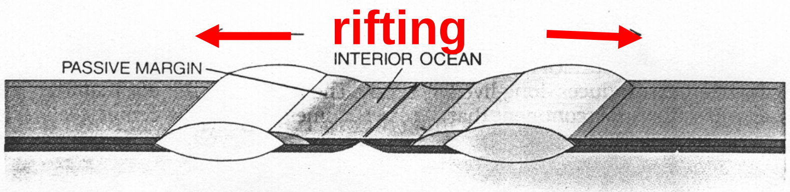
CONTINENTAL COLLISIONS happen after the interior oceans are consumed. Collisions create interior mountain belts and broad areas of intense deformation, uplift and erosion (*left*). Subduction zones occur around the margin of the supercontinent, leading to widespread peripheral volcanism. Island arcs may be swept in from the exterior ocean and accreted onto the edges of the supercontinent (*above*).



NEXT SUPERCONTINENT BREAKUP results from thermal and rotational forces. Exterior subduction continues where the continental margin is roughly perpendicular to the direction of its motion (*left figure, top*). Transform, or sideways, faults appear where the motion of the plate is nearly parallel to the orientation of the margin (*left figure, bottom*). Passive margin sediments resume collecting (*above*).

The Wilson Cycle (after J. B. Murphy and R. D. Nance, <u>Scientific American</u>, April 1992)

ow the Supercontinent Cycle Works



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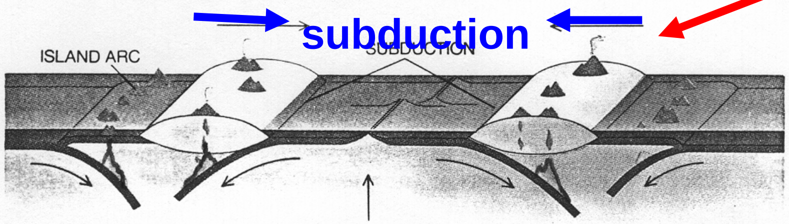

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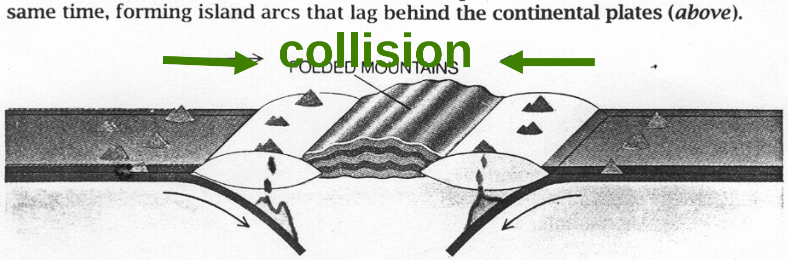

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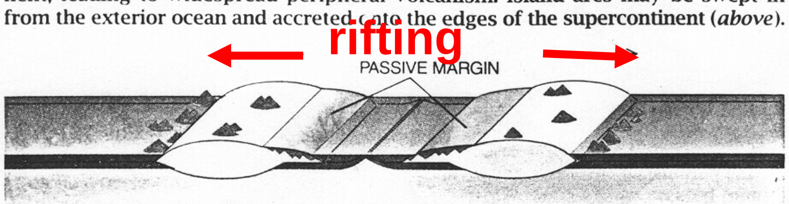

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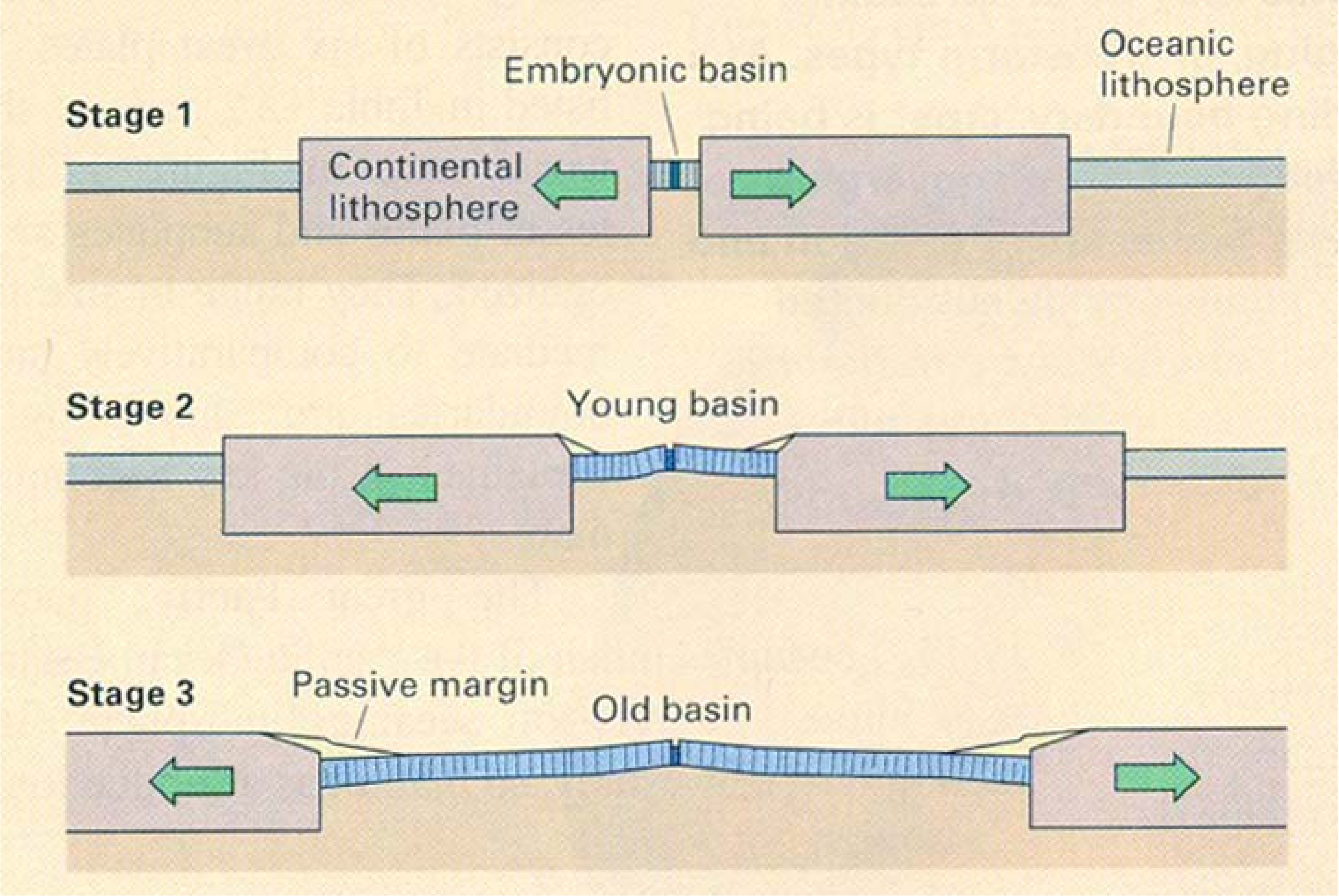
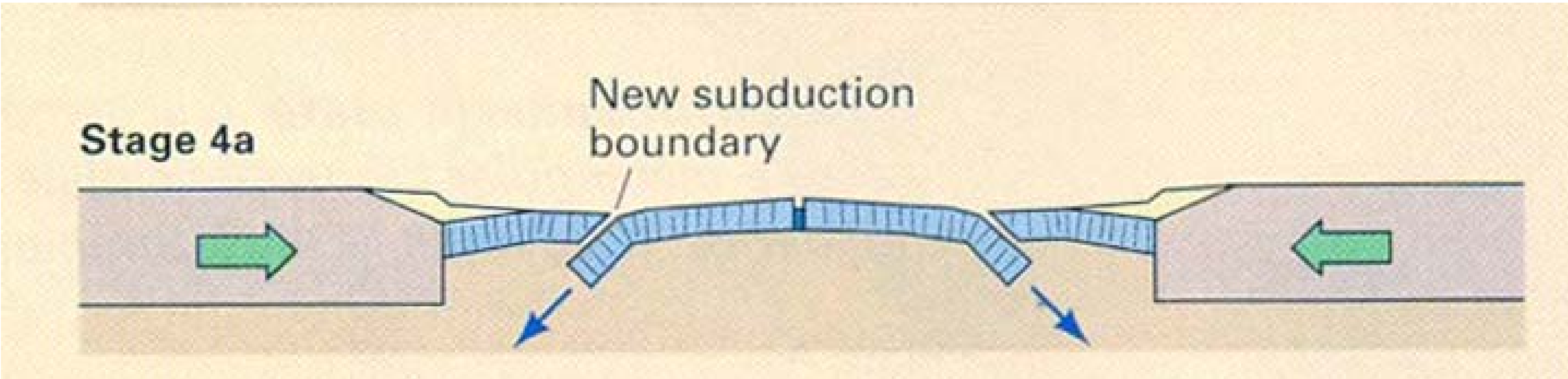
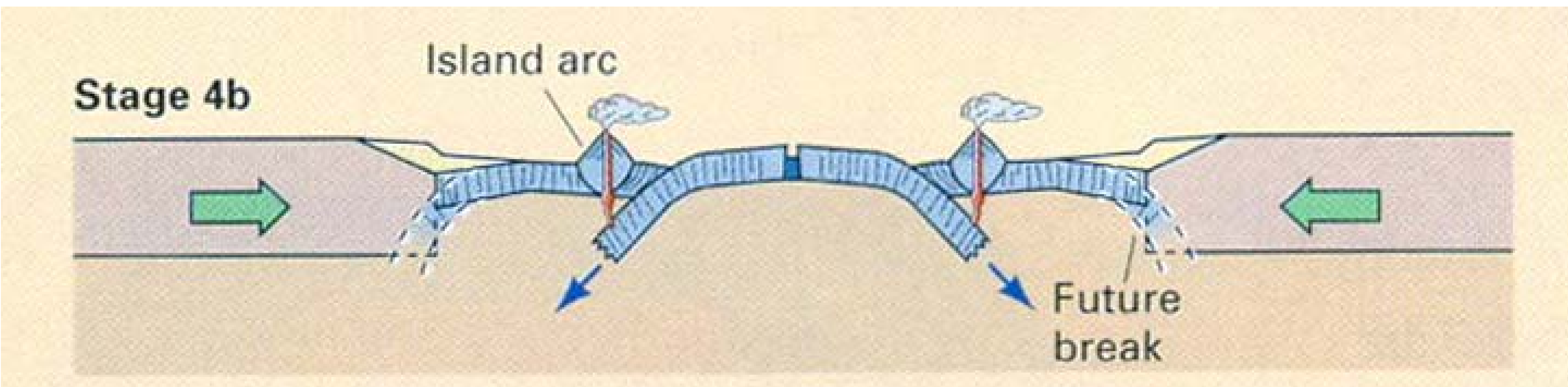
The Wilson Cycle (after J. B. Murphy and R. D. Nance, Scientific American, April 1992)

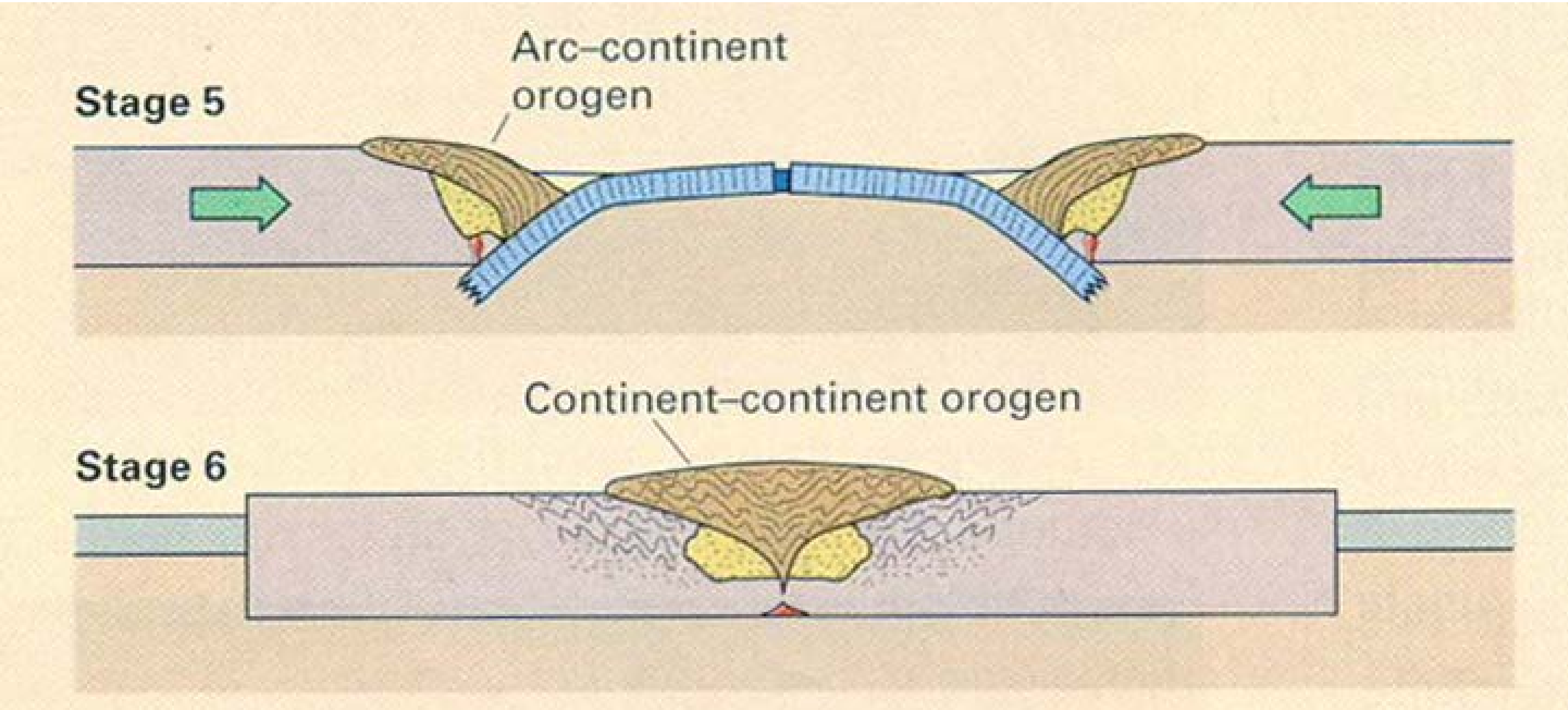
These diagrams can be much too simple. For example, in the first "rifting" diagram the "interior ocean" doesn't have to close by "subduction". The spreading ocean can continue to spread so that the rifted continental fragments may come together in a "collision" on the other side of planet Earth!



Stage 1
Embryonic basin
Oceanic
lithosphere
Continental
lithosphere
Stage 2
Young basin
Stage 3
Passive margin
Old basin


Stage 4a
New subduction boundary


Stage 4b
Island arc
Future break


Stage 5
Arc–continent
orogen
Stage 6
Continent–continent orogen

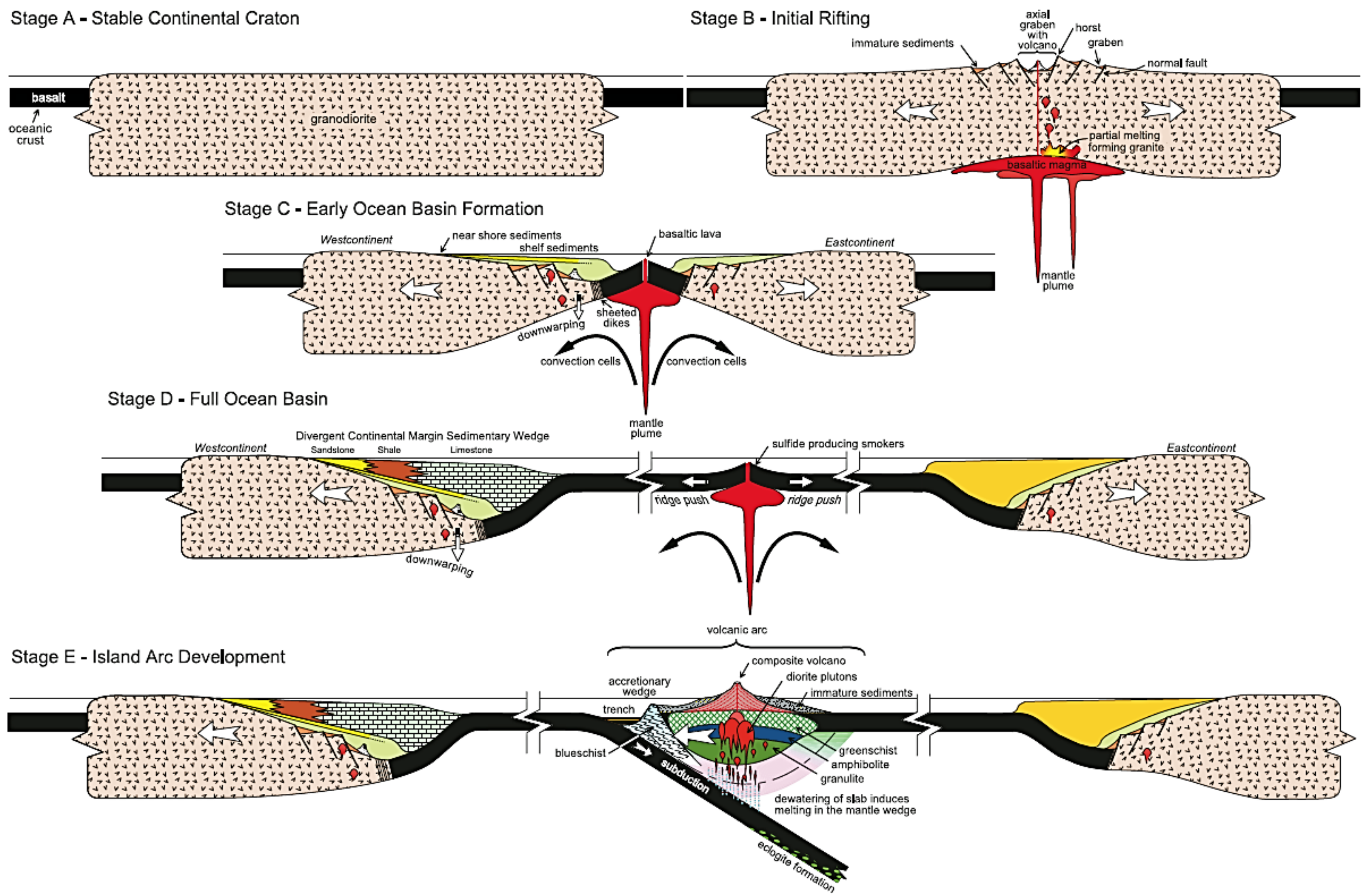
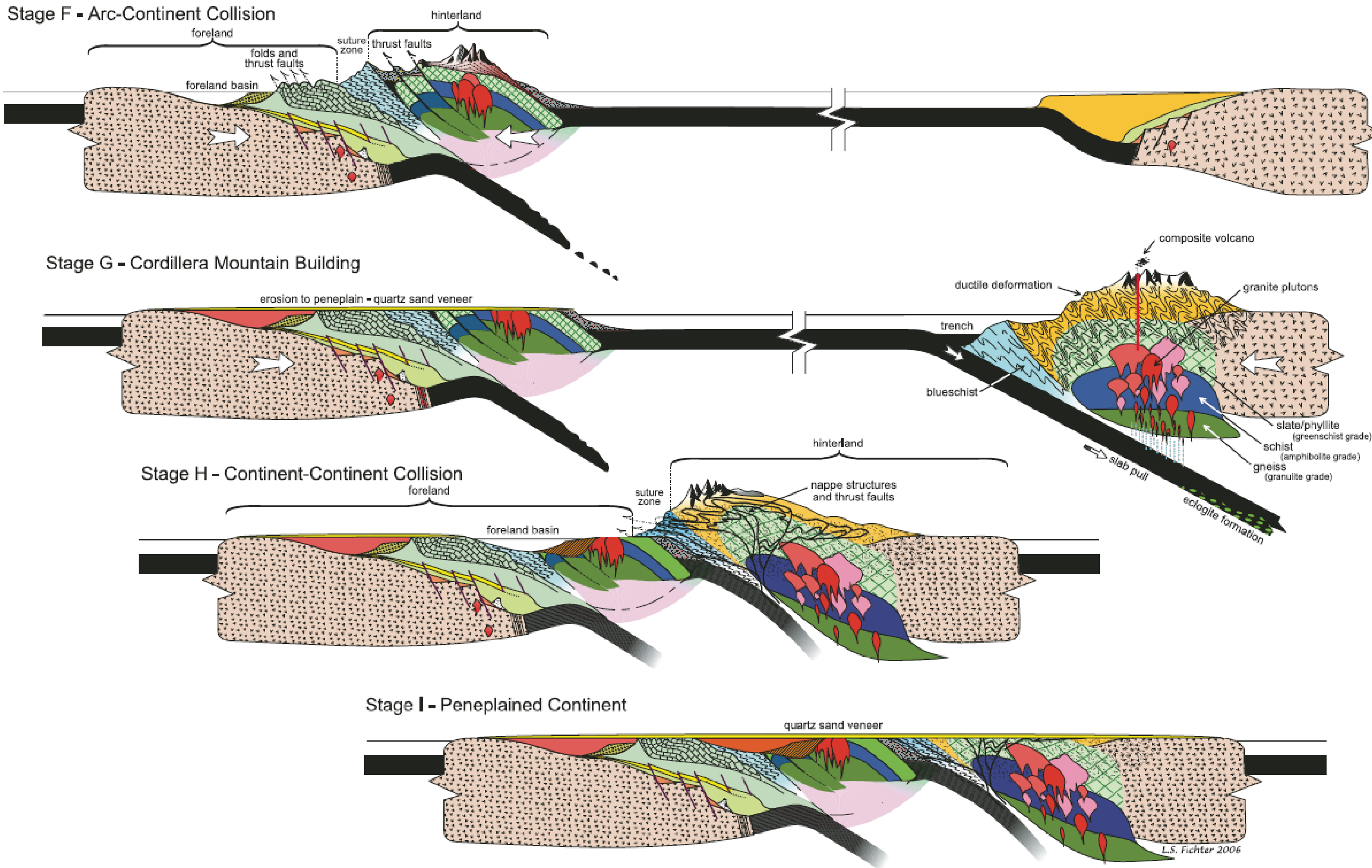


Figure 5 (*on this and following page*) A nine-stage, heuristic Wilson Cycle, encompassing the life cycle of an ocean basin: Stage A—Stable Continental Craton starting point; Stage B—Initial Rifting phase of the continent from mantle plume(s); Stage C—Early Ocean Basin Formation, the rift to drift phase; Stage D—Full Ocean Basin, with divergent continental margins (DCM) on both continental fragments; Stage E—Island Arc Development, following initiation of a subduction zone, polarity could be either direction; Stage F—Arc-Continent Collision, first collisional event with shrinking of ocean basin; Stage G—Cordillera Mountain Building, continental arc develops above subduction zone under Eastcontinent; Stage H—Continent-Continent Collision, full closure of ocean basin; Stage I—Peneplained Continent, erosion of mountains to stable craton; after Fichter (1999a) and Fichter and Pyle (2007). Cross sections are reprinted with permission from Science Kit, LLC ©2007.

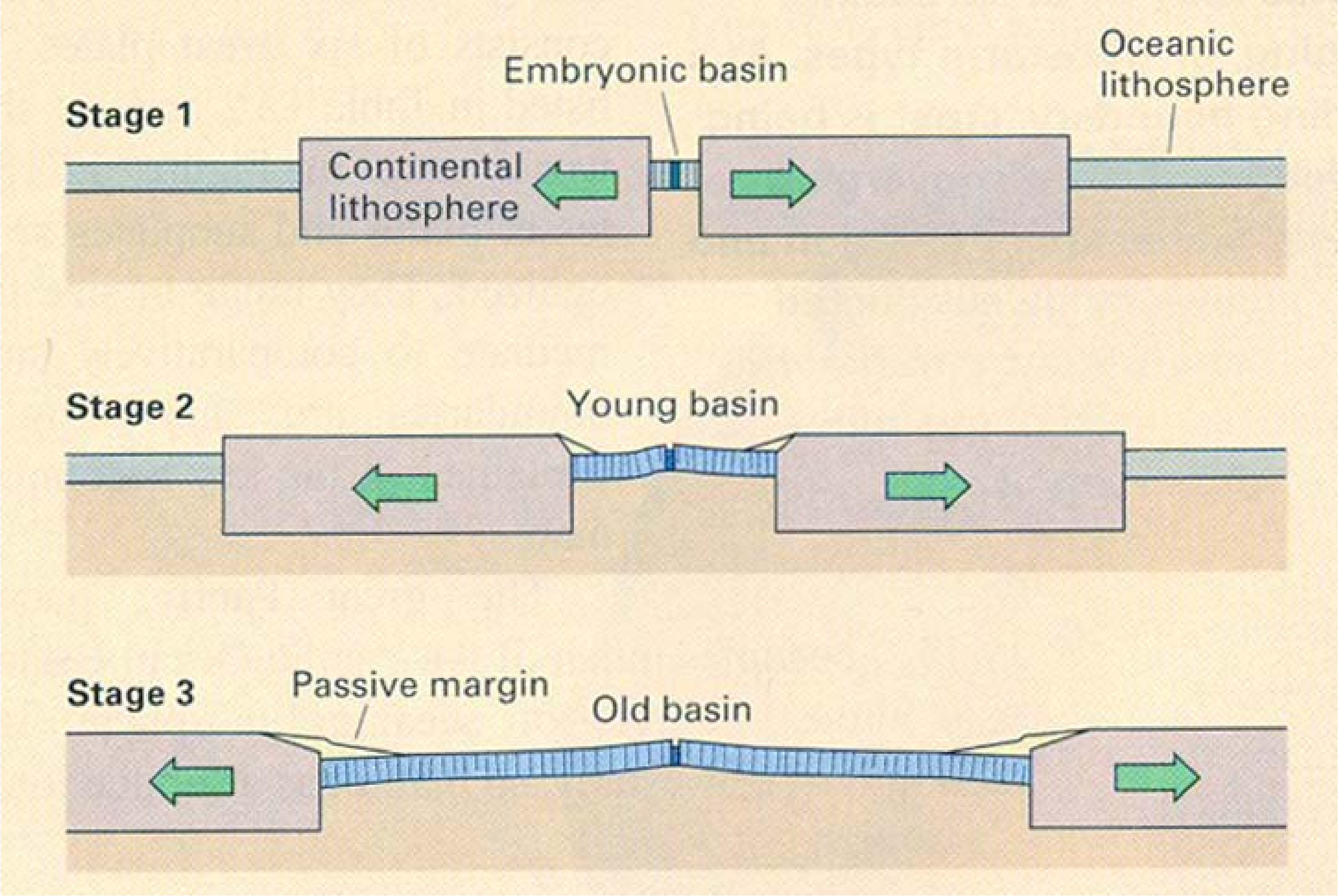


Stage F - Arc-Continent Collision
foreland
hinterland
suture zone
thrust faults
folds and thrust faults
foreland basin
Stage G - Cordillera Mountain Building
erosion to peneplain - quartz sand veneer
composite volcano
ductile deformation
granite plutons
trench
blueschist
slate/phyllite
(greenschist grade)
schist
(amphibolite grade)
gneiss
(granulite grade)
slab pull
eclogite formation
Stage H - Continent-Continent Collision
hinterland
foreland
suture zone
nappe structures and thrust faults
foreland basin
Stage I - Peneplained Continent
quartz sand veneer
L.S. Fichter 2006

***Stage* 1. Embryonic ocean basin. The Red Sea separating the Arabian Peninsula from Africa is an active example.**

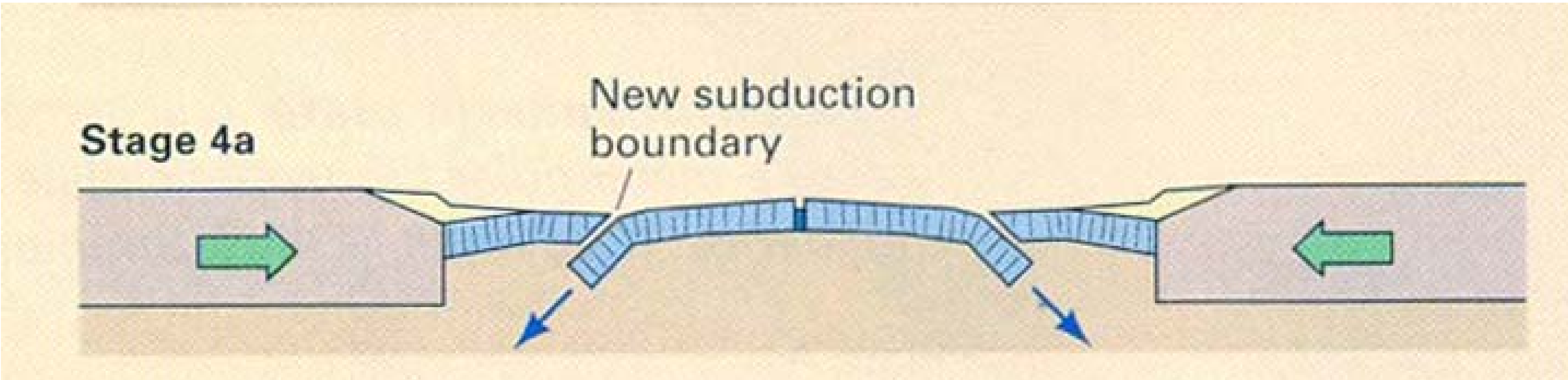
***Stage* 2. Young ocean basin. The Labrador Basin, a branch of the North Atlantic lying between Labrador and Greenland, is a fair example of this stage.**

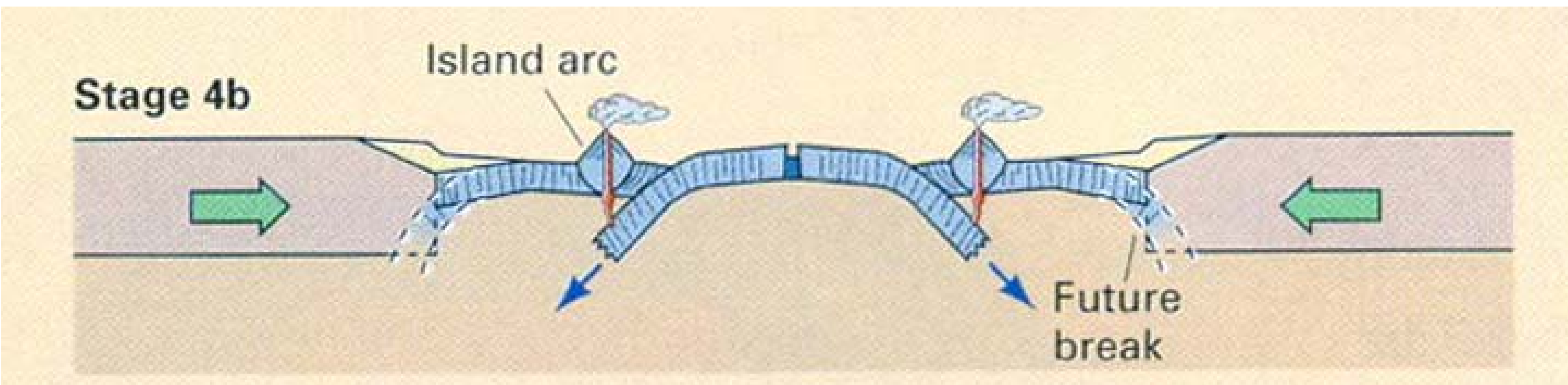
***Stage* 3. Old ocean basin. (Figure *12.19c.)* Includes all of the vast expanse of the North and South Atlantic oceans and the Antarctic Ocean. Passive margin sedimentary wedges have become wide and thick.**


Stage 1
Embryonic basin
Oceanic
lithosphere
Continental
lithosphere
Stage 2
Young basin
Stage 3
Passive margin
Old basin

Stage 4a. **The ocean basin begins to close as continental plates collide with it. New subduction boundaries begin to form.**

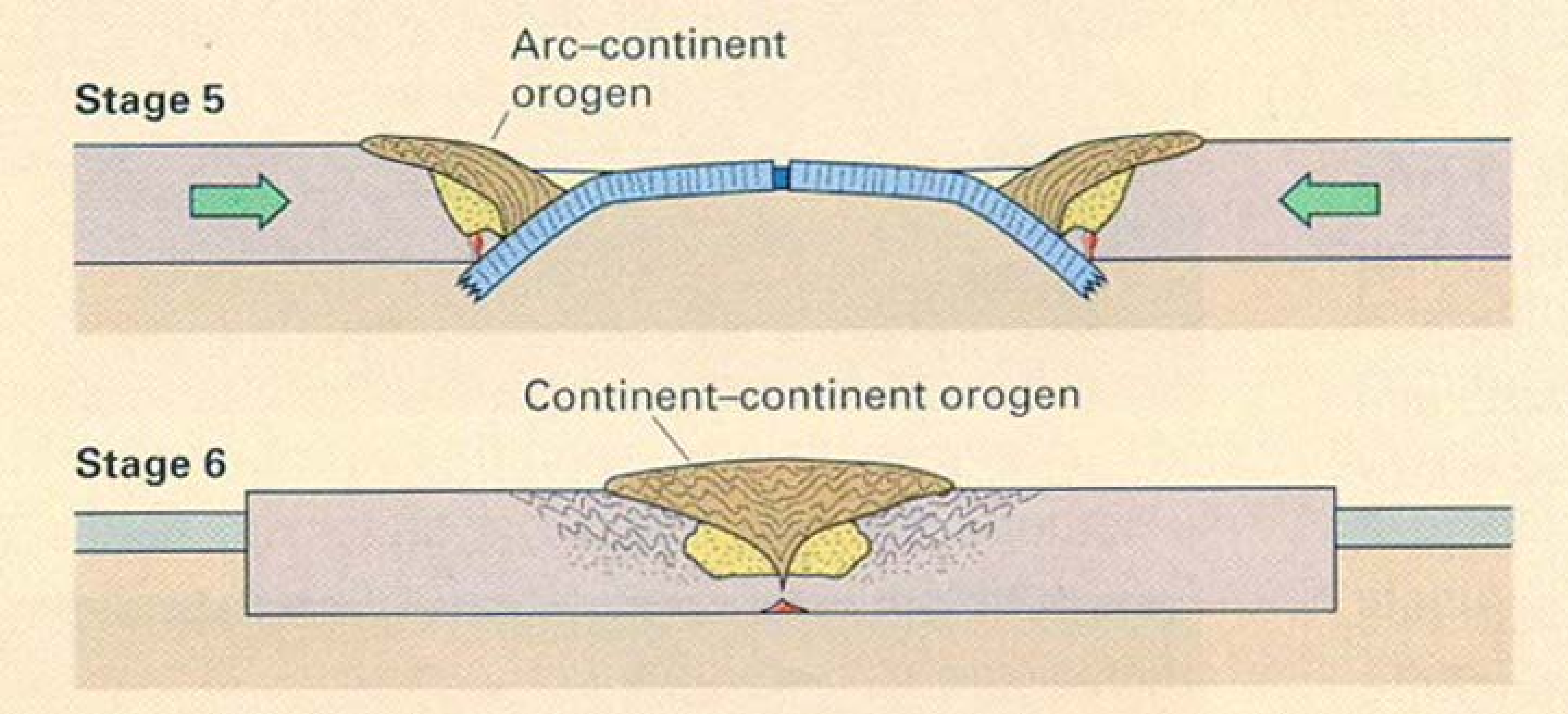
Stage 4b. **Island arcs have risen and grown into great volcanic island chains. These are found surrounding the Pacific plate, with the Aleutian arc as a fine example.**


Stage 4a
New subduction boundary


Stage 4b
Island arc
Future break

***Stage* 5.** **Closing continues.**
Formation of new subduction margins close to the continents is followed by arc-continent collisions. The Japanese Islands represent this stage.

***Stage* 6.** **The ocean basin has finally closed with a collision orogen forming a continental suture. The Himalayan orogen is a fine recent example, with activity continuing today.**


Stage 5
Arc–continent
orogen
Stage 6
Continent–continent orogen

Note that the continent of the final stage is wider than the continent of the first stage because of the additional continental lithosphere formed during the intervening collisions.

This is how continents can grow over geologic time.

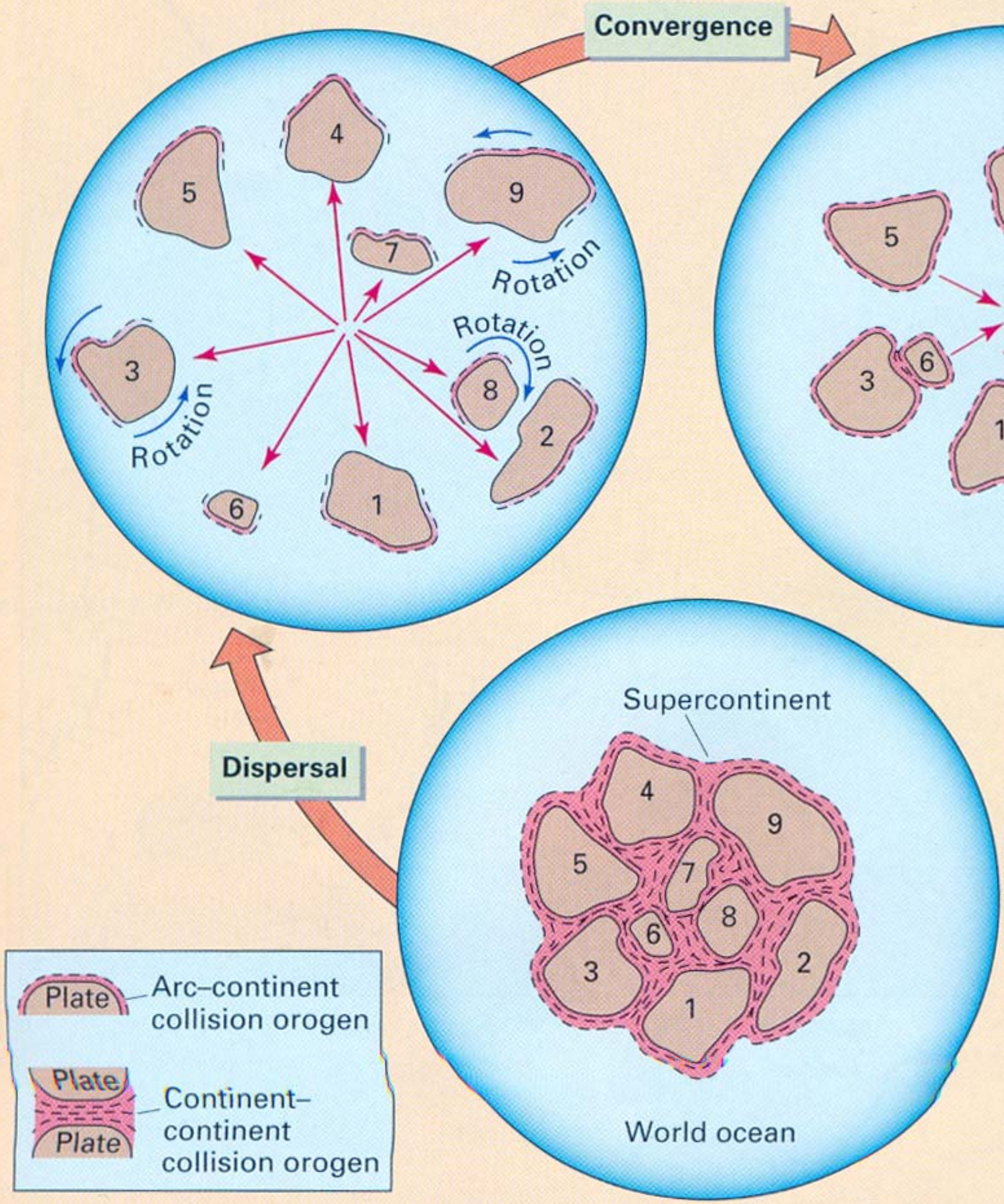
Our stage diagrams show a single continent splitting into two continents, then rejoining to form one.

Suppose that over the entire globe several continents are splitting apart and reclosing at about the same time.

Expanding on this idea, imagine that these fragments become detached from a single world continent that can be called a *supercontinent*.

Several powerful lines of evidence show that a supercontinent actually came into existence, starting about 200 million years ago. Called *Pangea*.

Good evidence has now been found that an earlier supercontinent, dubbed *Rodinia*, was fully formed about 700 million years ago



Supercontinent cycle *Schematic diagram of the supercontinent cycle in three phases. A pattern of wiggly dashes shows collision orogens that accumulate around and between the original continents. (From Plate Tectonics, copyright © 1998 by Arthur N. Strahler. Used by permission.)*

It consisted of early representatives of the same continents that later made up Pangea.

Rodinia **broke apart, and its fragments were carried away in different directions.**

Then they reversed their motions and headed back toward a common center, where many continent-continent collisions bonded them together by sutures to comprise *Pangea*.

Some interesting evidence has also pointed to the former existence of a supercontinent even older than Rodinia.

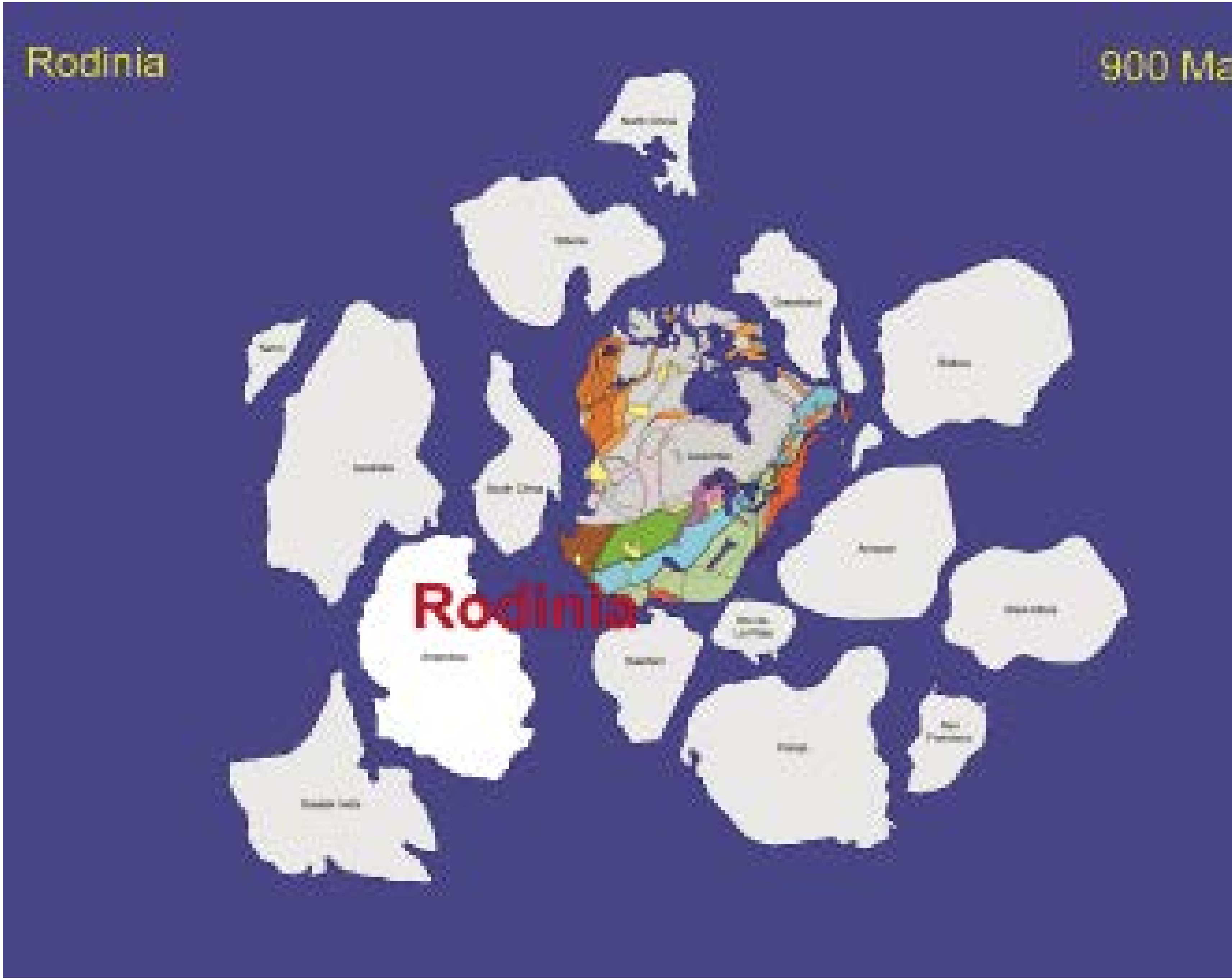
The illustration above presents the supercontinent cycle as a loop with three stages,

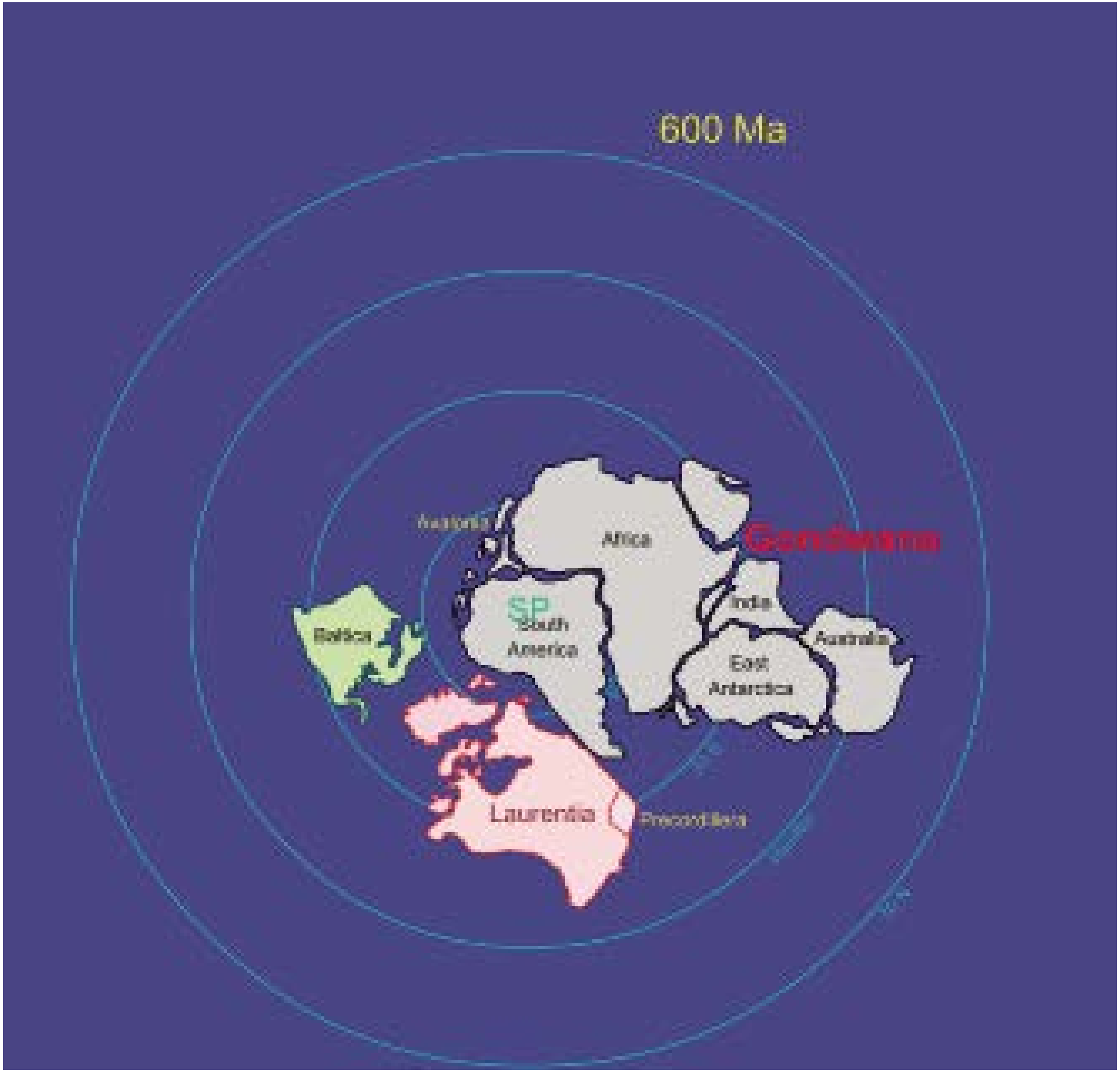
1. **Analogous to Stages 1-3 of the Wilson cycle is the dispersal phase,**
2. **followed by a convergence phase that corresponds to Wilson stages 4 through 6.**

The cycle ends in a complete new supercontinent. Many new collision orogens are formed between the original continental fragments.

Given, say, 3000 million years ago (Middle Archean time) as the first occurrence of a full-blown supercontinent cycle, there could have been some 6 to 10 such cycles.

The hypothesis of a time cycle of supercontinents, repeating the Wilson cycle over and over again, now holds its place as the basic theme of the geologic evolution of our planet.


Rodinia
900 Ma
Rodinia


600 Ma
Africa
Gondwana
SP
South
America
India
Australia
East
Antarctica
Baltica
Laurentia

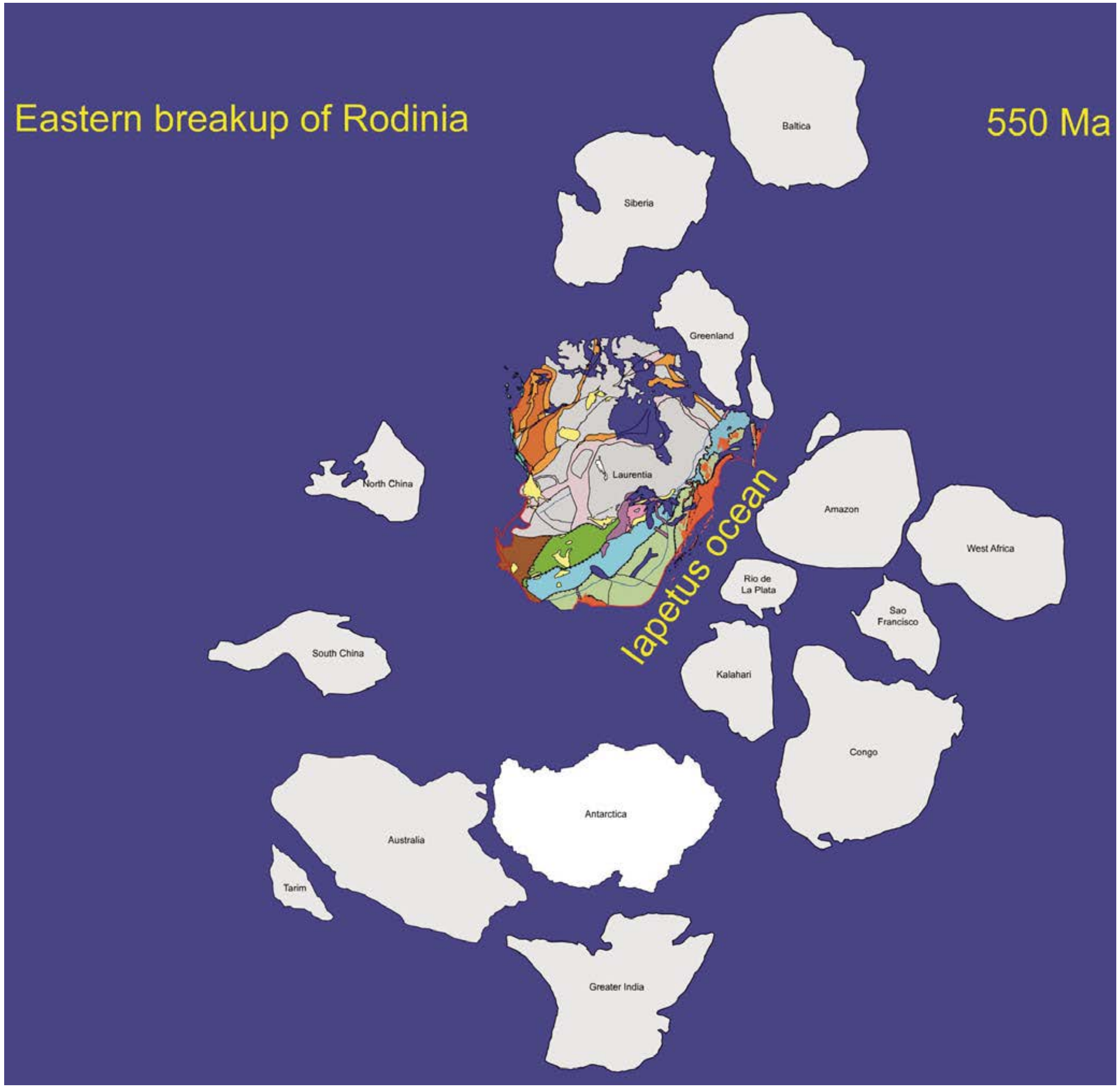


Figure 3. The Rio de La Plata and Amazon cratons rifting away from Laurentia (ancestral North America).

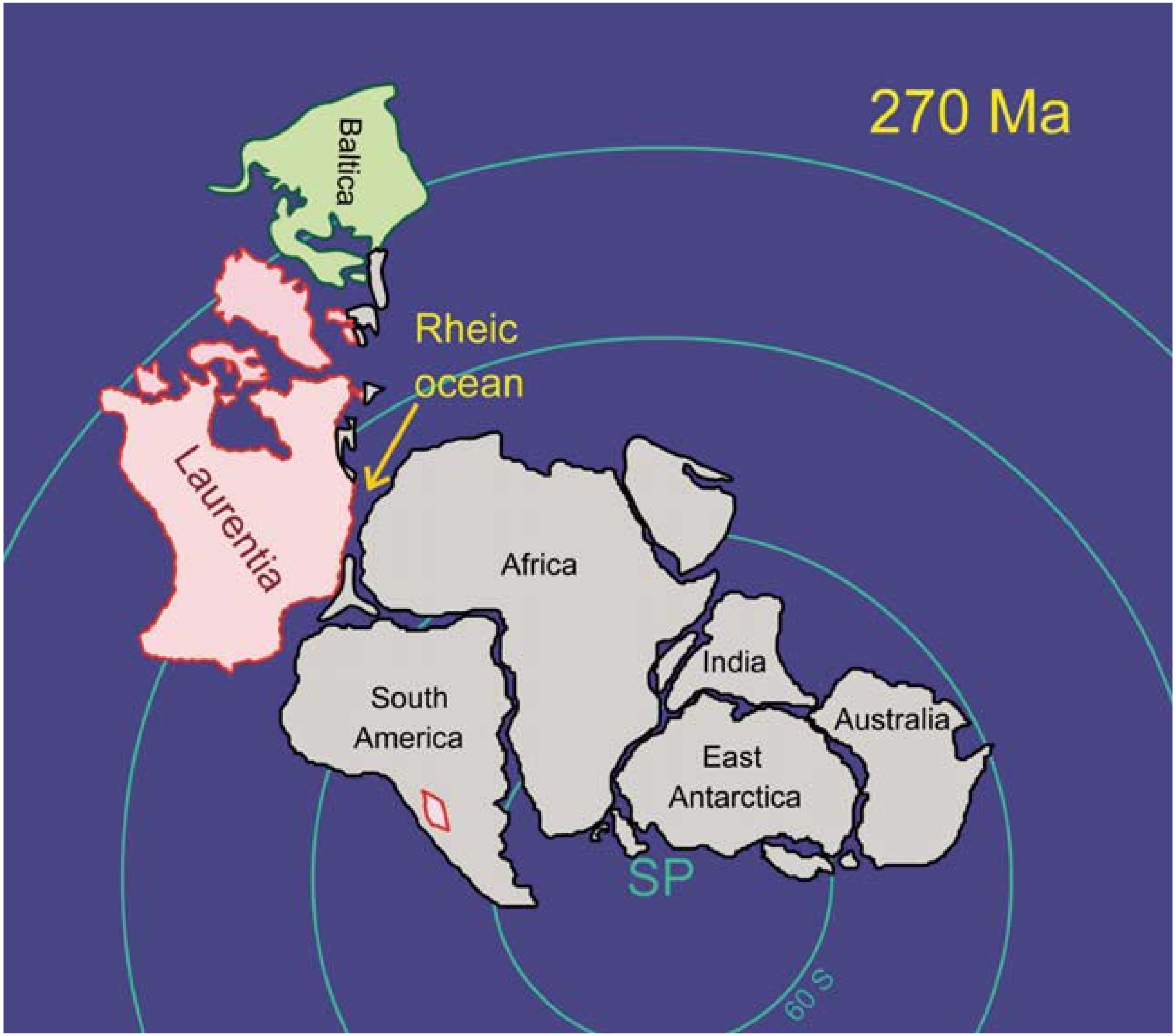


Figure 4. The closing of the Iapetus ocean culminates with the collision of Laurentia and the African part of Gondwana.

Did the Atlantic Ocean Close and Reopen?

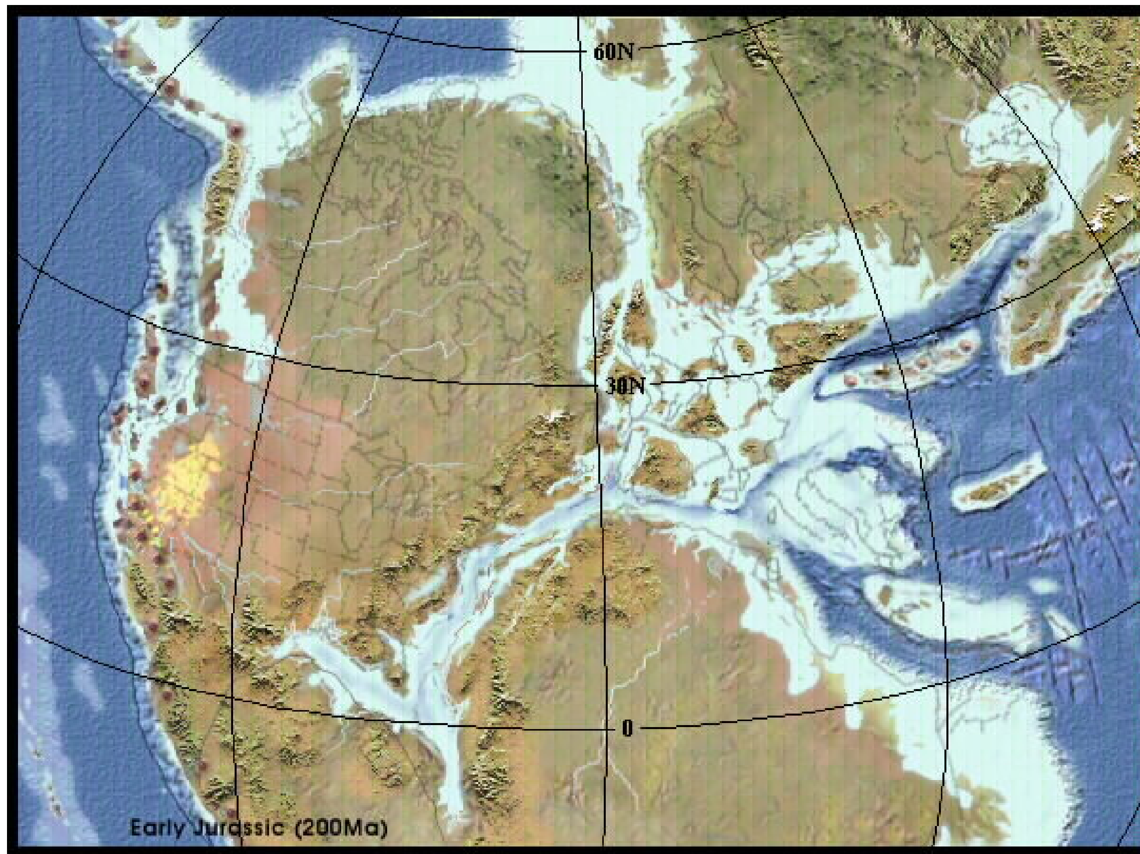
Tectonic inheritance at a continental margin

William A. Thomas, *Department of Geological Sciences, University of Kentucky, Lexington, Kentucky 40506-0053, USA, geowat@uky.edu*

INTRODUCTION

Forty years ago, the eastern margin of North America inspired Tuzo Wilson (1966) to ask, "Did the Atlantic close and then re-open?" The Wilson cycle of closing and opening of ocean basins incorporates the cyclic assembly and breakup of supercontinents. Alternate processes of extension and compression of continental margins suggest an important potential for tectonic inheritance and overprinting.

Now, we recognize a succession of two complete Wilson cycles in eastern North America: closing of an ocean and assembly of the Rodinia supercontinent, breakup of Rodinia and opening of the Iapetus Ocean, closing of Iapetus and assembly of the Pangaea supercontinent, and breakup of Pangaea and opening of the Atlantic Ocean (Fig. 1).



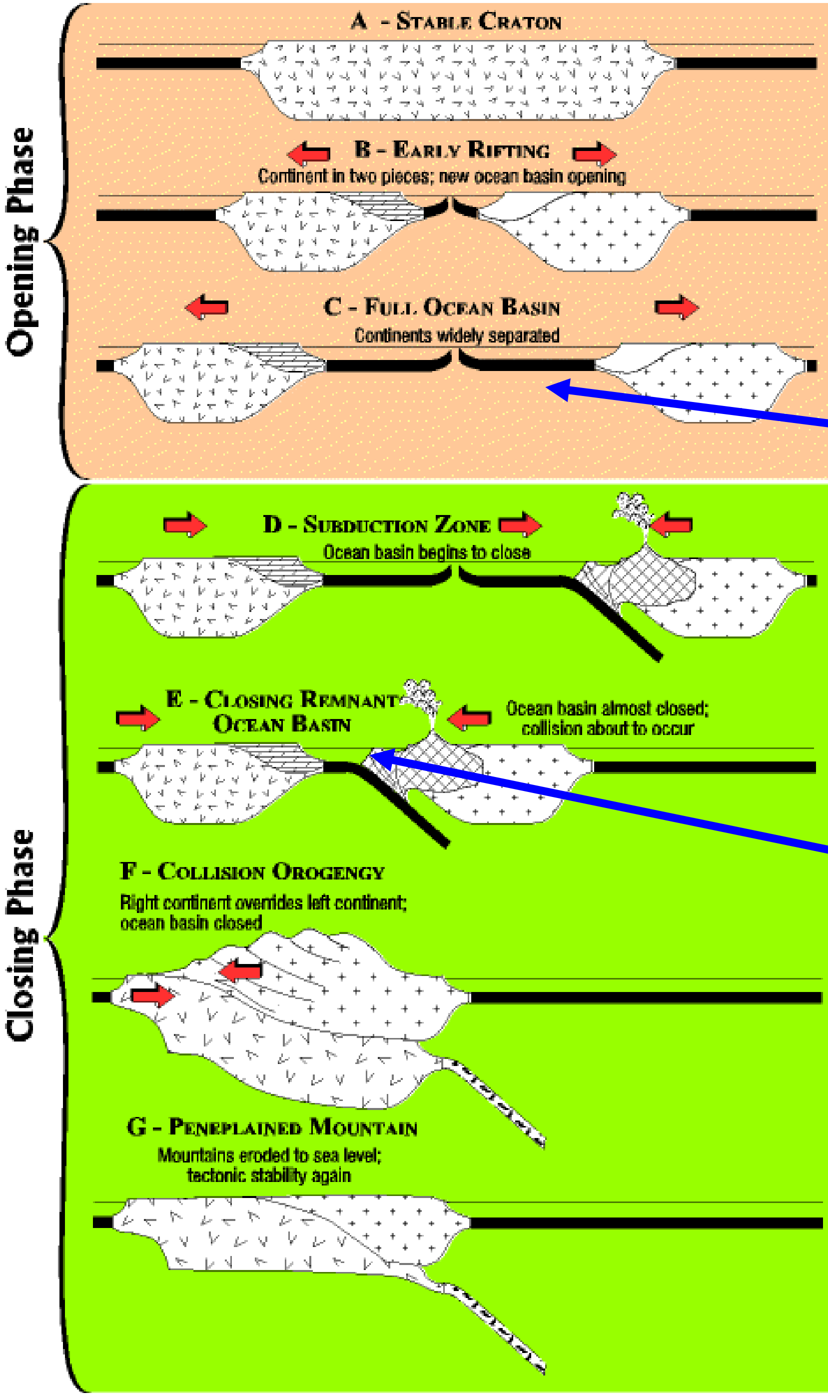
Yes!   Twice!

RODINIA

IAPETUS OCEAN

PANGEA

ATLANTIC OCEAN



RODINIA

rifting

IAPETUS OCEAN

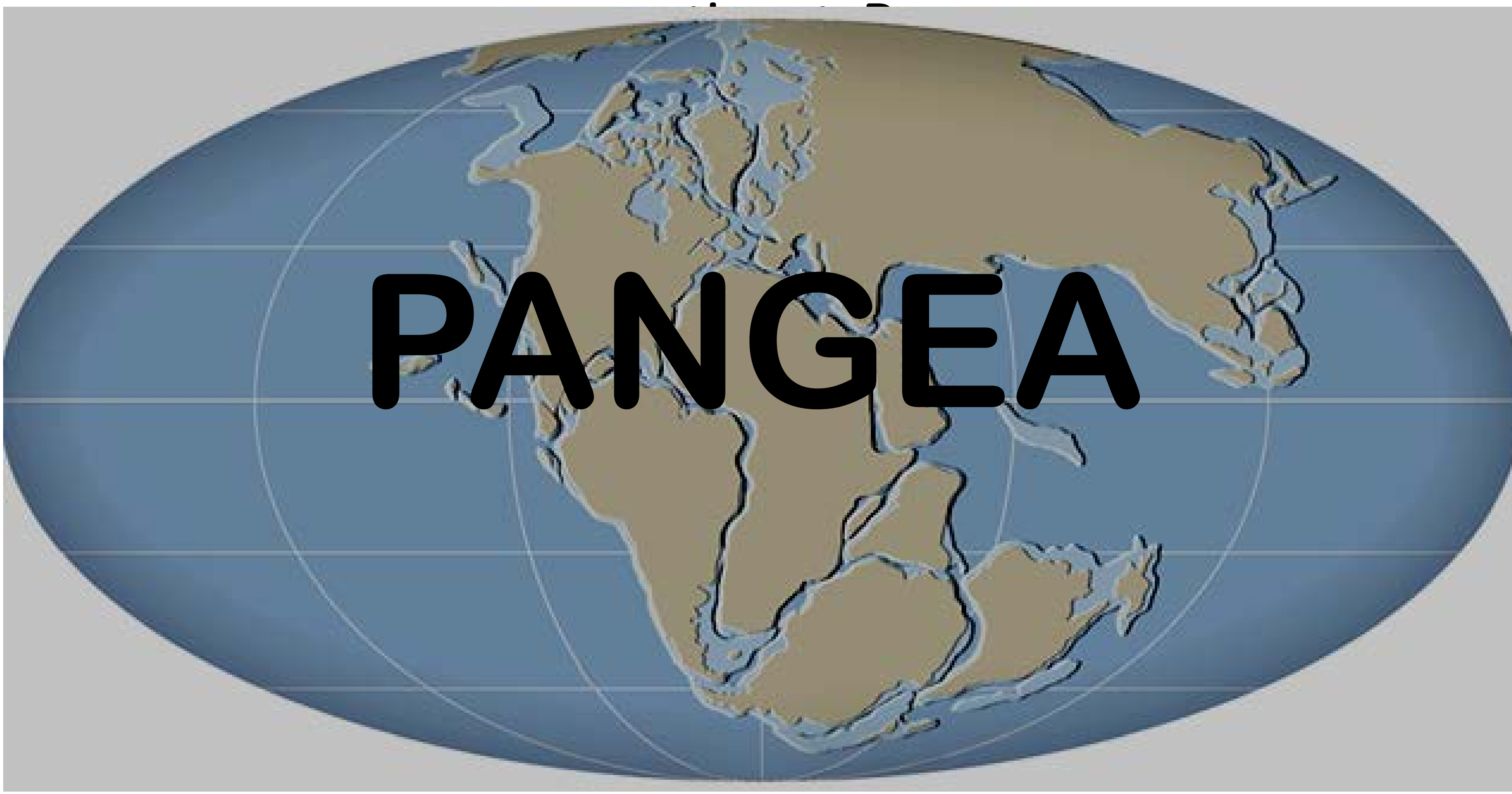
subduction, convergence

collision and closing of IAPETUS

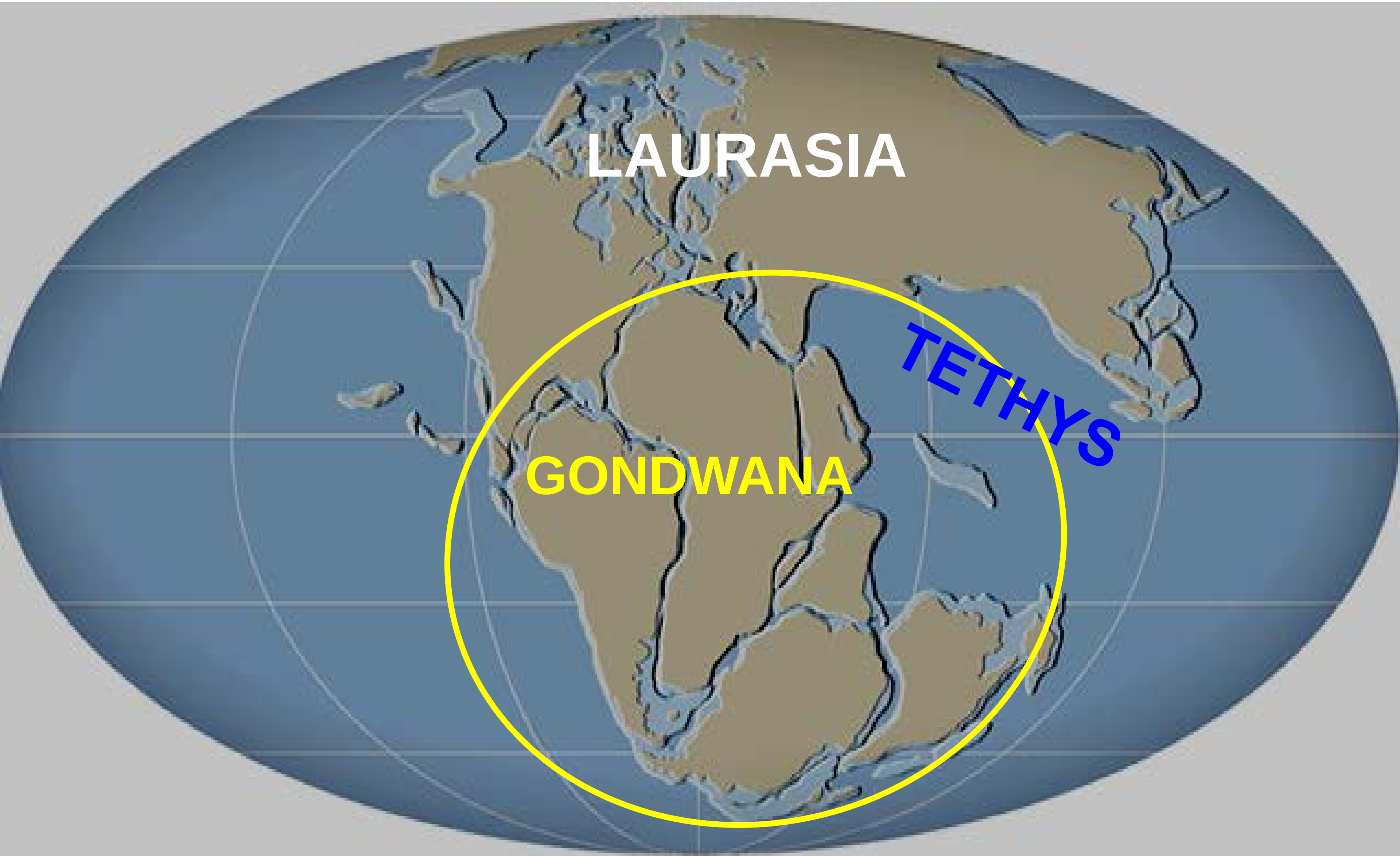
APPALACHIAN and CALEDONIAN OROGEN

PANGEA

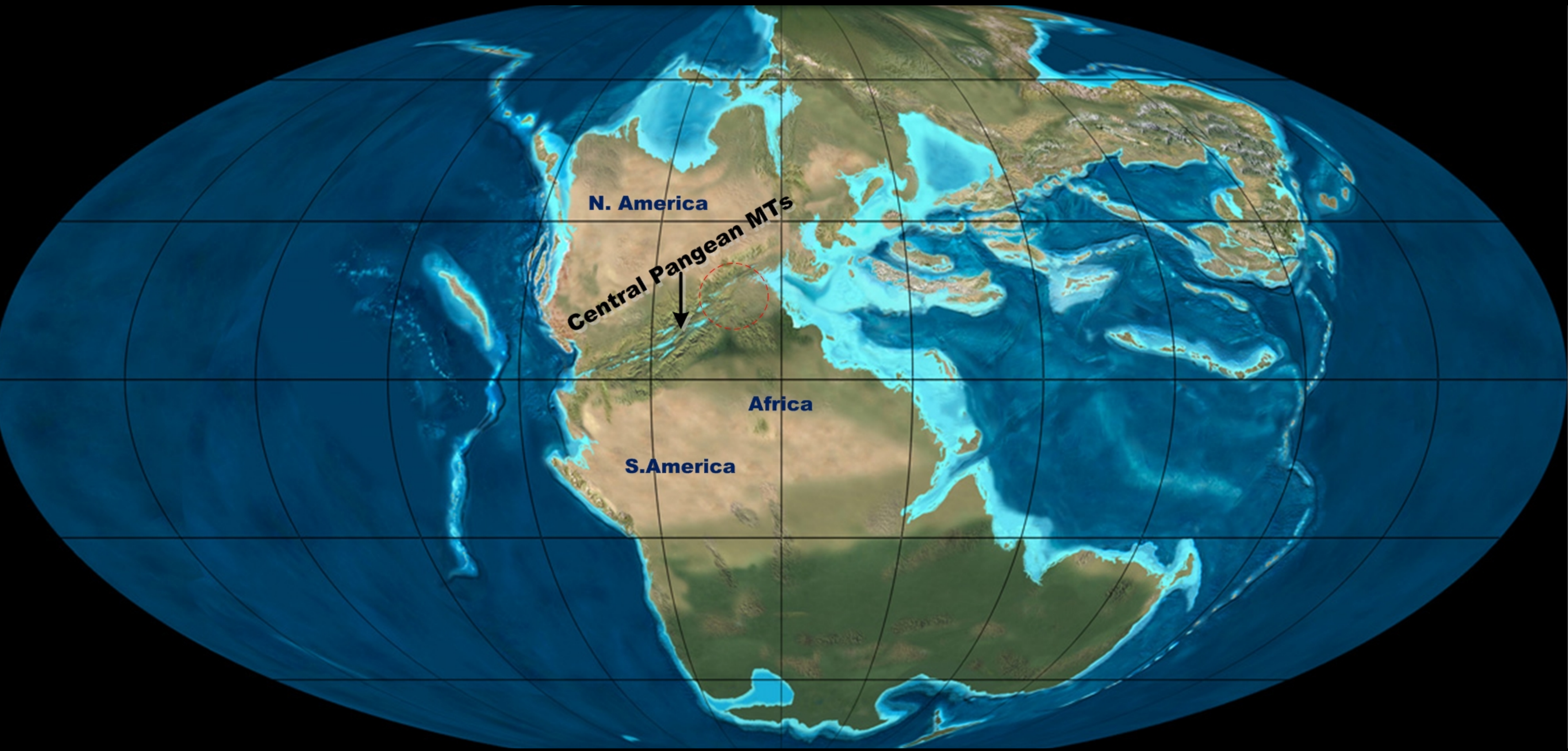
The continents have changed shapes and positions throughout geologic time! This is a reconstruction of the



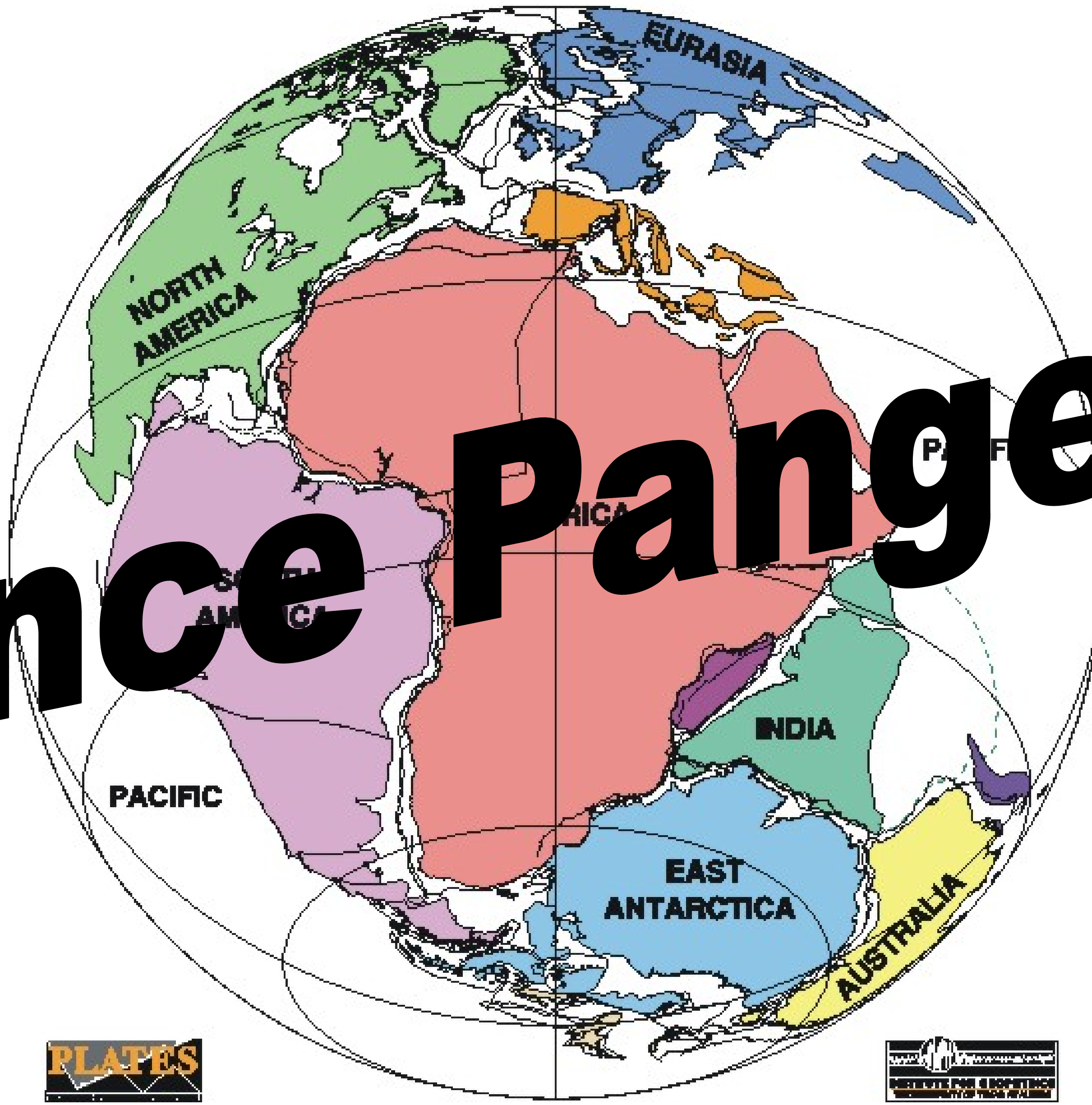
The continents have changed shapes and positions throughout geologic time! This is a reconstruction of the supercontinent Pangea as it may have looked in Permian time.



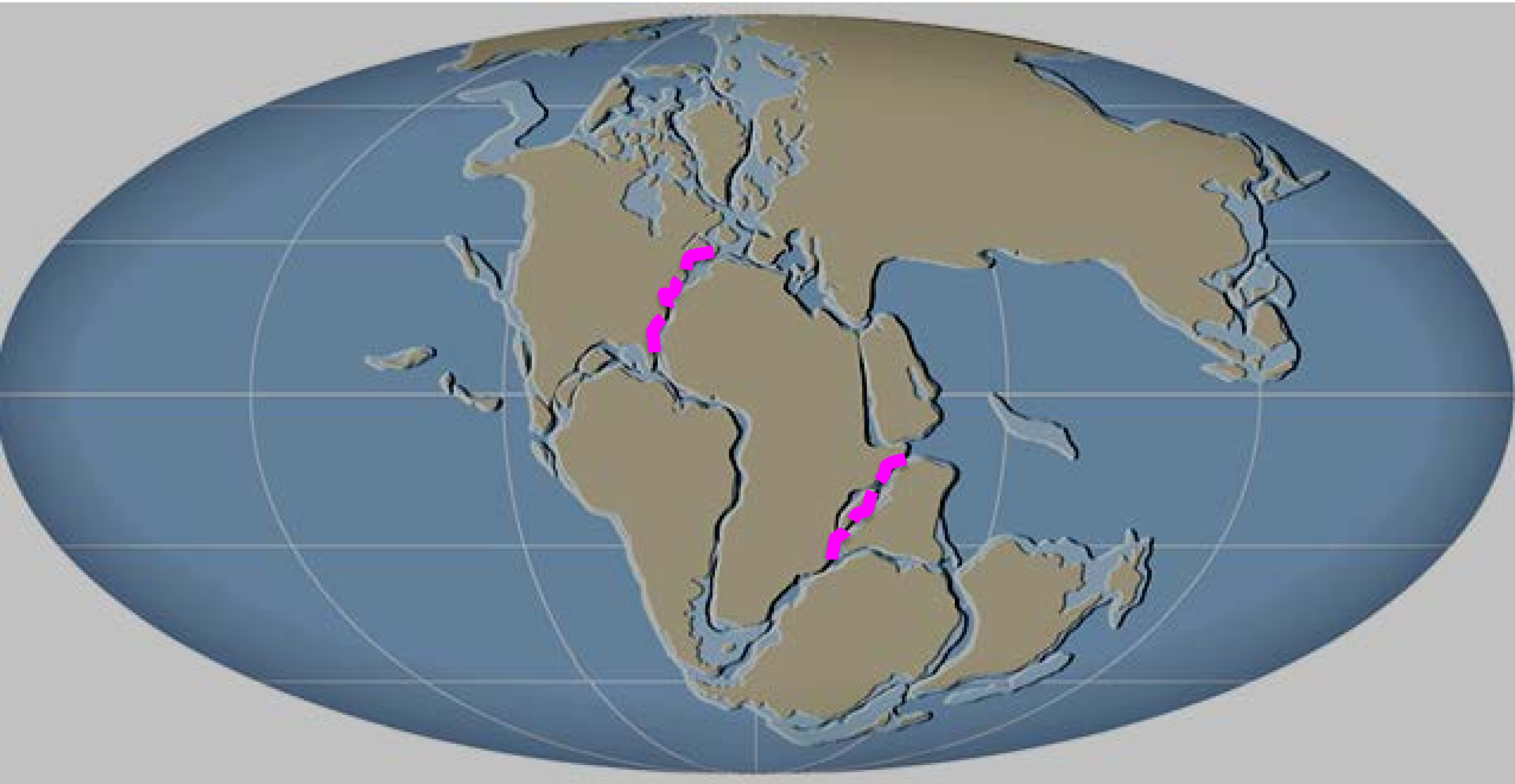
PANGEA — AN IMPROVEMENT OVER WEGENER

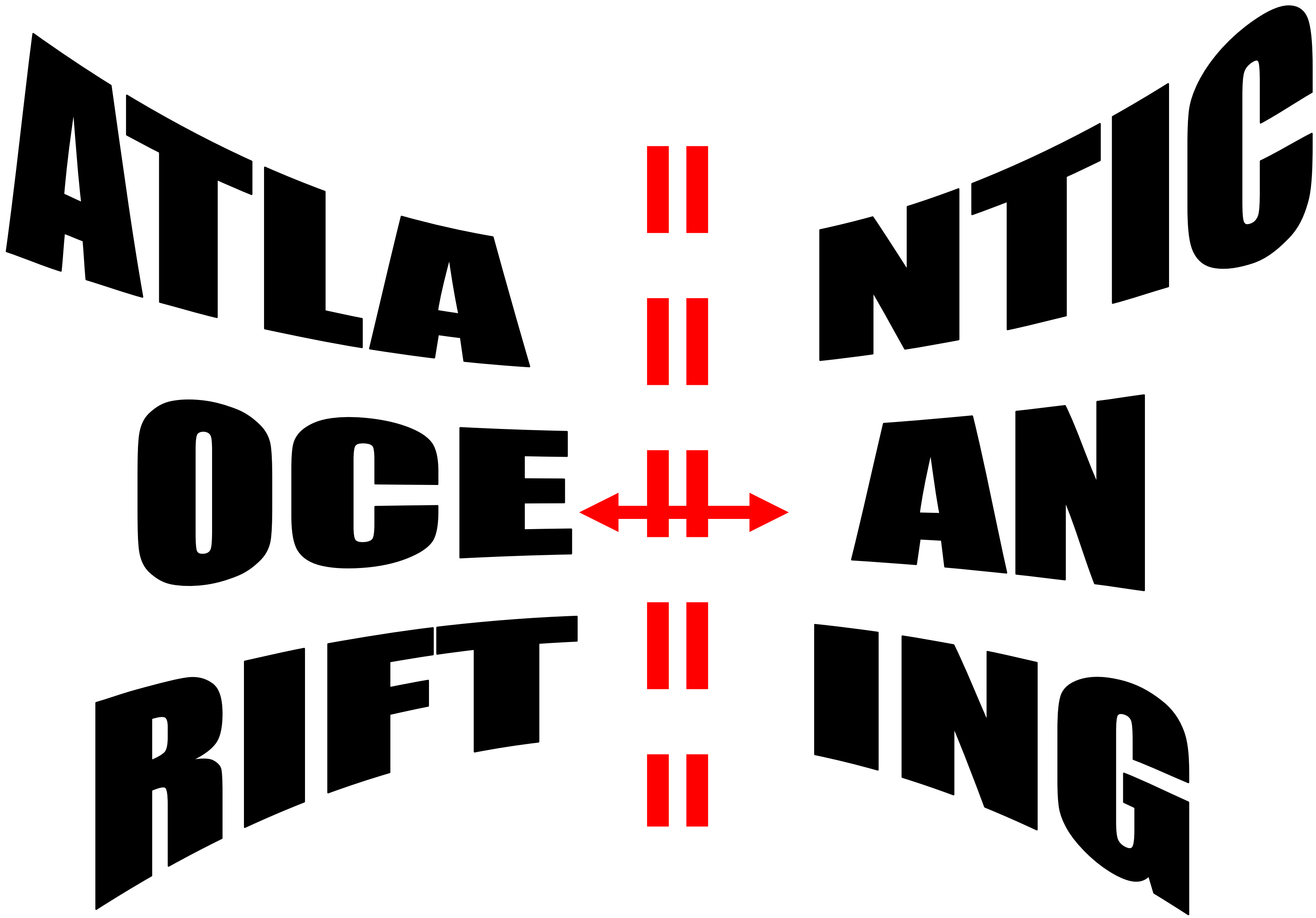


Since Pangea

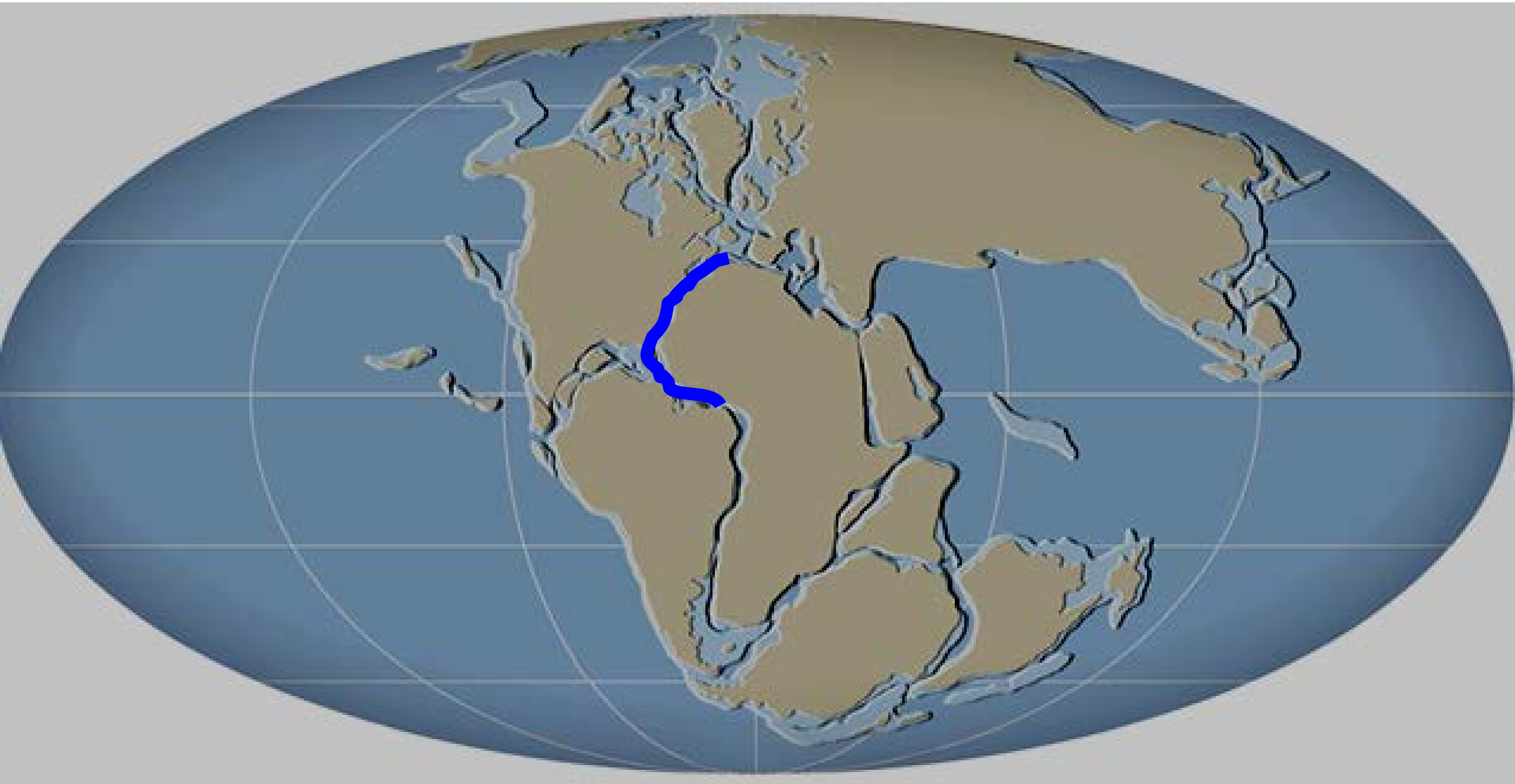


Beginning in the Triassic around 230-220 million years ago, Pangea began to split up




ATLA NTIC
OCE AN
RIFT ING

The process was complicated in space and in time.
for example, the Atlantic Ocean opened in 3 stages:
Jurassic, Cretaceous, and Tertiary



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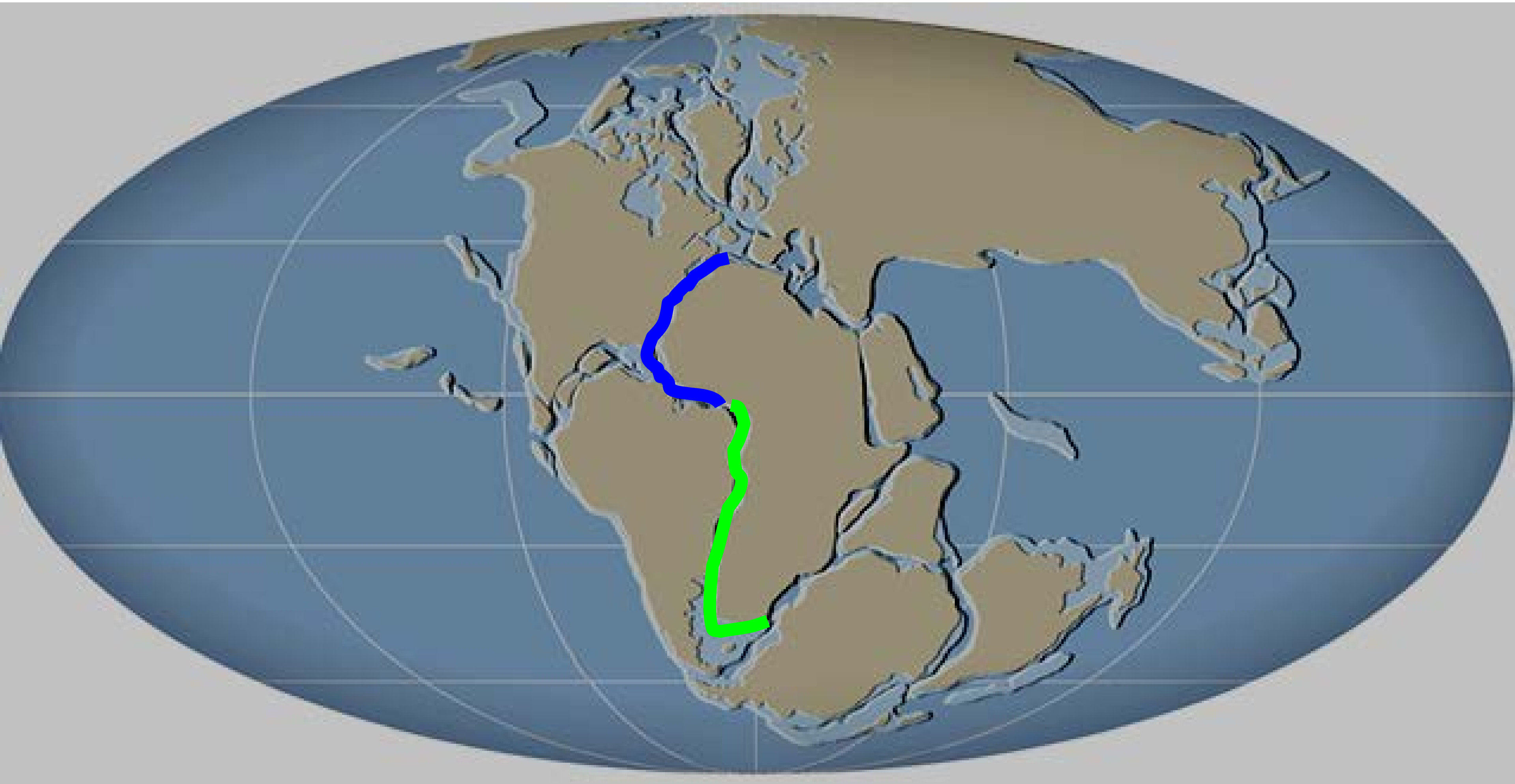

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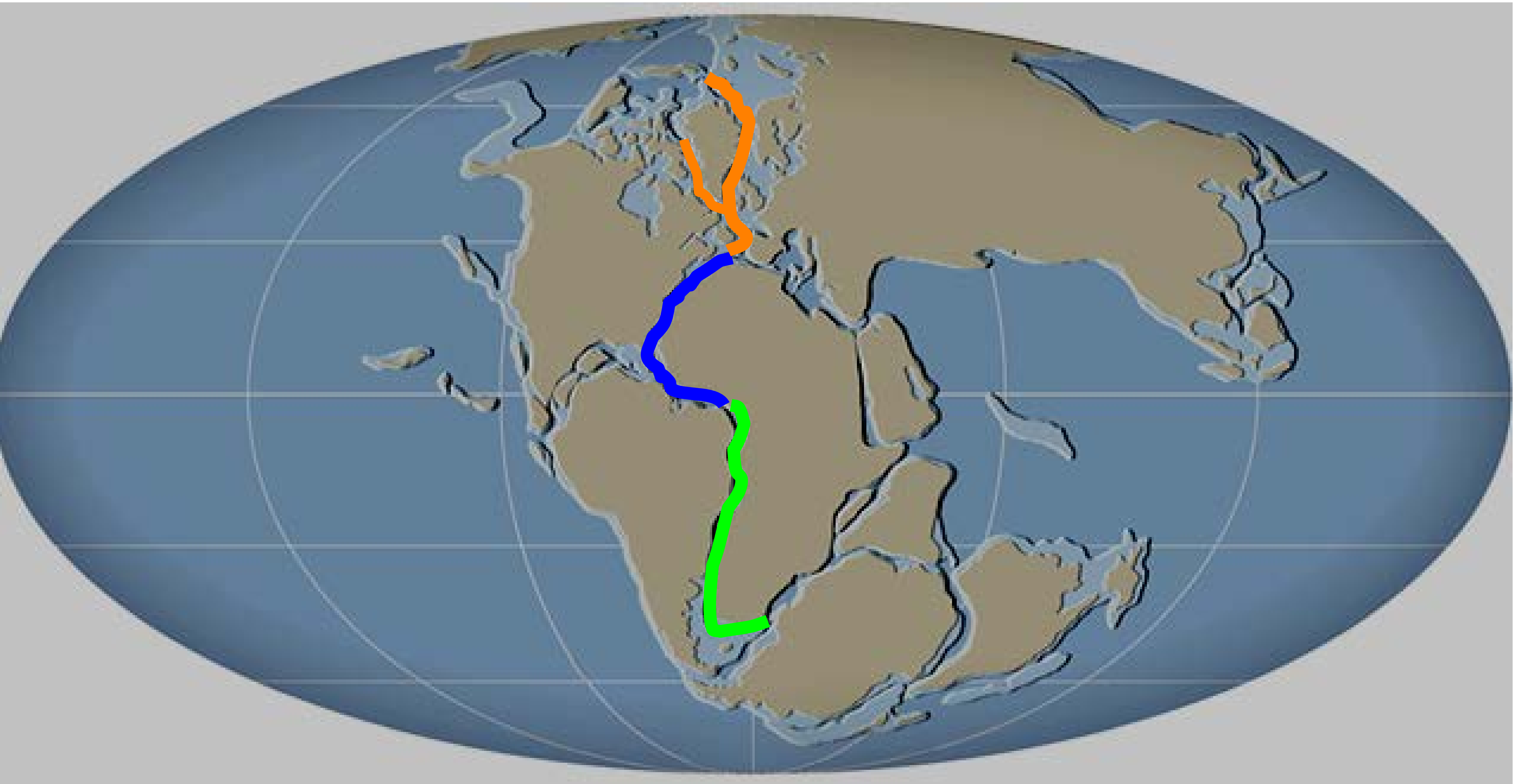
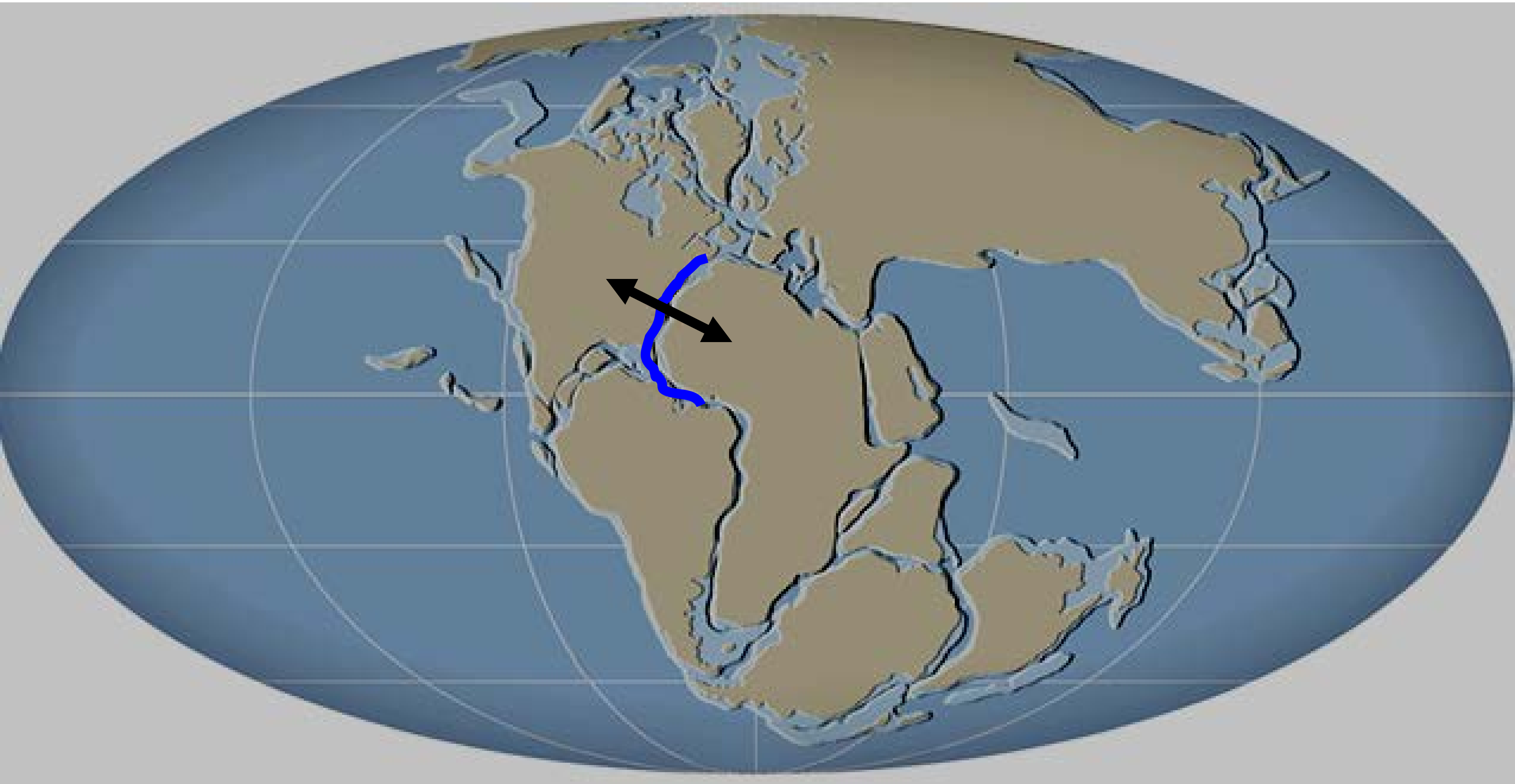
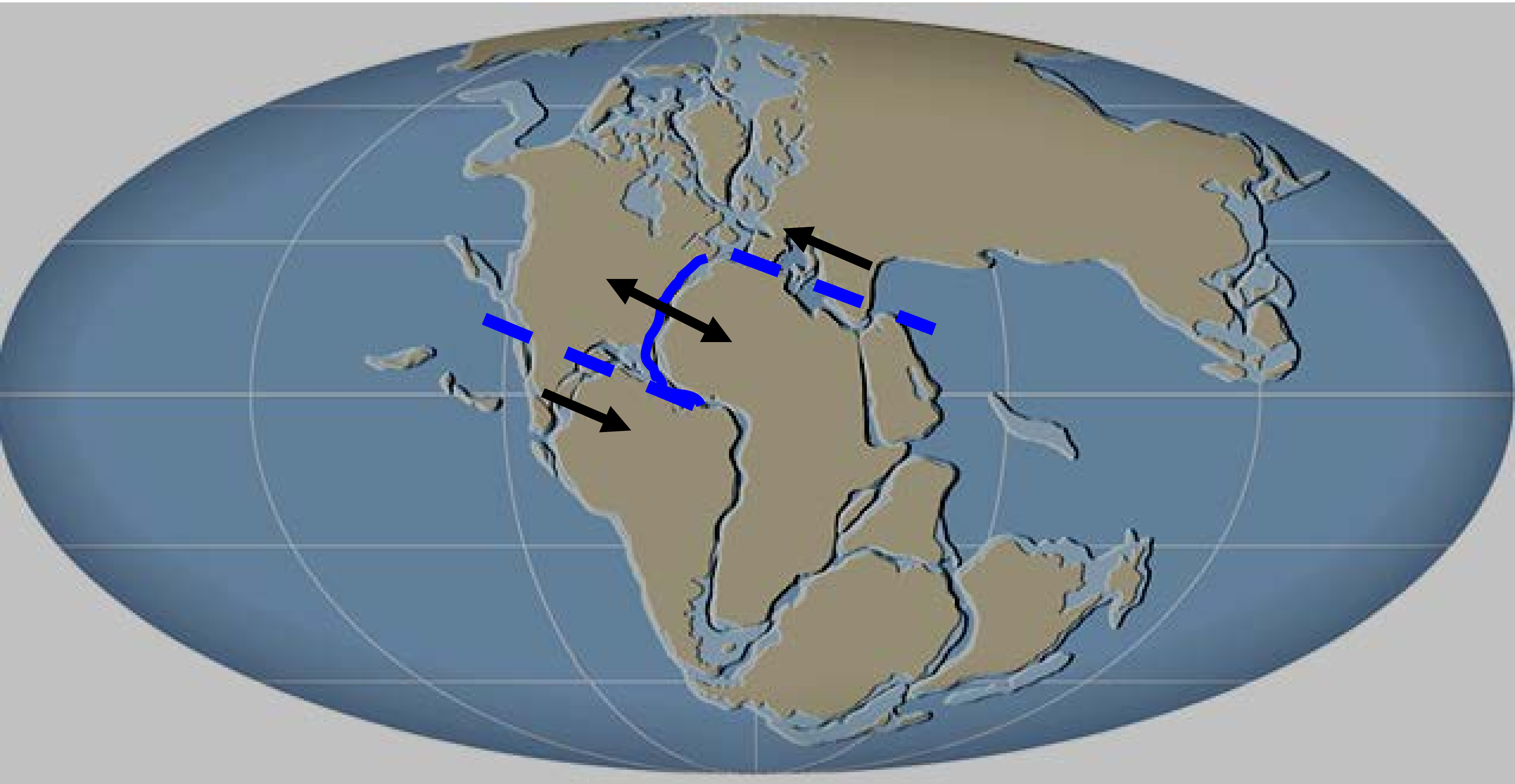
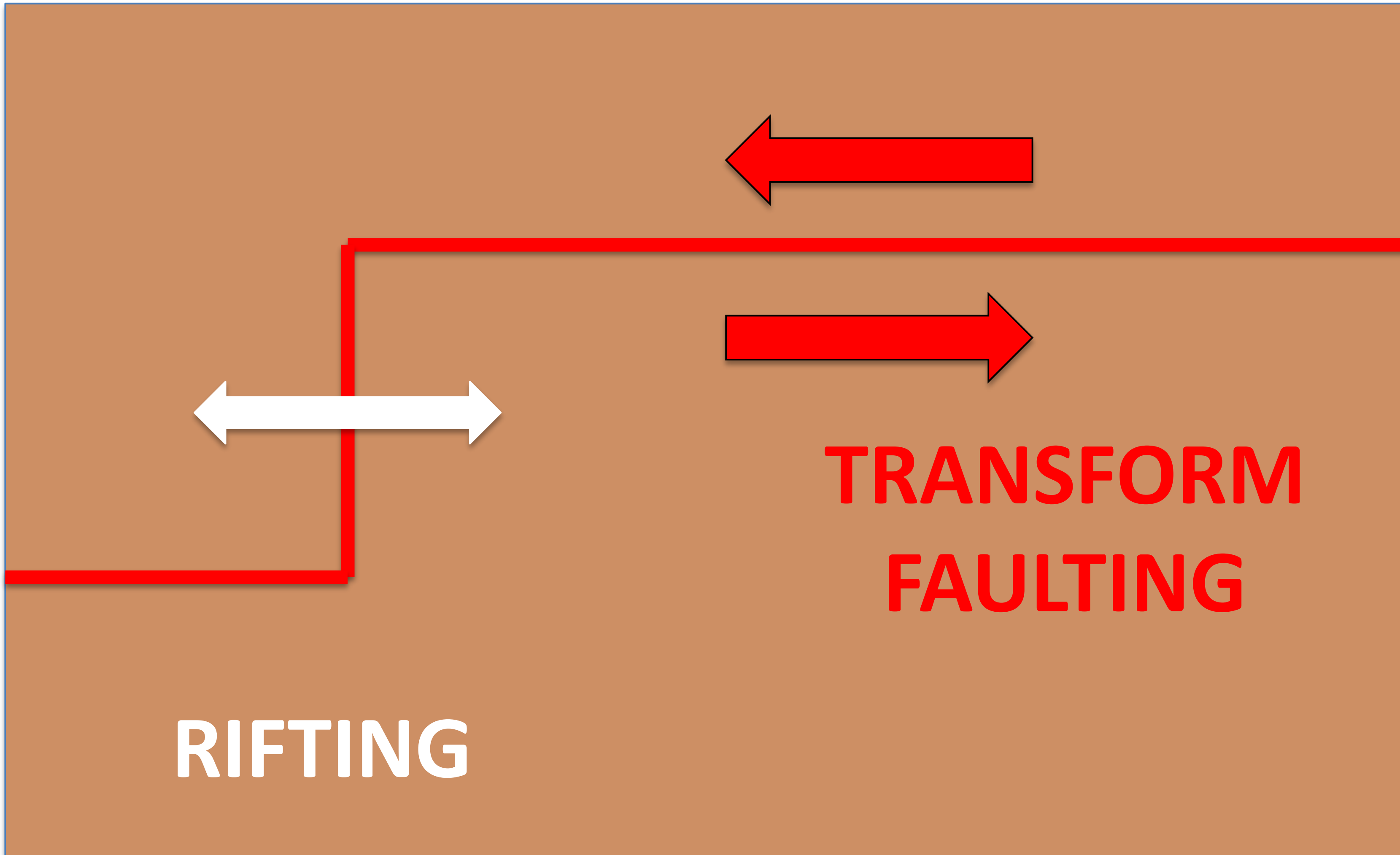


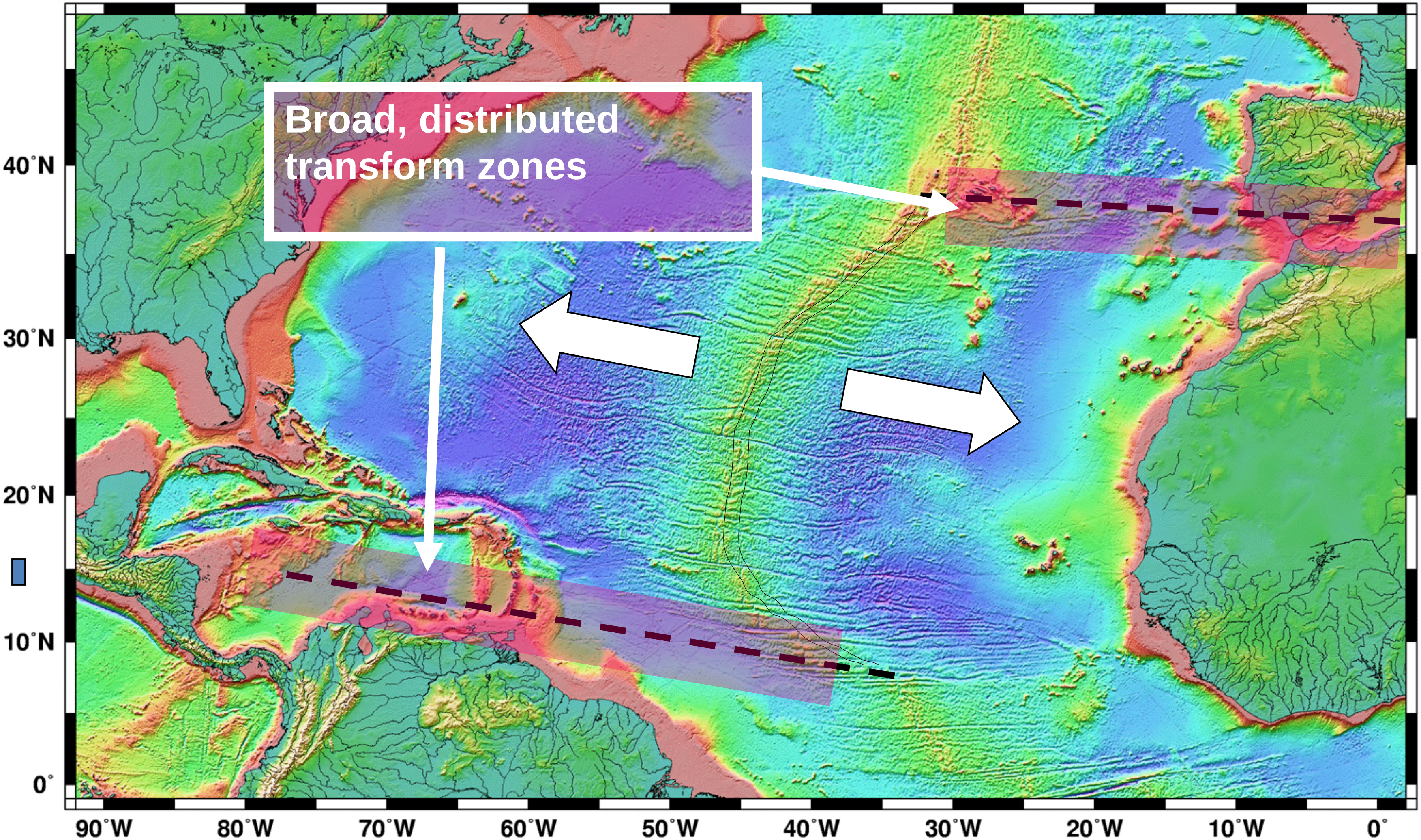
How could JUST the middle Atlantic open?



This way! By transform fault zones as shown …



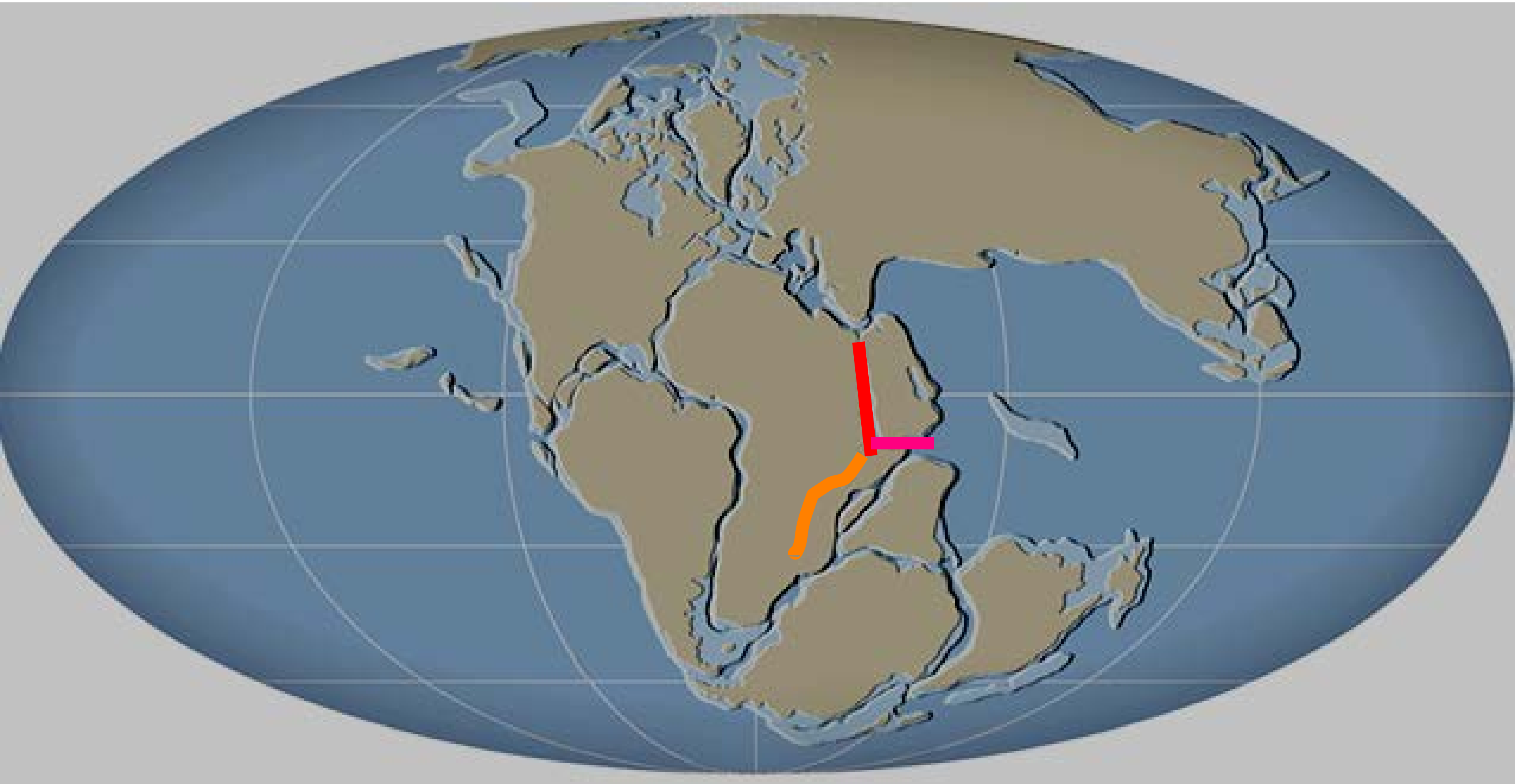

TRANSFORM
FAULTING
RIFTING

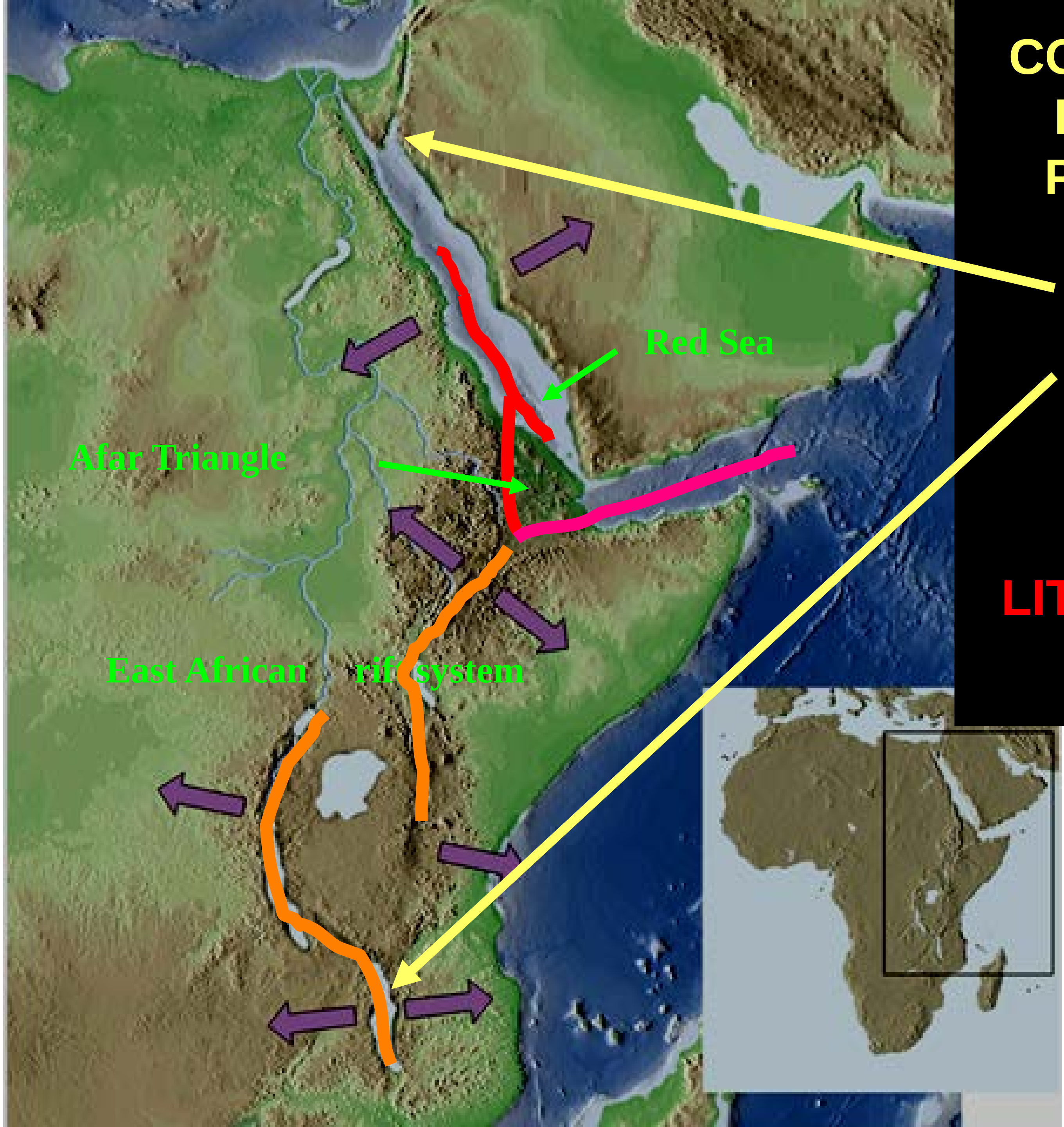


Topography Version 8.2, SIO, November 17, 2000

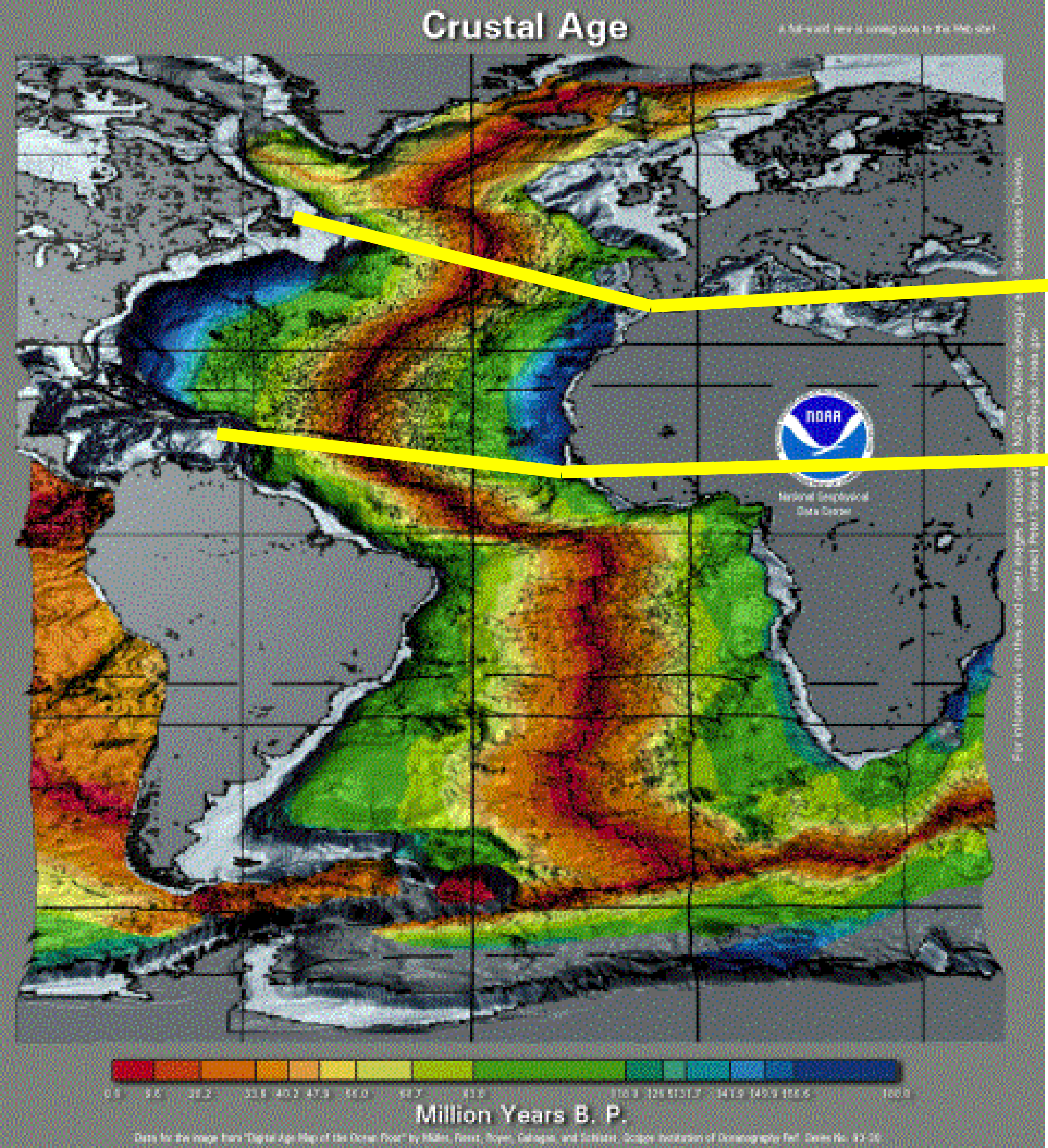
GMT 2003 Mar 20 13:06:59

The process of the splitting up of Pangea continues to this day in the Red Sea, Gulf of Aden, and East Africa.





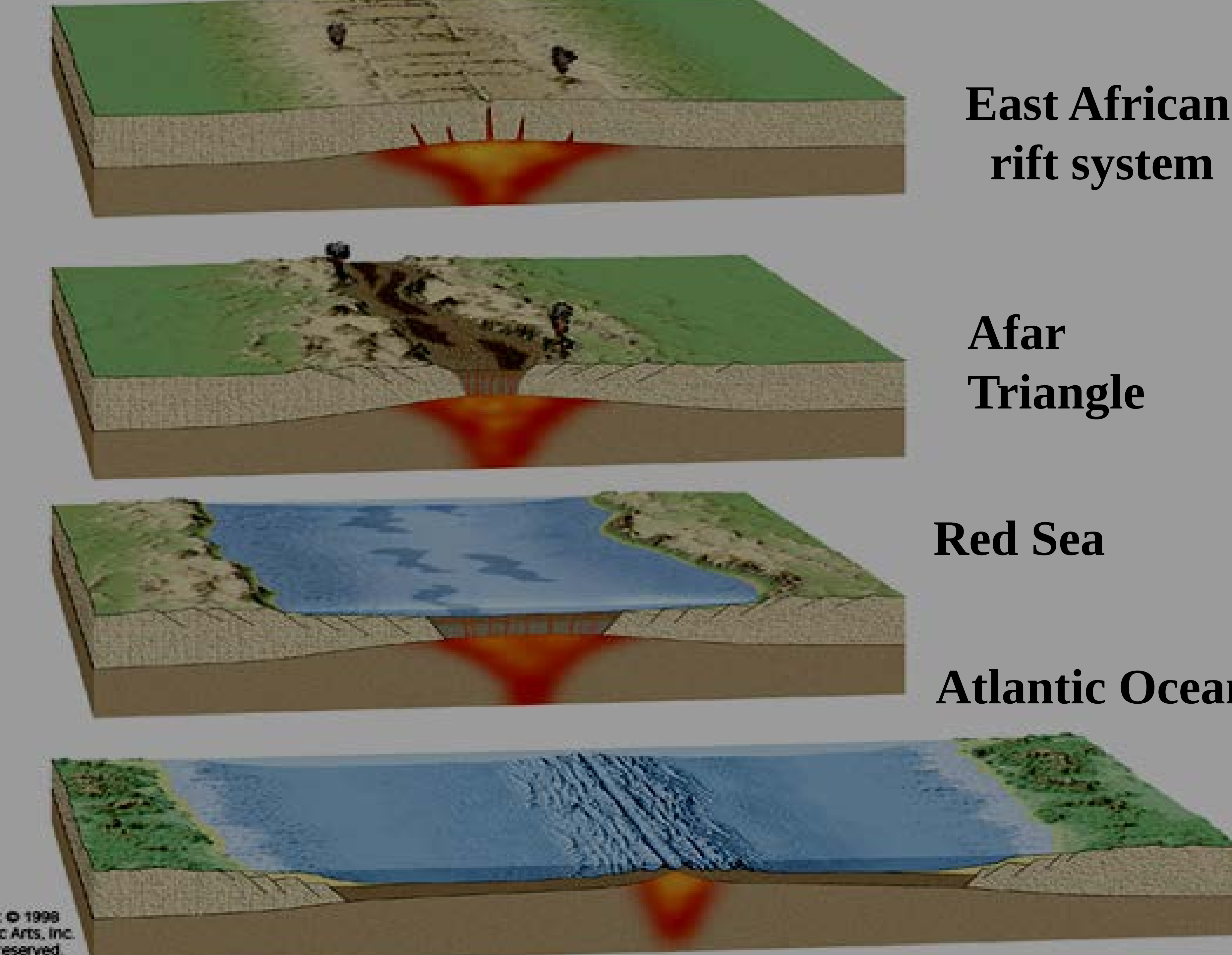
CONTINENTAL RIFTING IN PROGRESS FROM NORTH TO SOUTH WITH OCEAN LITHOSPHERE IN RED & PINK



Cenozoic rifting

Jurassic rifting

Cretaceous rifting

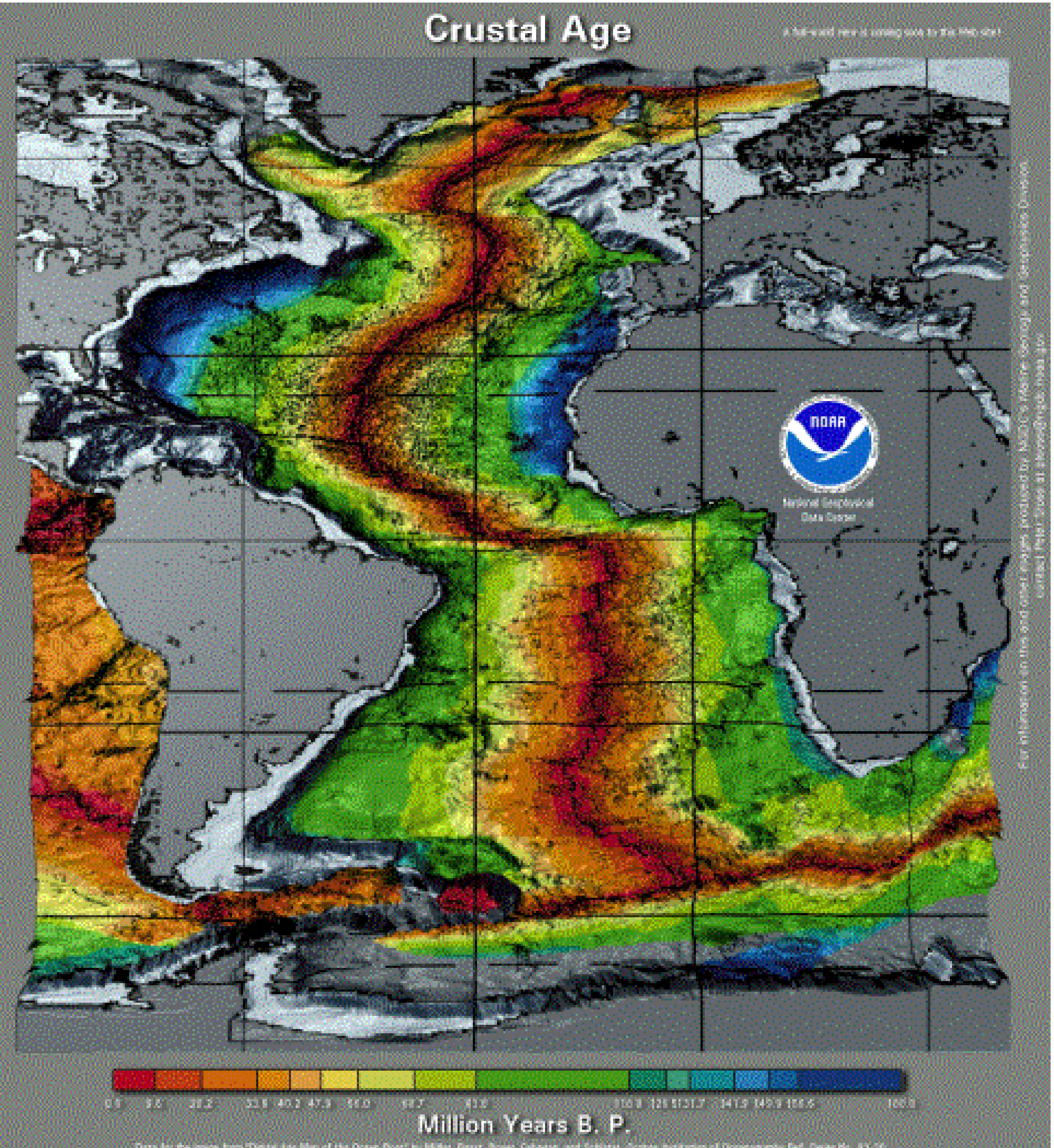


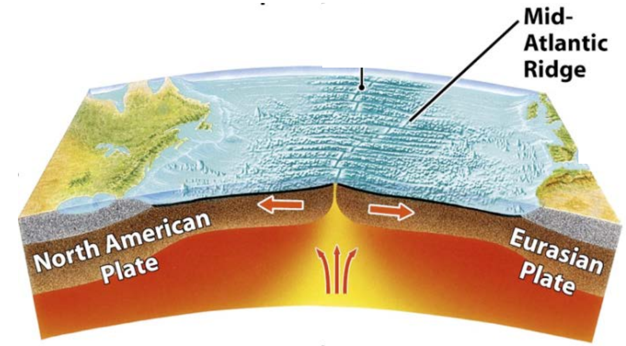
East African rift system

Afar Triangle

Red Sea

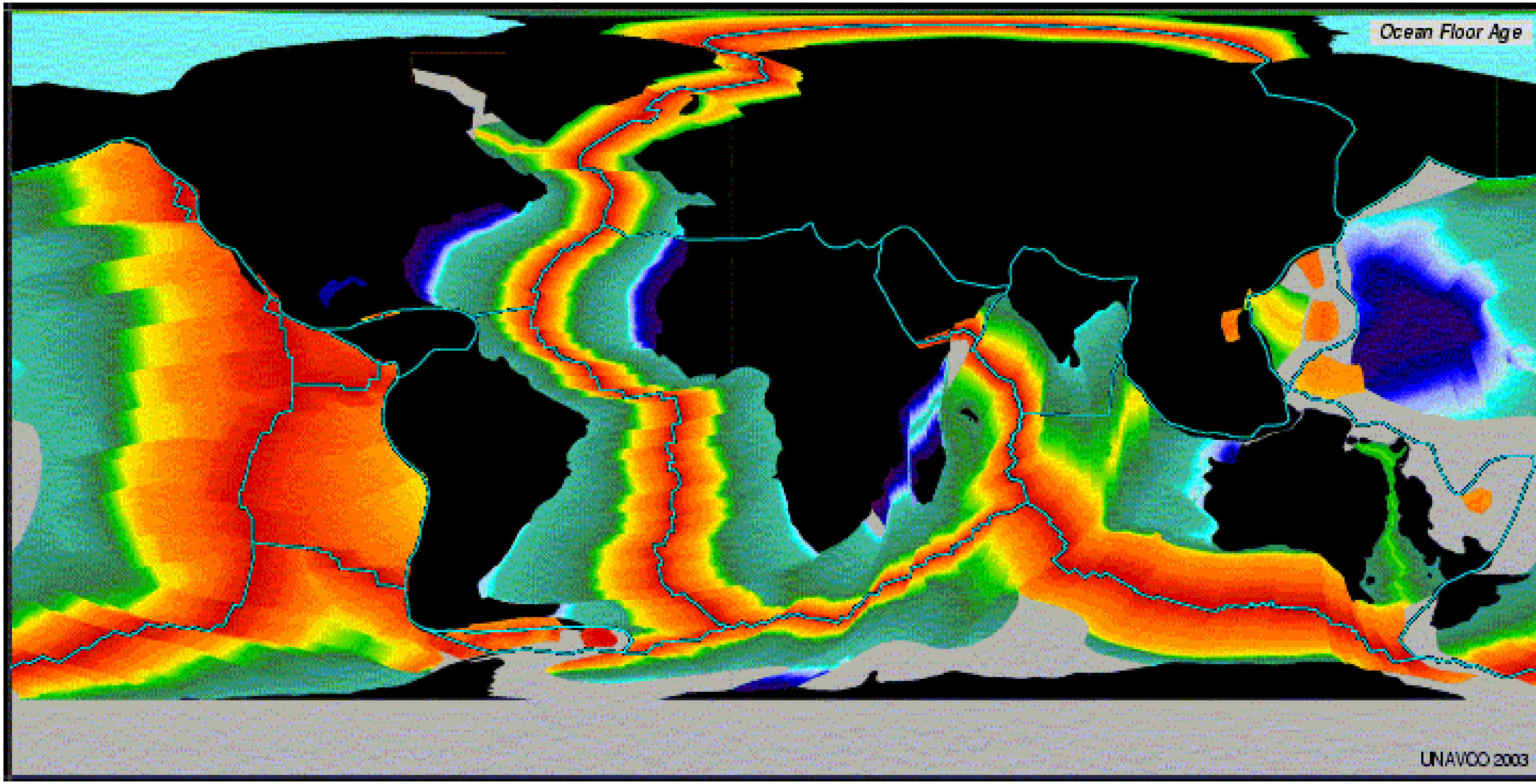
Atlantic Ocean



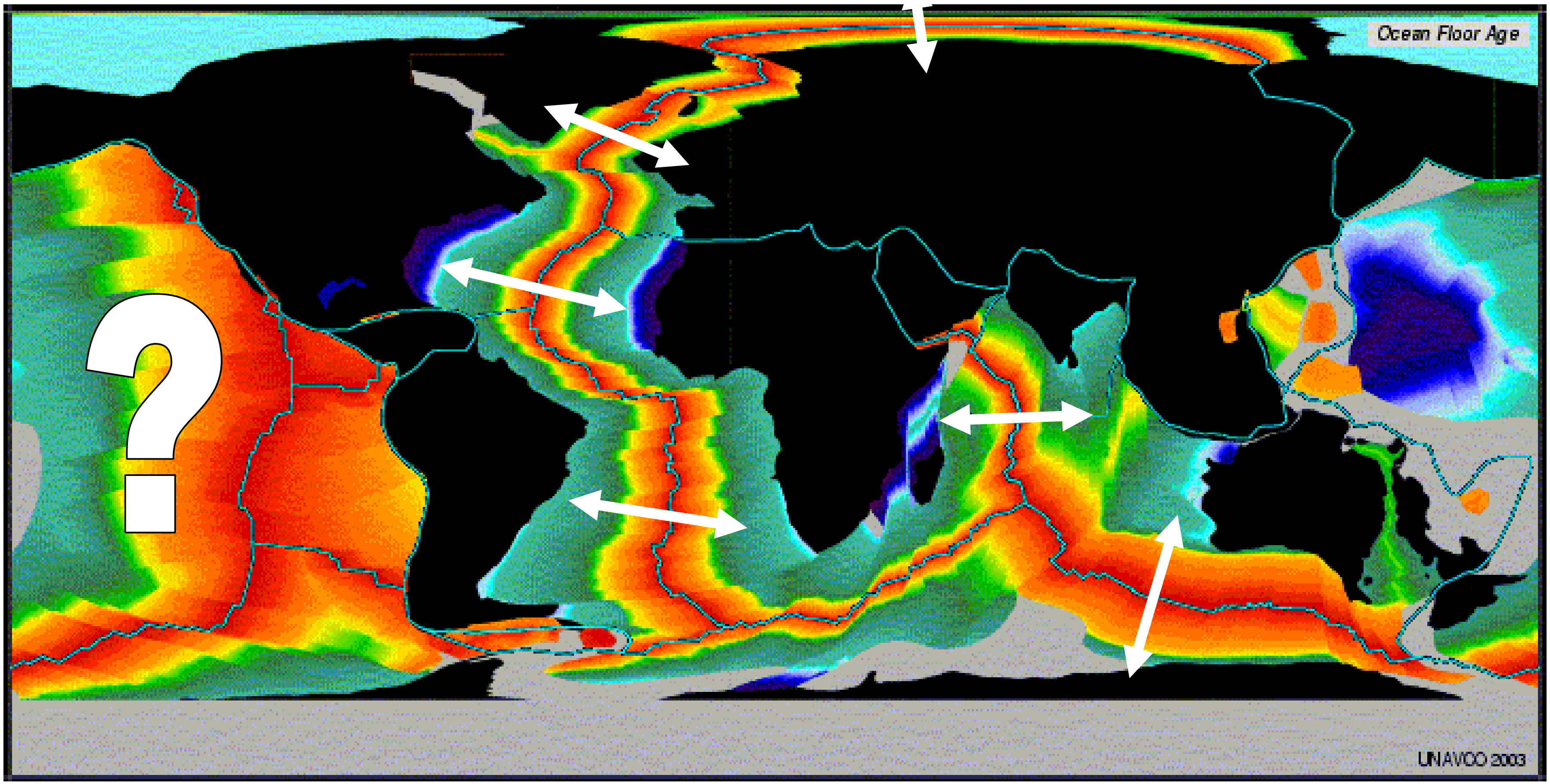


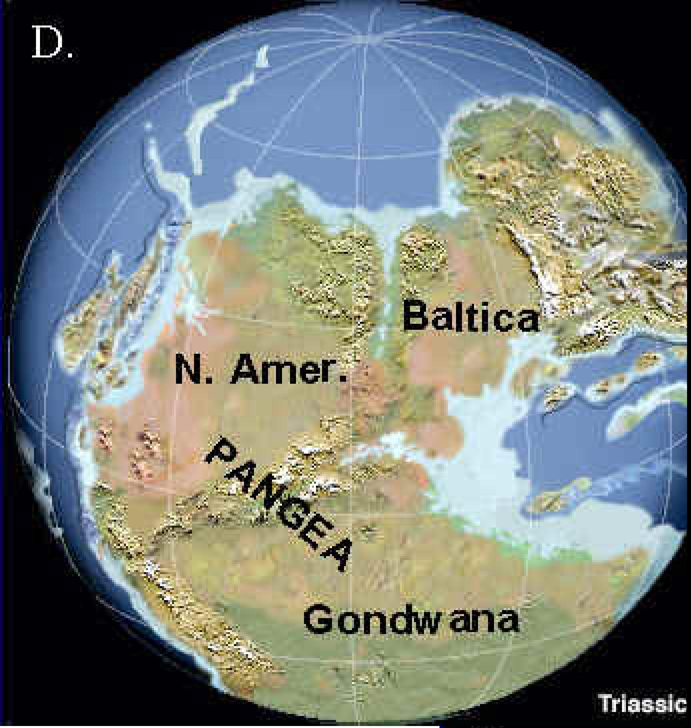
As the plates move apart the rising hot plastic mantle beneath the ridges begins to melt — producing not just mafic (basaltic) volcanoes, but the mafic oceanic crust they sit on. For the Atlantic this process began 180 million years ago.

The break-up of Pangea created three new rifted ocean basins — the Atlantic, the Arctic, and Indian

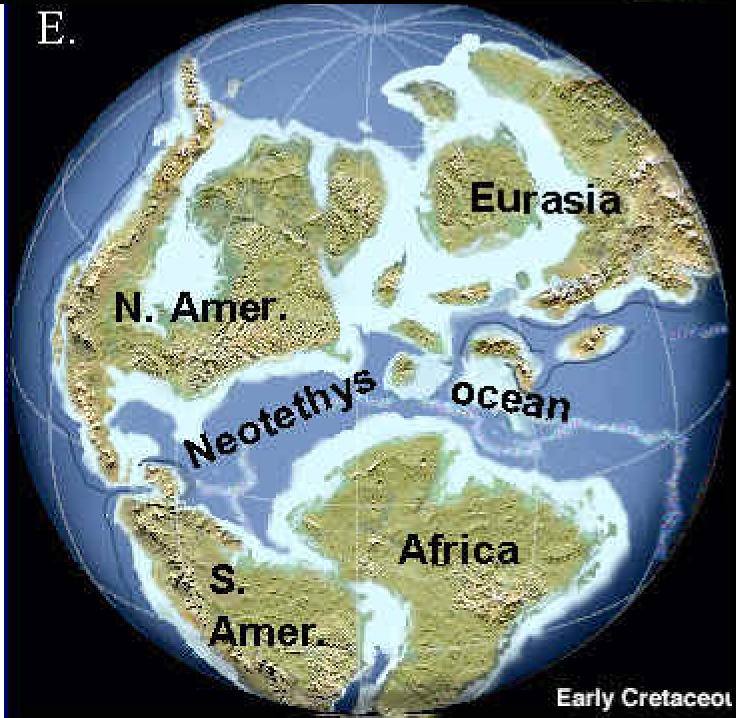


and so what happened to the pre-existing Pacific Ocean?

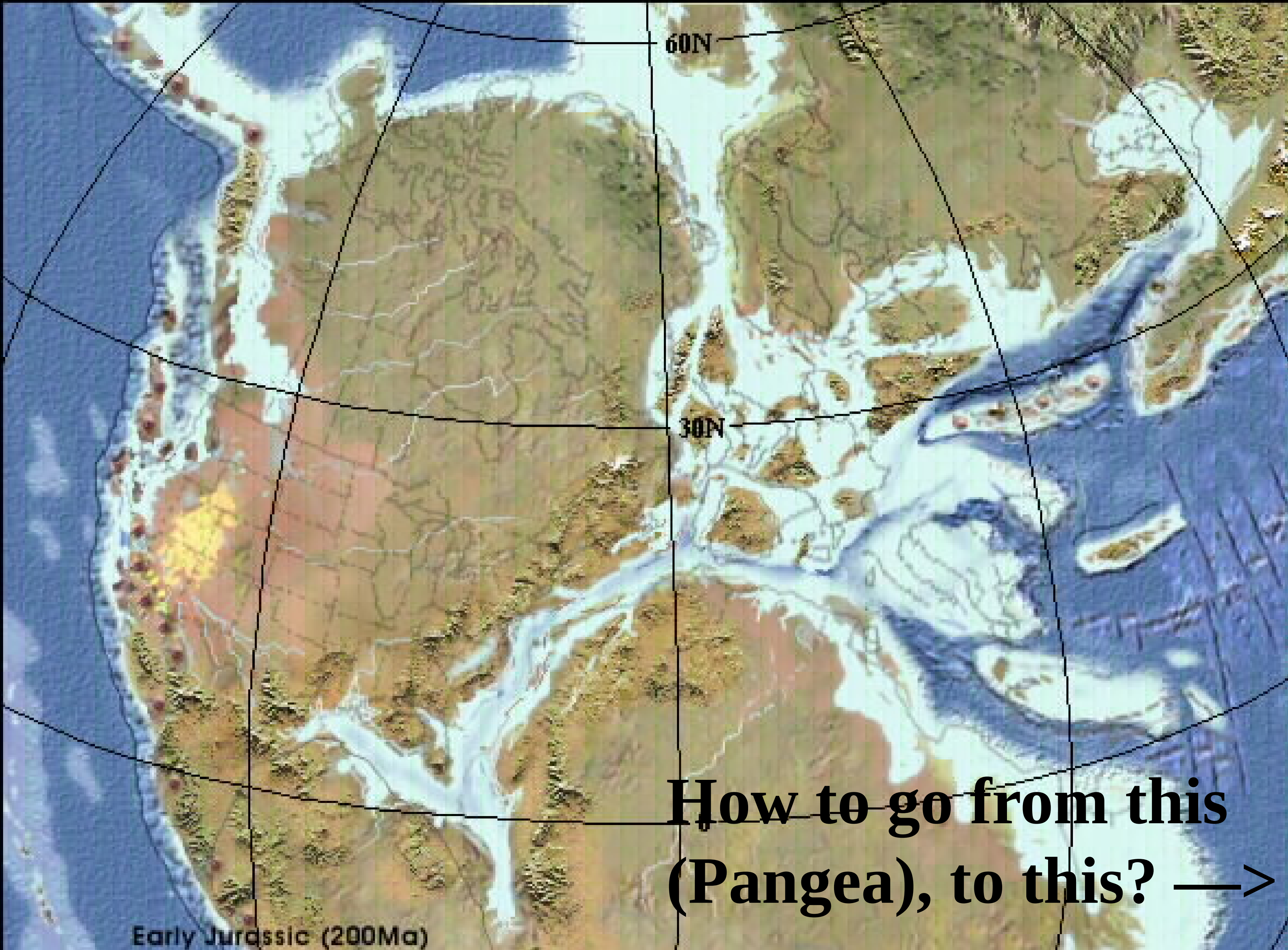

Ocean Floor Age
?
UNAVCO 2003



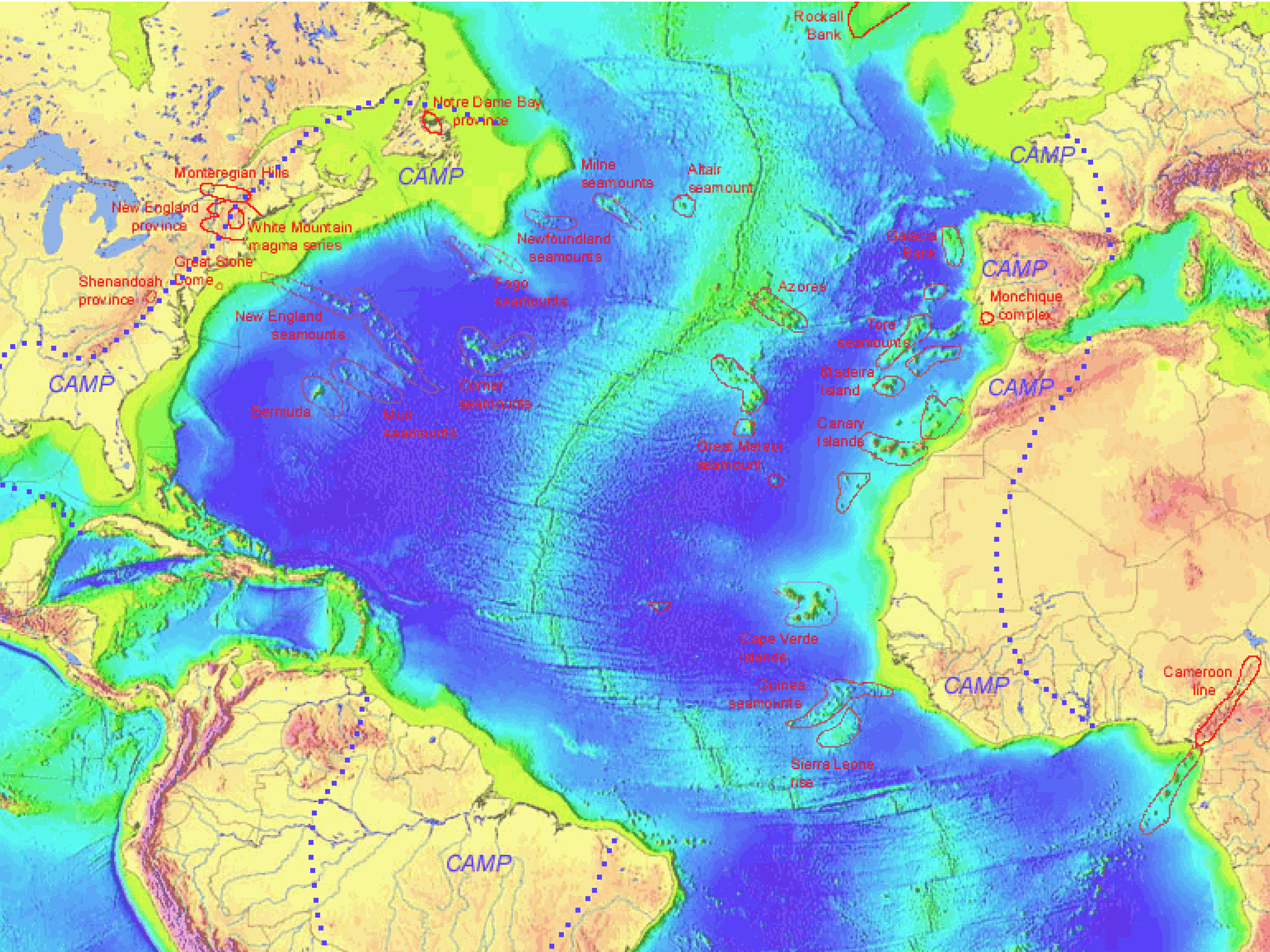
What is now the central Atlantic Ocean was not present in Triassic time, but was well developed by th Middle Jurassic. Study of this region tells us much about the continental rifting process for this example of continental breaku

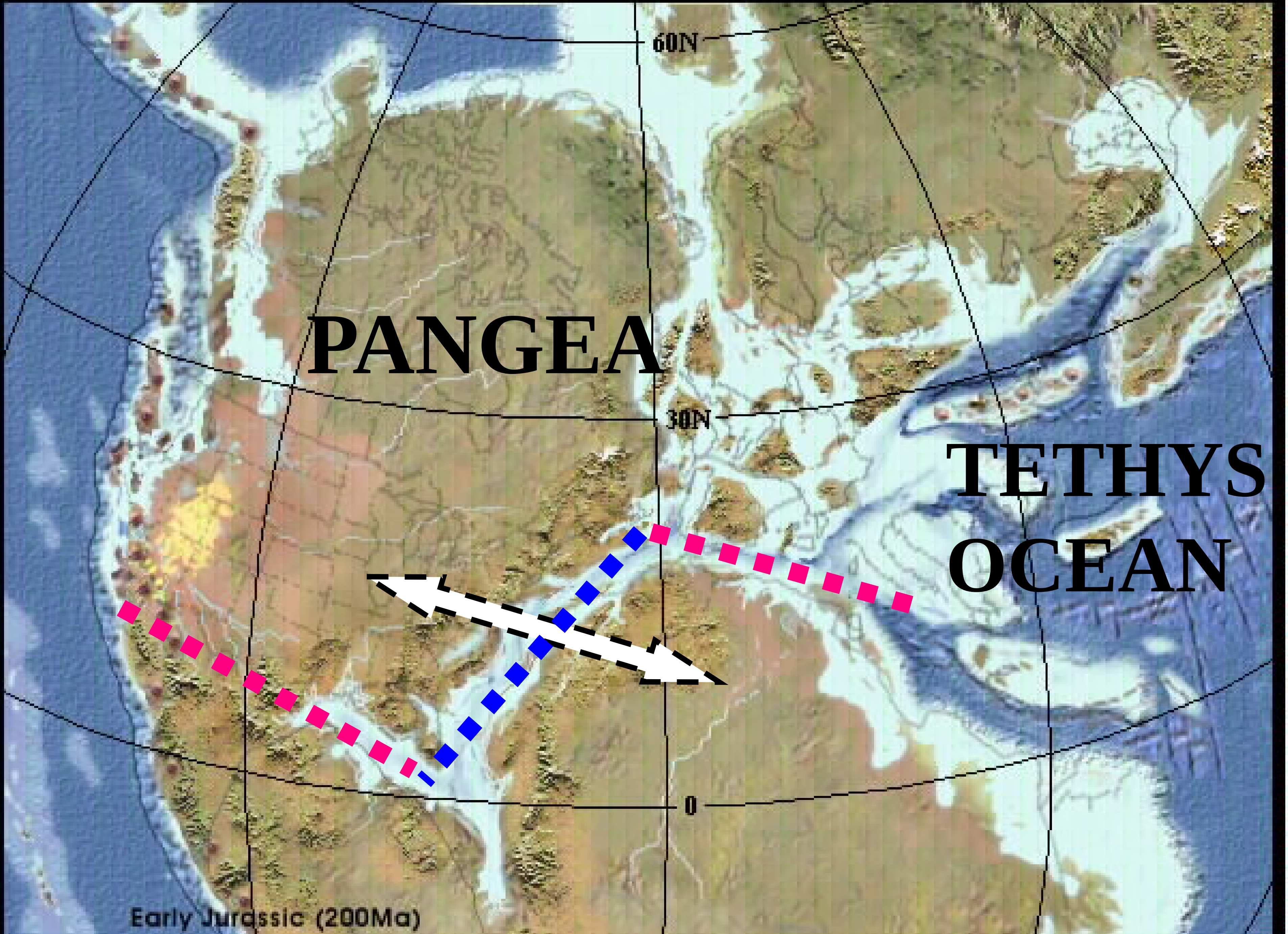


EARLY CRETACEOUS



How to go from this (Pangea), to this? —>


Rockall Bank
Notre Dame Bay province
CAMP
Monteregian Hills
New England province
White Mountain magma series
Great Stone Dome
Shenandoah province
Milne seamounts
Altair seamount
Newfoundland seamounts
Fogo seamounts
Galacia Bank
CAMP
Azores
Monchique complex
New England seamounts
Tore seamounts
Corner seamounts
Madeira Island
CAMP
CAMP
Bermuda
Muir seamounts
Canary Islands
Great Meteor seamount
Cape Verde Islands
Guinea seamounts
CAMP
Cameroon line
Sierra Leone rise
CAMP

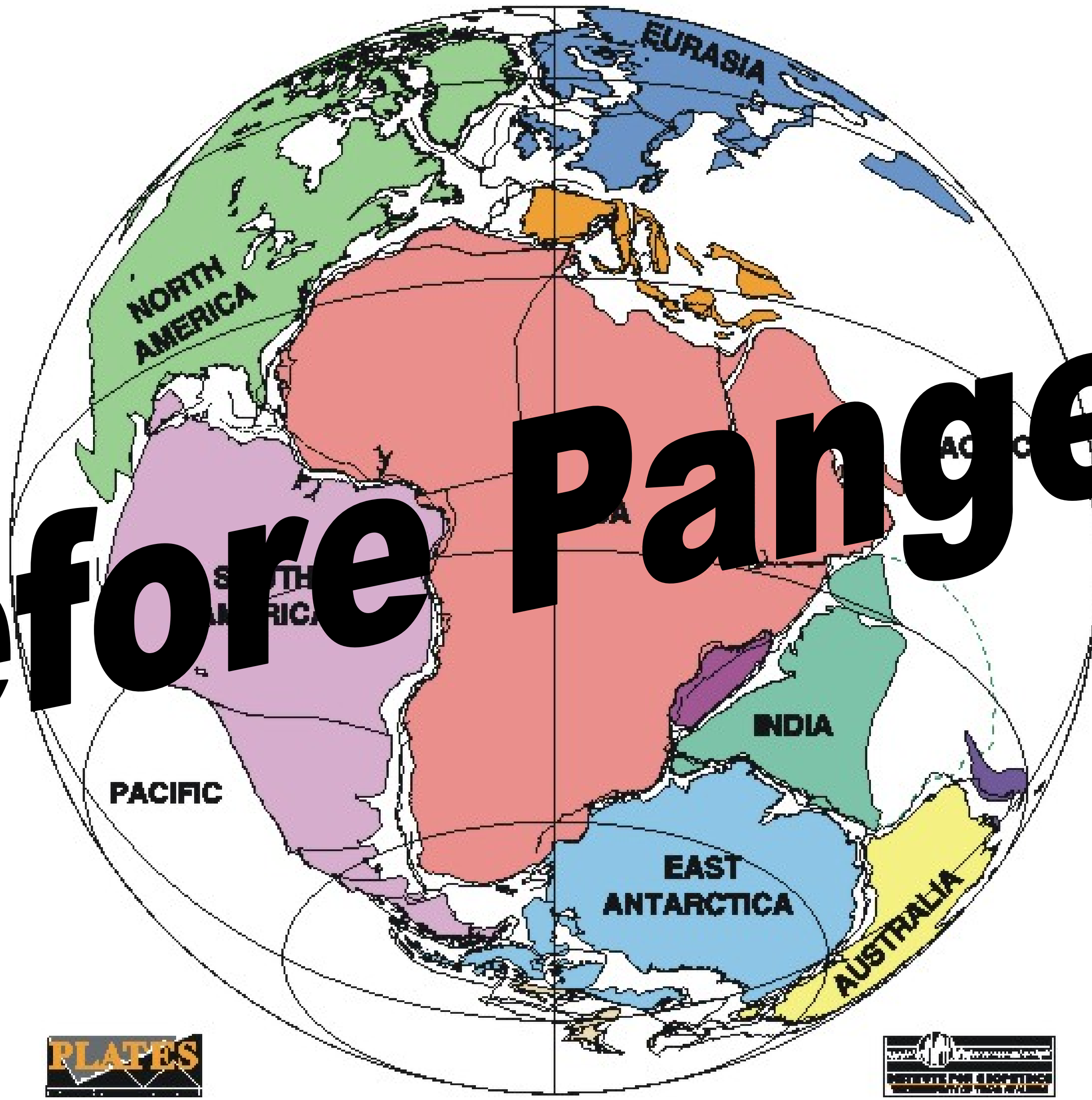

60N
PANGEA
30N
TETHYS
OCEAN
0
Early Jurassic (200Ma)

Thank you

Super Continents

From Greg Davis

Before Pangea



SUPERCONTINENTS

Supercontinents result when separate continental plates collide with each other in a general process known as suturing.

Pangea — the youngest of Earth's supercontinents — was preceded by an older supercontinent generally known as *Rodinia* (Russian for "motherland").

It had grown out an earlier cycle of continental suturing at about 1.3 billion years (Ga) and

entered a time of rifting, and fragmentation starting between ca. 800 and 550 Ma.

Those and other fragments collided to became *Pangea*.

NEOPROTEROZOIC RIFTING

R O D I N I A

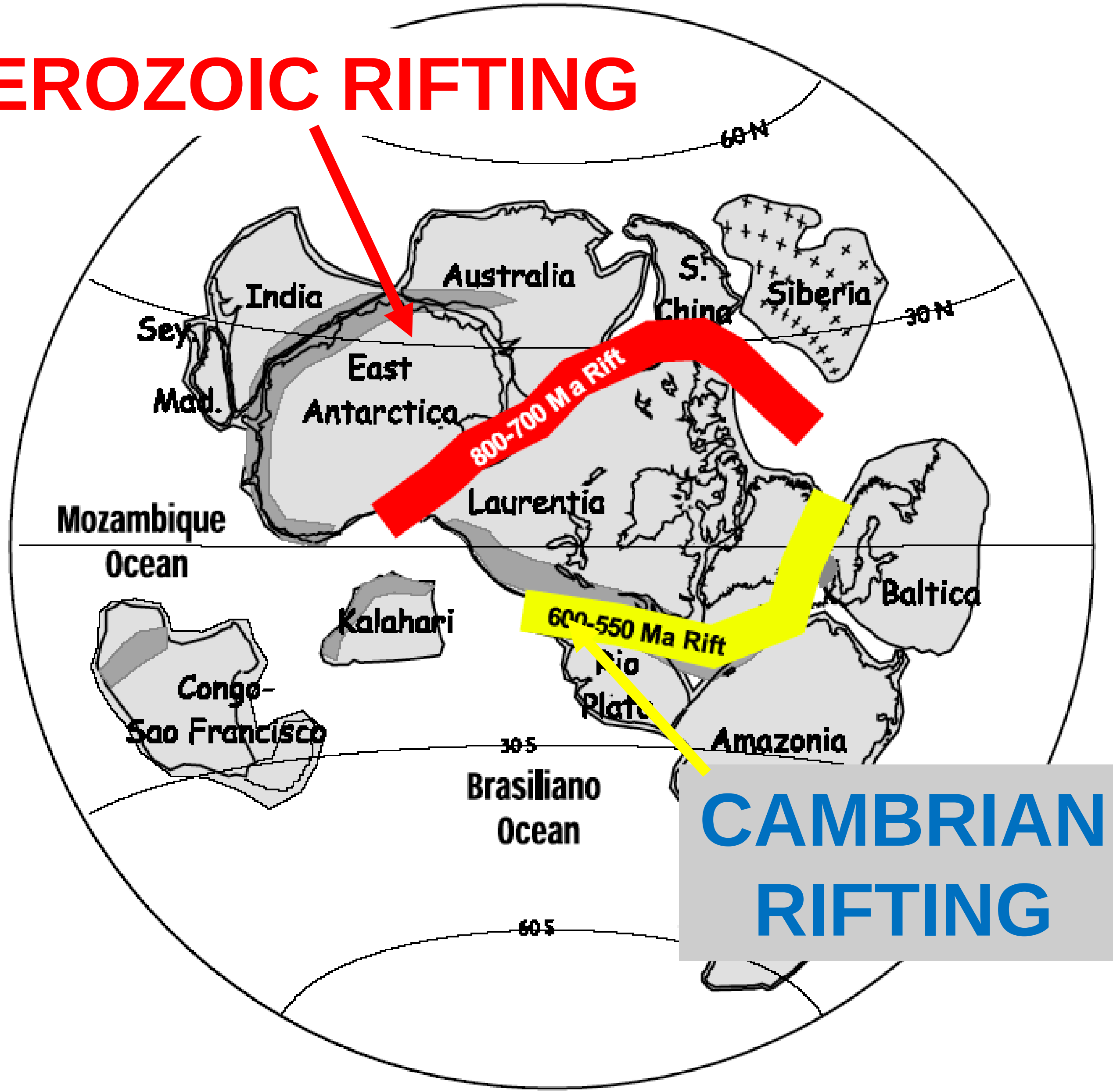
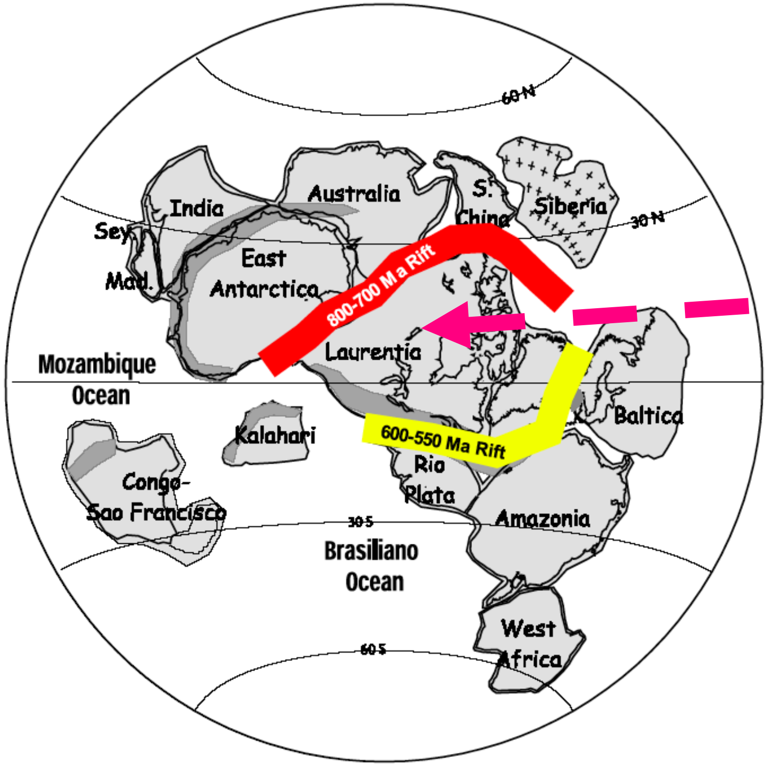


Fig. 1. The ‘traditional’ model of Rodinia adopted from Dalziel (1997) and Torsvik et al. (1996). The model posits two rifting events, the present-day western margin of Laurentia sometime between 800 and 700 Ma, and a second along the present-day eastern Laurentia between 600 and 550 Ma.

As Rodinia was being rifted apart at ca 750 Ma — along what is now the western margin of North America — some of its fragments were coming together 100 million years later in a collisional belt across what is now eastern Africa.

Therefore, Pangea was already starting to form while Rodinia was breaking up!



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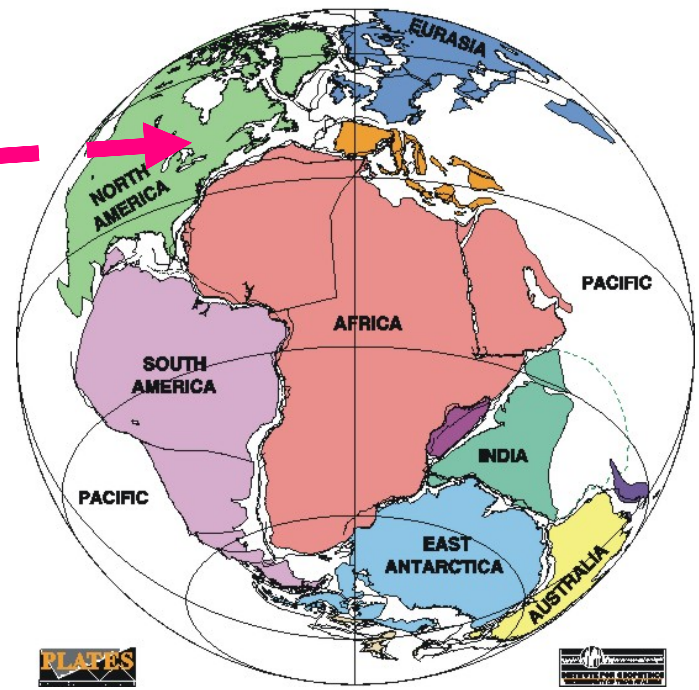
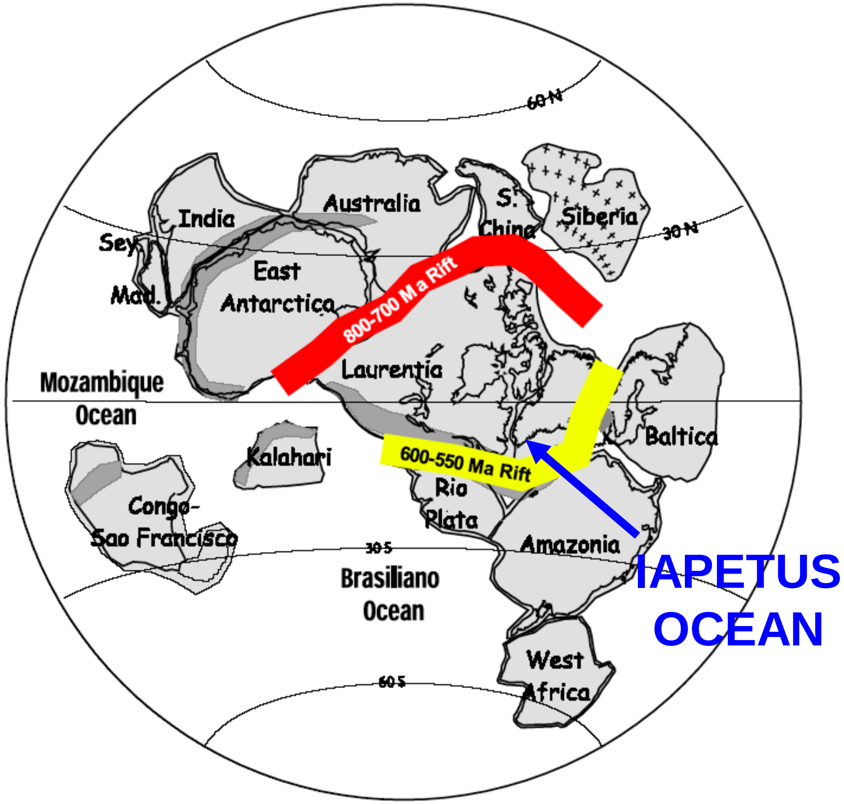
PANGEA



Is there a problem here? In the Rodinia map, rifting along the eastern side of Laurentia (now North America) is said to have occurred between 600 and 550 Ma, thus forming an ocean basin. Yet in the Pangea map of ca. 220 Ma there is no open ocean along the eastern edge of North America — only a continental orogenic belt. ?????



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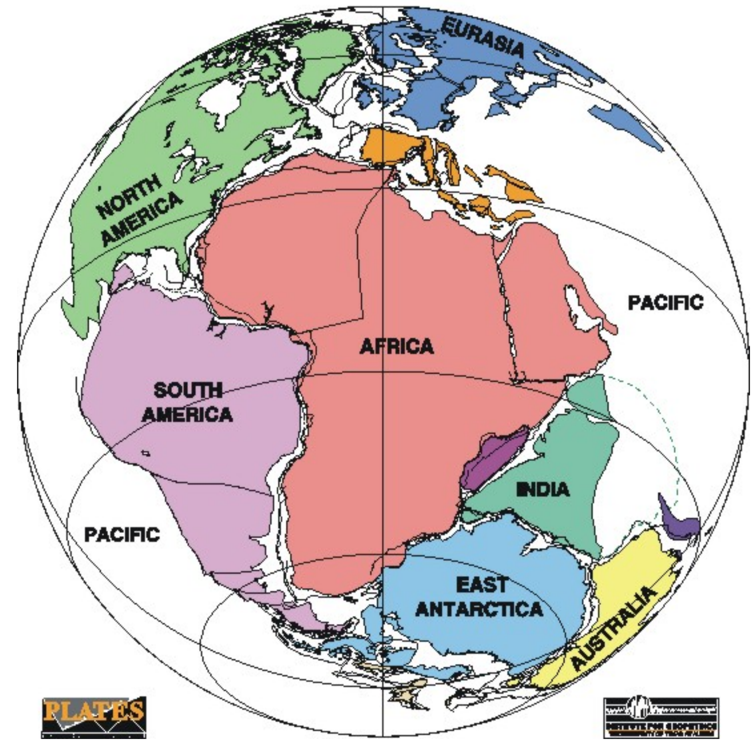
PANGEA



WAS AN EARLY OCEAN (IAPETUS) THAT OPENED BETWEEN 600 AND 500 MA, LATER CLOSED BY 220 MA? … AND THEN RE-OPENED AGAIN WITH THE BREAKUP OF PANGEA? THAT WAS A QUESTION ASKED BY J. TUZO WILSON IN 1966

THE WILSON CYCLE

The Making and Unmaking of Supercontinents ….

THE WILSON CYCLE

The Wilson Cycle (after J. B. Murphy and R. D. Nance, Scientific American, April 1992)

GOOGLE :

James Wilson's Cycle

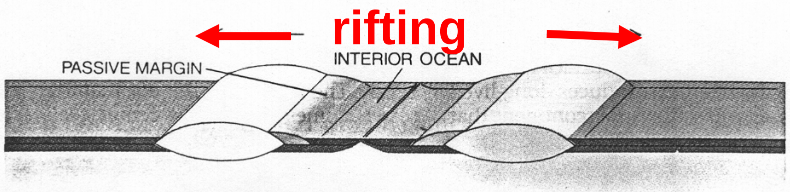
?

The Wilson Cycle (after J. B. Murphy and R. D. Nance, Scientific American, April 1992)

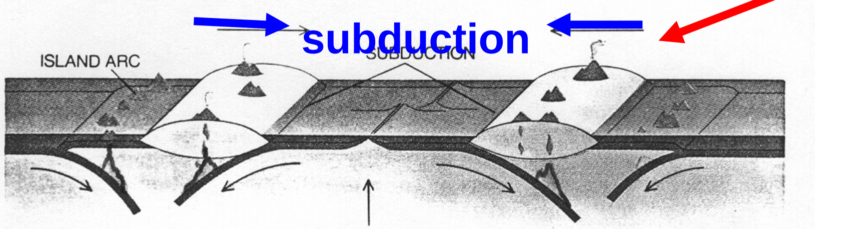
GOOGLE :

James Wilson's Cycle

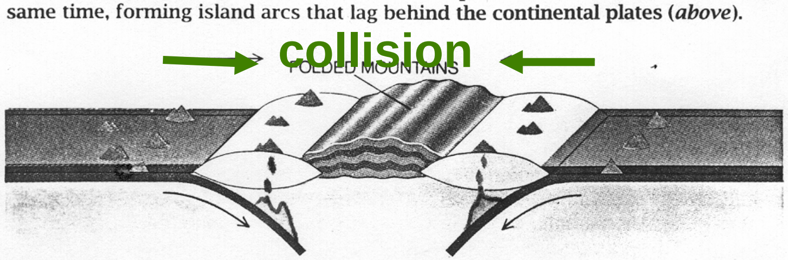
ow the Supercontinent Cycle Works



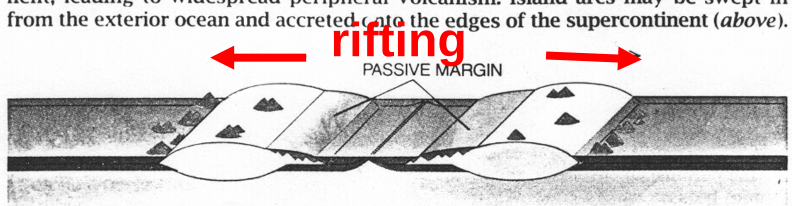
BREAKUP OF A SUPERCONTINENT results in the birth of interior oceans like the present Atlantic (*left*). Inward-facing margins of the separating continents are tectonically stable; undisturbed sediments collect along the margins, recording this period of relative placidity (*above*). Passive margin sediments continue to collect until the continents reach their maximum dispersal.



MAXIMUM DISPERSAL of the continents occurs when the interior oceans are about 200 million years old. Then the oldest parts of the interior oceans begin to sink, or subduct, into the earth (*left*). Subduction generates magma that fuels volcanoes in the overlying continent. Subduction can take place in the exterior ocean at the same time, forming island arcs that lag behind the continental plates (*above*).



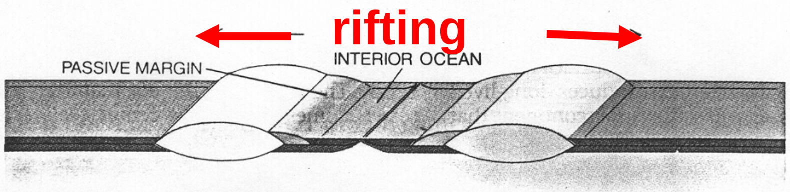
CONTINENTAL COLLISIONS happen after the interior oceans are consumed. Collisions create interior mountain belts and broad areas of intense deformation, uplift and erosion (*left*). Subduction zones occur around the margin of the supercontinent, leading to widespread peripheral volcanism. Island arcs may be swept in from the exterior ocean and accreted onto the edges of the supercontinent (*above*).



NEXT SUPERCONTINENT BREAKUP results from thermal and rotational forces. Exterior subduction continues where the continental margin is roughly perpendicular to the direction of its motion (*left figure, top*). Transform, or sideways, faults appear where the motion of the plate is nearly parallel to the orientation of the margin (*left figure, bottom*). Passive margin sediments resume collecting (*above*).

The Wilson Cycle (after J. B. Murphy and R. D. Nance, Scientific American, April 1992)

ow the Supercontinent Cycle Works



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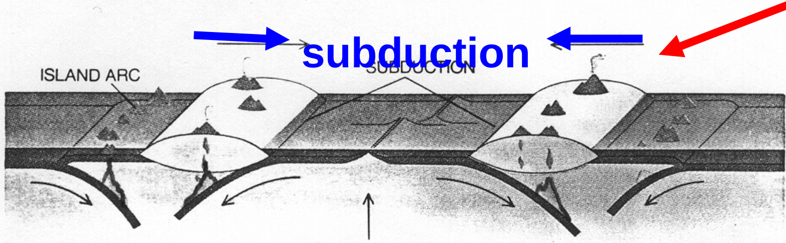

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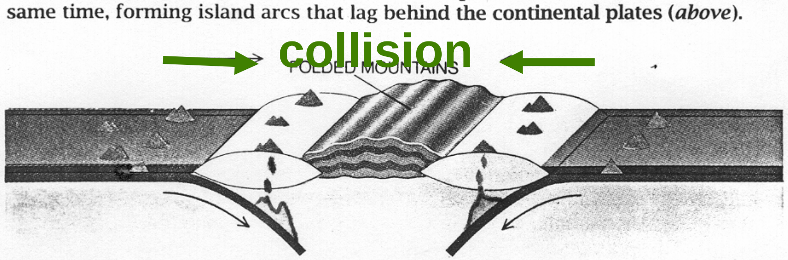

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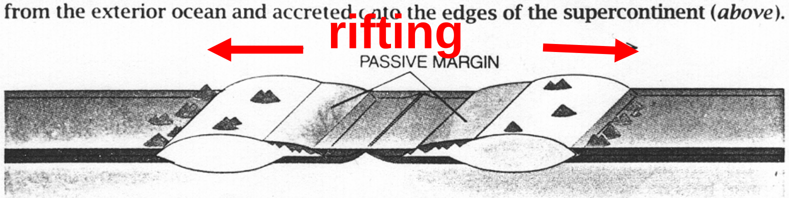

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The Wilson Cycle (after J. B. Murphy and R. D. Nance, Scientific American, April 1992)

These diagrams can be much too simple. For example, in the first "rifting" diagram the "interior ocean" doesn't have to close by "subduction". The spreading ocean can continue to spread so that the rifted continental fragments may come together in a "collision" on the other side of planet Earth!

<u>Did</u> the Atlantic Ocean Close and Reopen?

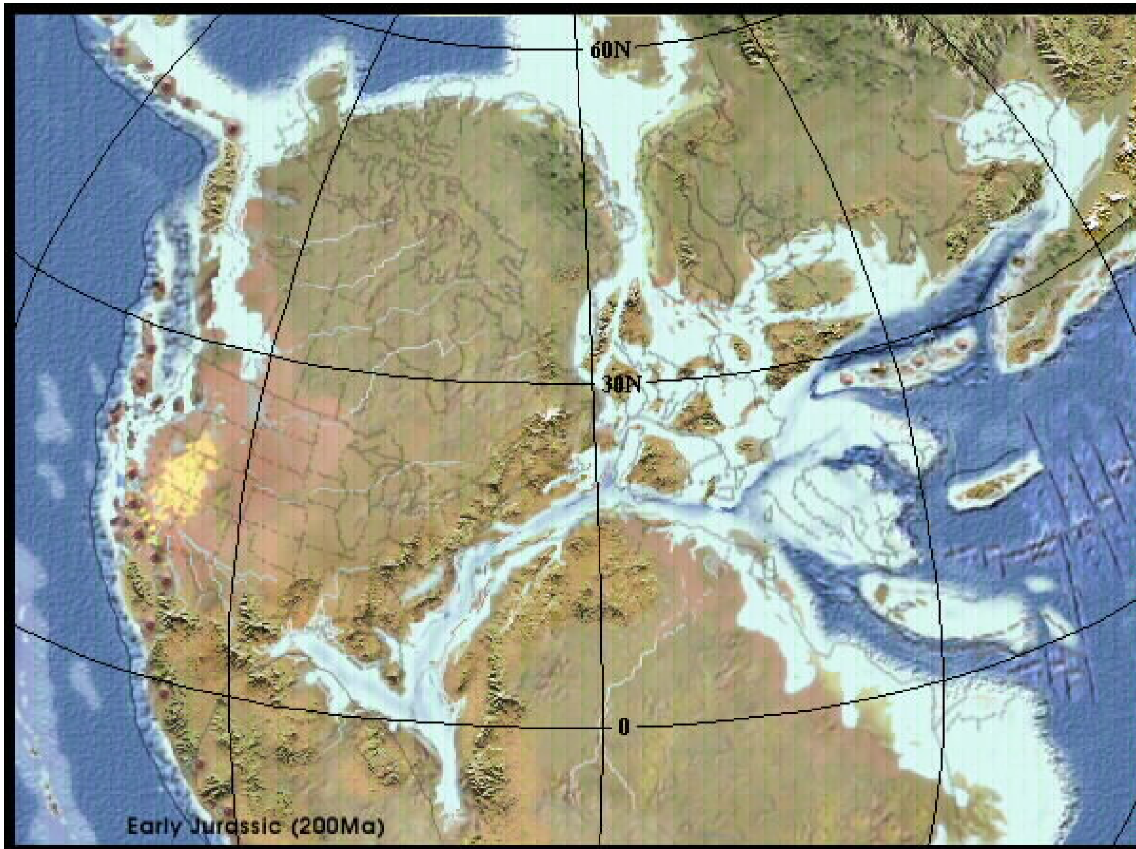
Tectonic inheritance at a continental margin

William A. Thomas, *Department of Geological Sciences, University of Kentucky, Lexington, Kentucky 40506-0053, USA, geowat@uky.edu*

INTRODUCTION

Forty years ago, the eastern margin of North America inspired Tuzo Wilson (1966) to ask, "Did the Atlantic close and then re-open?" The Wilson cycle of closing and opening of ocean basins incorporates the cyclic assembly and breakup of supercontinents. Alternate processes of extension and compression of continental margins suggest an important potential for tectonic inheritance and overprinting.

Now, we recognize a succession of two complete Wilson cycles in eastern North America: closing of an ocean and assembly of the Rodinia supercontinent, breakup of Rodinia and opening of the Iapetus Ocean, closing of Iapetus and assembly of the Pangaea supercontinent, and breakup of Pangaea and opening of the Atlantic Ocean (Fig. 1).



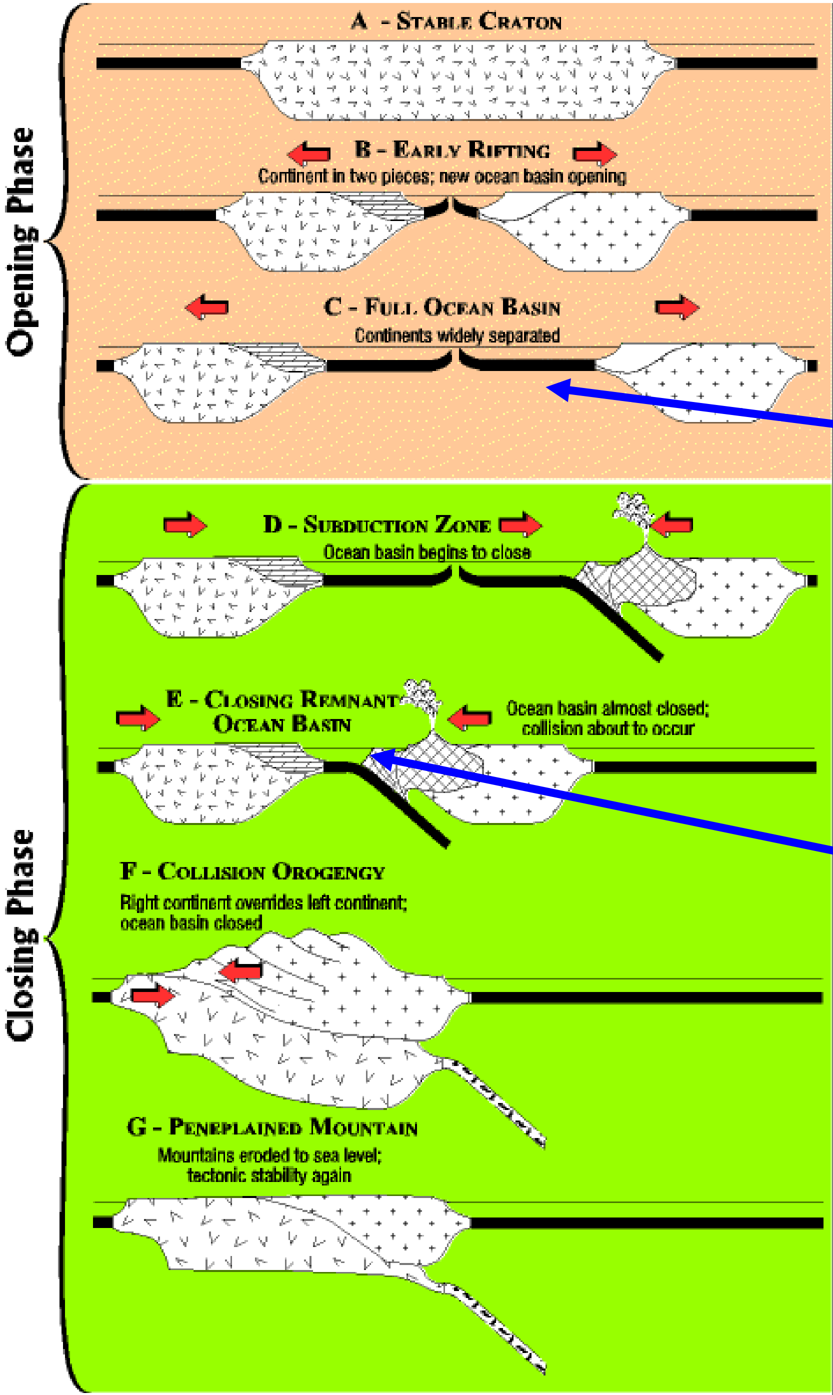
Yes! Twice!

RODINIA

IAPETUS OCEAN

PANGEA

ATLANTIC OCEAN



RODINIA

rifting

IAPETUS OCEAN

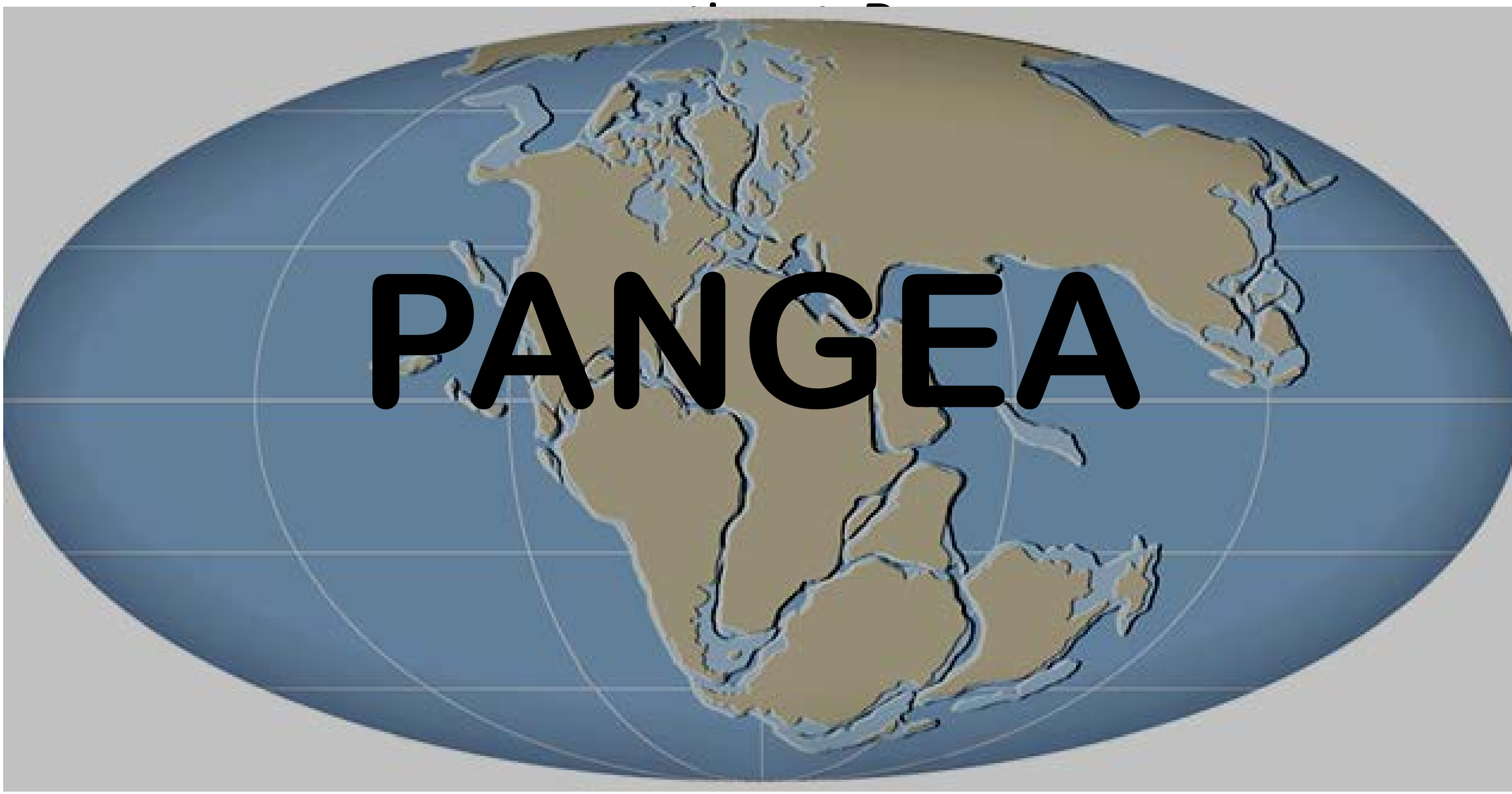
subduction, convergence

collision and closing of IAPETUS

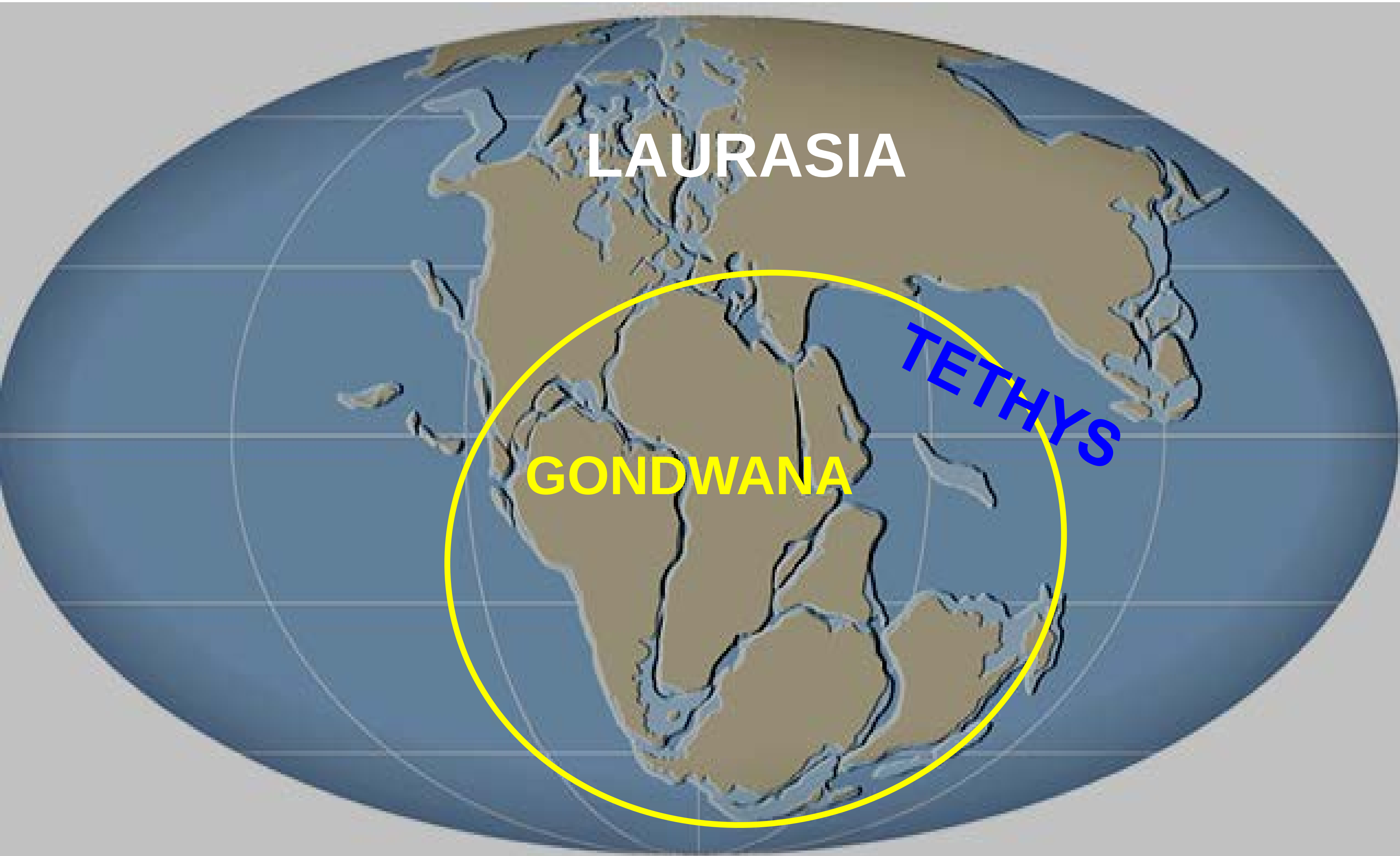
APPALACHIAN and CALEDONIAN OROGEN

PANGEA

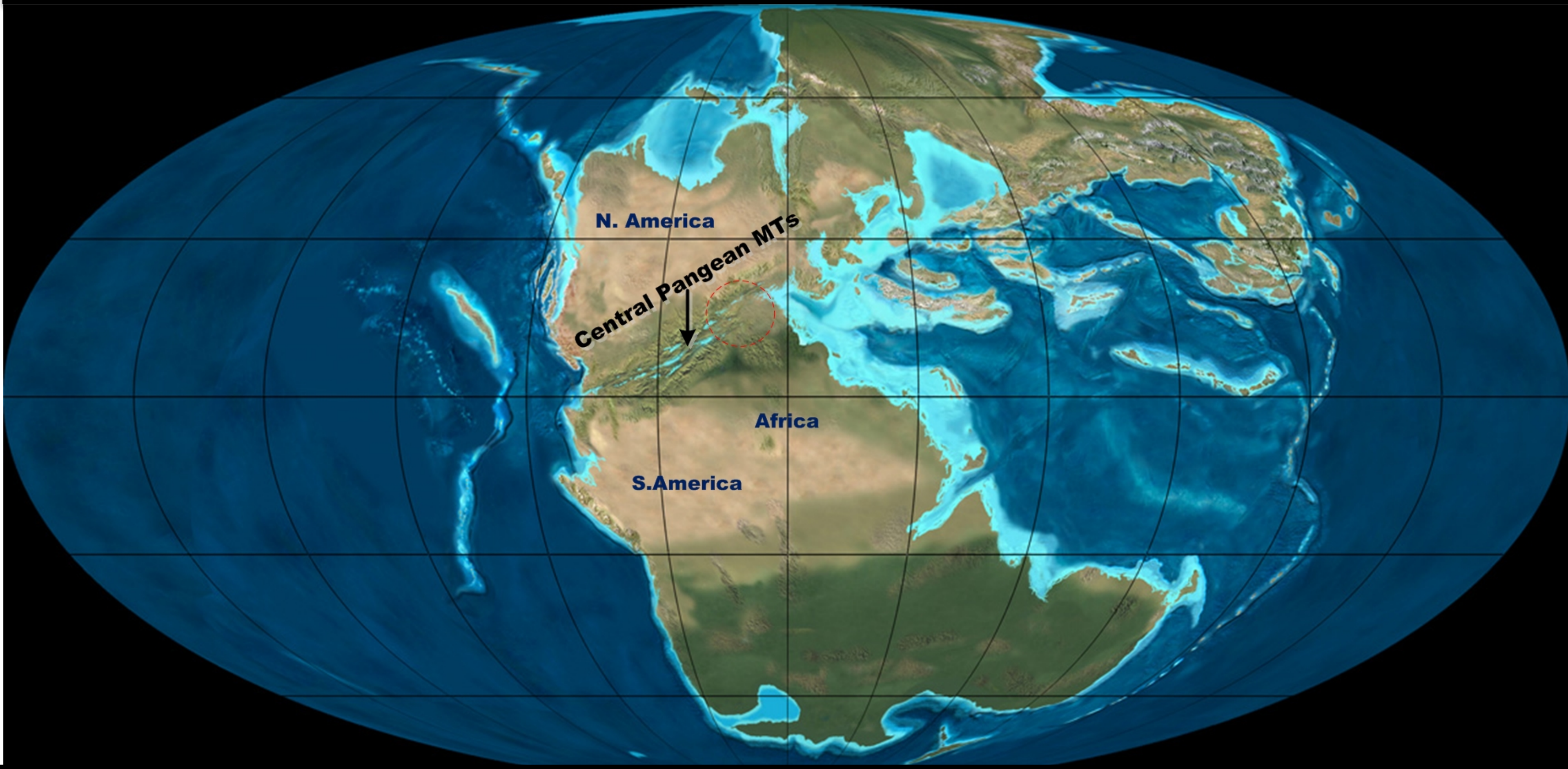
The continents have changed shapes and positions throughout geologic time! This is a reconstruction of the



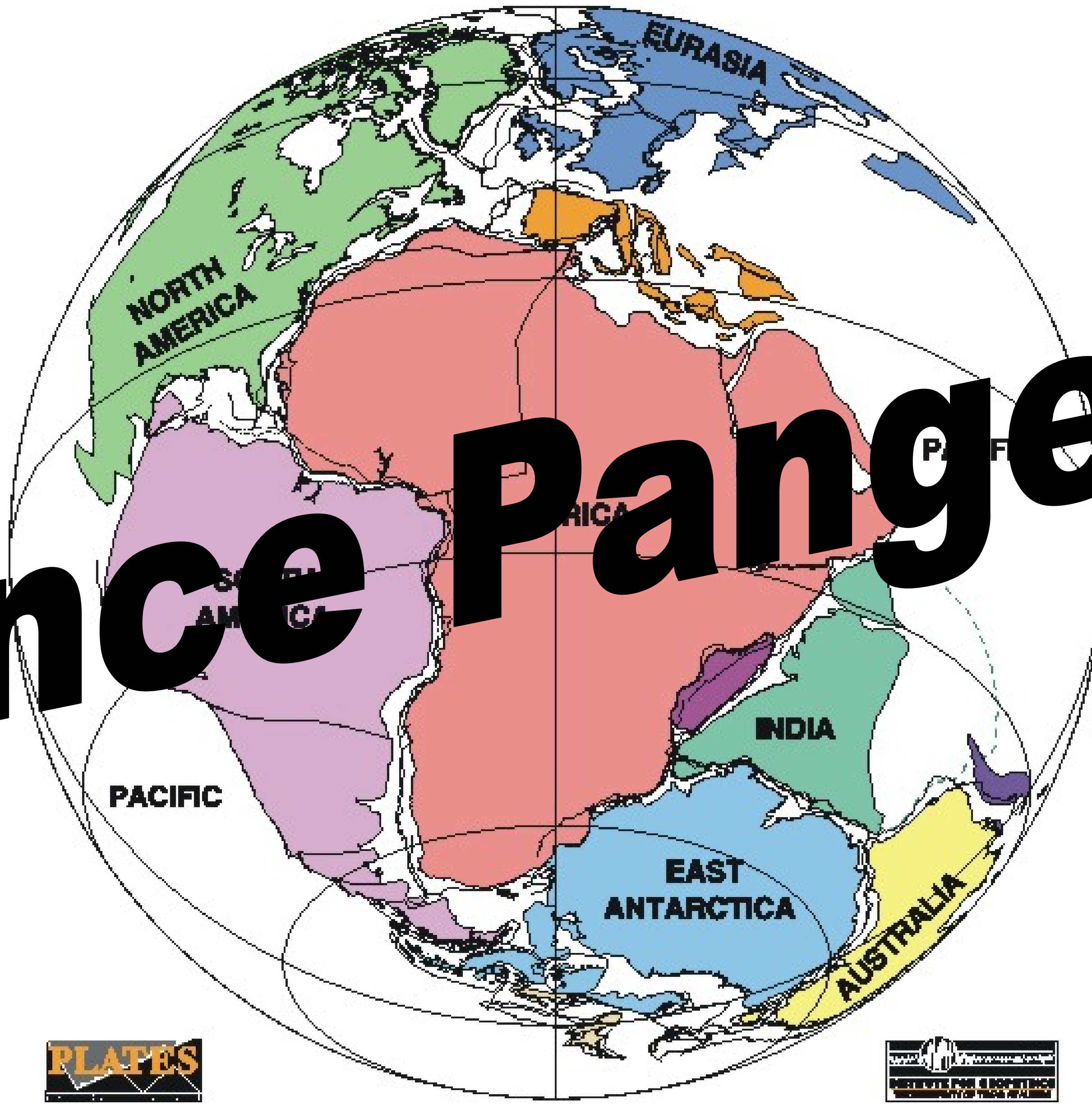
The continents have changed shapes and positions throughout geologic time! This is a reconstruction of the supercontinent Pangea as it may have looked in Permian time.



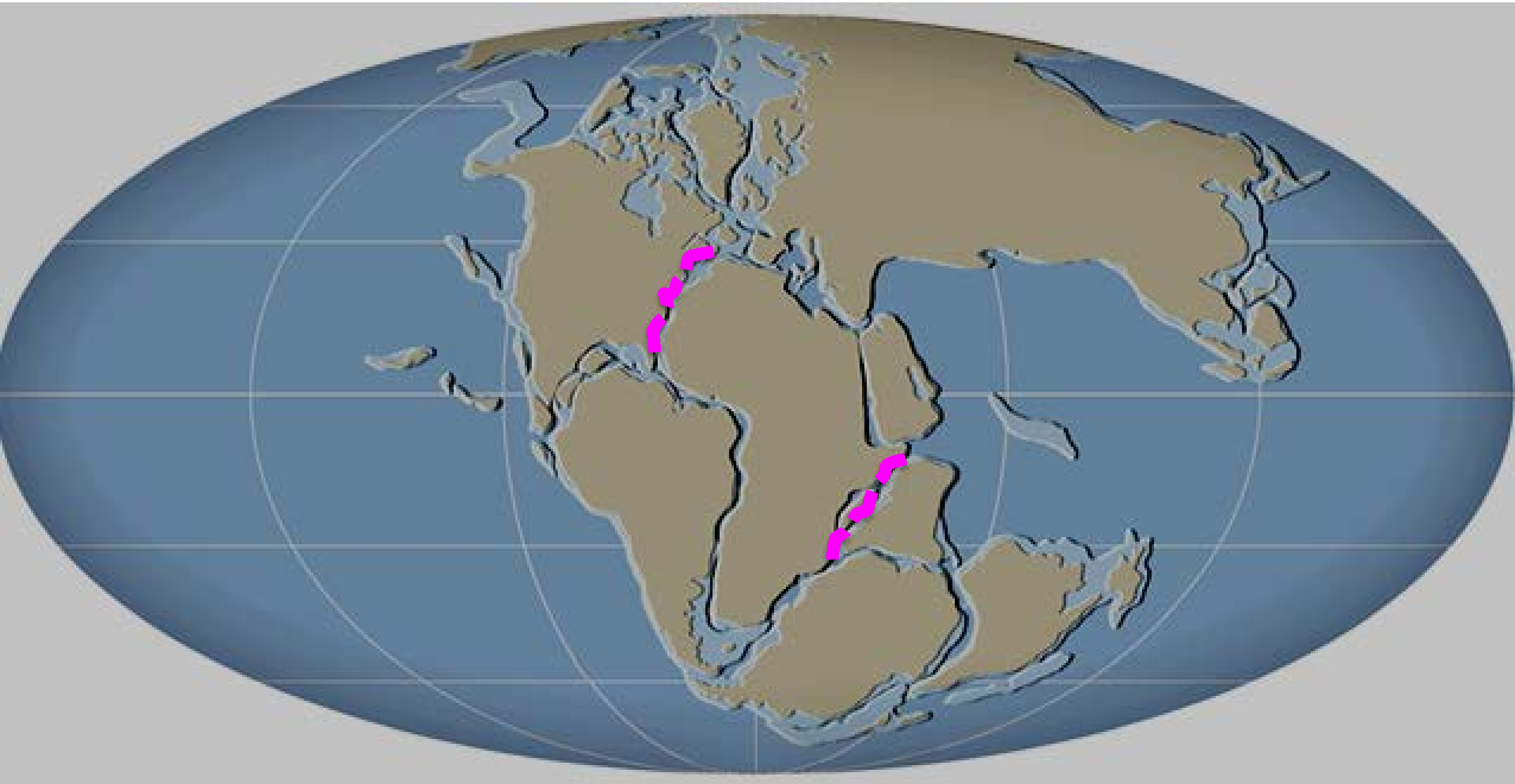
PANGEA — AN IMPROVEMENT OVER WEGENER

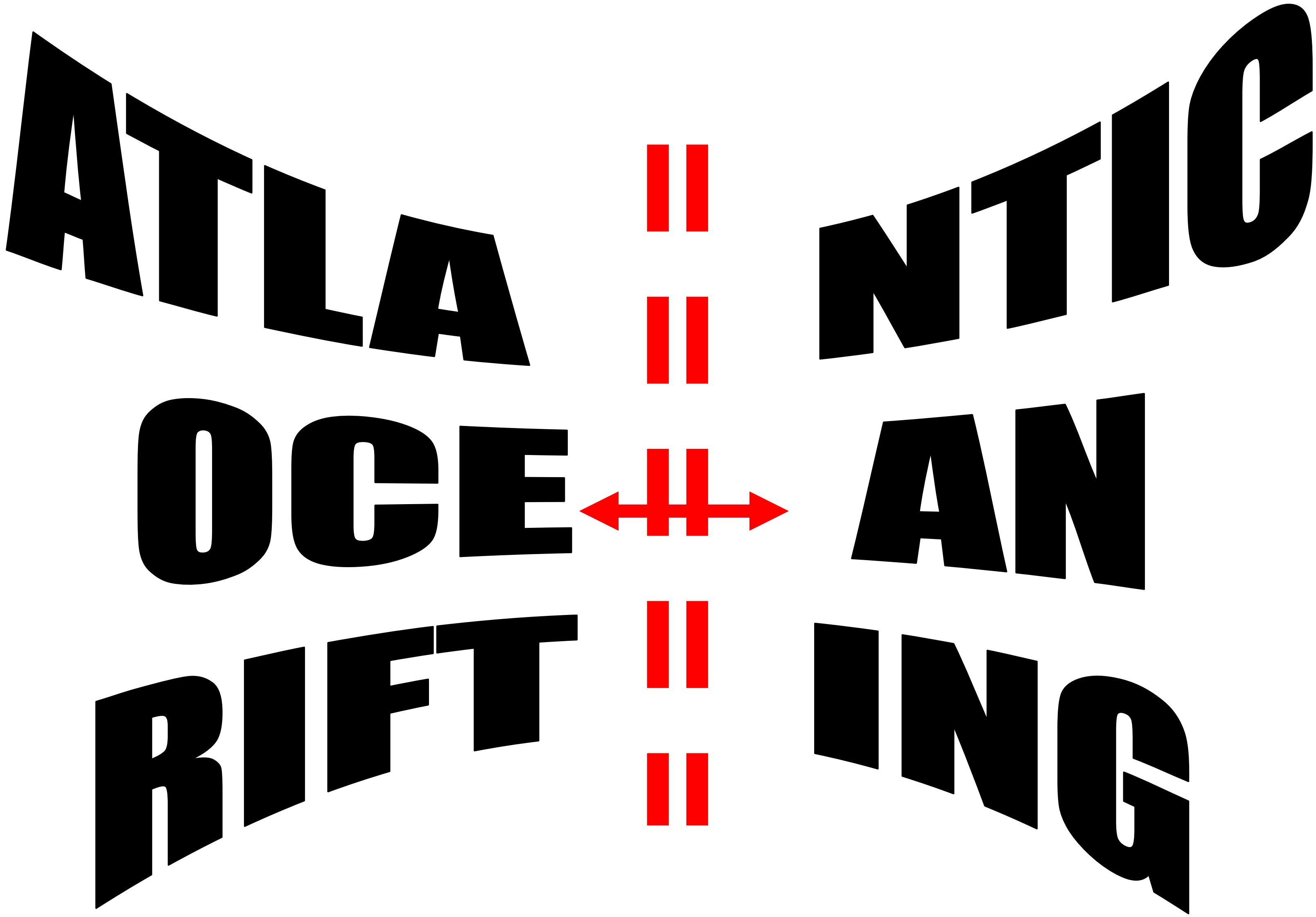


Since Pangea

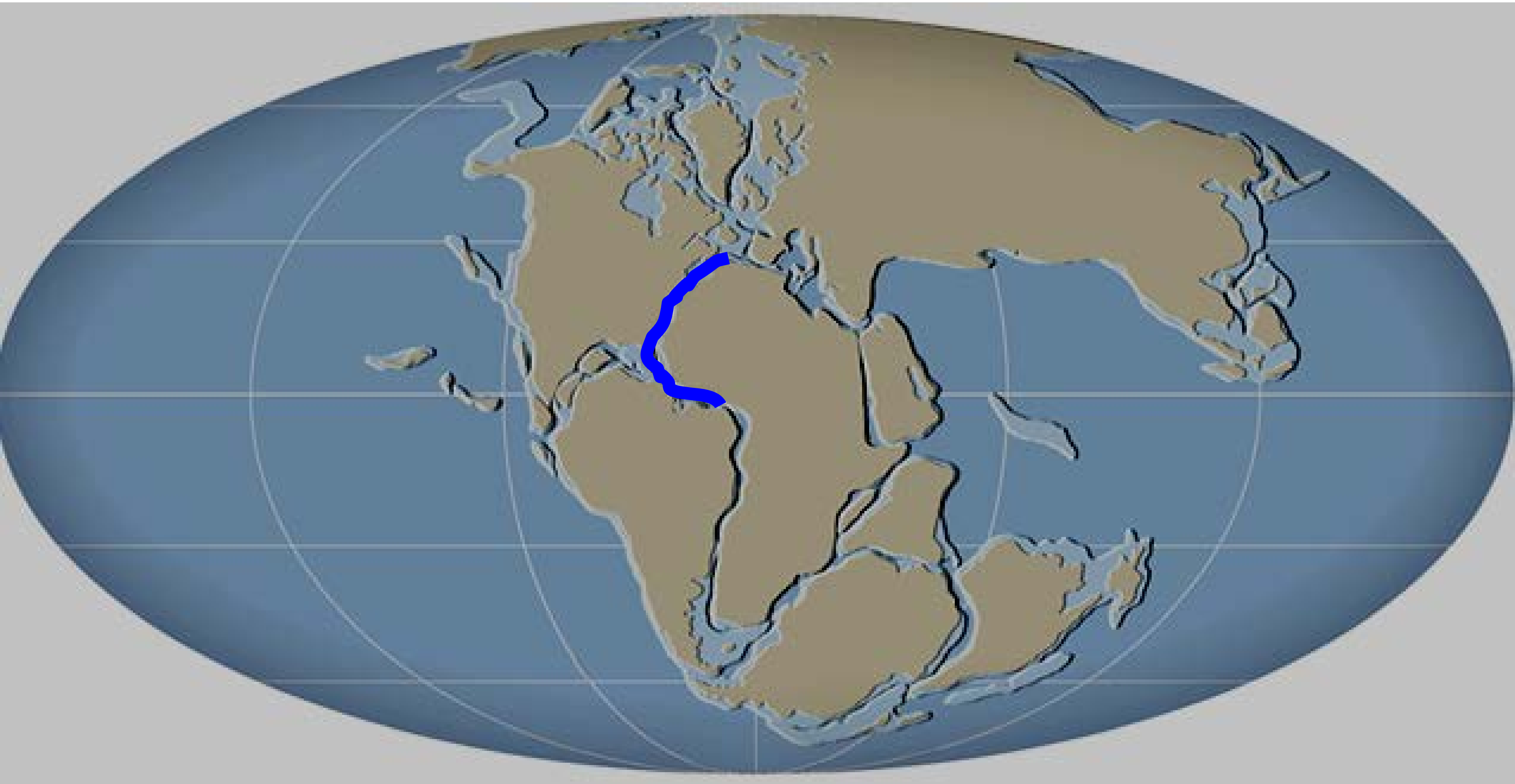


Beginning in the Triassic around 230-220 million years ago, Pangea began to split up




ATLA NTIC
OCE AN
RIFT ING

The process was complicated in space and in time.
for example, the Atlantic Ocean opened in 3 stages:
Jurassic, Cretaceous, and Tertiary



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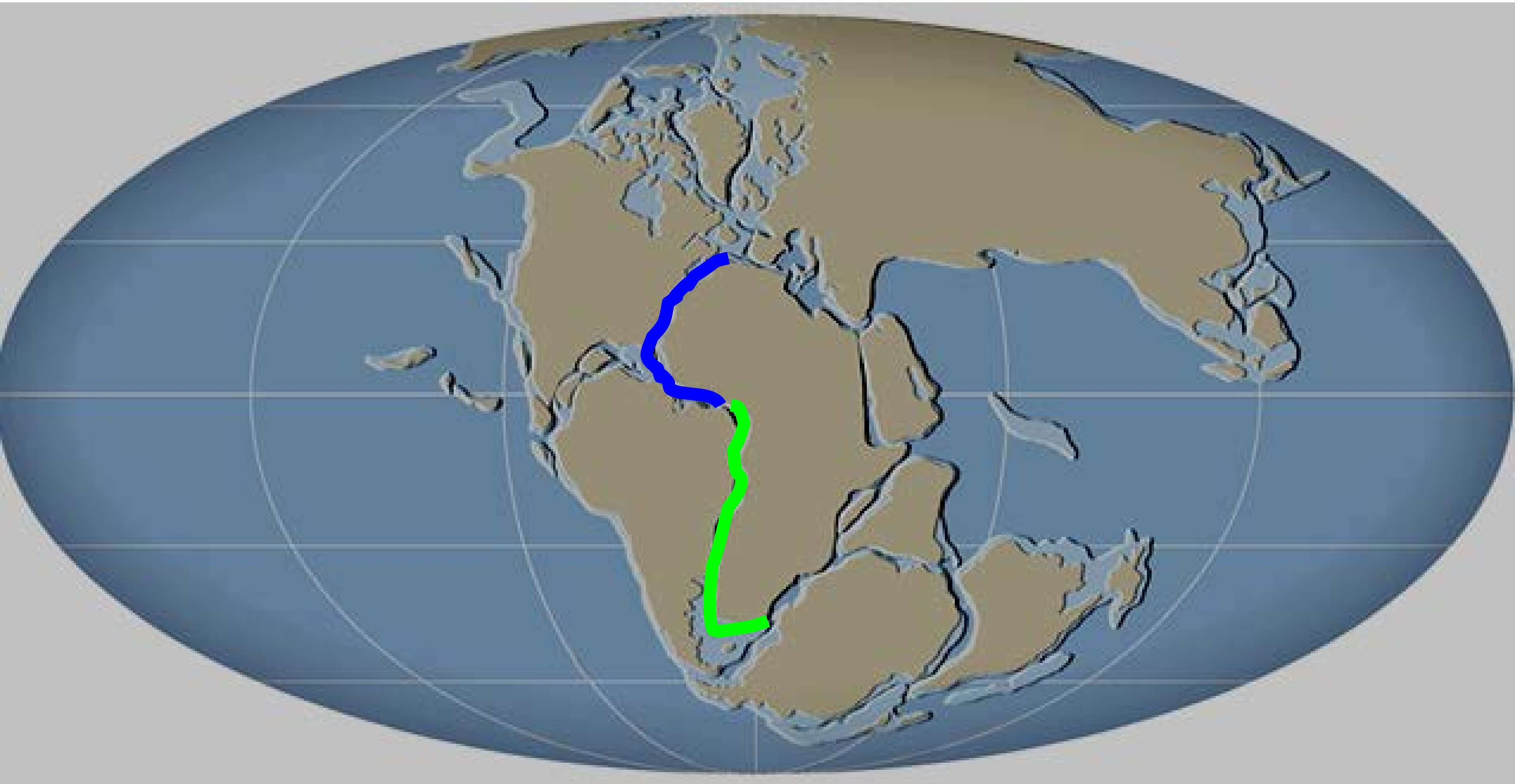
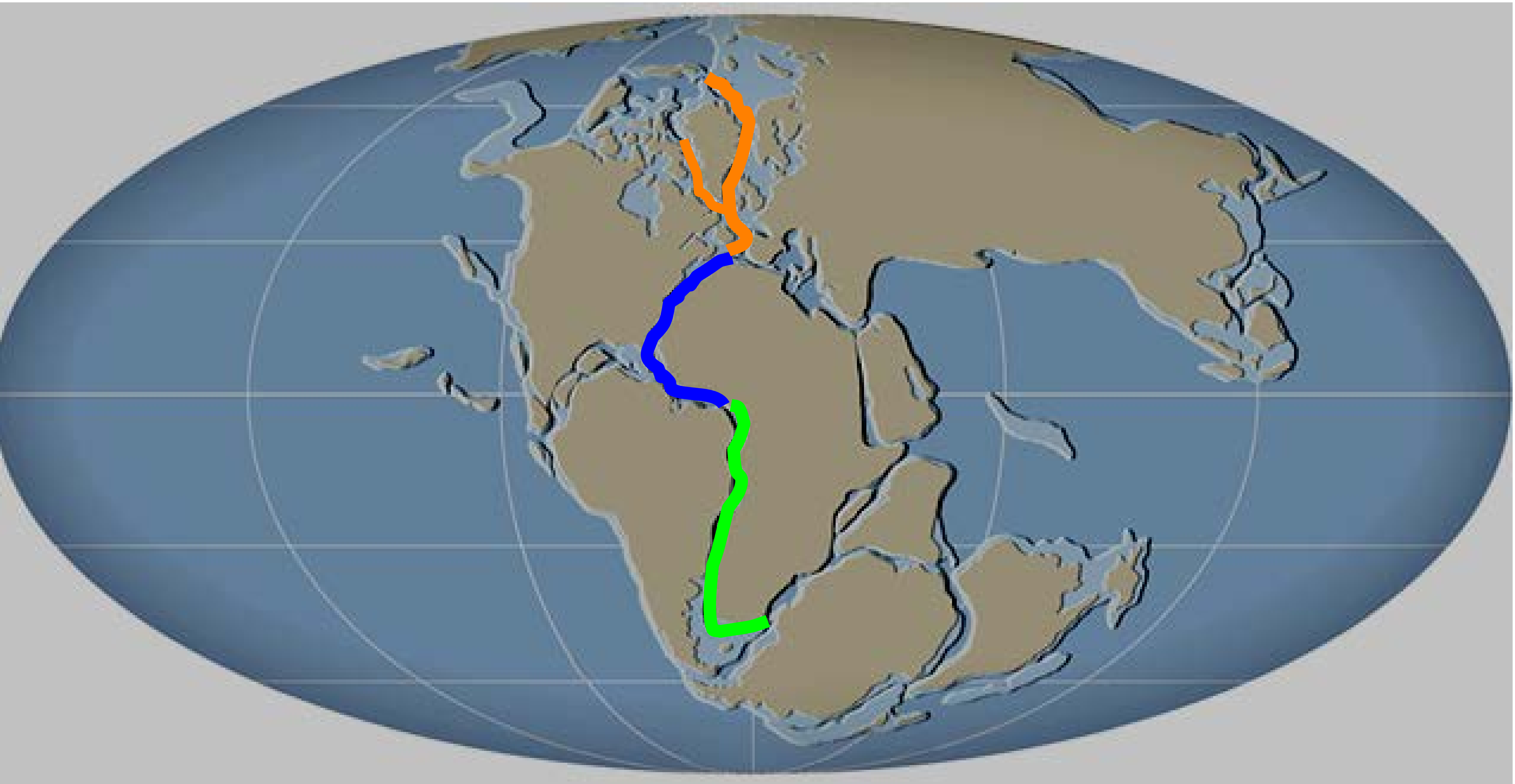
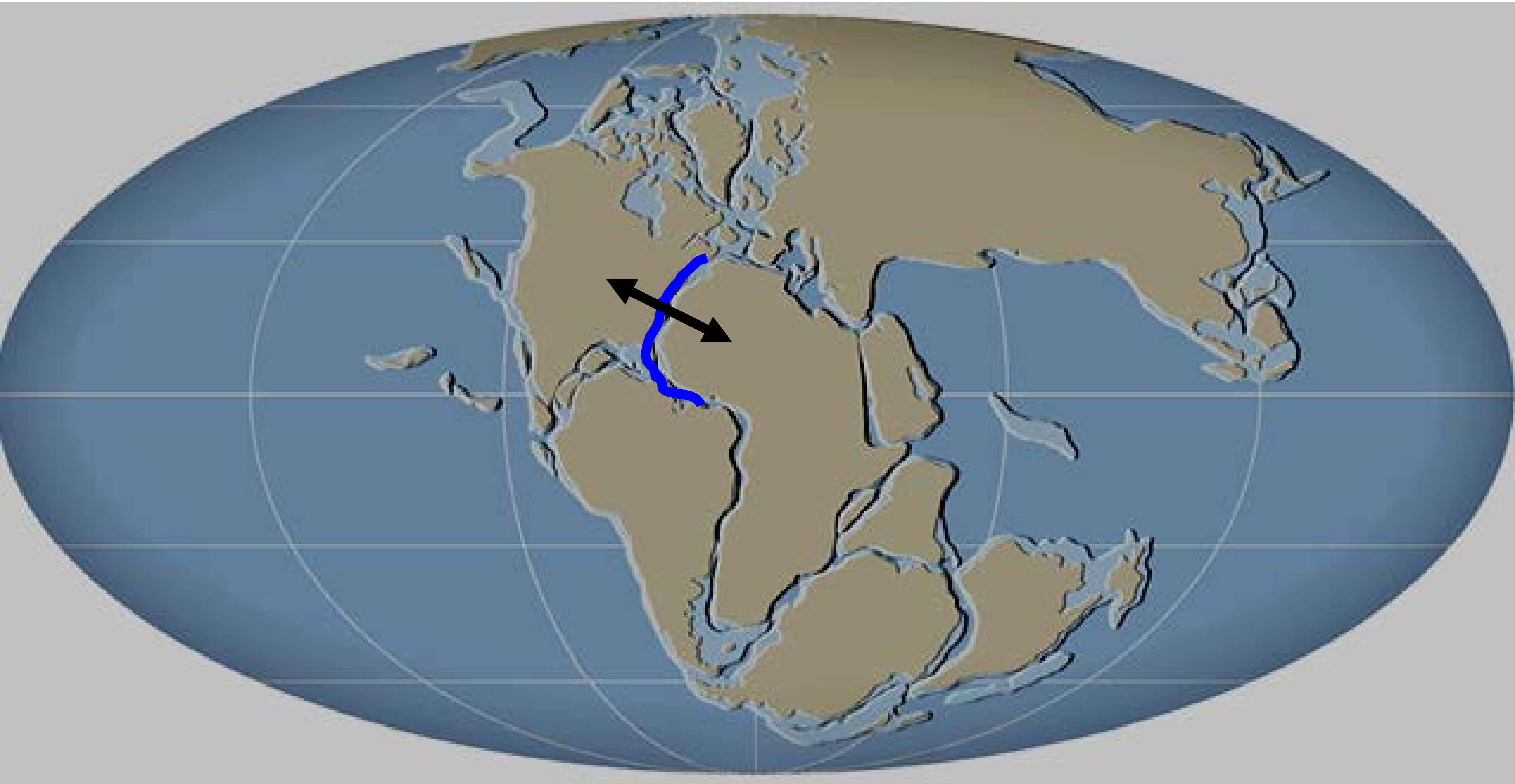


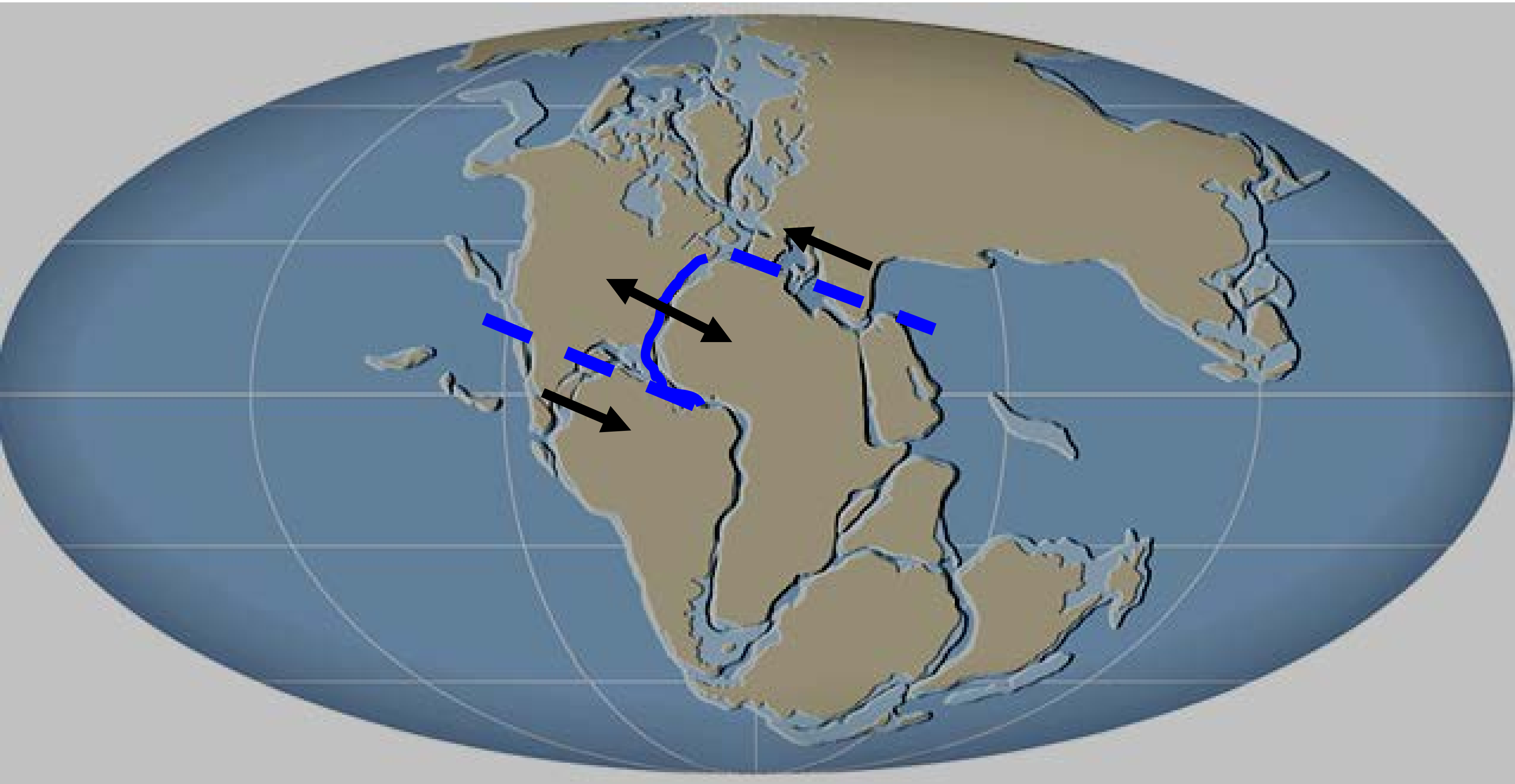
The process was complicated in space and in time. for example, the Atlantic Ocean opened in 3 stages: Jurassic, Cretaceous, and Tertiary

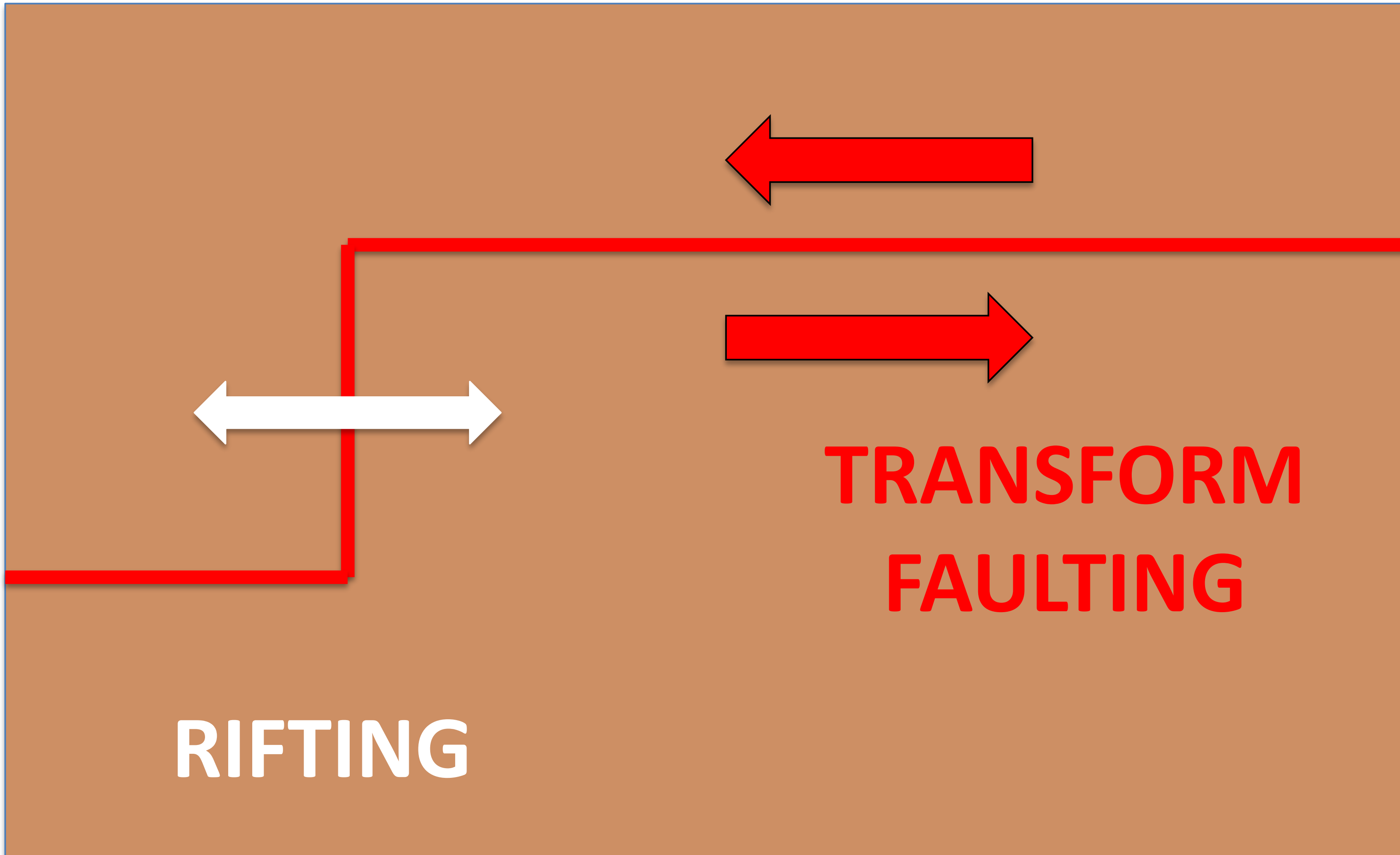


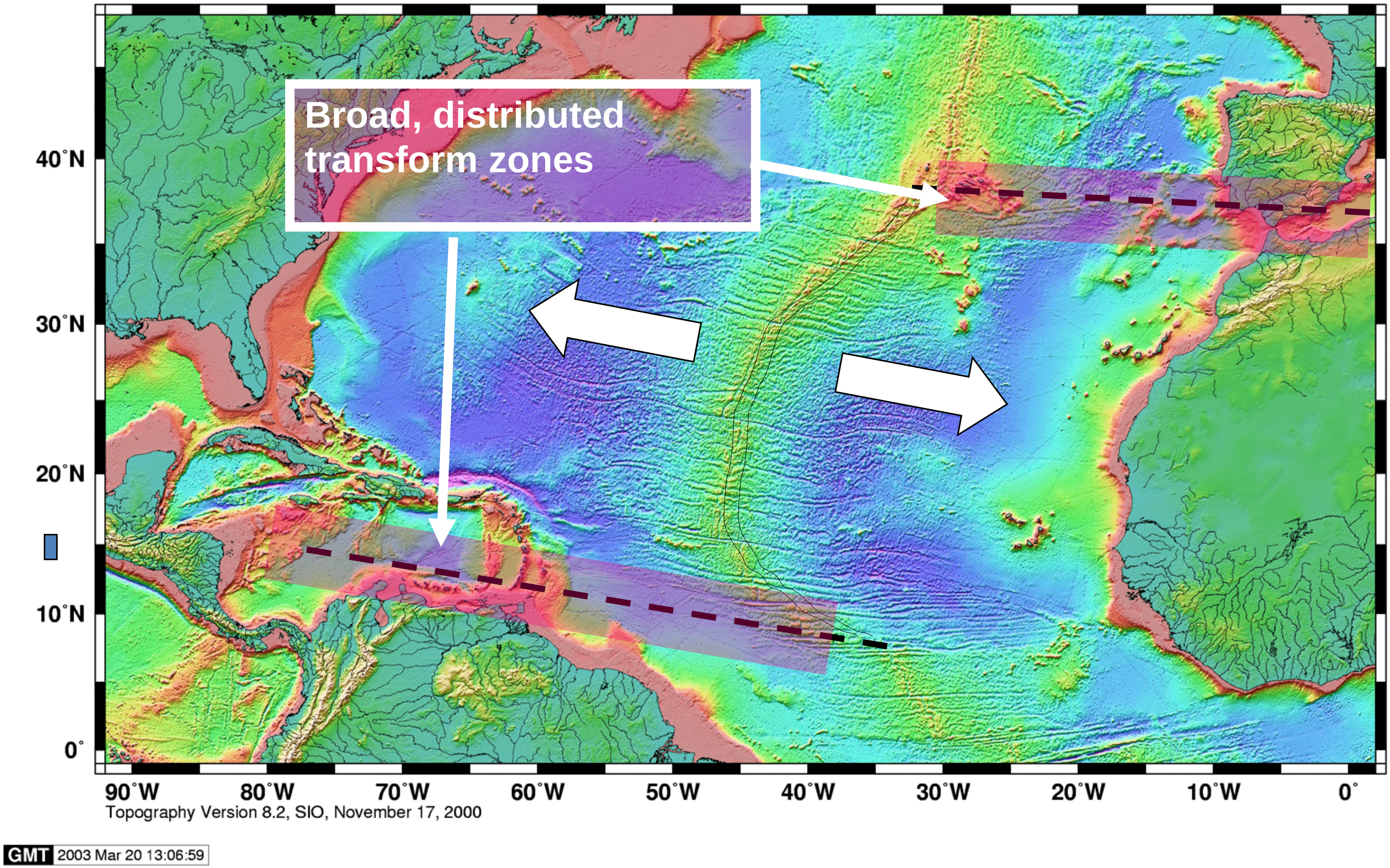
How could JUST the middle Atlantic open?



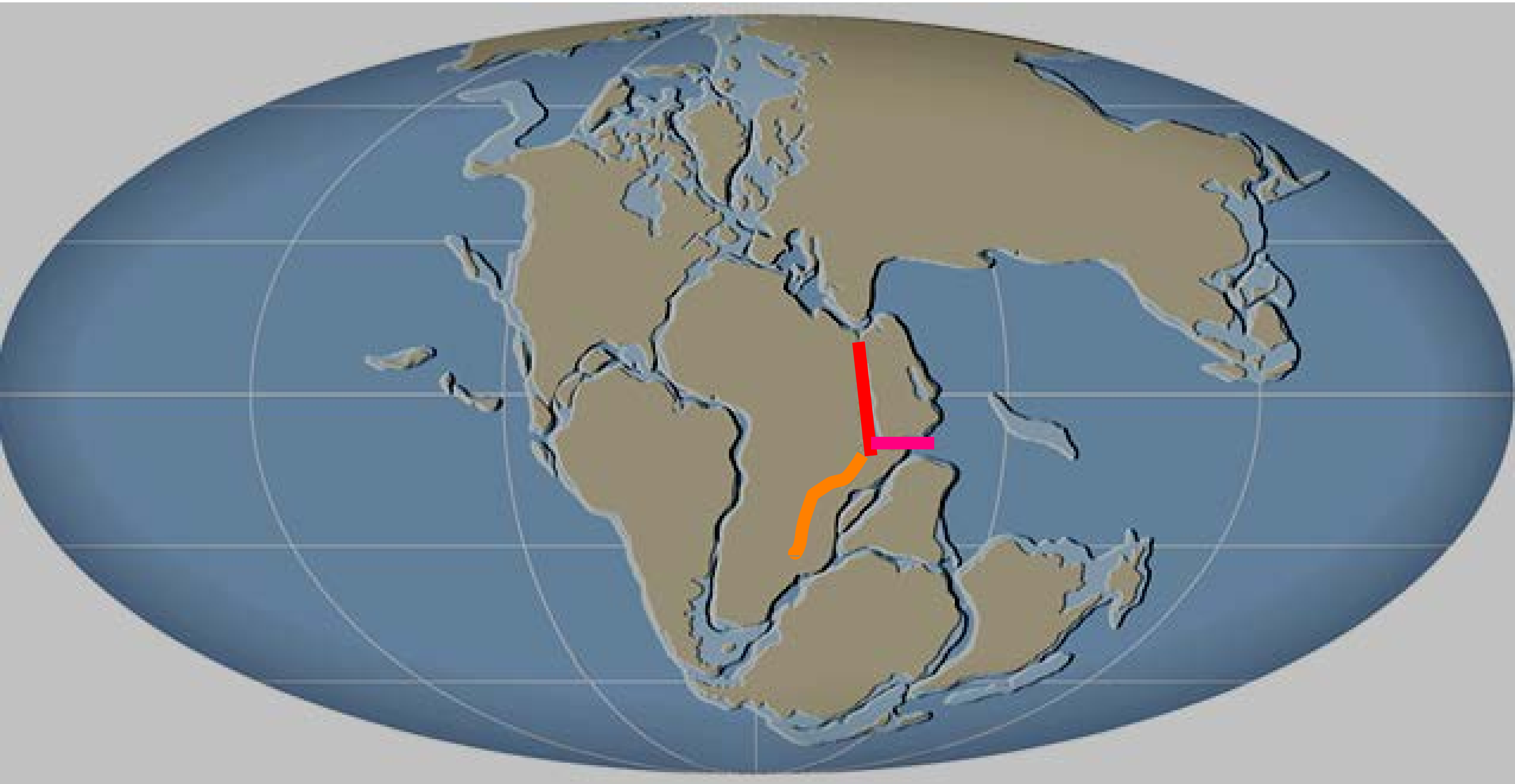
This way! By transform fault zones as shown …

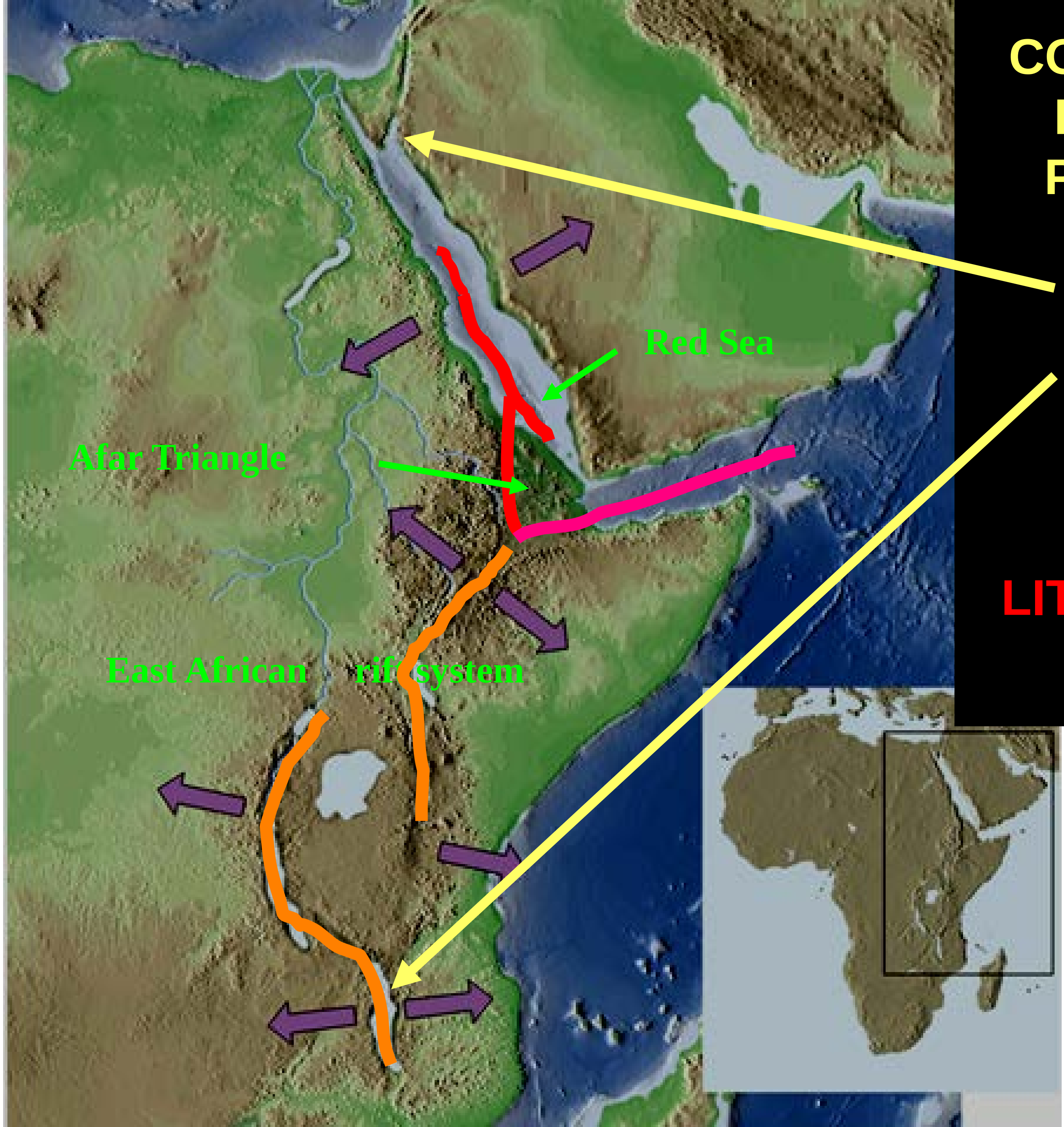



TRANSFORM
FAULTING
RIFTING


Broad, distributed transform zones
40°N
30°N
20°N
10°N
0°
90°W
80°W
70°W
60°W
50°W
40°W
30°W
20°W
10°W
0°
Topography Version 8.2, SIO, November 17, 2000
GMT 2003 Mar 20 13:06:59

The process of the splitting up of Pangea continues to this day in the Red Sea, Gulf of Aden, and East Africa.





CONTINENTAL RIFTING IN PROGRESS FROM NORTH TO SOUTH WITH OCEAN LITHOSPHERE IN RED & PINK

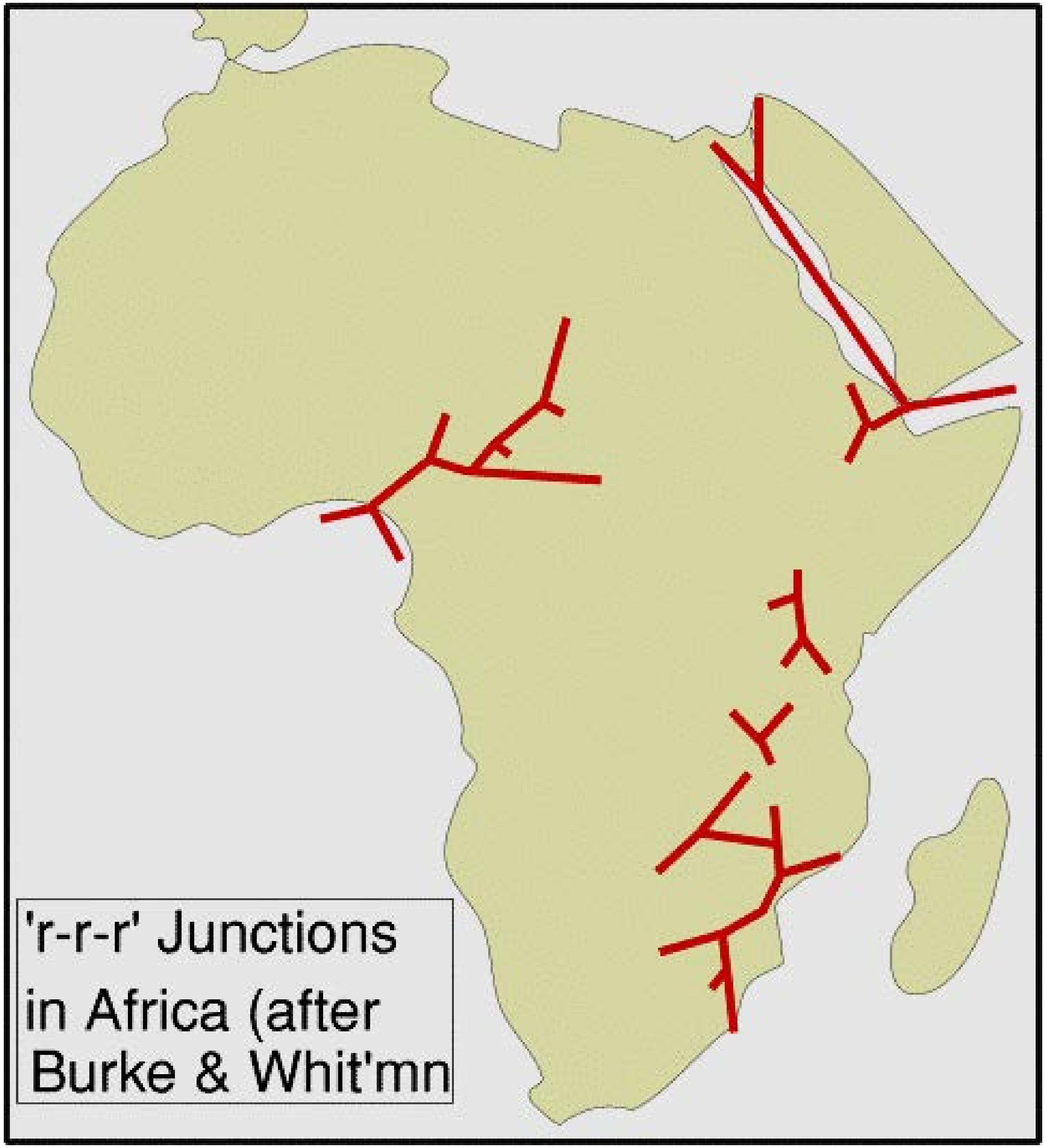
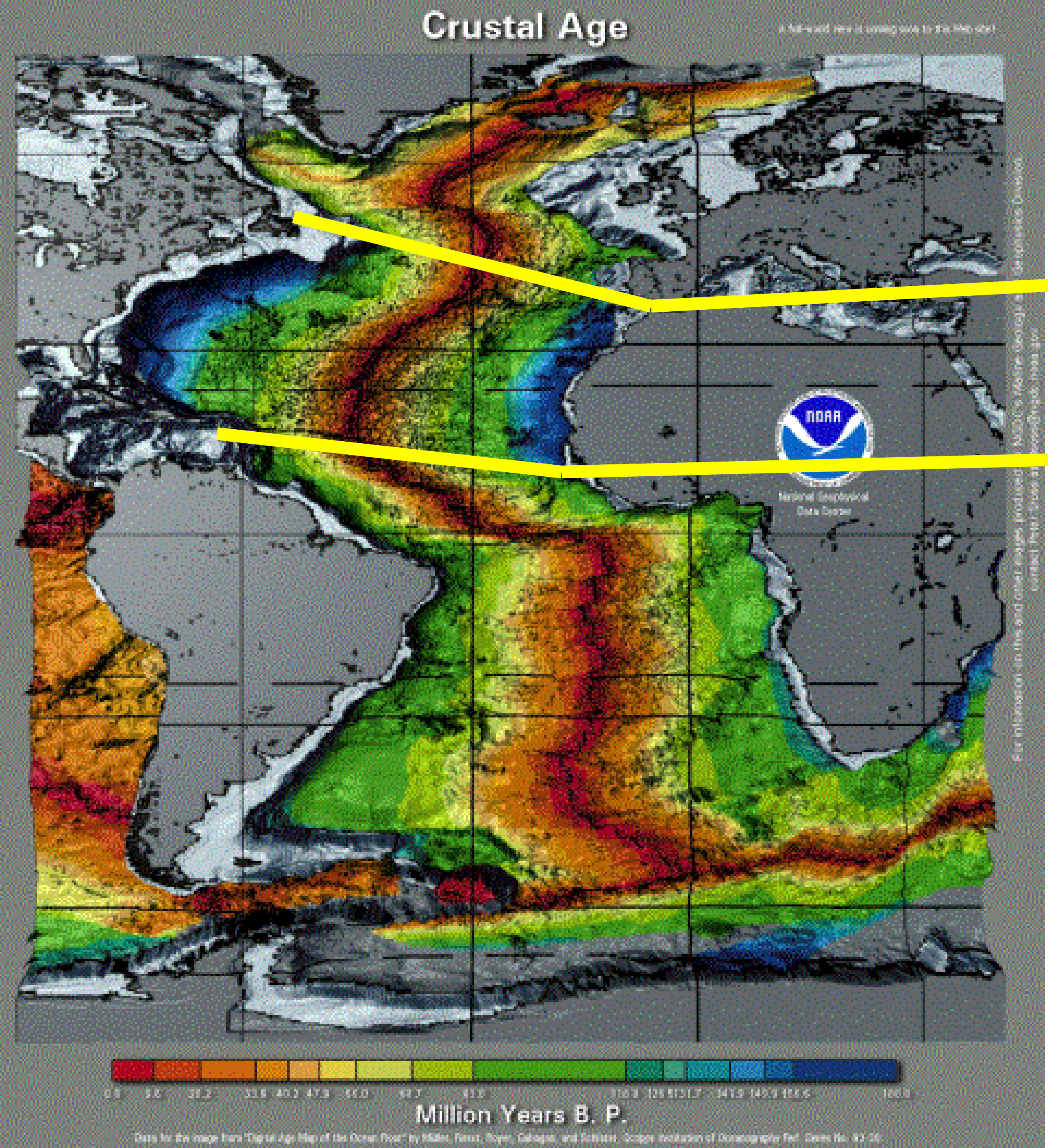


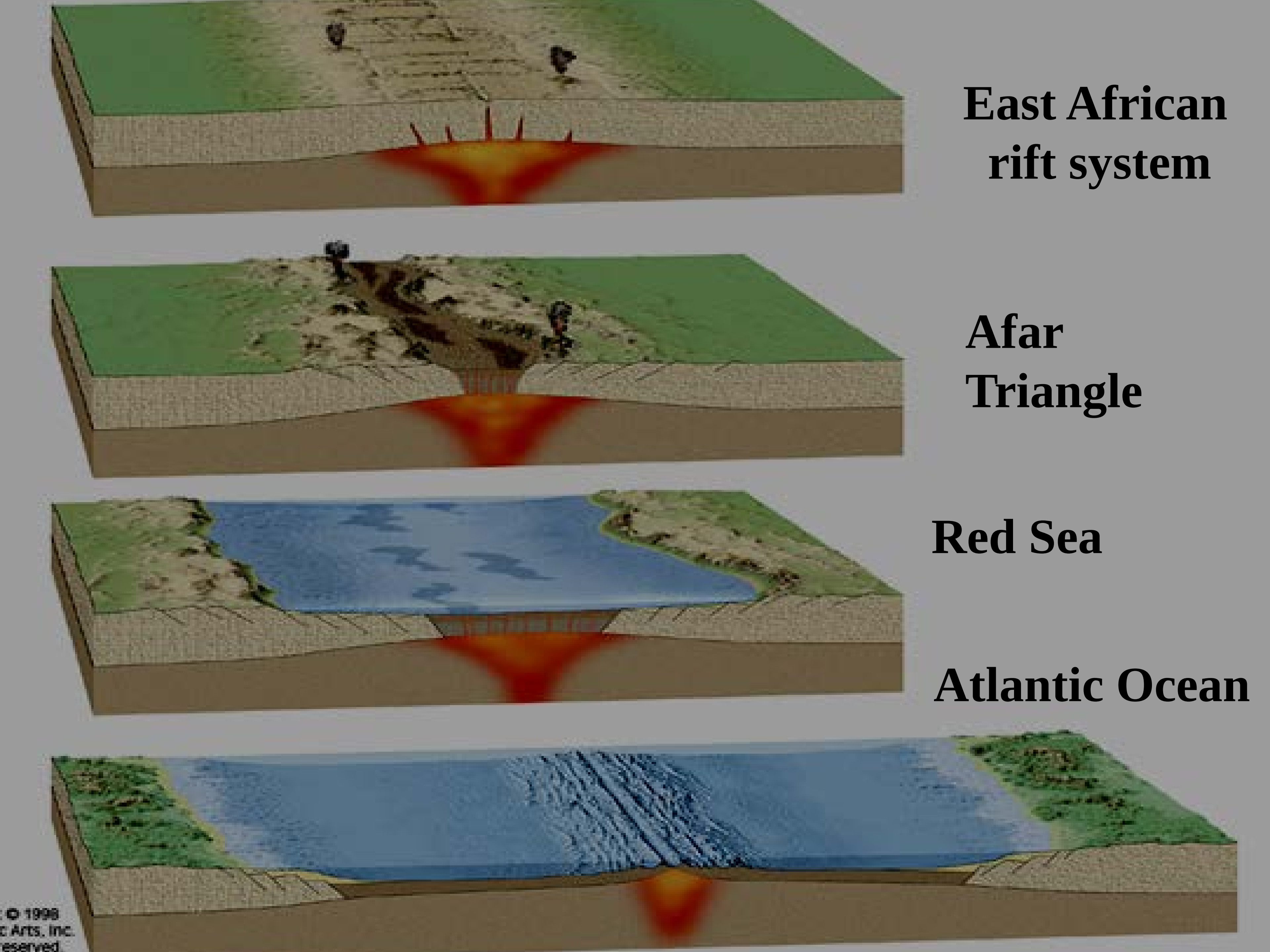
Fig. 3. The continent of Africa is thought to have been split by a series of rift valleys in various states of development. Those in East Africa are still in thick crust. Those in West Africa are associated with thick oil-bearing sediments. In the Red Sea area the rifting has gone so far as to form a narrow ocean. In the south-east Madagascar has been completely separated from Africa by rifting.

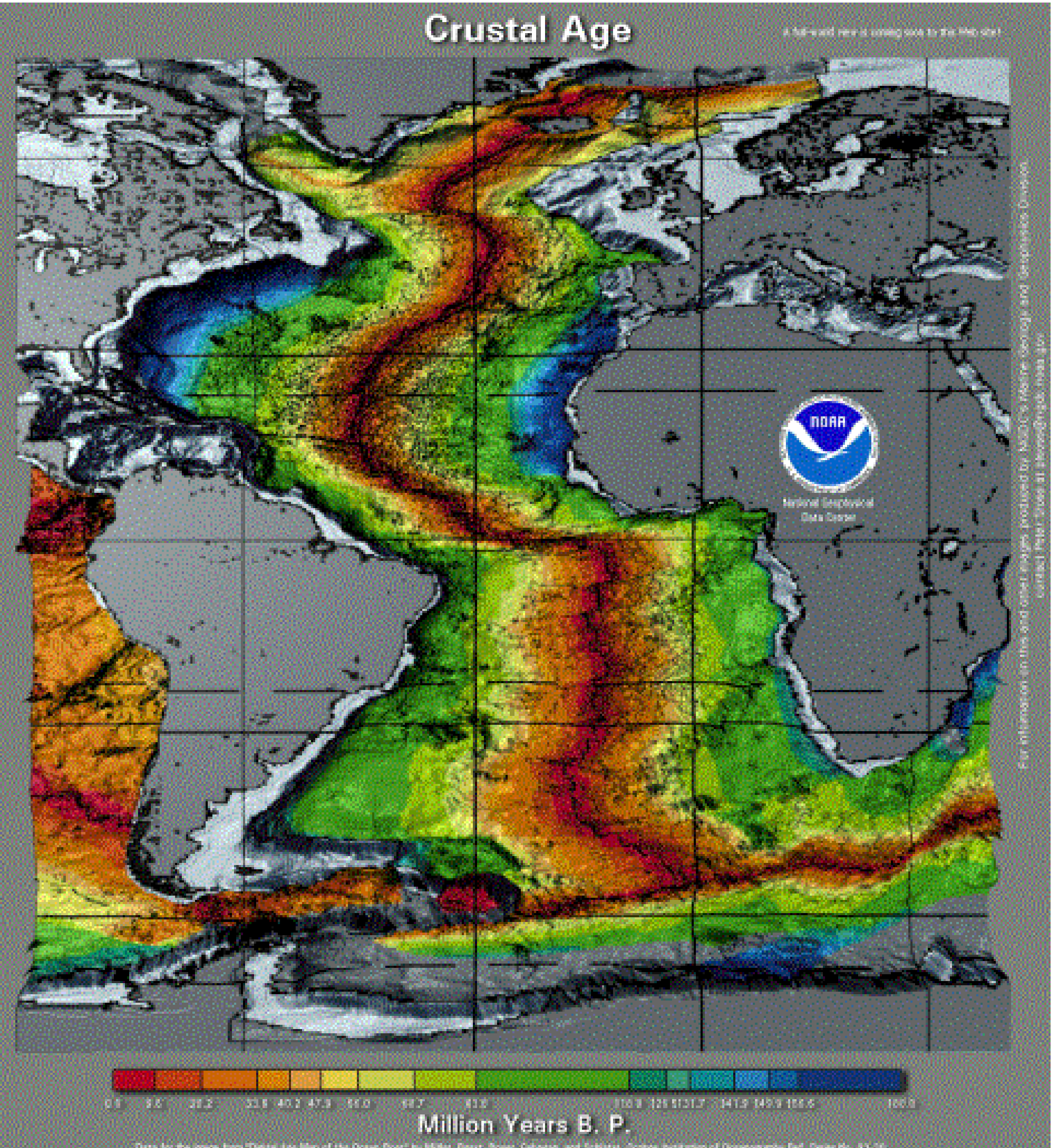


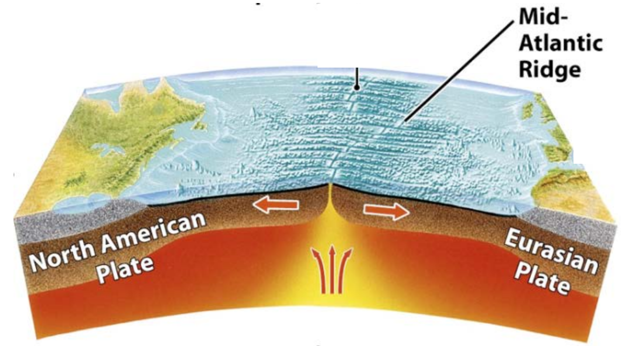
Cenozoic rifting

Jurassic rifting

Cretaceous rifting

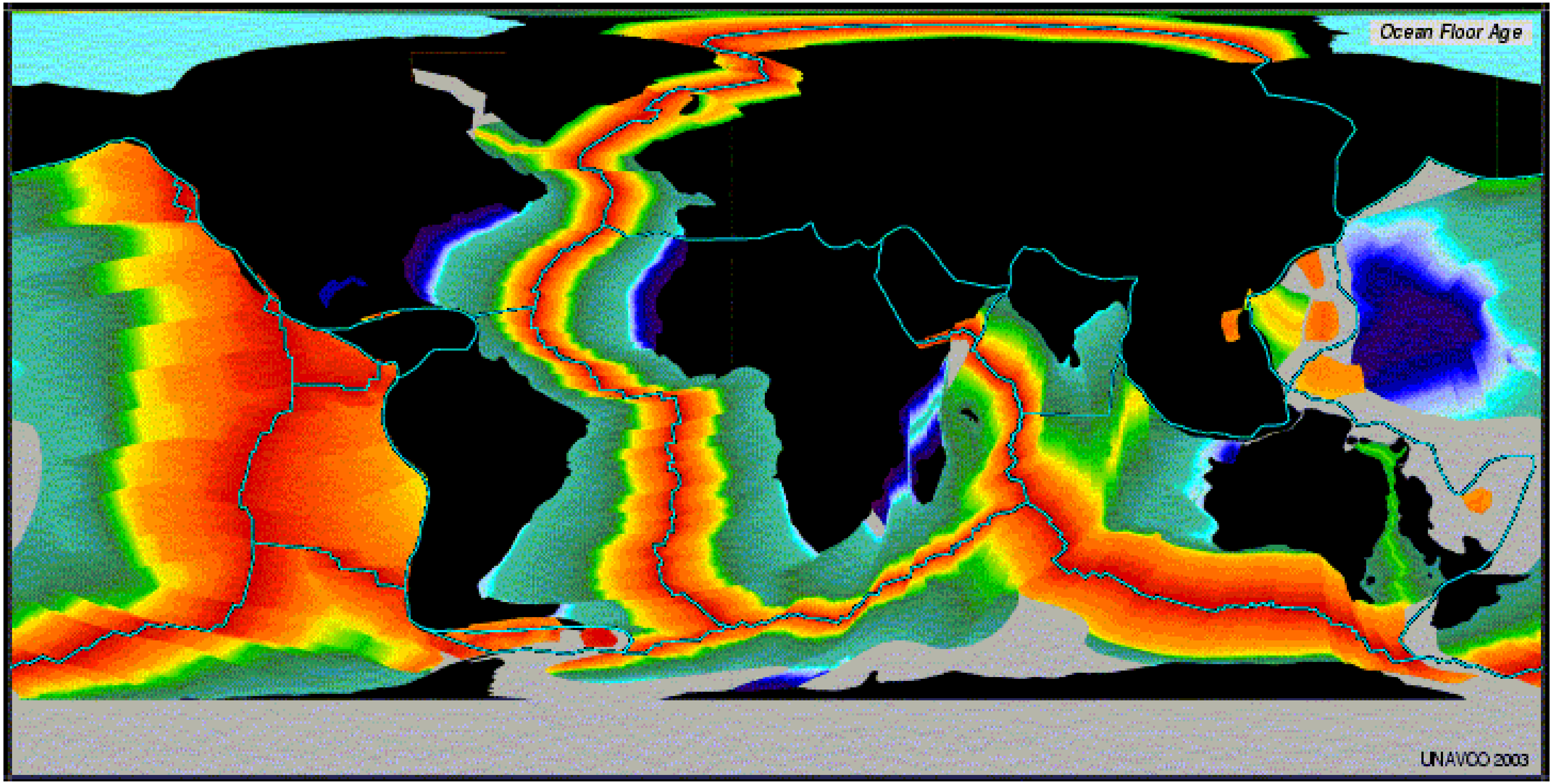

East African rift system
Afar Triangle
Red Sea
Atlantic Ocean
© 1998



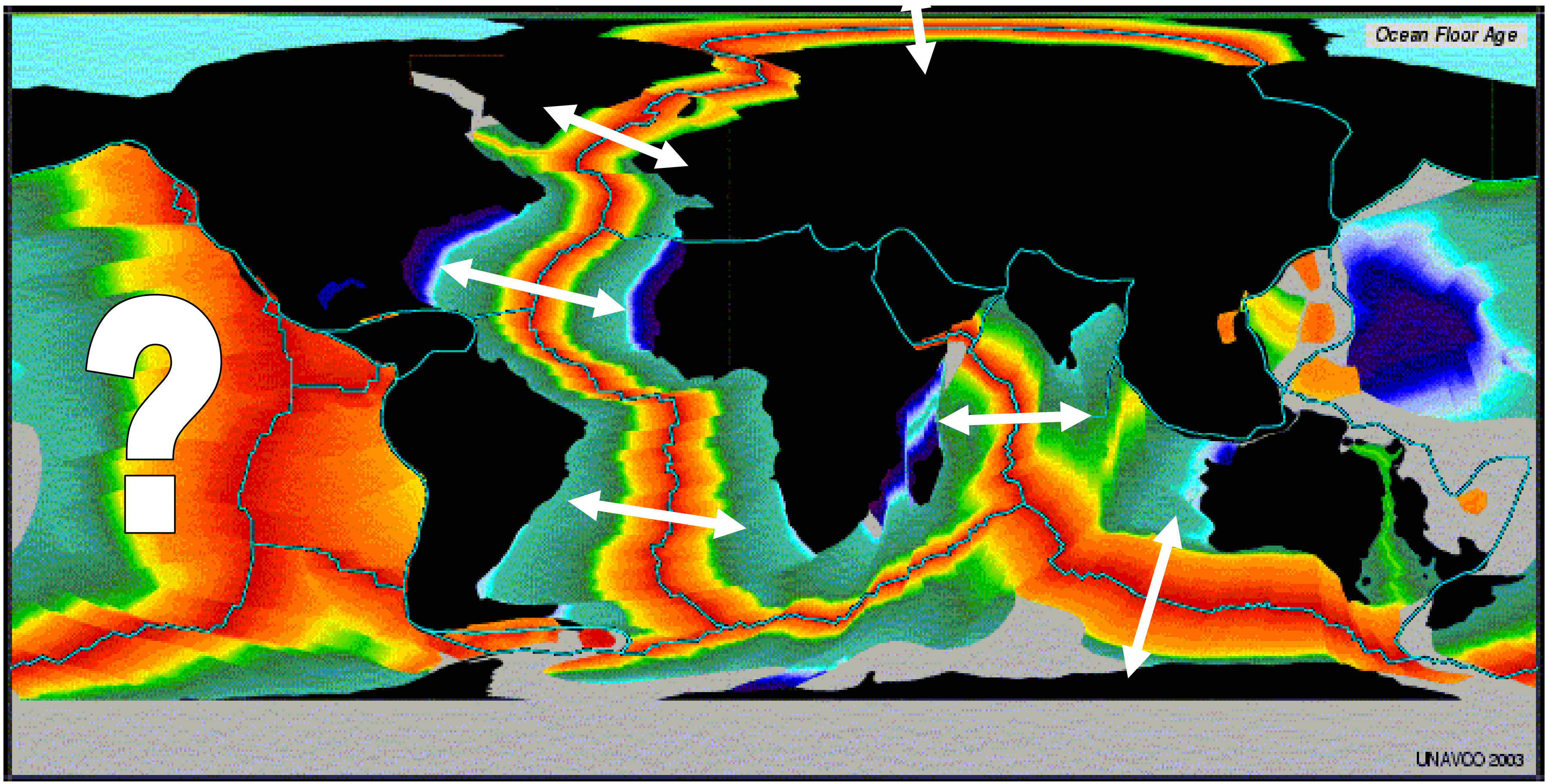


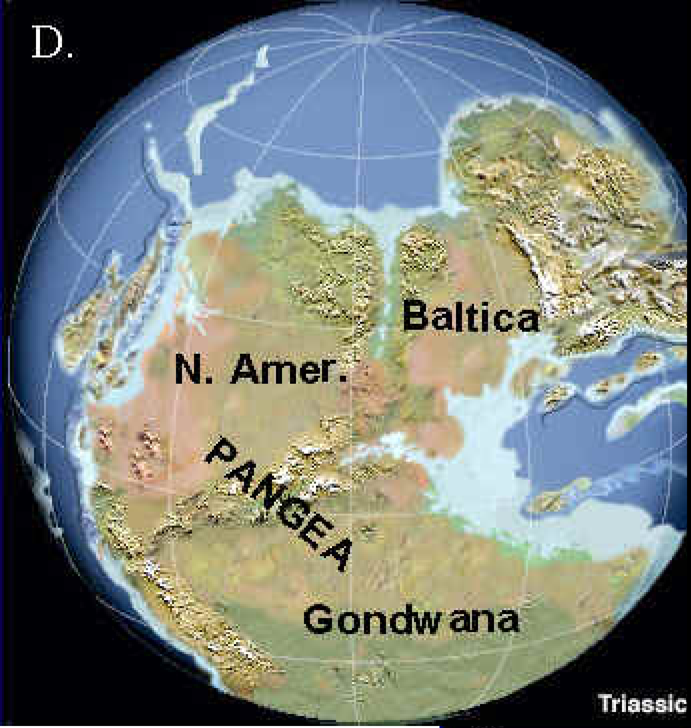
As the plates move apart the rising hot plastic mantle beneath the ridges begins to melt — producing not just mafic (basaltic) volcanoes, but the mafic oceanic crust they sit on. For the Atlantic this process began 180 million years ago.

The break-up of Pangea created three new rifted ocean basins — the Atlantic, the Arctic, and Indian

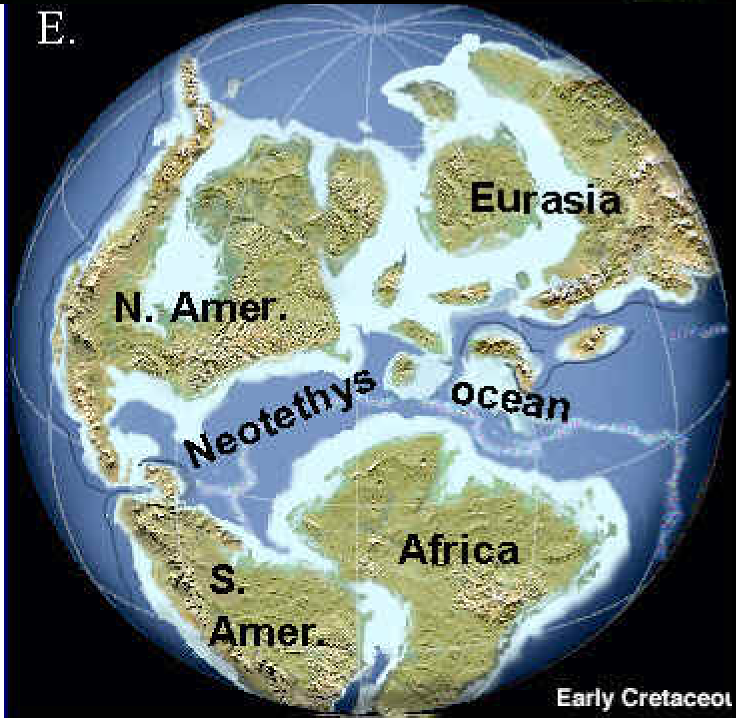


and so what happened to the pre-existing Pacific Ocean?

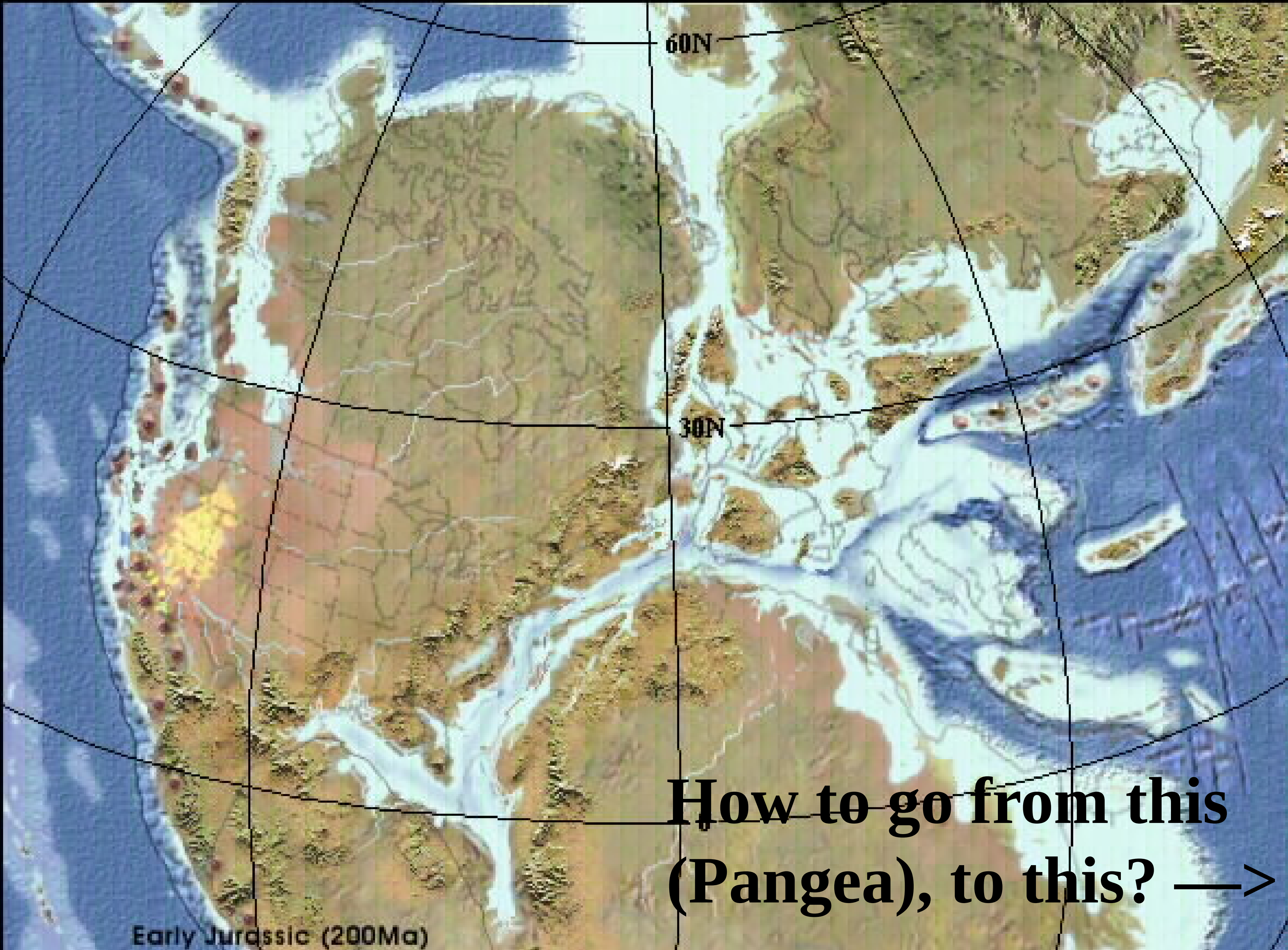

Ocean Floor Age
?
UNAVCO 2003



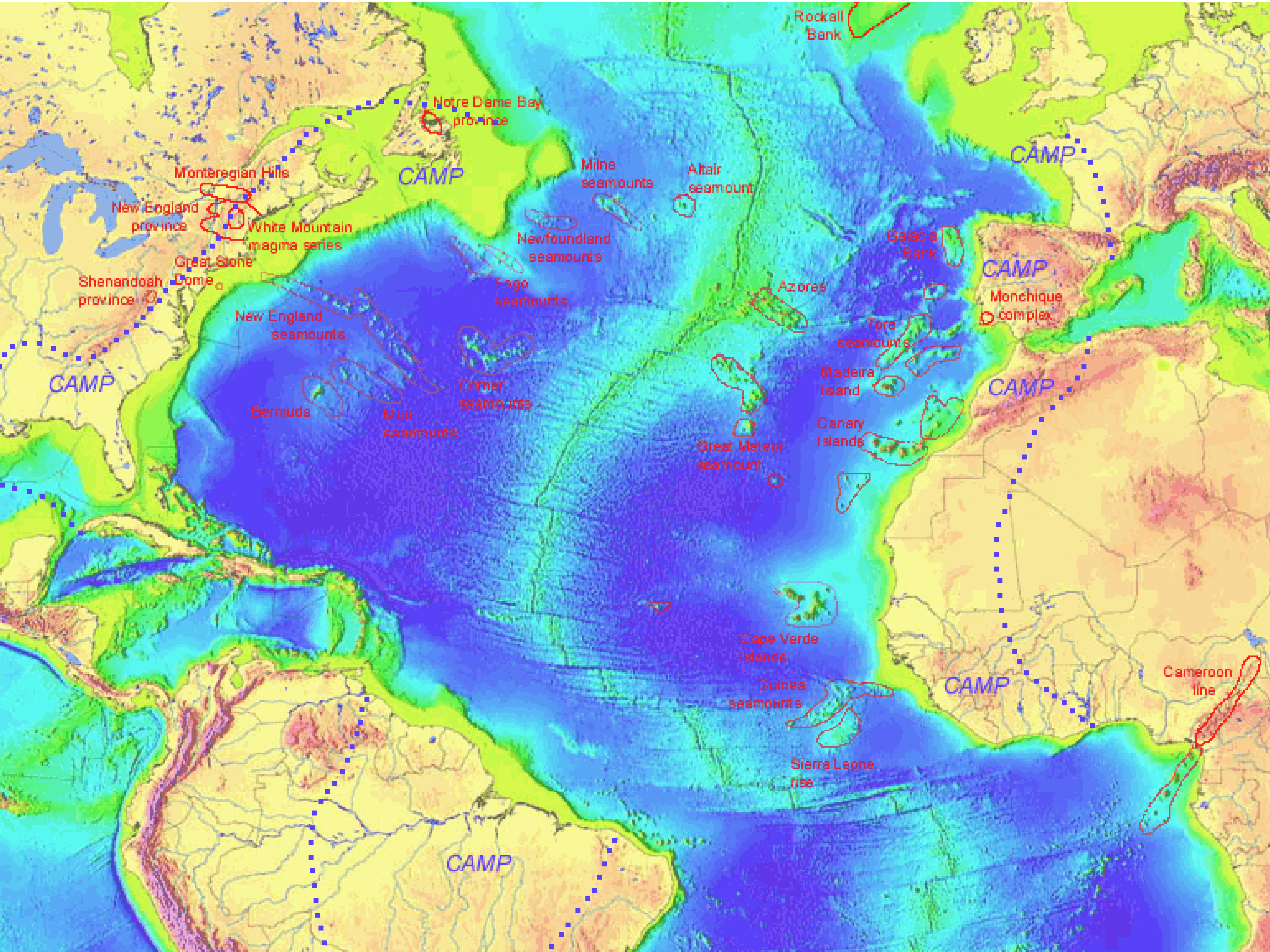
What is now the central Atlantic Ocean was not present in Triassic time, but was well developed by th Middle Jurassic. Study of this region tells us much about the continental rifting process for this example of continental breaku



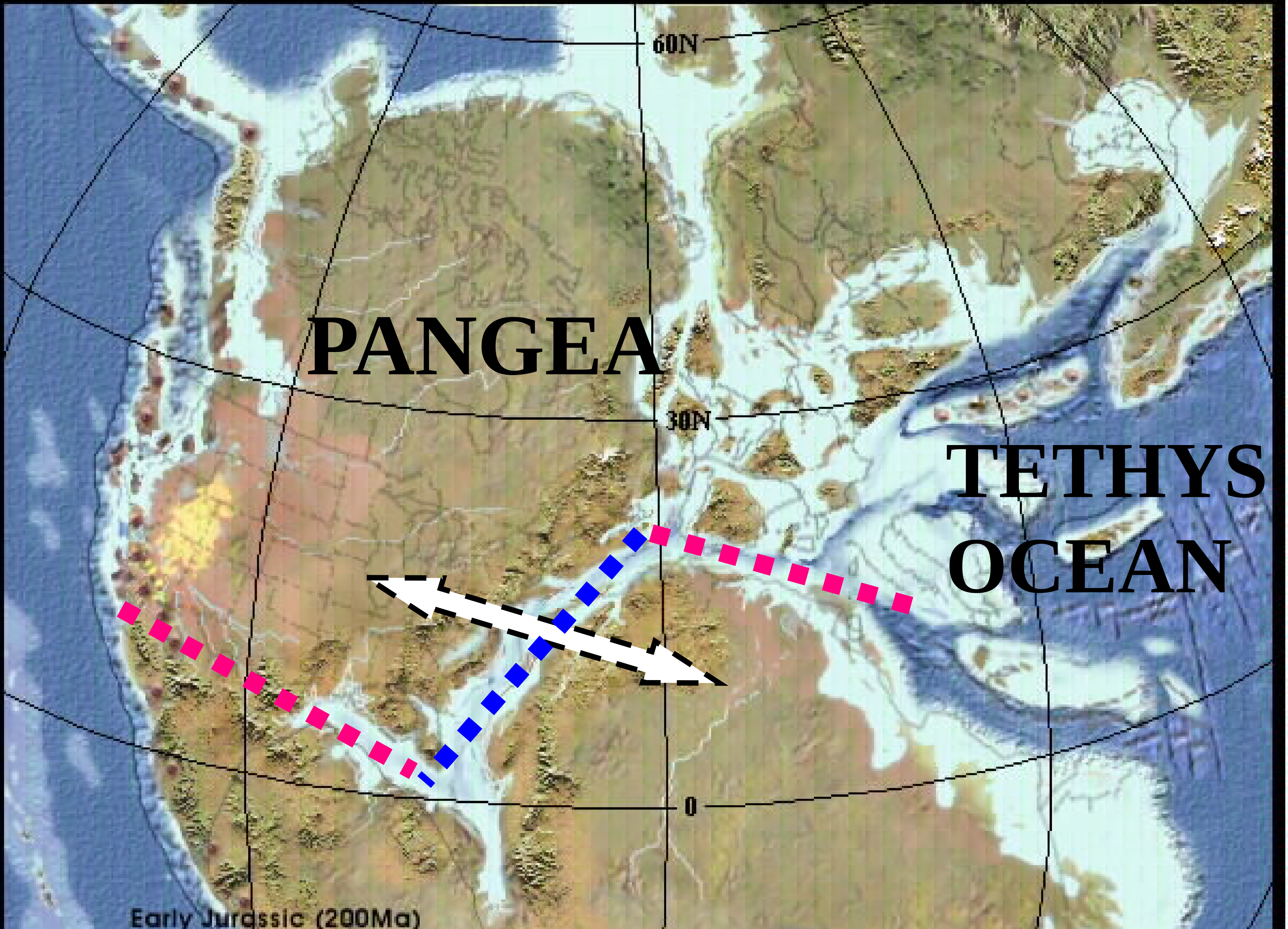
EARLY CRETACEOUS



How to go from this (Pangea), to this? —>

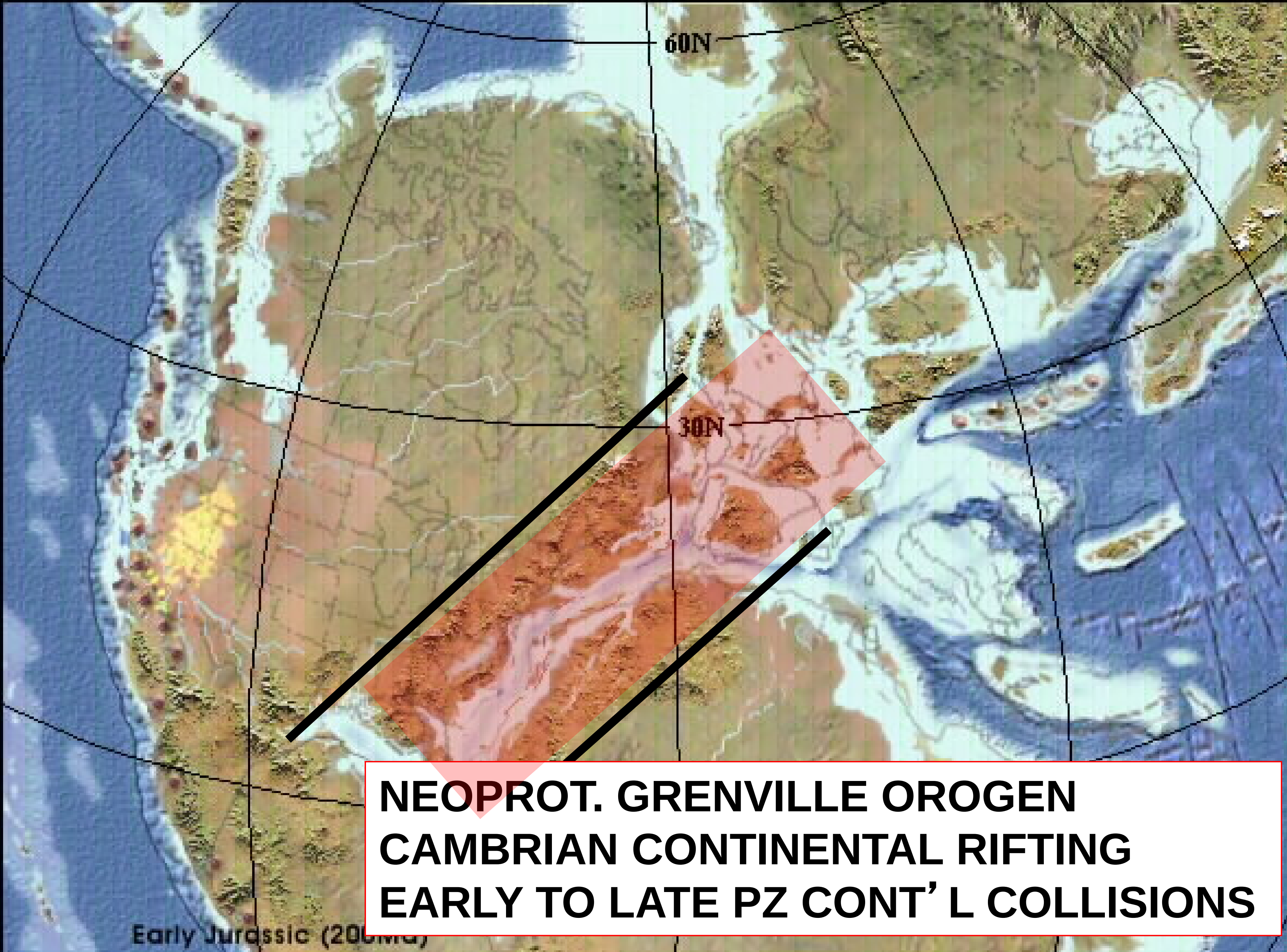


Rockall Bank
Notre Dame Bay province
CAMP
Monteregian Hills
New England province
White Mountain magma series
Great Stone Dome
Shenandoah province
Milne seamounts
Altair seamount
Newfoundland seamounts
Fogo seamounts
New England seamounts
Corner seamounts
Bermuda
Muir seamounts
Azores
Galacia Bank
CAMP
Monchique complex
Tore seamounts
Madeira Island
Canary Islands
CAMP
Great Meteor seamount
CAMP
Cape Verde Islands
Guinea seamounts
Sierra Leone rise
CAMP
Cameroon line
CAMP
CAMP


60N
PANGEA
30N
TETHYS
OCEAN
0
Early Jurassic (200Ma)

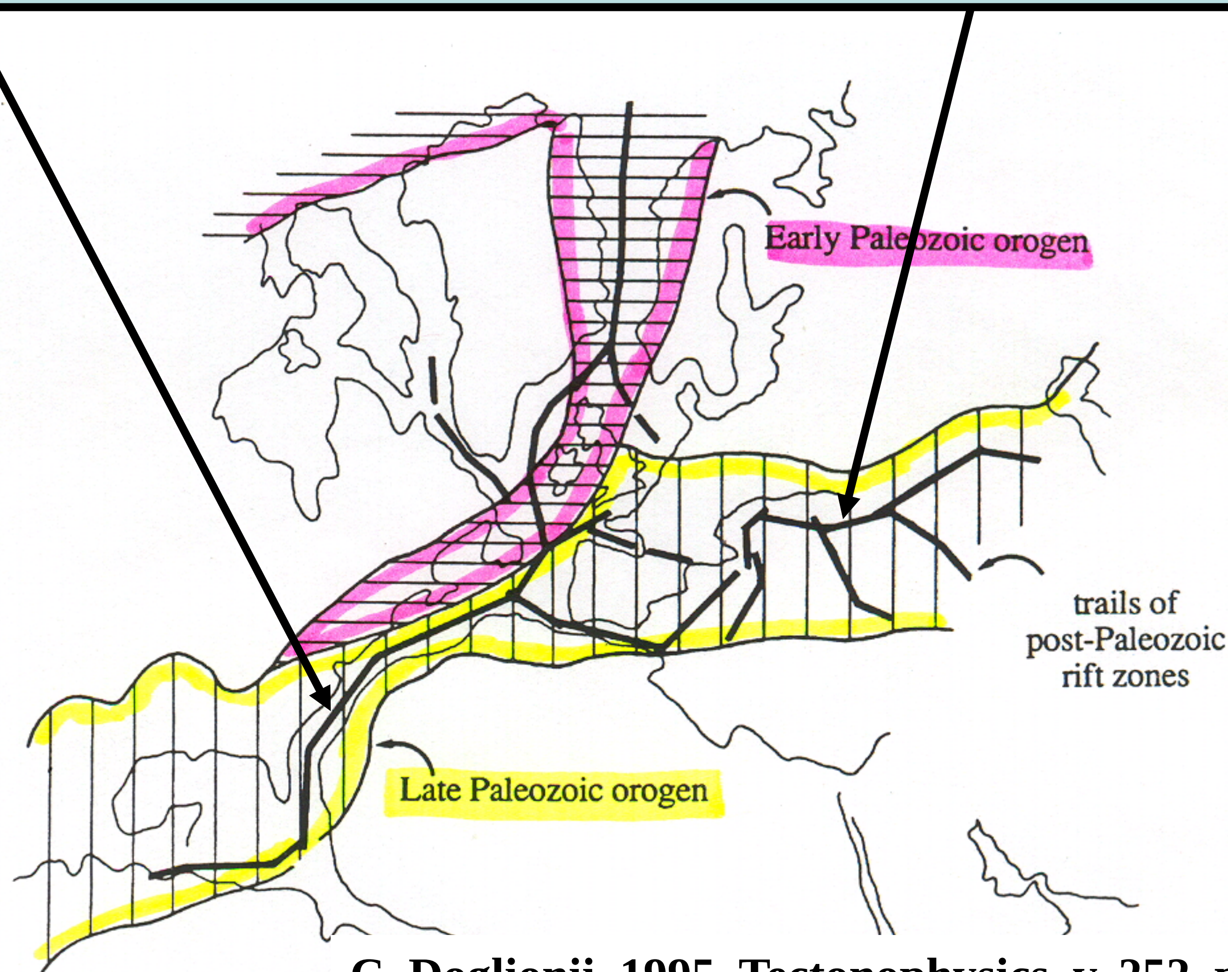
WERE THERE PRE-EXISTING LITHOSPHERIC CONTROLS ON CENTRAL ATLANTIC RIFTING?


60N
PALEOZOIC
COLLISIONAL
BELT
0
YES !
Early Jurassic (200Ma)



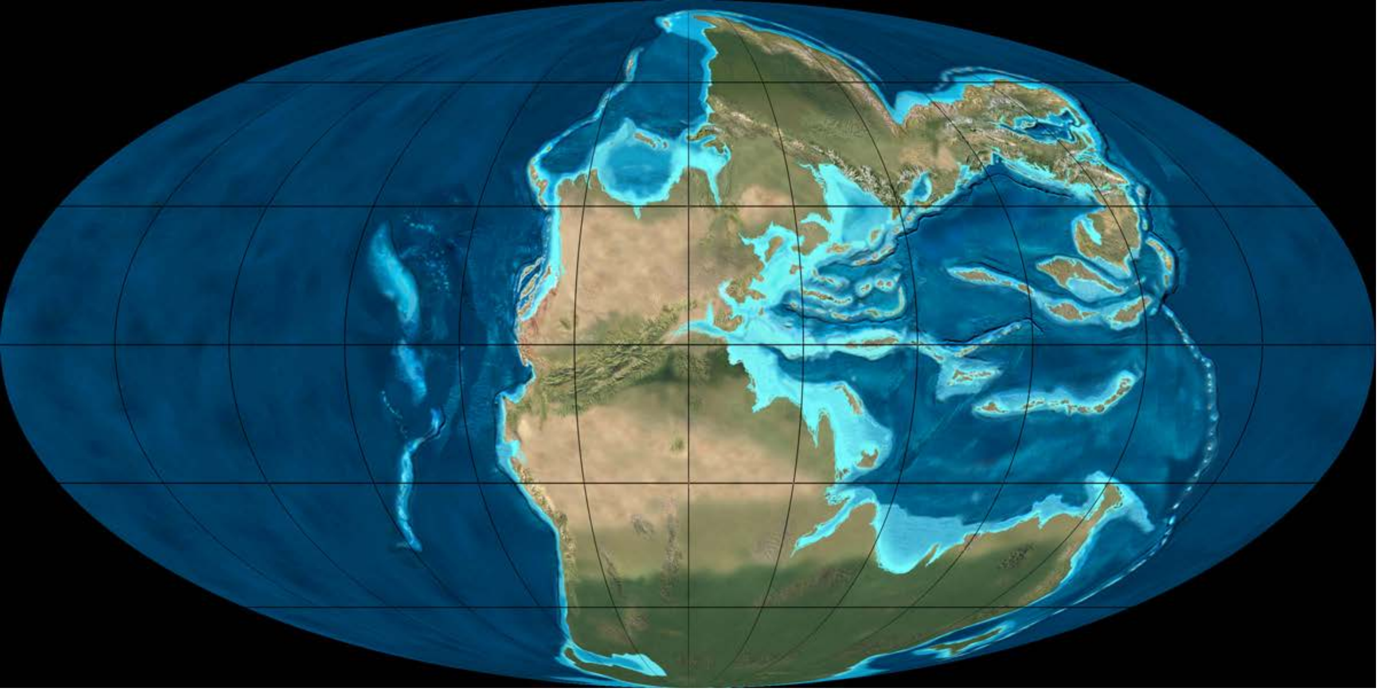
NEOPROT. GRENVILLE OROGEN
CAMBRIAN CONTINENTAL RIFTING
EARLY TO LATE PZ CONT’L COLLISIONS

North Atlantic Paleozoic orogenic belts and younger Atlantic rift zones (heavy black lines)



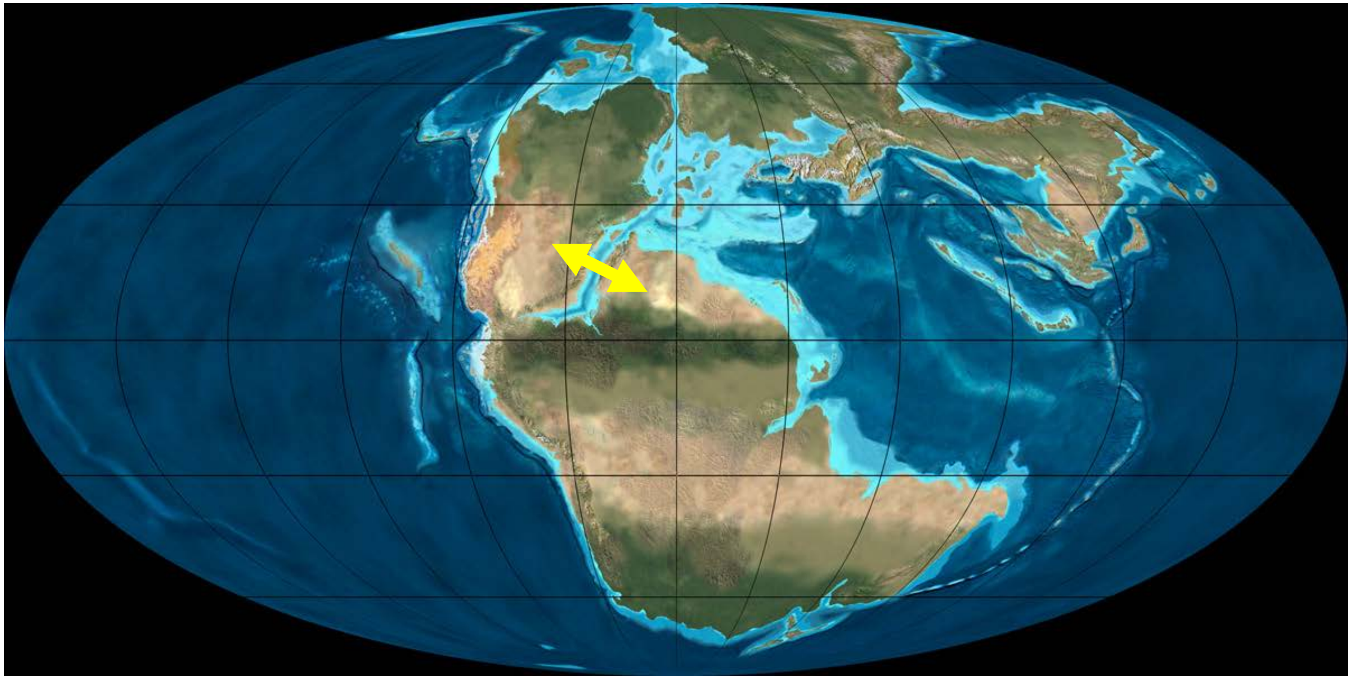
C. Doglionii, 1995, Tectonophysics, v. 252, p. 253-67

Fig. 6. This map shows the distribution of the Paleozoic collisional belts, namely Variscan (or Hercynian) and Caledonian, and the trace of the later Atlantic or Tethyan rifting which strictly followed the pre-existing lithospheric thickening due to the orogens (modified after Bernoulli and Lemoine, 1980). This observation shows that the lithospheric thickness directly controls the location of rift zones.



EARLY TRIASSIC
240 MY
(R. BLAKEY)

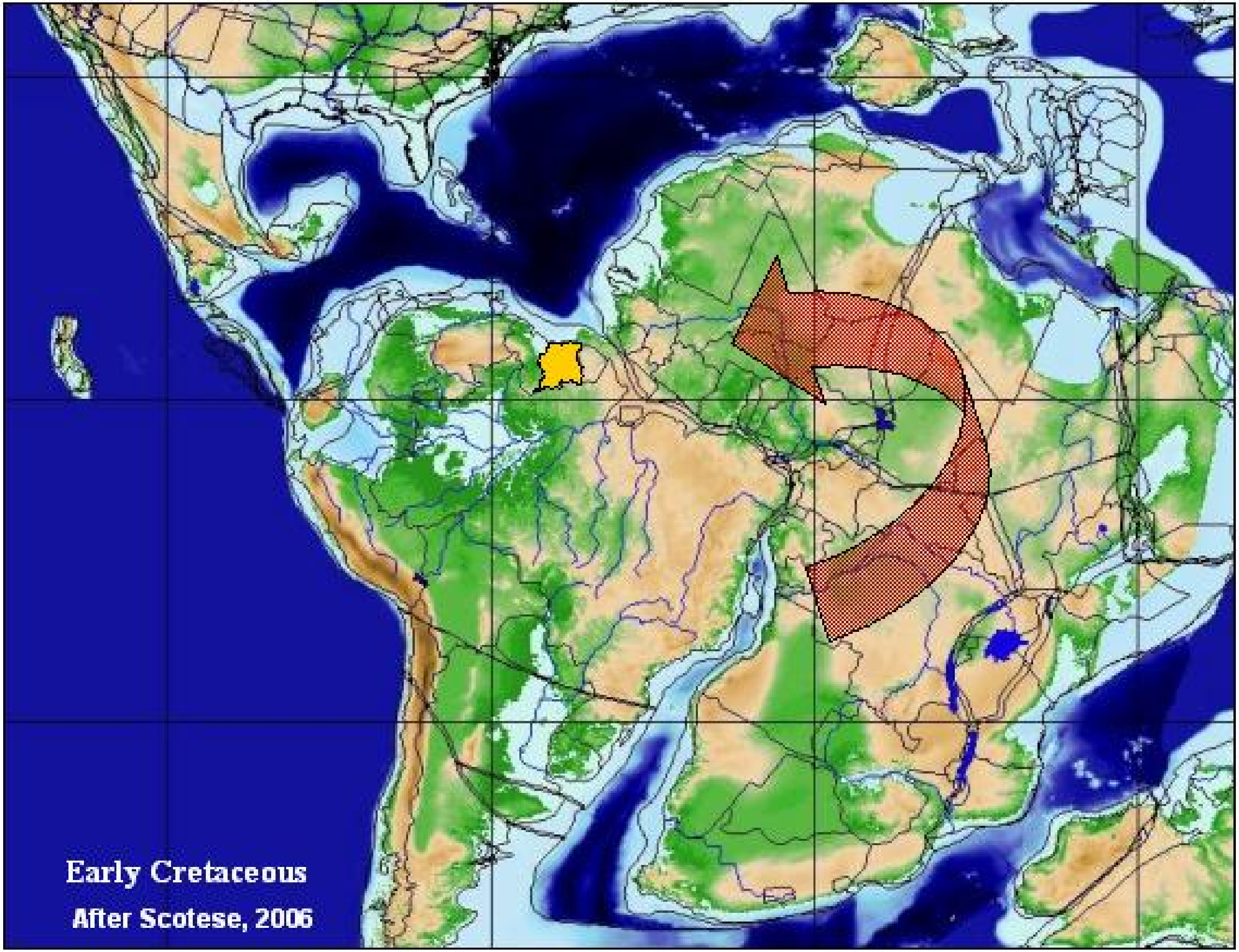
http://jan.ucc.nau.edu/~rcb7/200moll.jpg

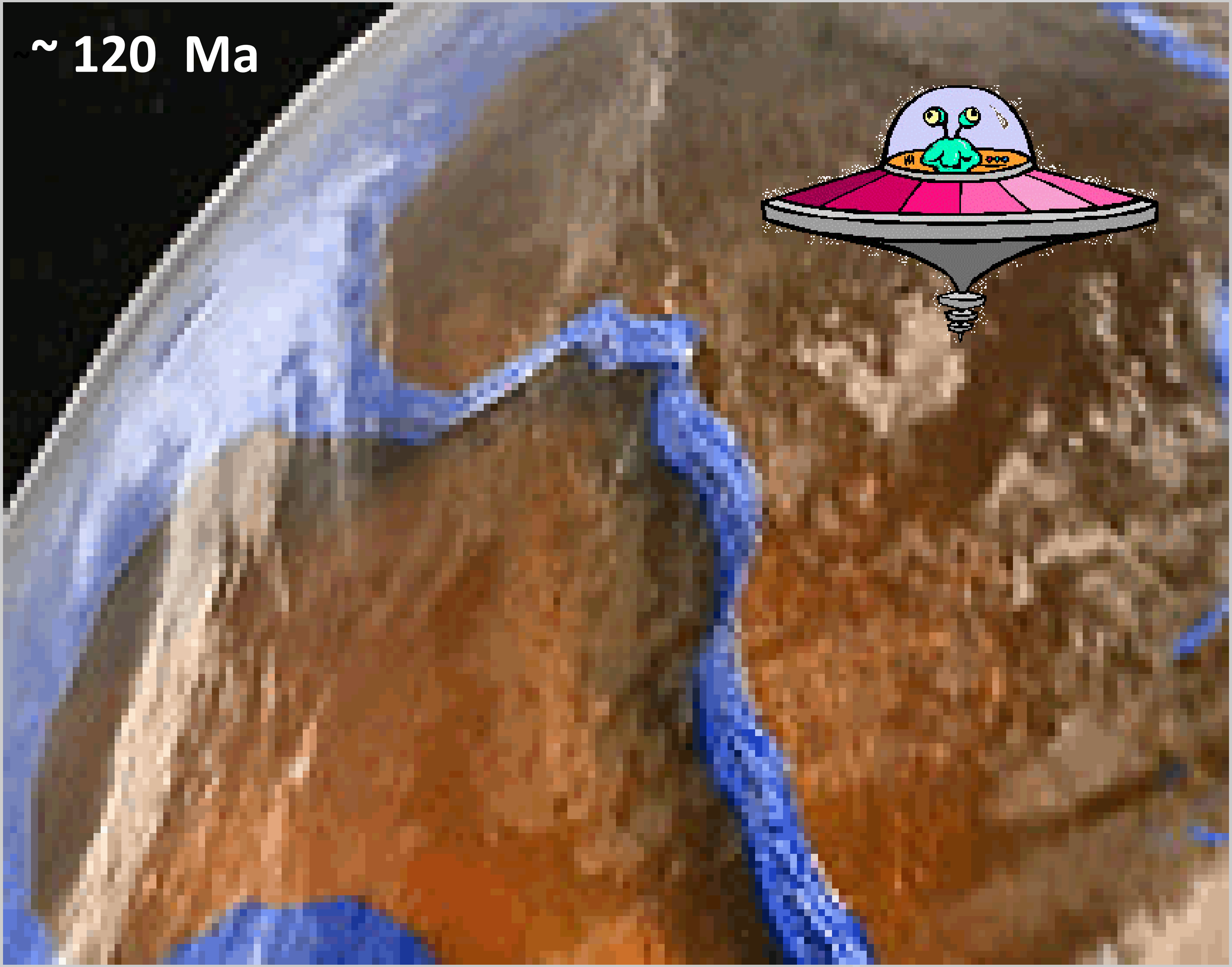


EARLY
JURASSIC
200 MY
(R. BLAKEY)

WERE THERE PRE-EXISTING LITHOSPHERIC CONTROLS ON SOUTH ATLANTIC RIFTING?

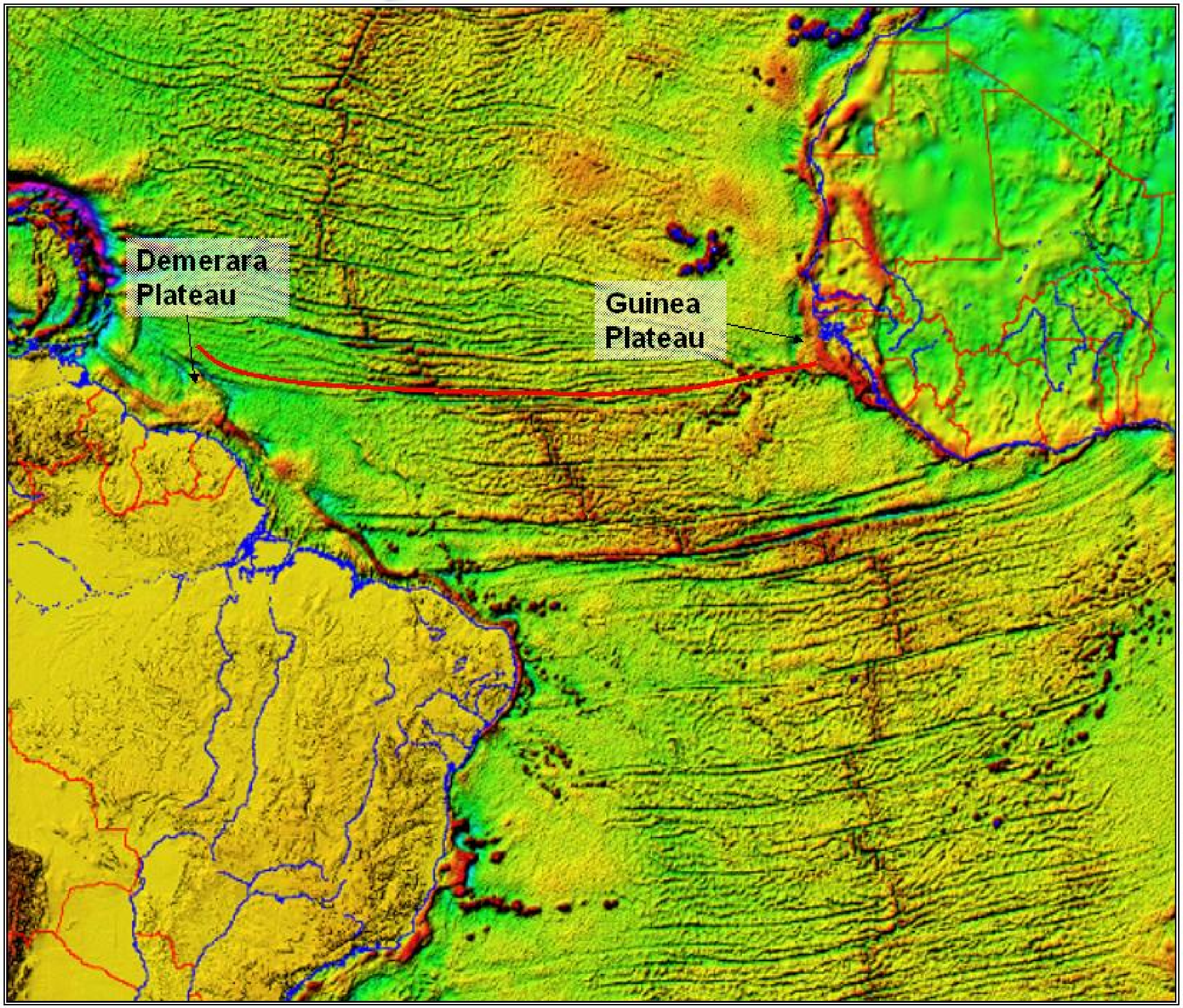
Early Cretaceous Plate Reconstruction



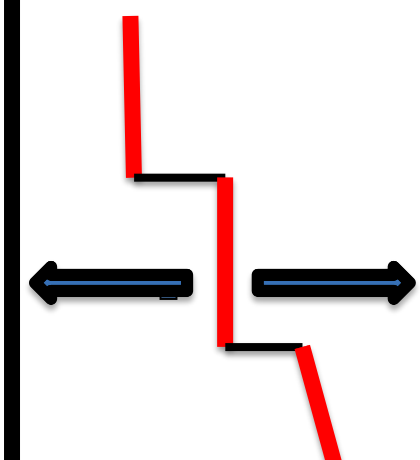

~ 120 Ma

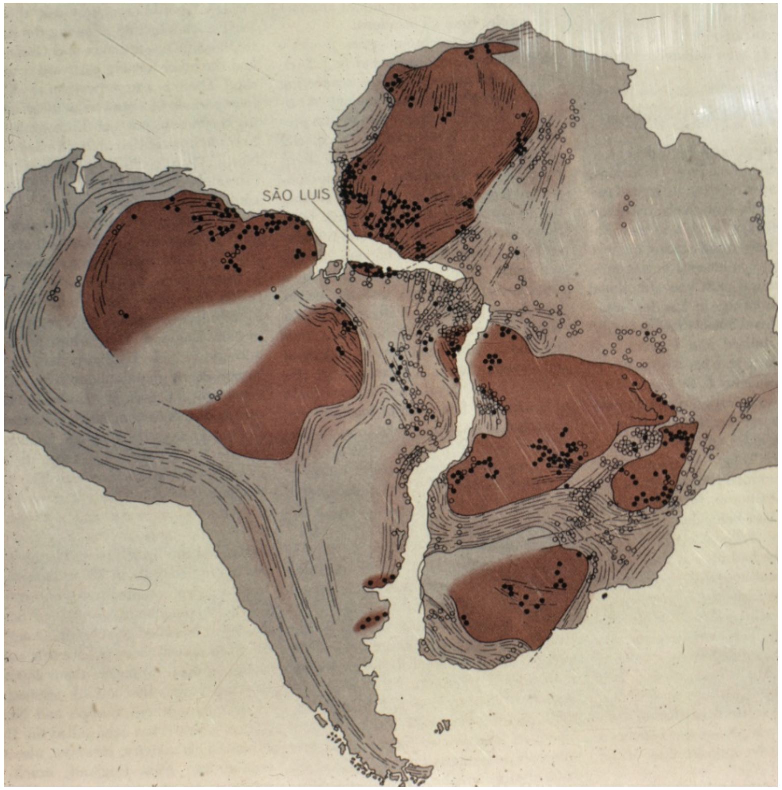
The Mid-Atlantic Ridge (MAR) has the general geometry of the initial Cretaceous continental rift of about 120 Mybp

SEASAT Satellite Image over the Atlantic Ocean

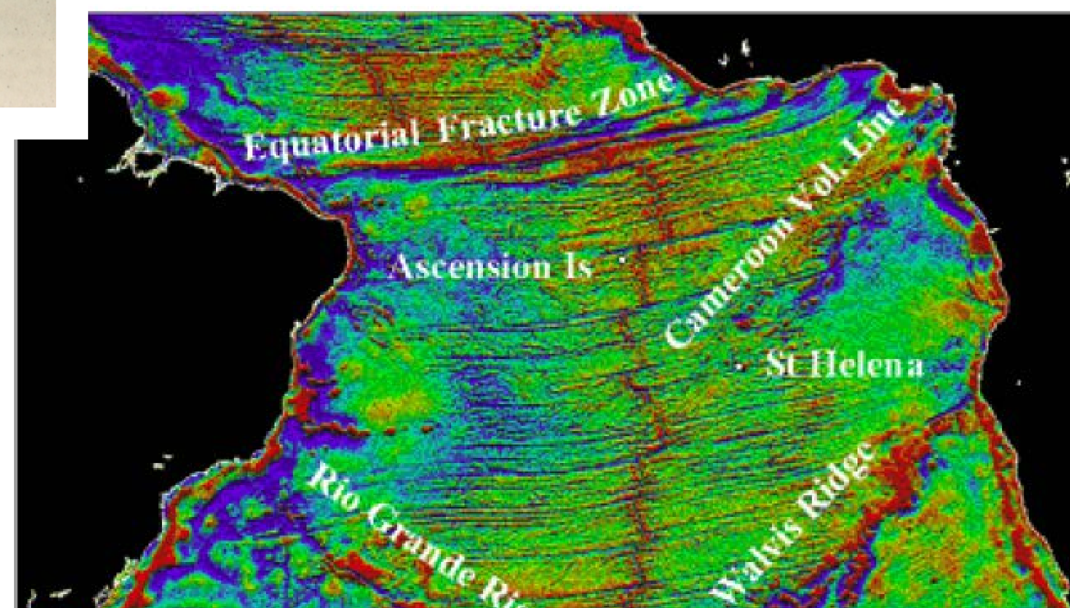


Fracture zones appear to offset the MAR, but they do not. They formed when the initial rift had offsets along it

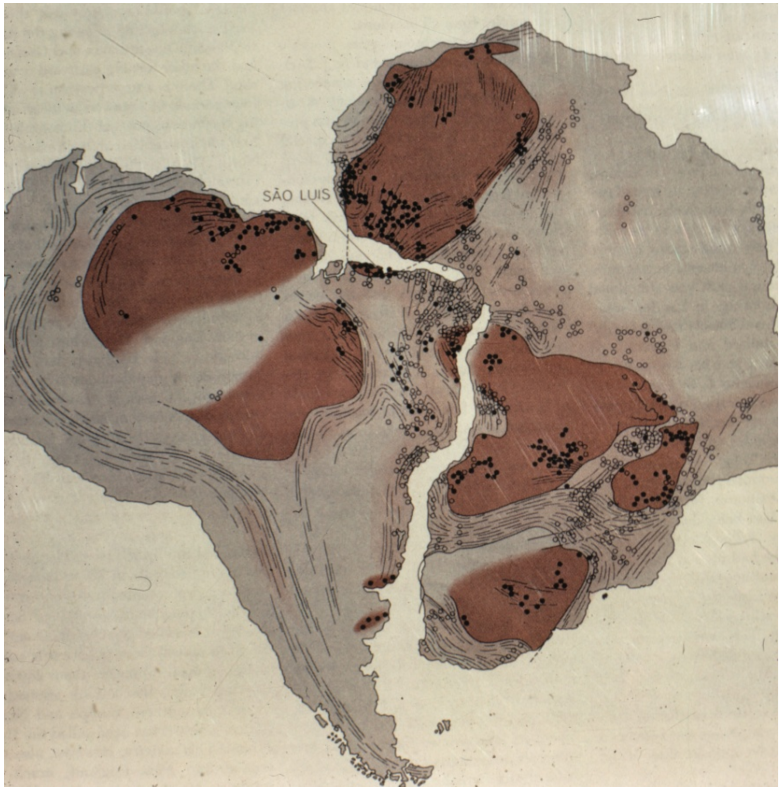




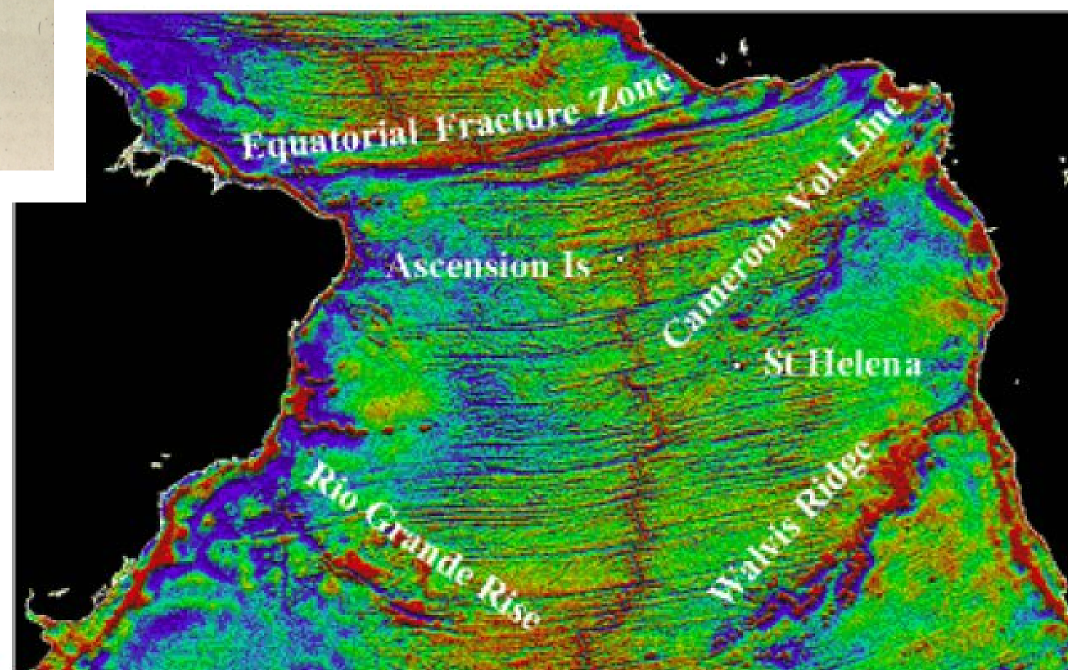
Were there pre-rifting lithospheric controls in the South Atlantic?



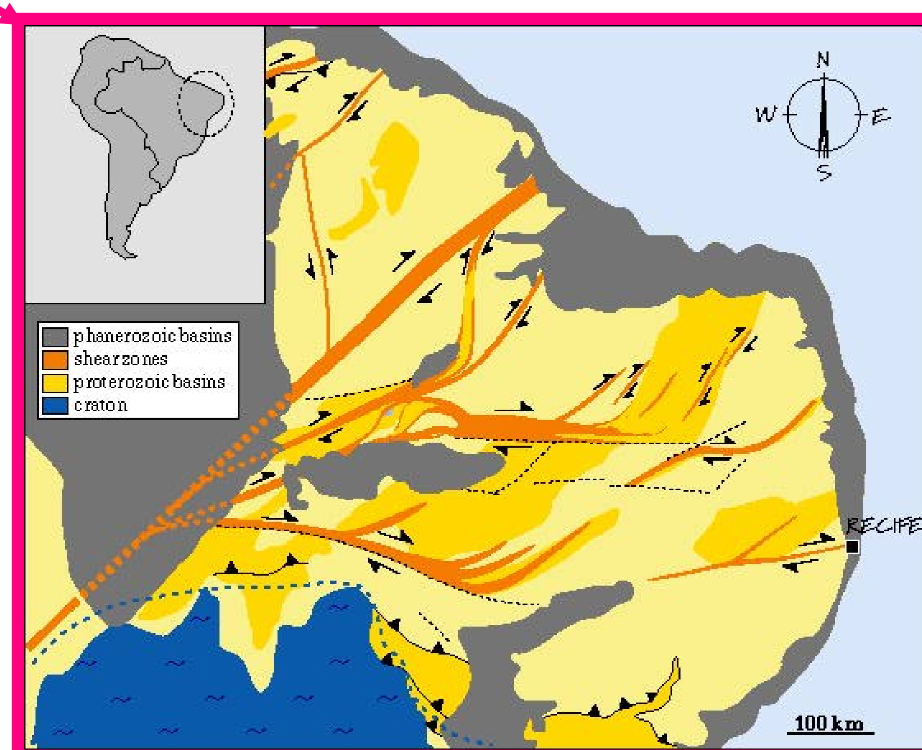
Were there pre-rifting lithospheric controls in the South Atlantic?



NO !



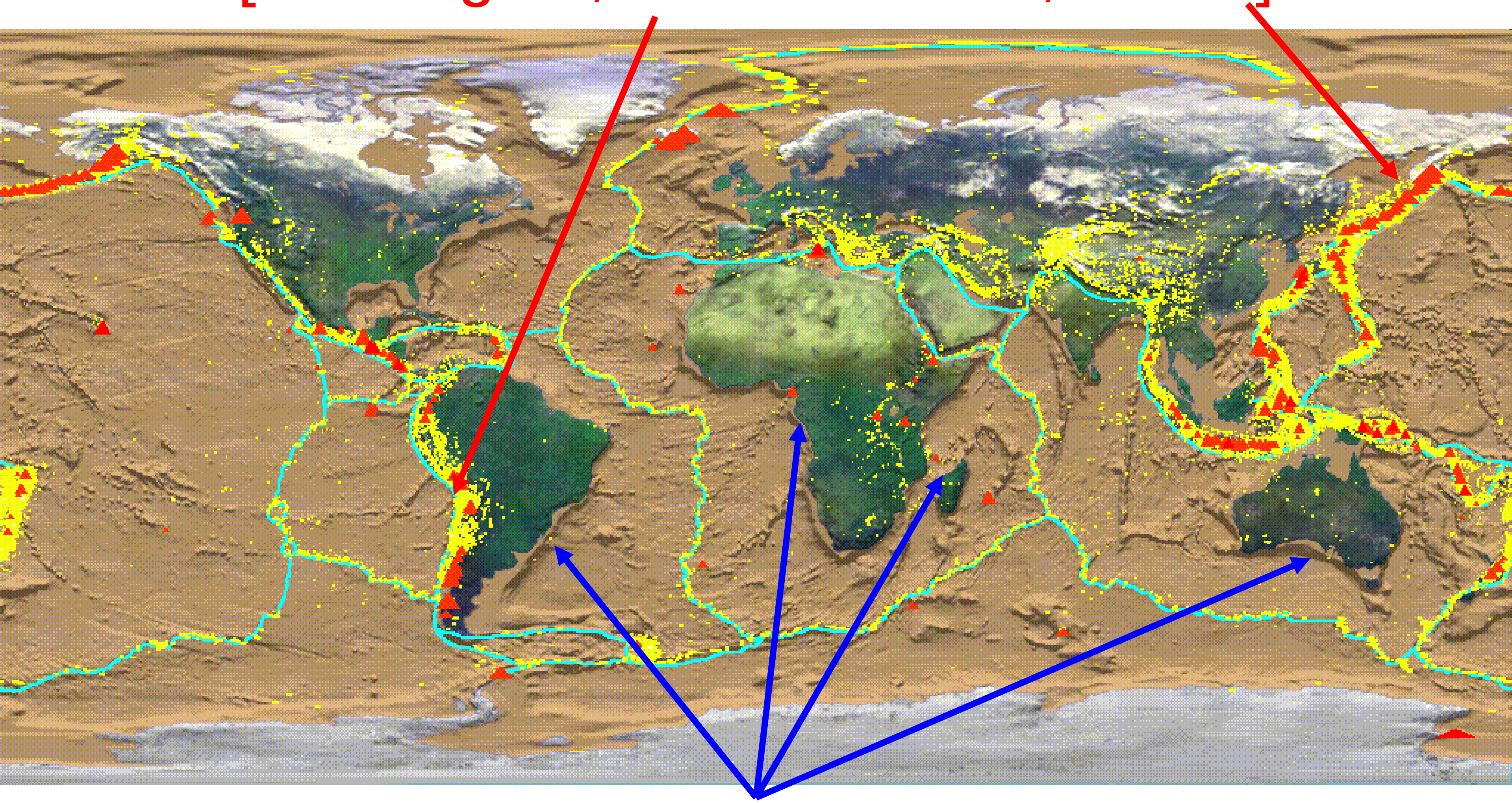
The rifted margin cuts across huge Neoproterozoic ductile shear zones (as seen in Brazil).



The Borborema dextral shear zone

Active (Leading Edge) Continental Margins

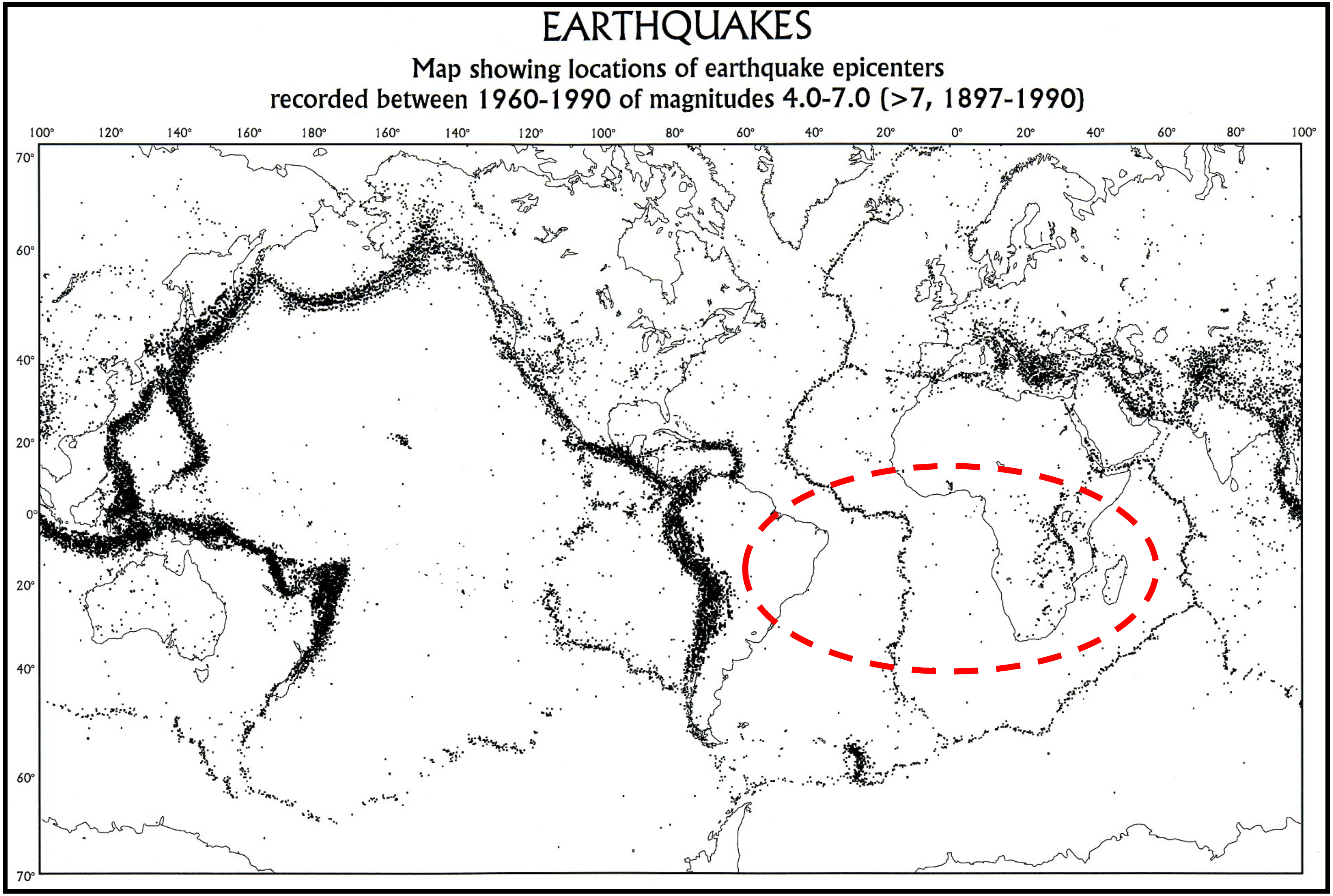
[convergent, ie. subduction, zones]



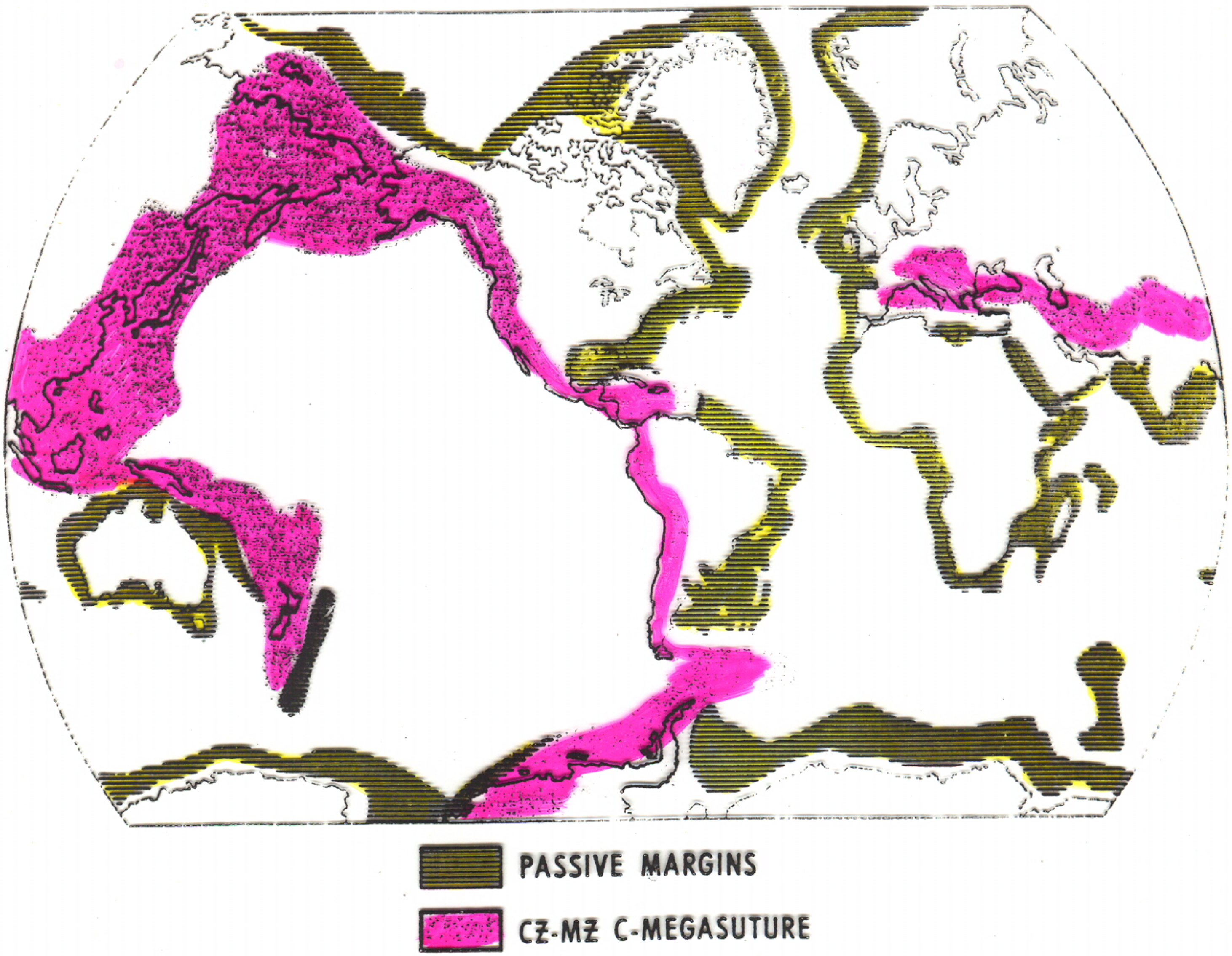
Passive (Trailing Edge) Continental Margins

[original rifted continental margins)

Obviously, all continent-ocean boundaries are NOT plate boundaries.



Passive (Rifted) Continental Margins



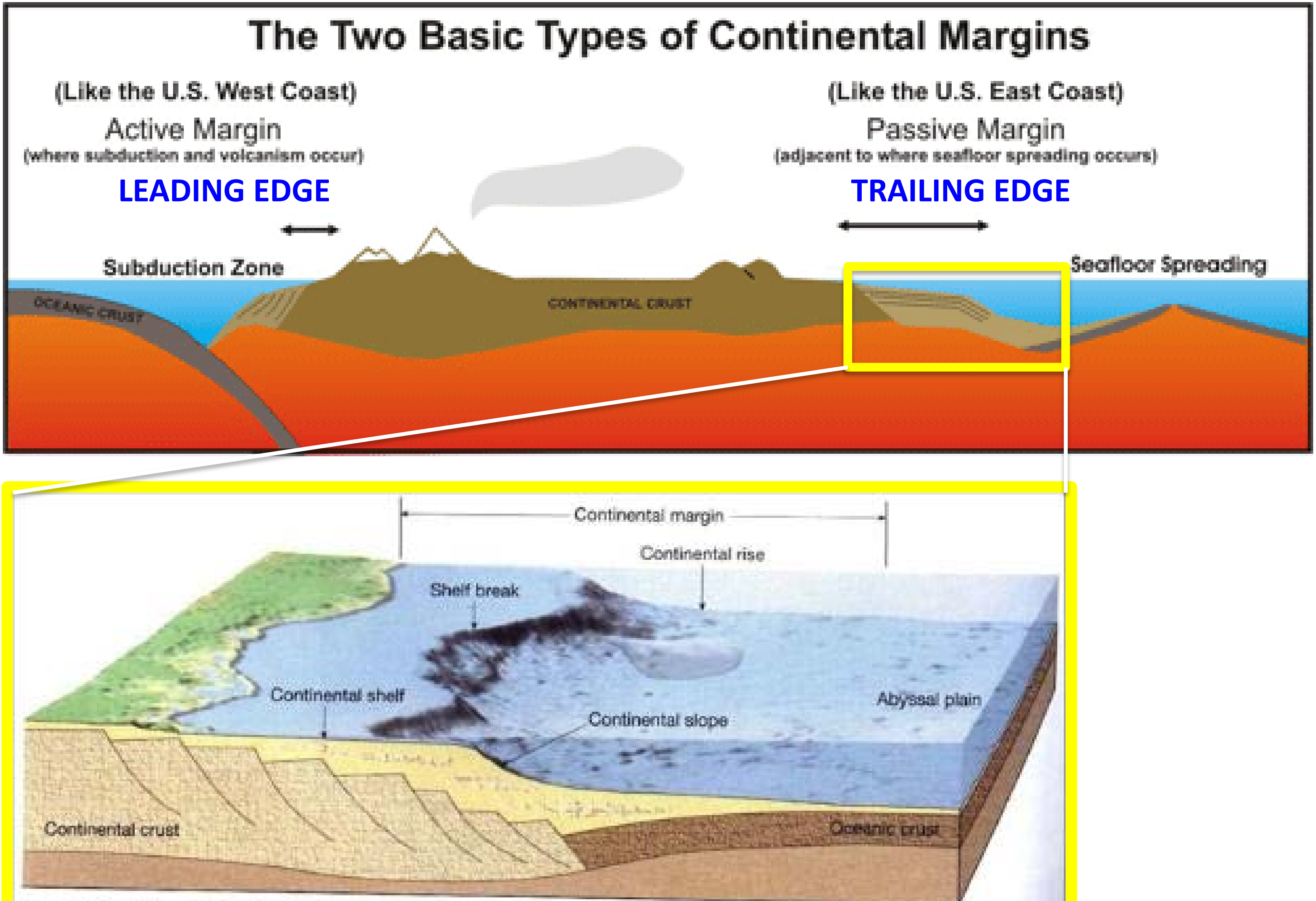
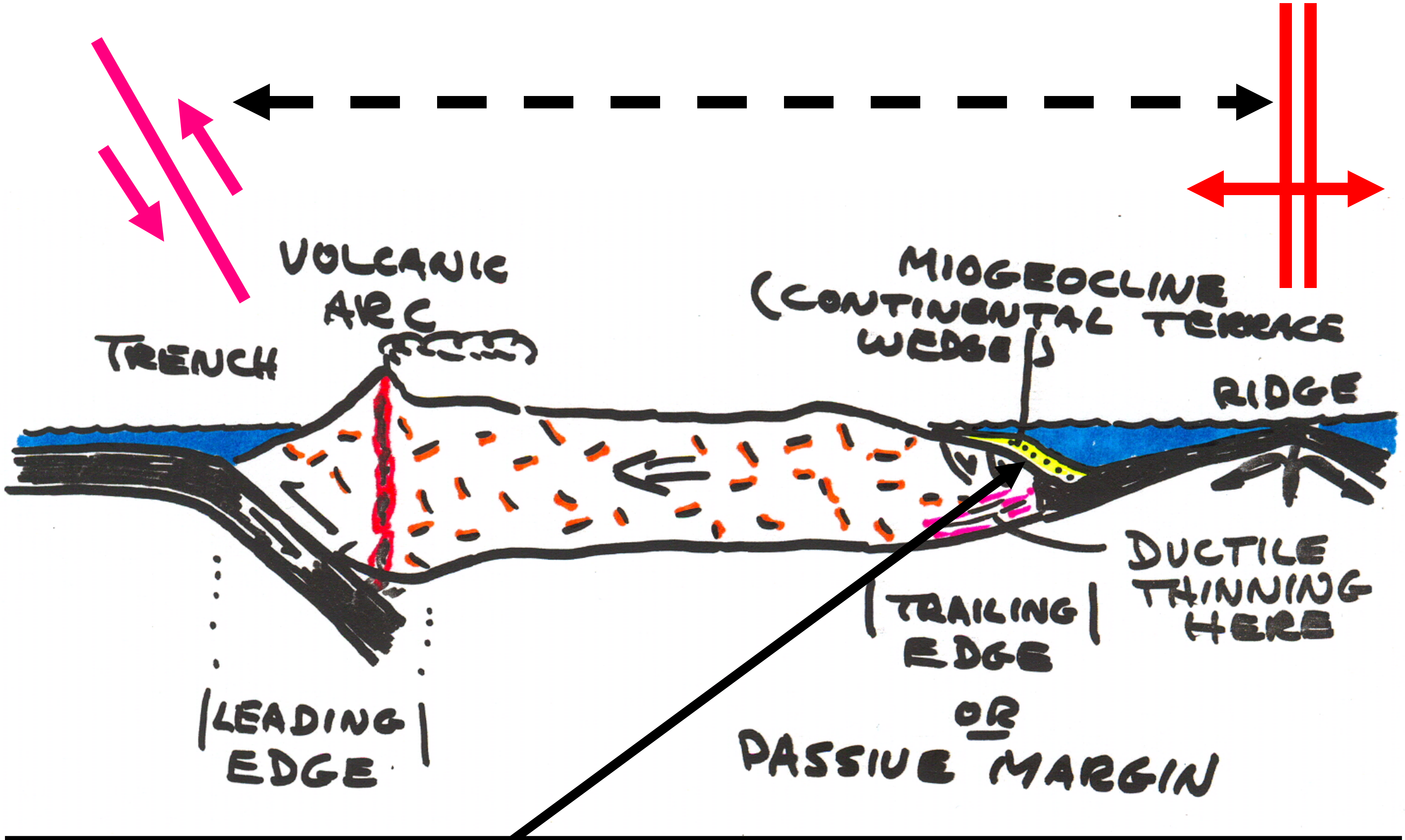
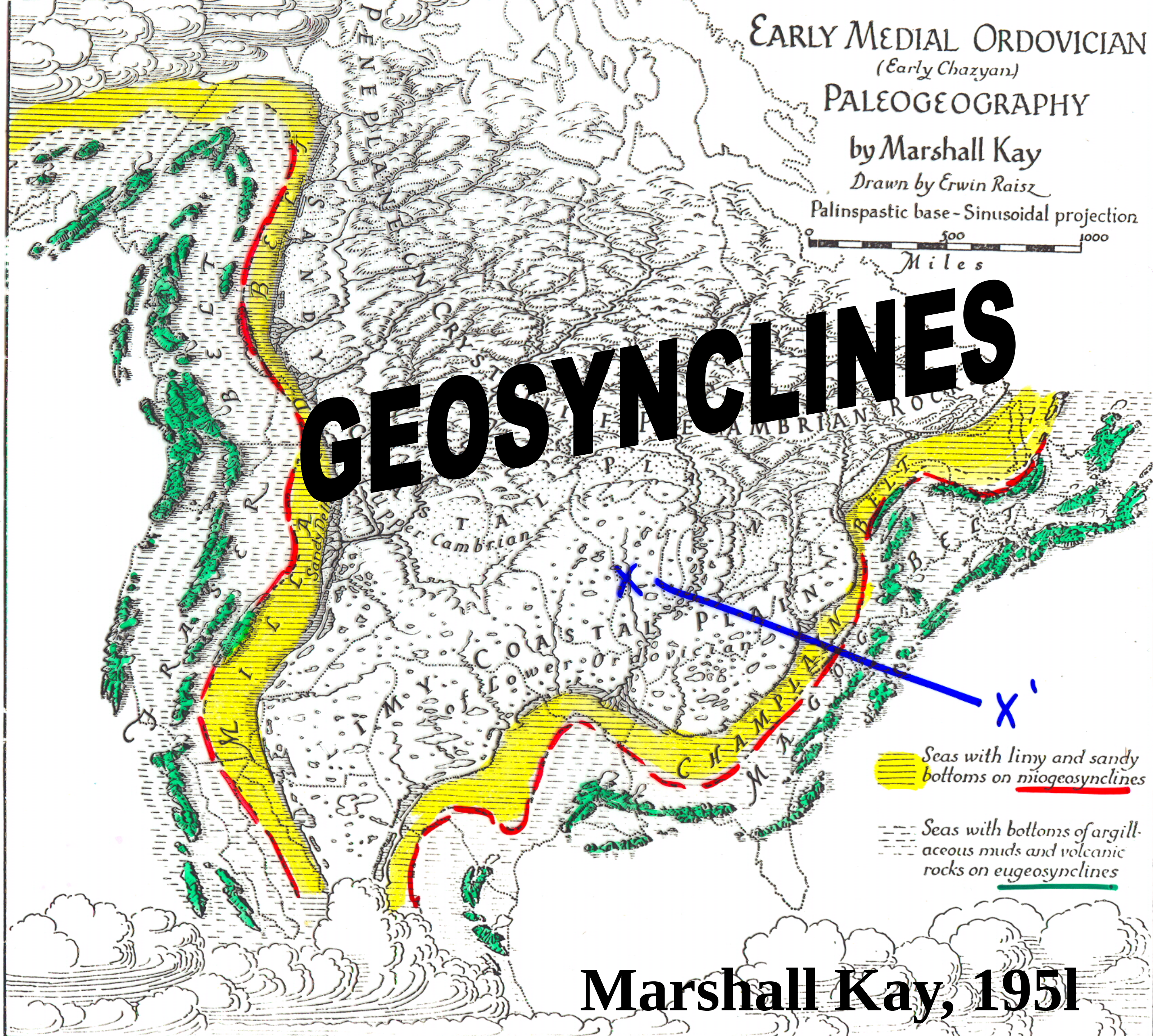


Figure 19.4 Schematic view showing the provinces of the continental margin. Note that the slopes shown for the continental shelf and continental slope are greatly exaggerated. The continental shelf has an average slope of one-tenth of one degree, while the continental slope has less than a 10-degree slope.



passive margin sedimentary strata =
“continental terrace wedges” or “miogeoclines”

GEOSYNCLINES



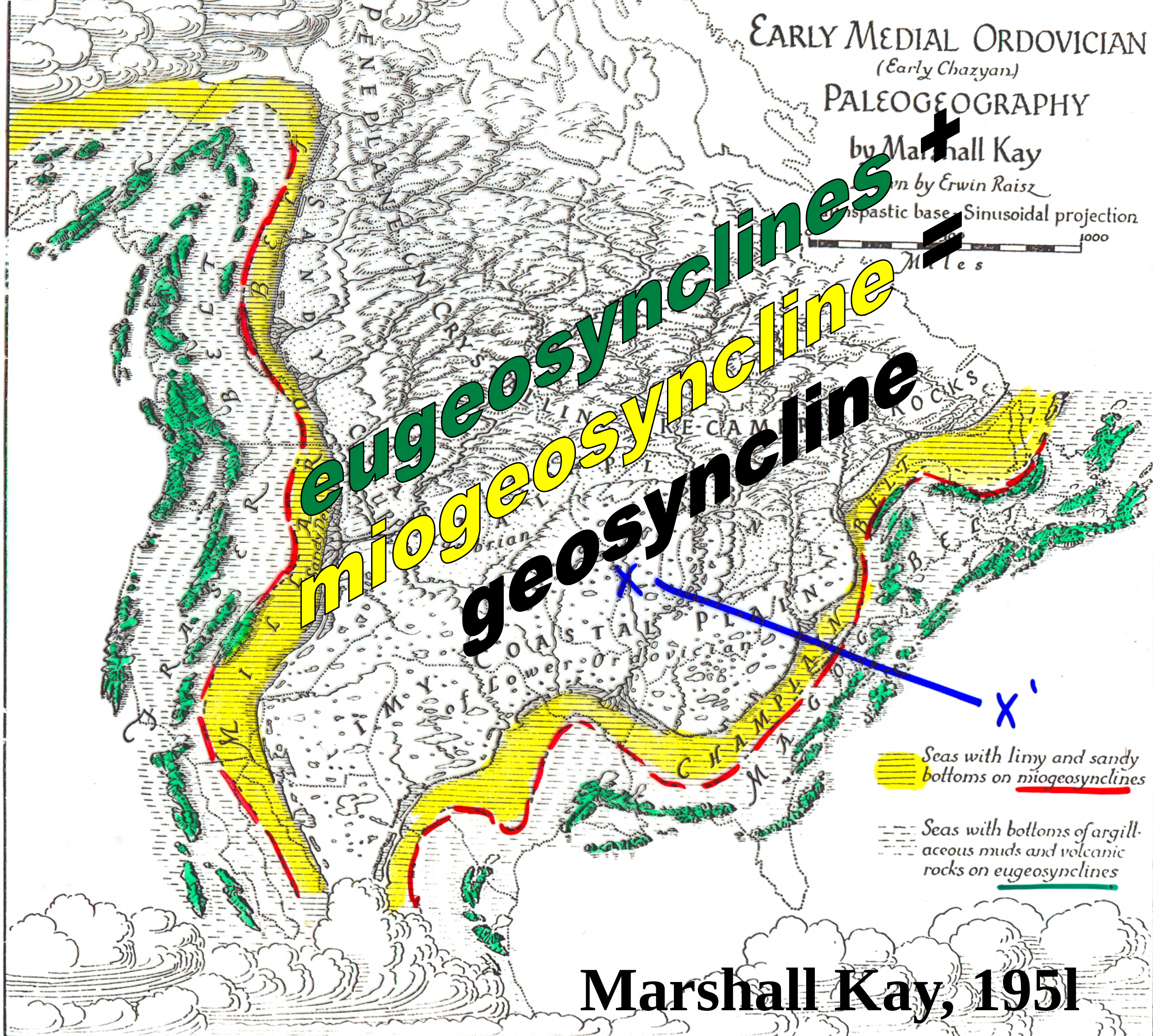
Marshall Kay, 1951

“GEOSYNCLINES” — A common geologic or tectonic term in the earth science literature that no longer has significance and should be abandoned.

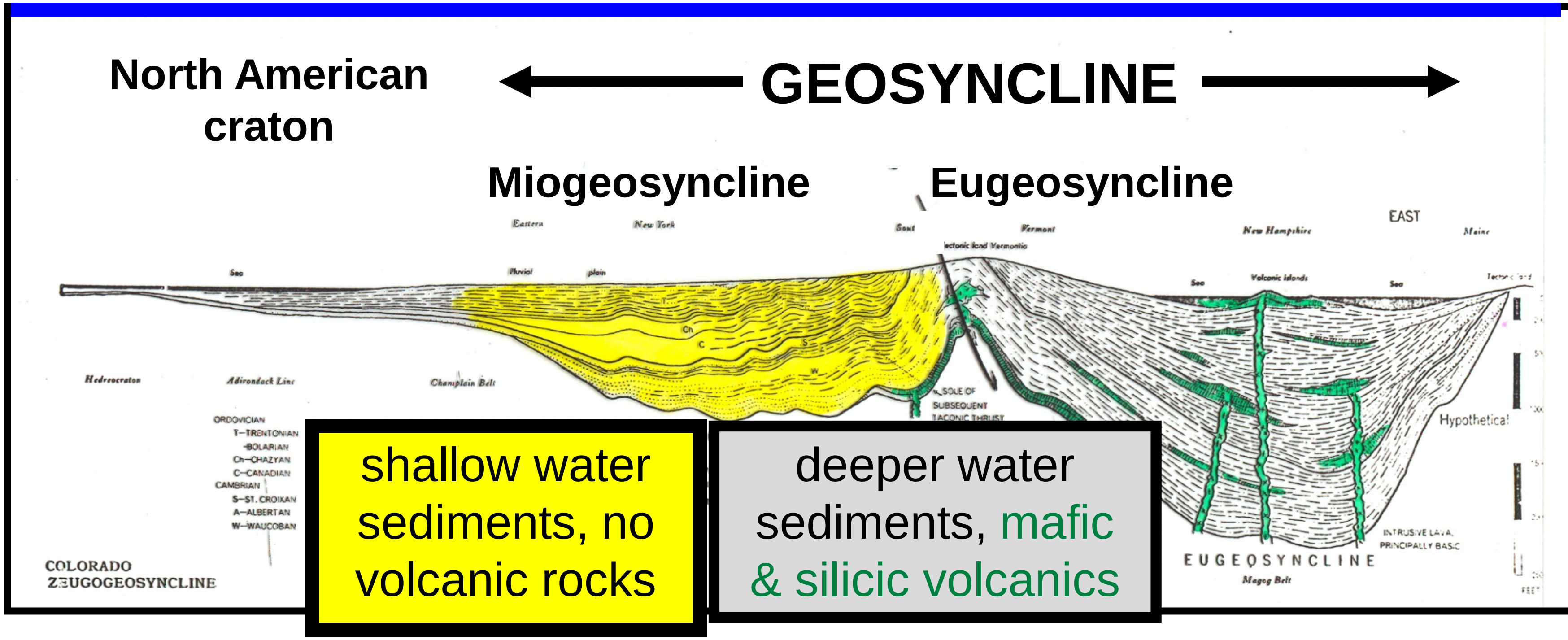
- Most mountain belts (Andes, Appalachians, Yanshan) contain thick, deformed sequences of marine (ocean-deposited) strata that were deposited in shallow water [Marshall Kay = “miogeosynclines”]
- Most mountain belts also contain deep water marine sedimentary strata, deformed mafic igneous rocks, granitic plutons, metamorphic rocks [Kay = “eugeosynclines”]

A MISTAKEN IDEA !

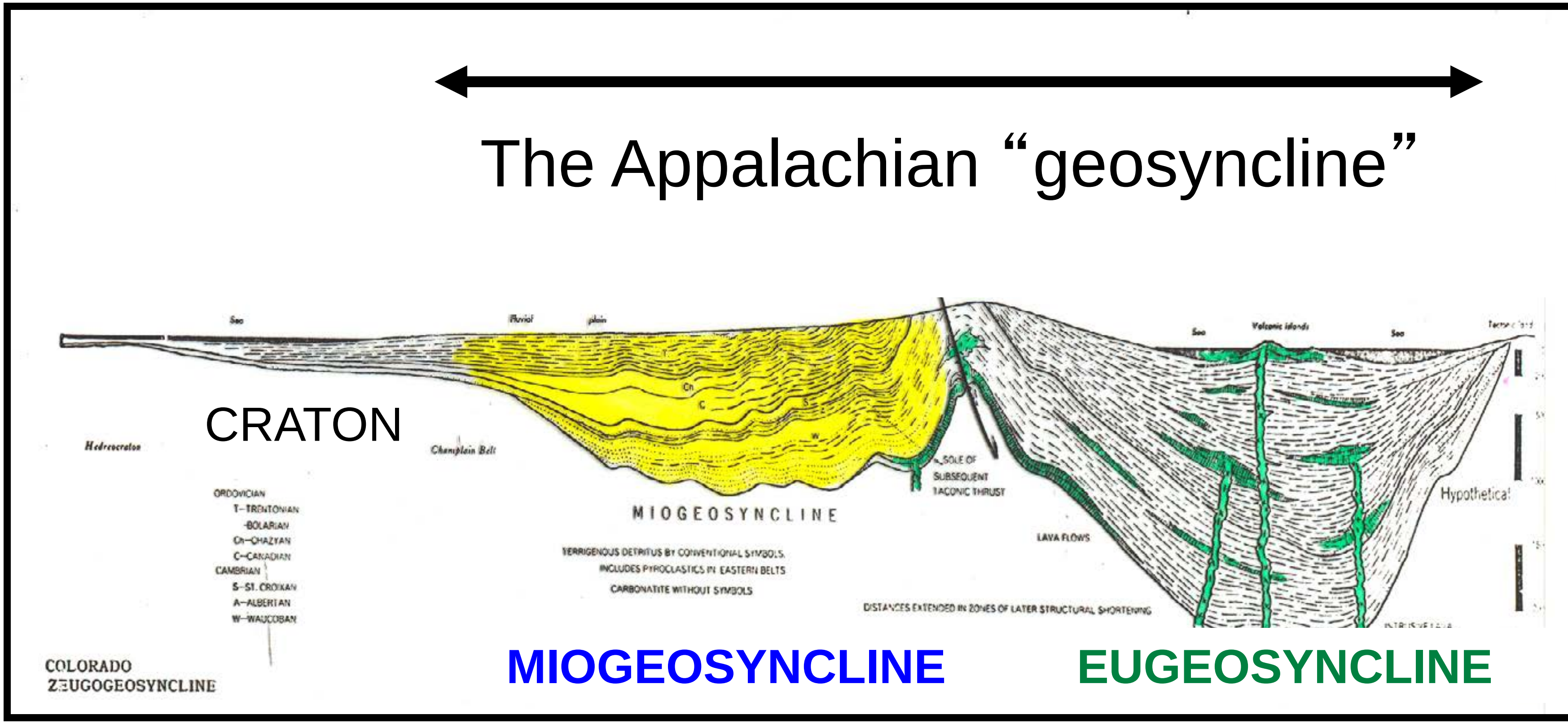
Marshall Kay, 1951


EARLY MEDIAL ORDOVICIAN
(Early Chazyan)
PALEOGEOGRAPHY
by Marshall Kay
Sinusoidal projection
1000
Miles
eugeosynclines +
miogeosyncline =
geosyncline
X
X'
Seas with limy and sandy bottoms on miogeosynclines
Seas with bottoms of argillaceous muds and volcanic rocks on eugeosynclines
COASTAL PLAIN
CHAMPLAIN BELT
Marshall Kay, 1951

Kay's Ordovician reconstruction of the Appalachian "geosyncline"



Kay: Geosynclines become orogenic mountain belts such as the Alps & Appalachians when deformed by contraction



Kay’s miogeosyncline was the North American Paleozoic continental terrace wedge —> a miogeocline
Kay’s eugeosyncline was never a separate basin, but was the result of later subduction along the passive margin, the deformation, metamorphism, and intrusion of the deeper parts of the continental terrace wedge, and the addition of oceanic crustal and mantle materials to the collisional zone

Students — if you are interested in learning more about "geosynclines" and "continental terrace wedges" the internet reading below is a good summary of how ideas evolved …

http://www.uwsp.edu/geo/projects/geoweb/participants/dutch/platetec/geosync.htm

Robert Dietz (1966): the "geosynclines" of orogenic belts start off as the shelf, slope, and rise sediments of rifted continental margins

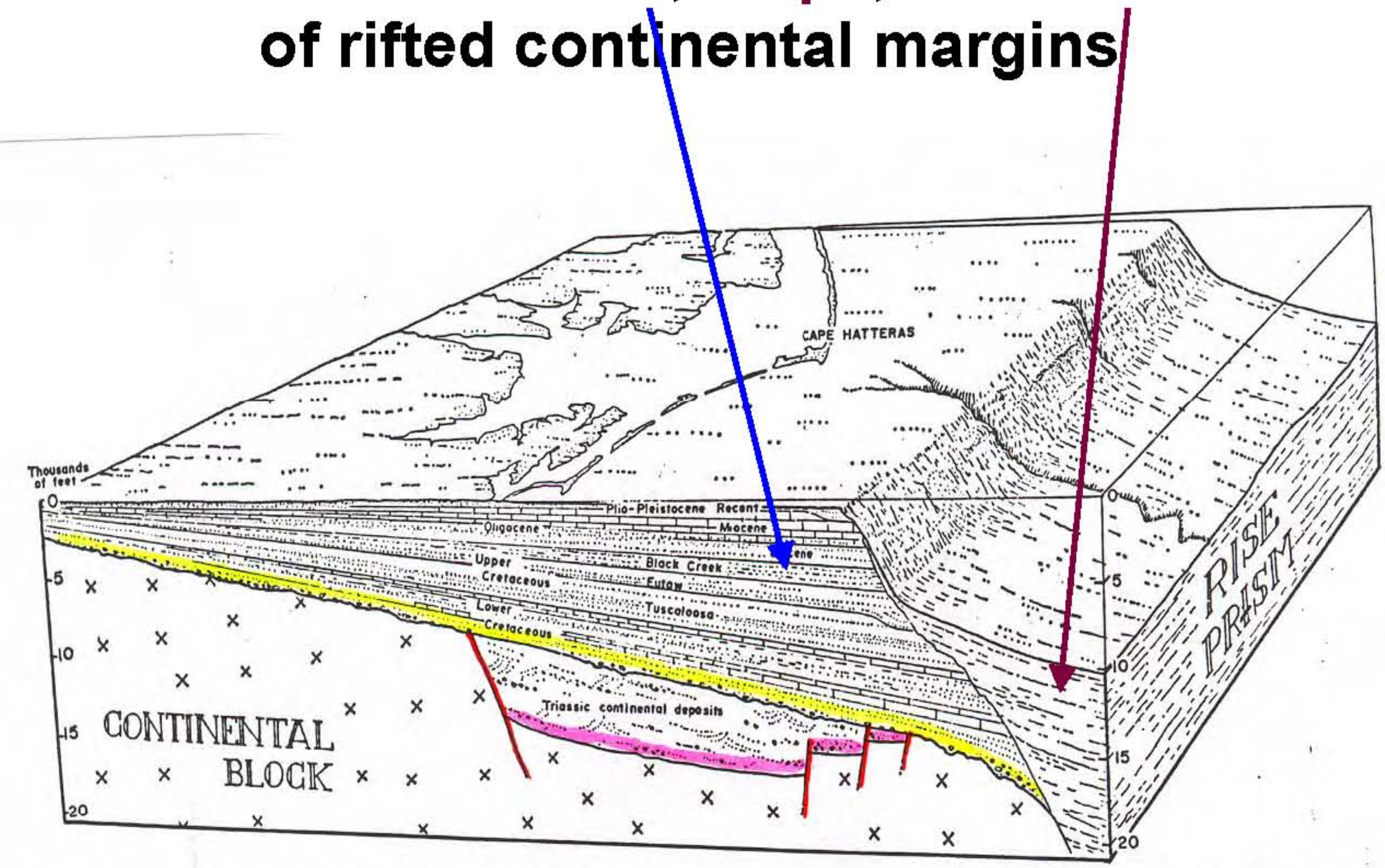
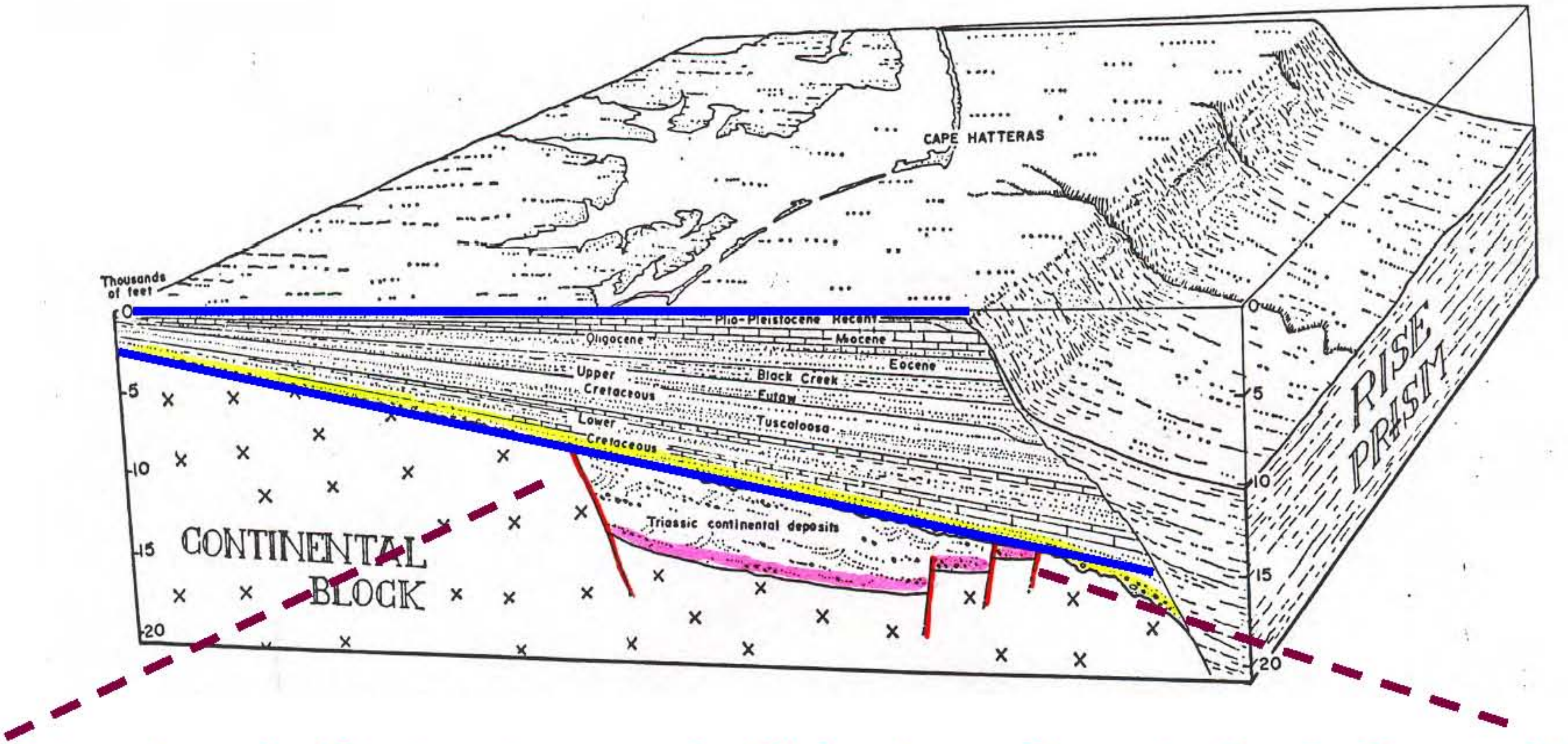


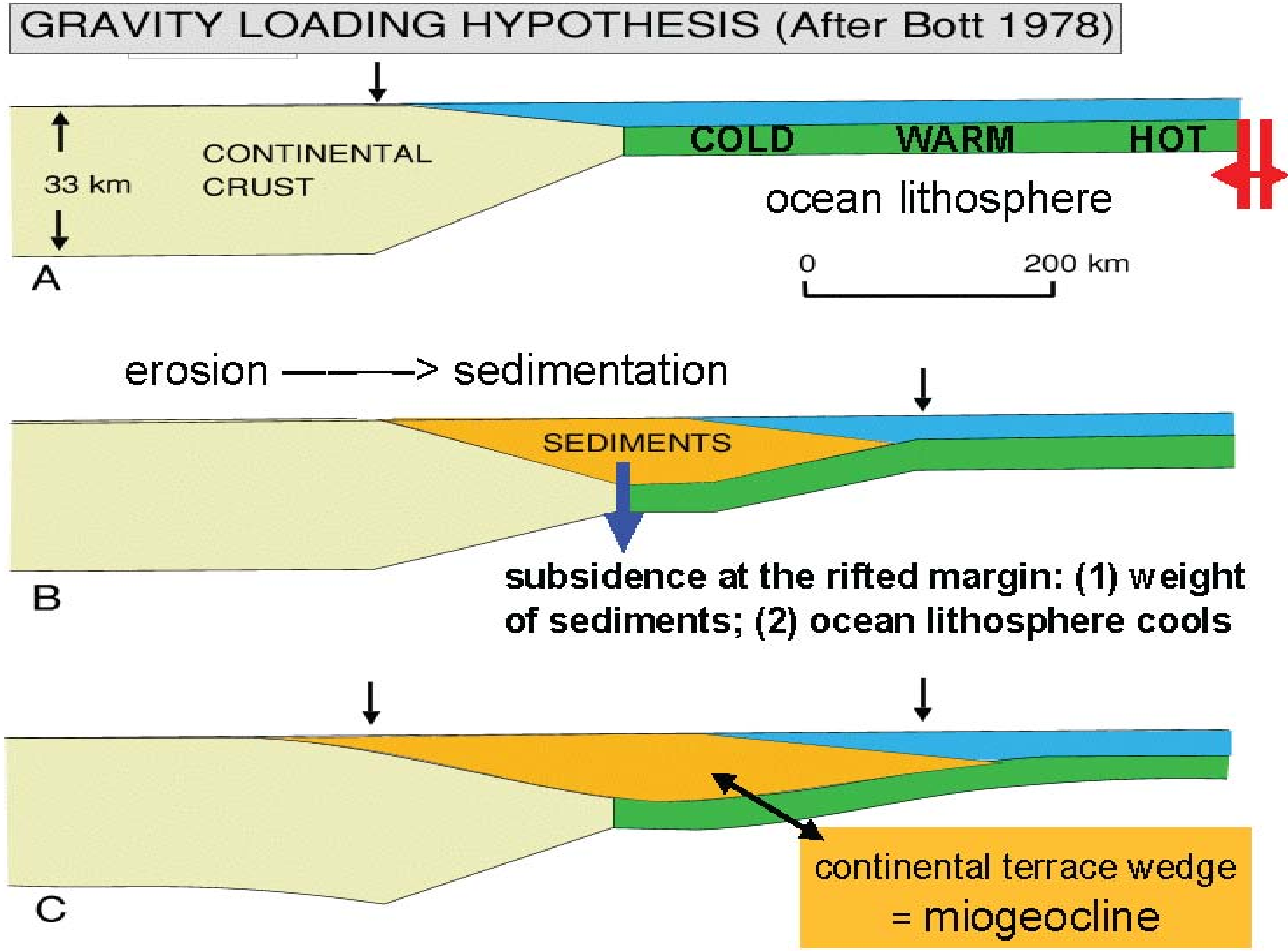
FIG. 1.—Simplified block diagram of the modern active continental terrace wedge or miogeocline off the eastern United States in the vicinity of Cape Hatteras. Cretaceous and younger strata dip monoclinally seaward and thicken out at the continental slope. The wedge is laid down on a Lower Cretaceous peneplain, the basement rocks presumably being composed of intrusives and metasediments of the crystalline Appalachian fold belt. Triassic basins filled with continental detritus also presumably are present in this basement, so one is shown here for diagrammatic purposes. Data for the section have been adapted from Swain (1947), Spangler (1950), Heezen, Tharp, and Ewing (1959).

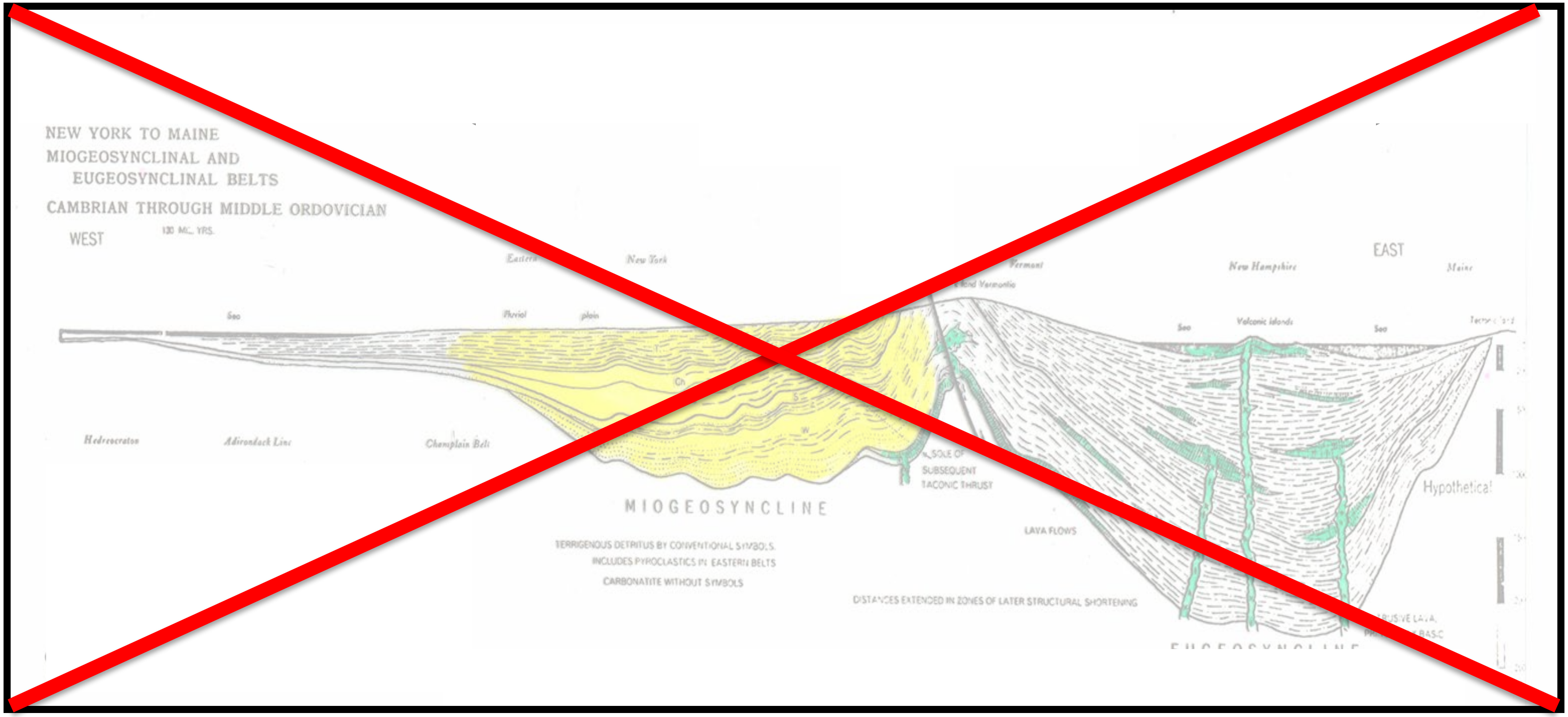
Robert Dietz (1966): shallow water continental shelf sedimentary strata have a wedge-like geometry and should be called a <u>miogeocline</u> or a <u>continental terrace wedge</u>.



Extensional rift structure and rift basin sediments (including salt)

These rift basins form during the early extension of continental crust.

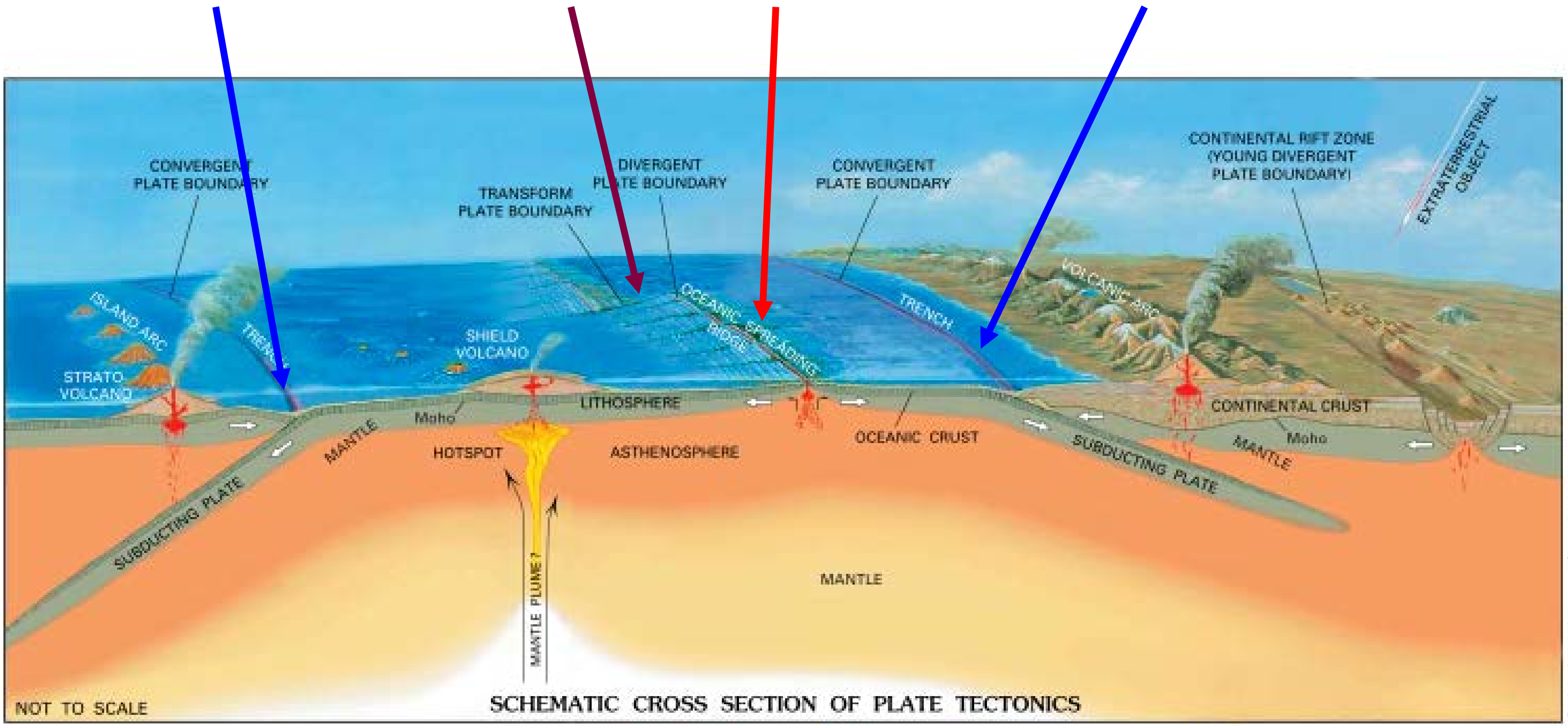

GRAVITY LOADING HYPOTHESIS (After Bott 1978)
33 km
CONTINENTAL
CRUST
COLD
WARM
HOT
ocean lithosphere
0
200 km
A
erosion ———> sedimentation
SEDIMENTS
subsidence at the rifted margin: (1) weight of sediments; (2) ocean lithosphere cools
B
C
continental terrace wedge
= miogeocline



The geologic terms "geosyncline","miogeosyncline", and "eugeosyncline" should no longer be used. "Miogeocline" is an acceptable term for continental terrace wedges.

SCHEMATIC CROSS SECTION OF PLATE TECTONICS

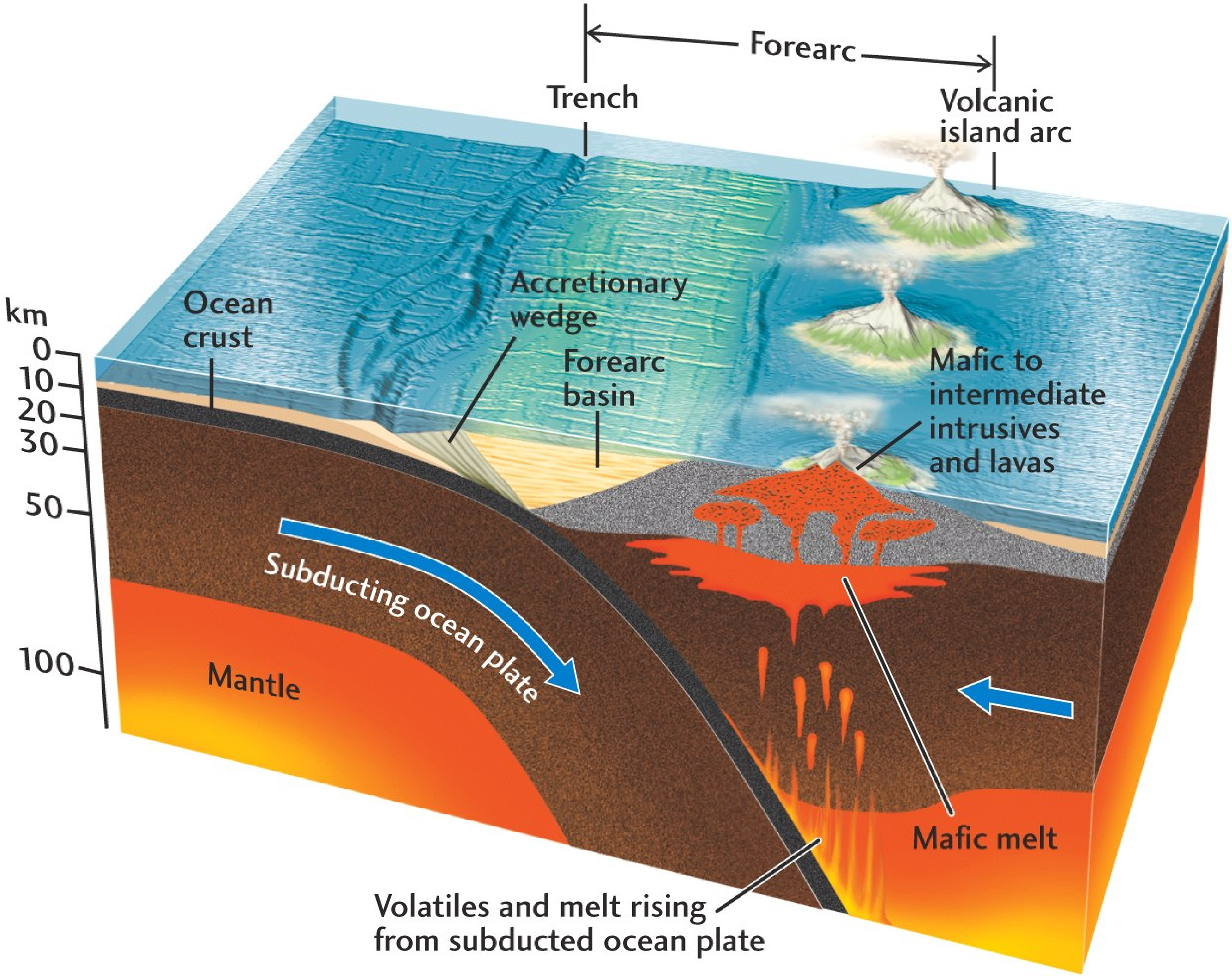
convergent transform divergent convergent **boundaries**



USGS Smithsonian Institution U.S. Naval Research Laboratory

Convergence—I: Subduction tectonics

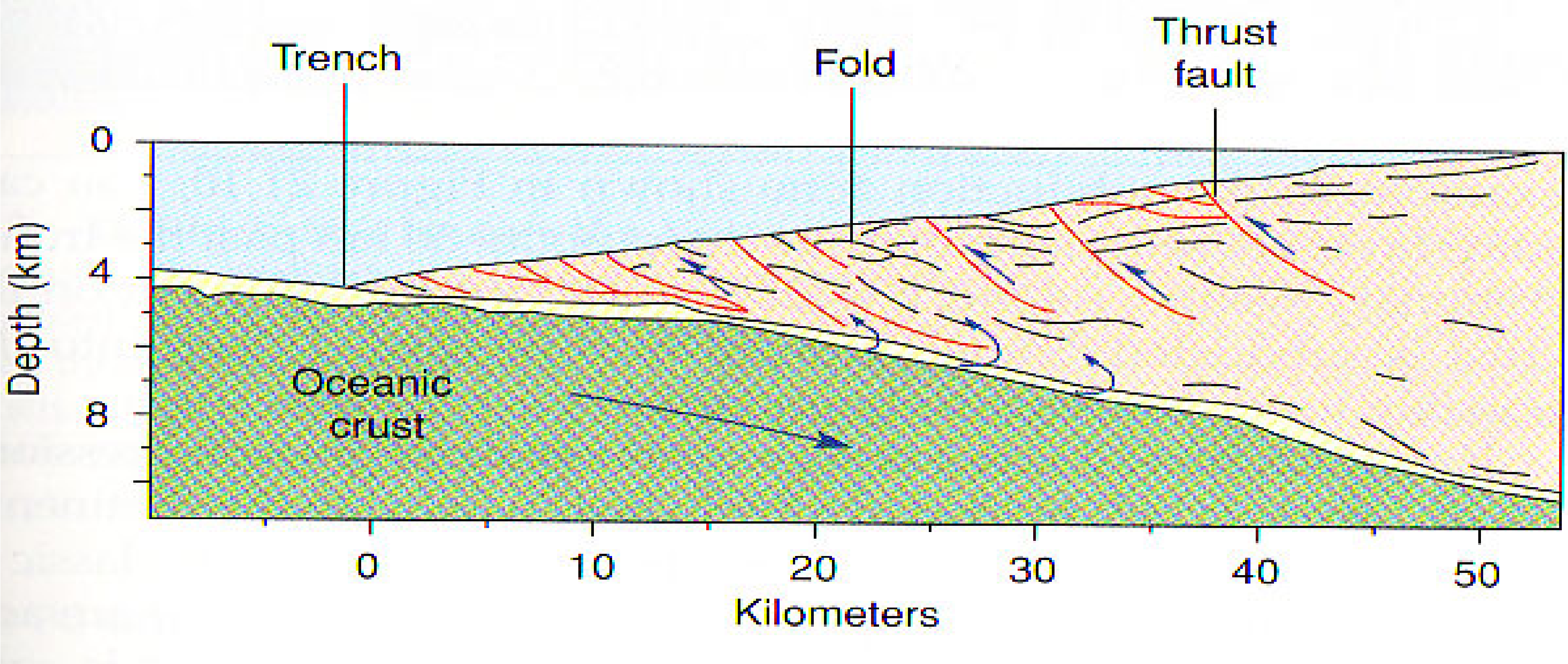
Greg Davis 5/27/2016
DIZHI DAXUE/Beijing


Forearc
Trench
Volcanic
island arc
km
0
10
20
30
50
100
Ocean
crust
Accretionary
wedge
Forearc
basin
Mafic to
intermediate
intrusives
and lavas
Subducting ocean plate
Mantle
Mafic melt
Volatiles and melt rising
from subducted ocean plate

The deepest parts of the ocean are the ocean trenches next to continents and arcs. They receive **sediment eroded from the nearly land masses** AND they receive **sediment deposited out in the oceans** and carried into the trenches on the tops of subducting plates.

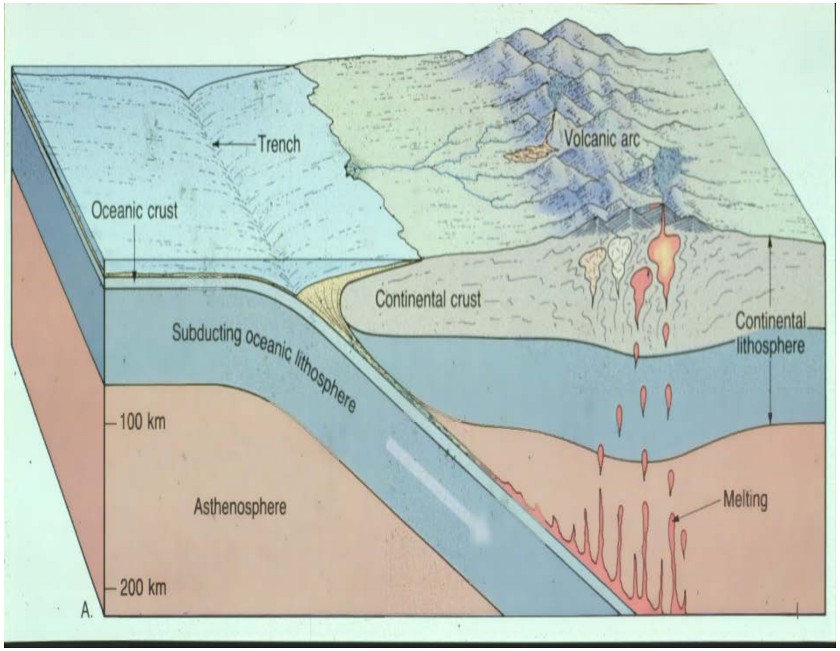
WHAT HAPPENS TO THIS SEDIMENT?

Accretionary Wedges

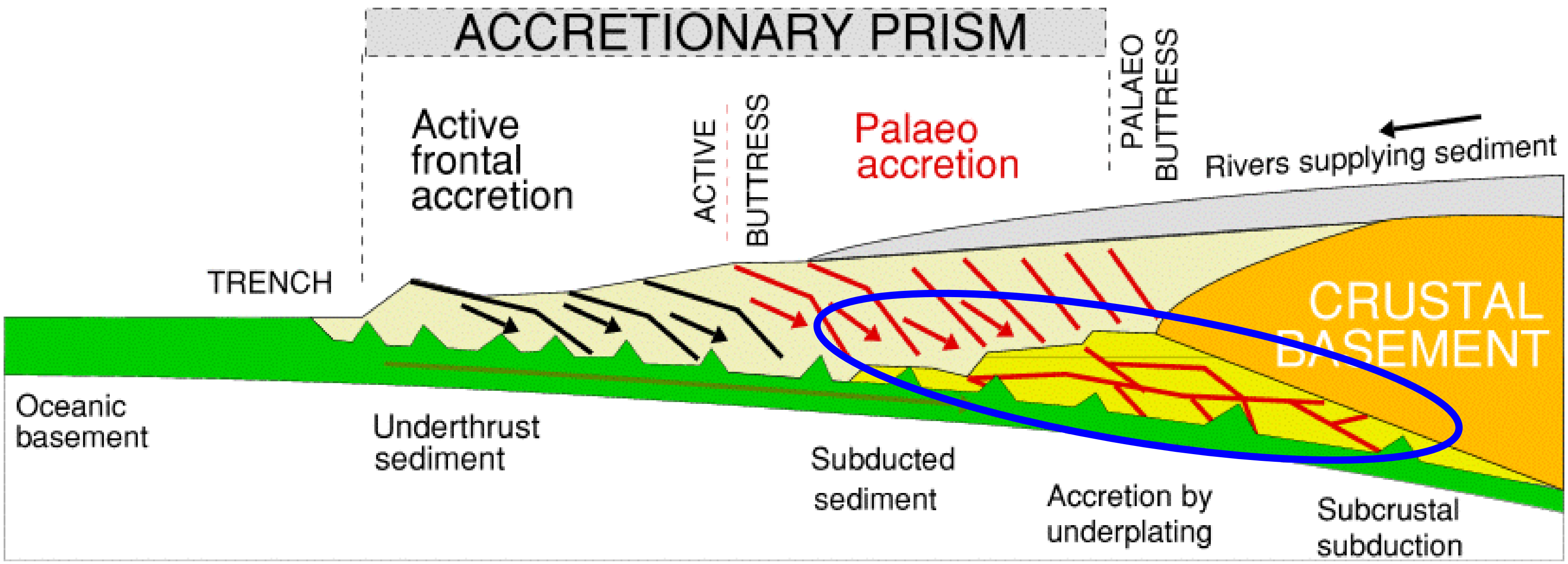


Accretionary Wedges

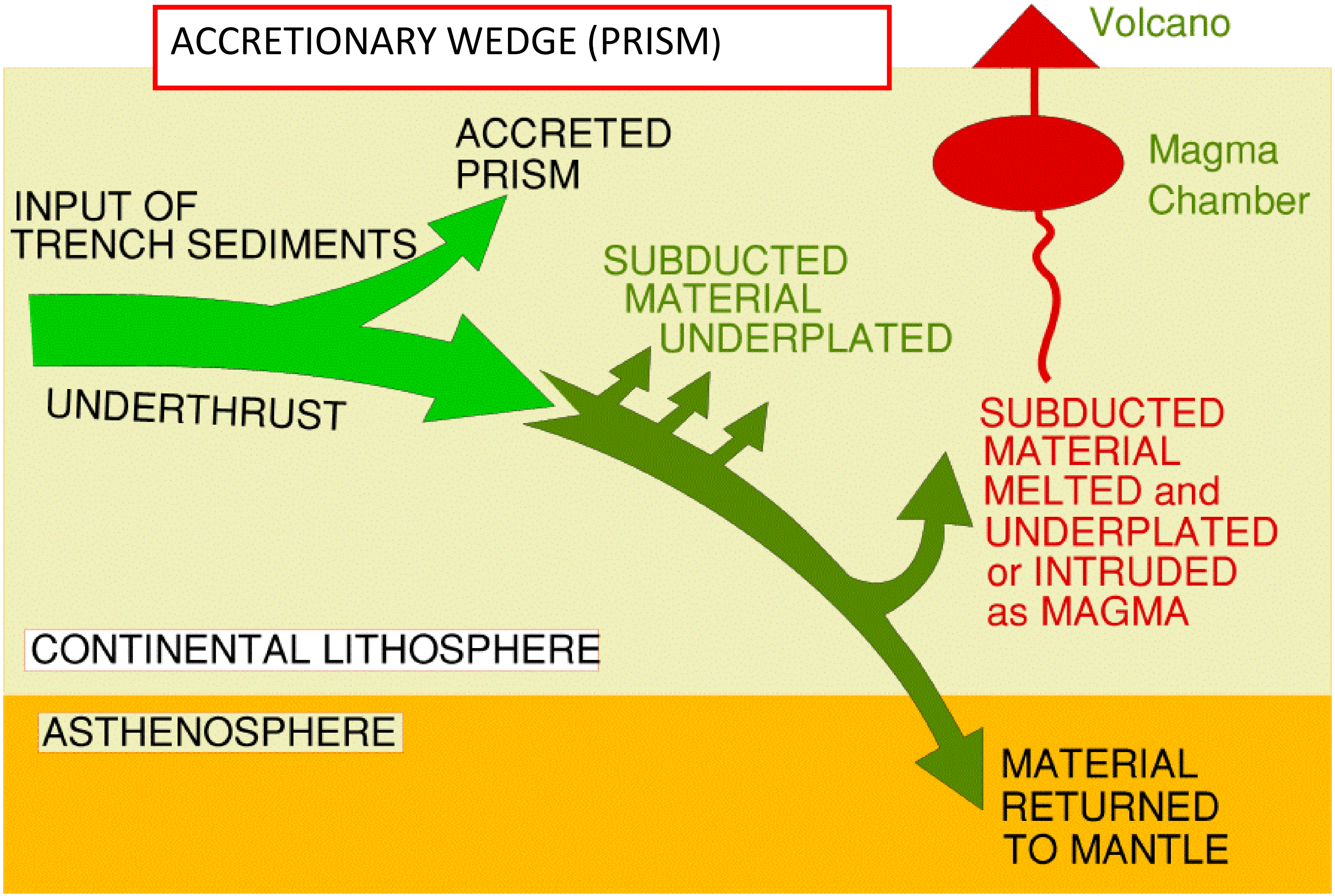
www.geosci.usyd.edu.au/…/Report2/hydro.htm
www.phys.ocean.dal.ca/…/lect12/lect12.html



An oversimplified view of an accretionary prism or wedge (both terms are used). Prisms typically grow by the addition of sediment at their near-trench fronts, but they can also grow from below by **"underplating"** of subducted materials (sediments, sea-floor volcanoes, etc.)

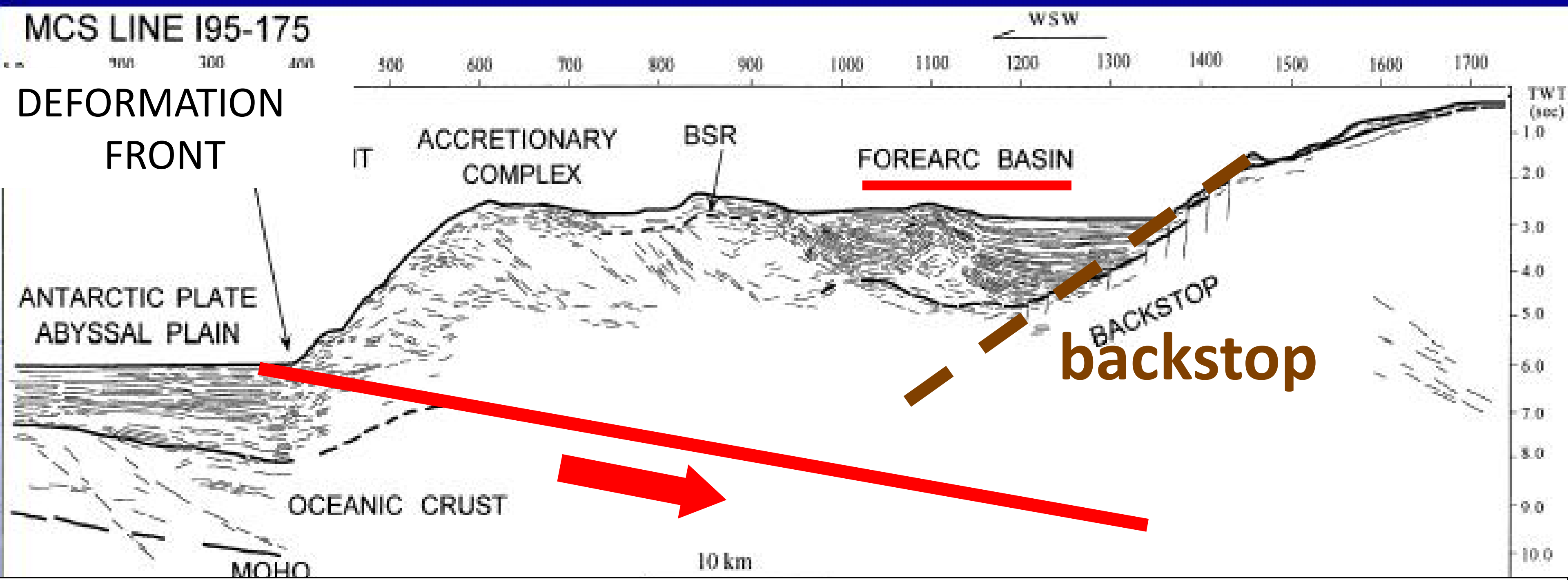


Fate of Sediment at Convergent Plate Margins: Summary



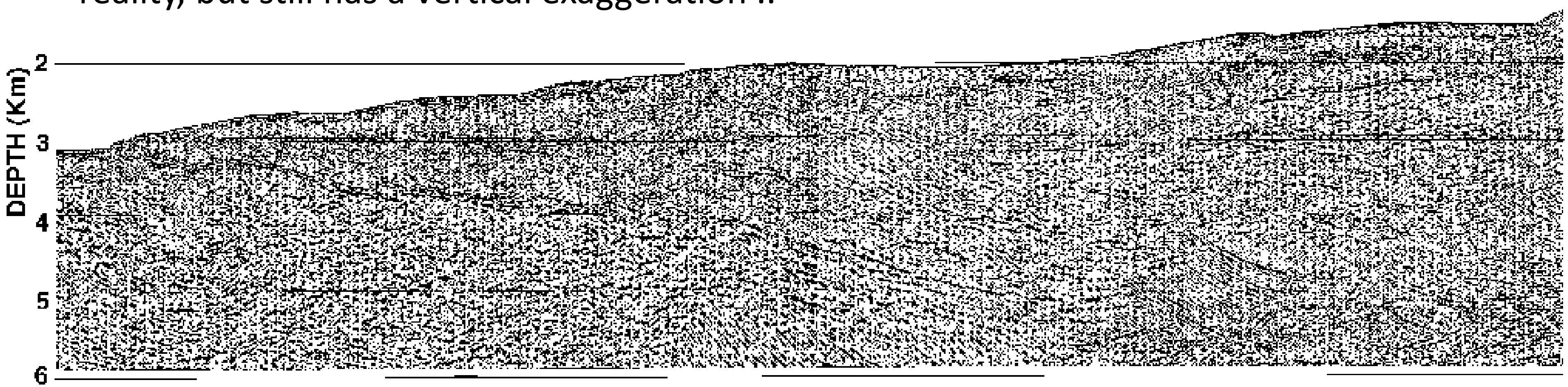
Chile: accretionary prism, forearc, backstop

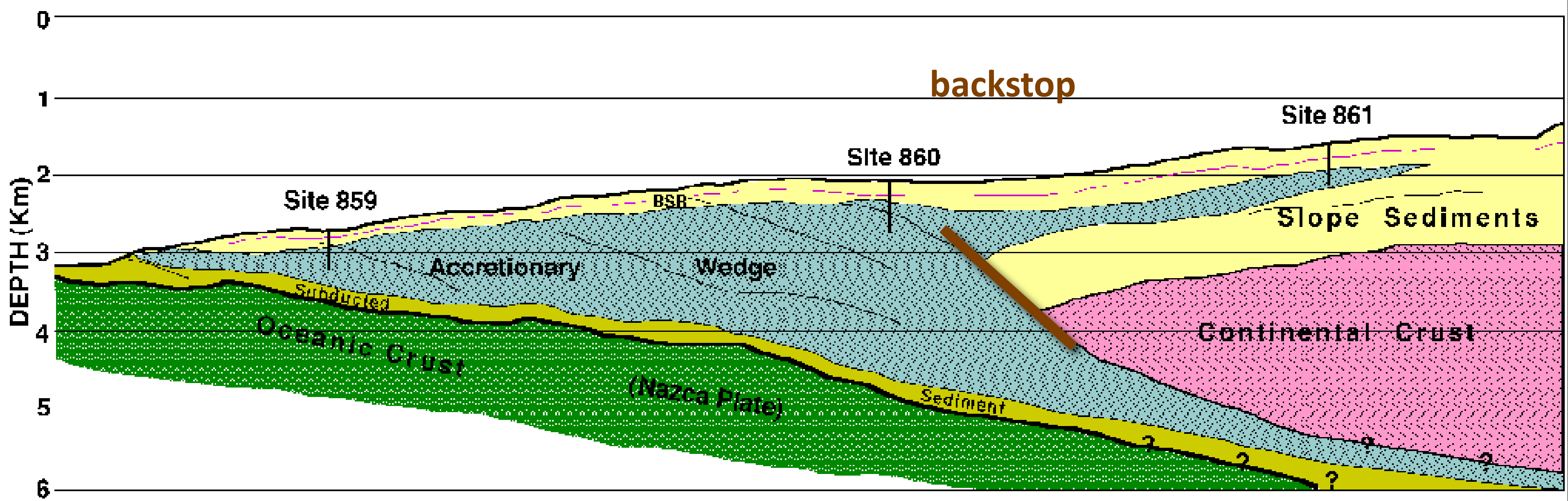
(with great vertical exaggeration)



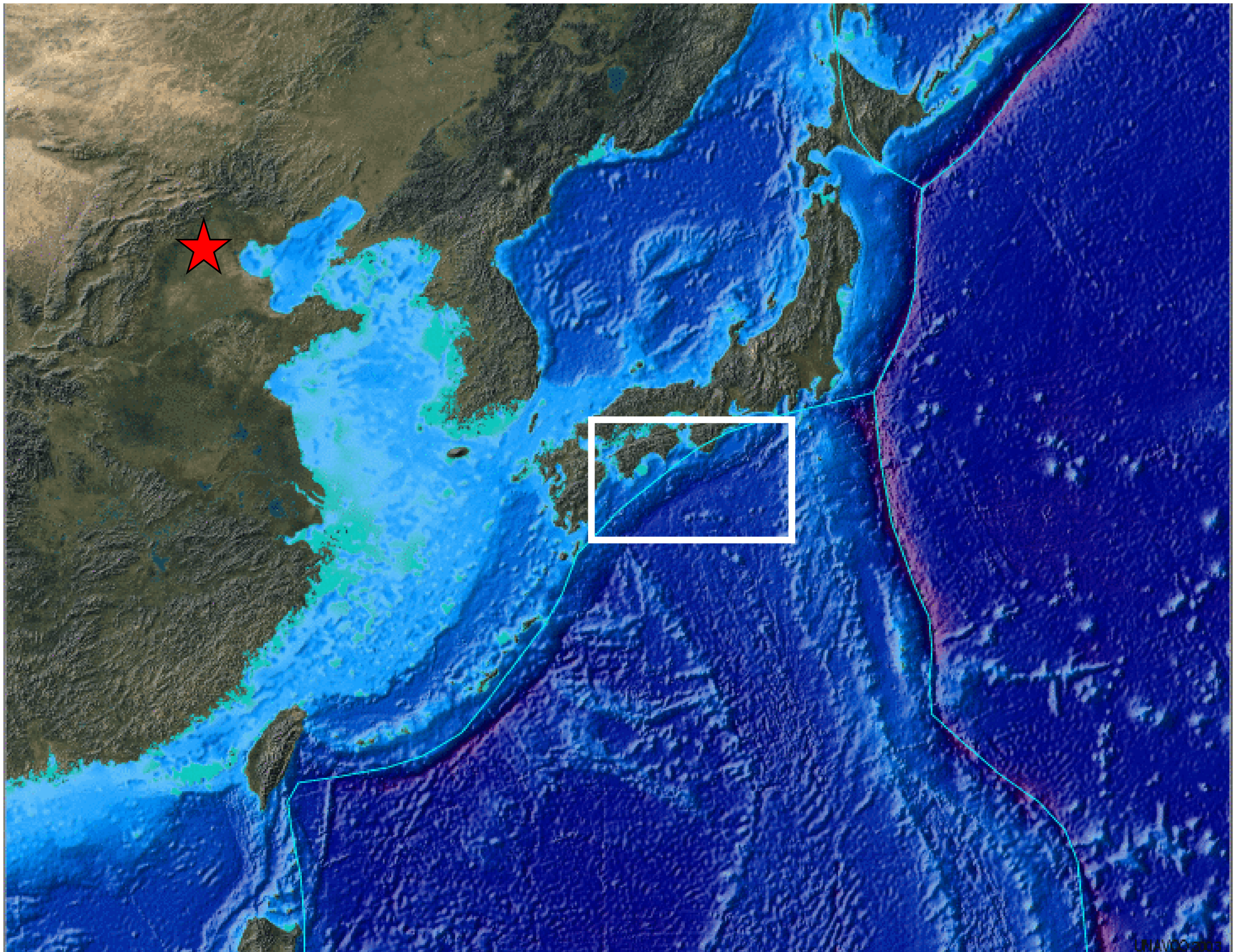
Line 745

This geometry of a Chilean subduction zone is closer to reality, but still has a vertical exaggeration ..

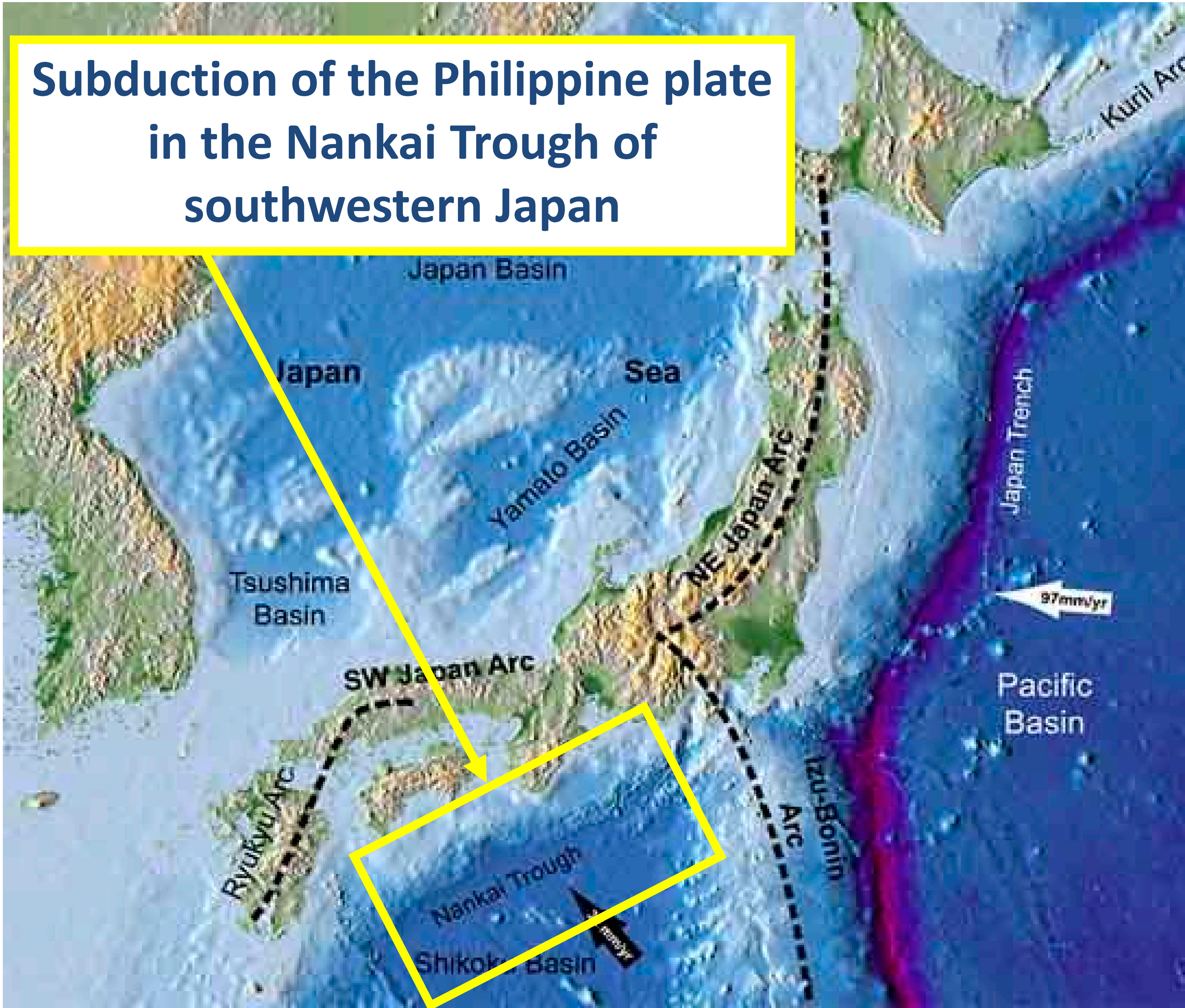


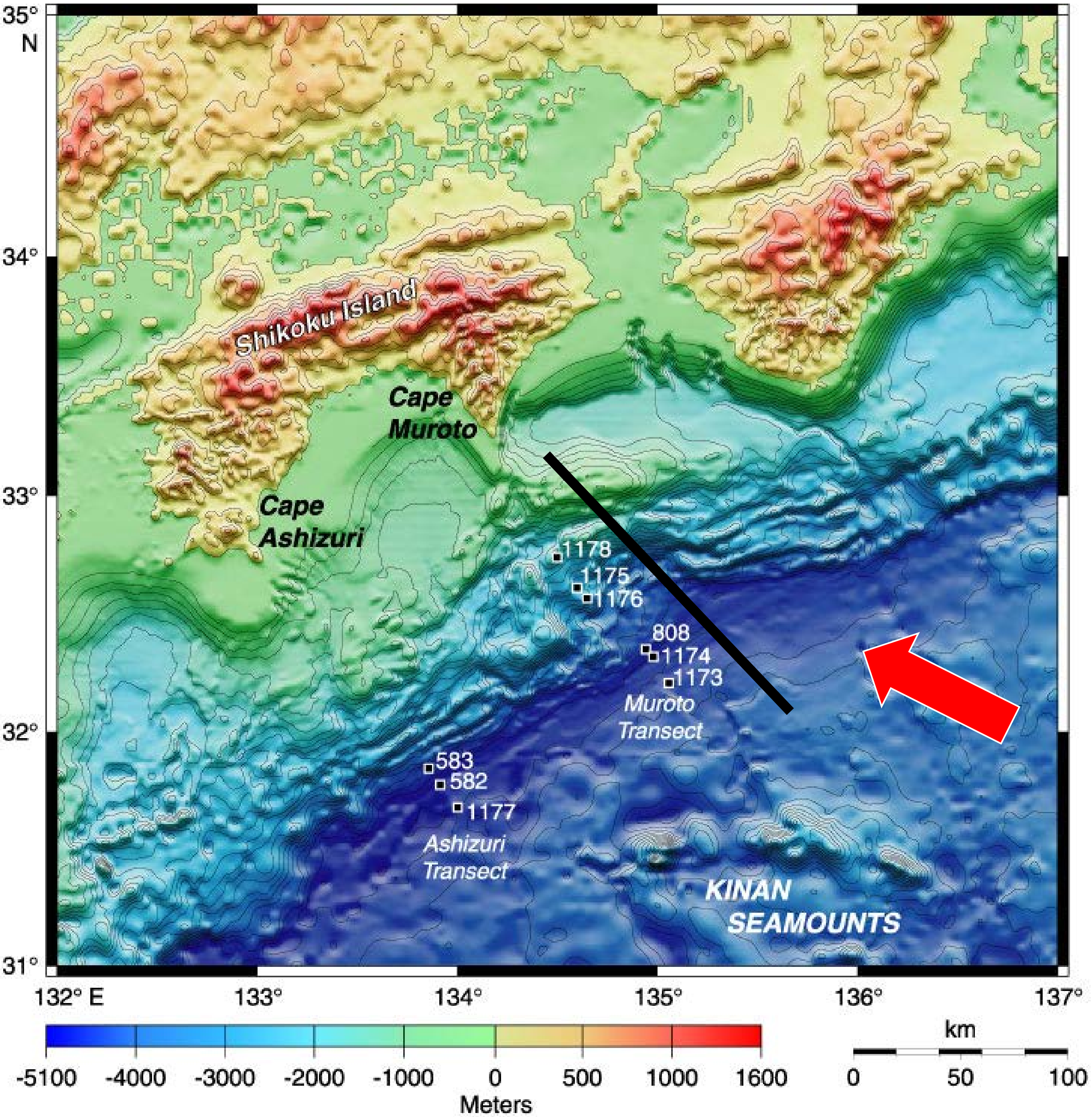


The best example of what happens to sediments when they enter an oceanic trench is the Nankai trough (trench) south of Shikoku Island, Japan



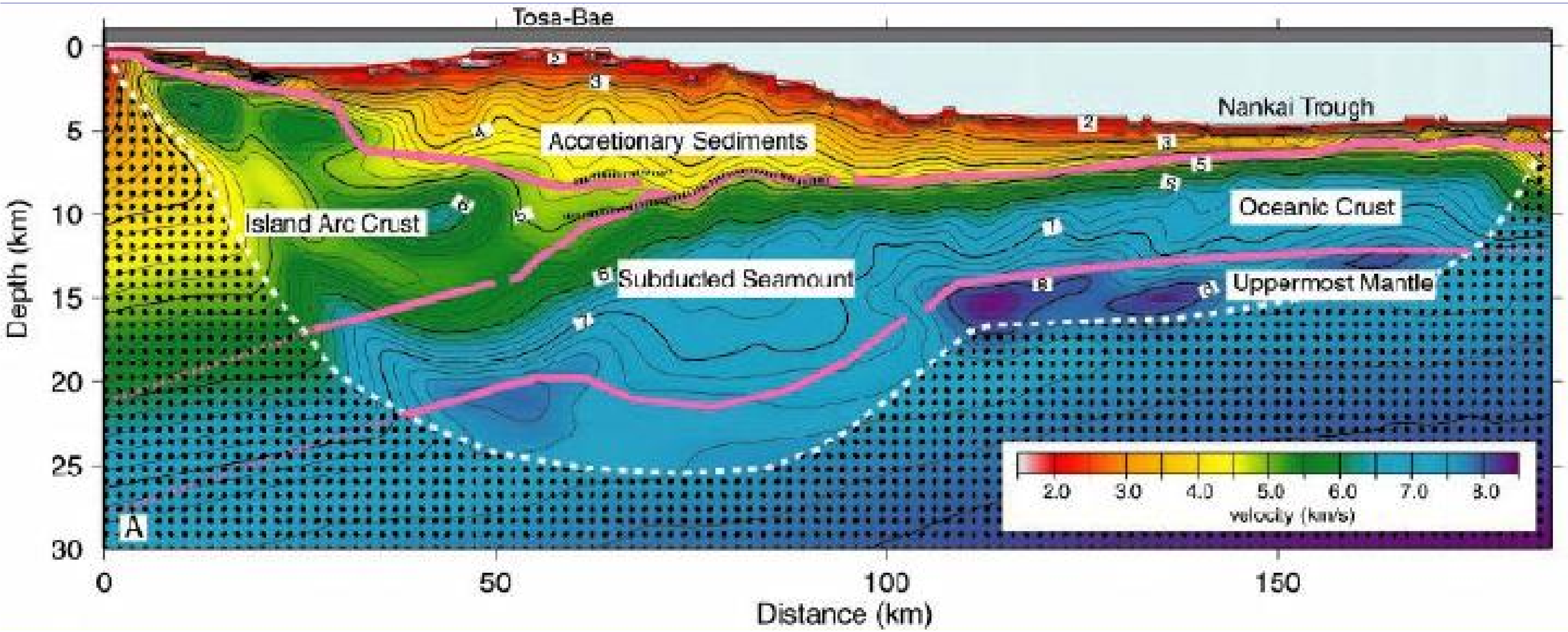
Subduction of the Philippine plate in the Nankai Trough of southwestern Japan

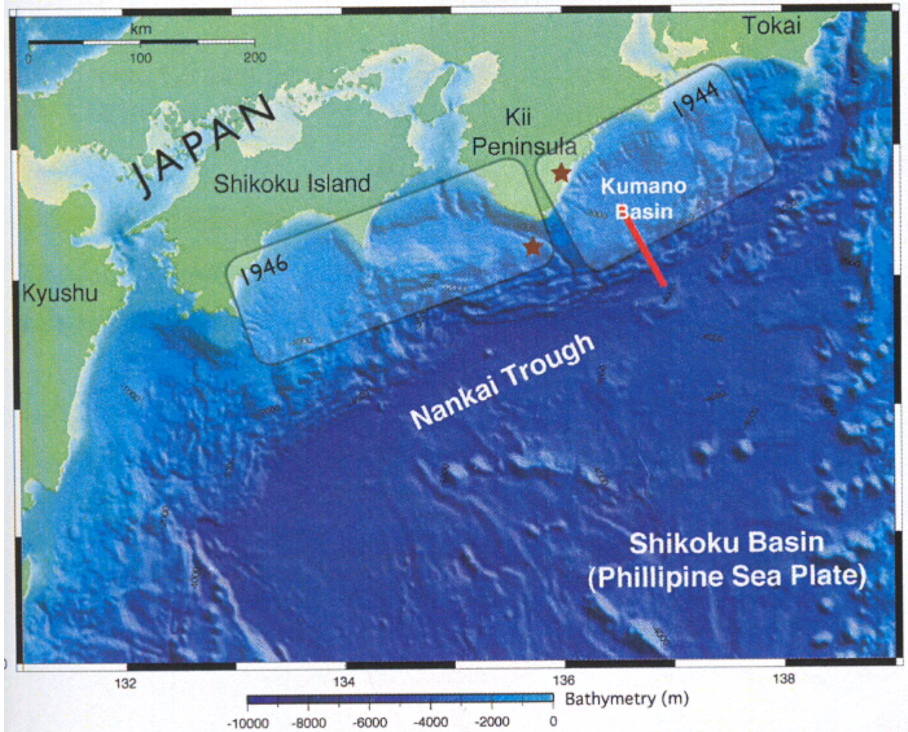




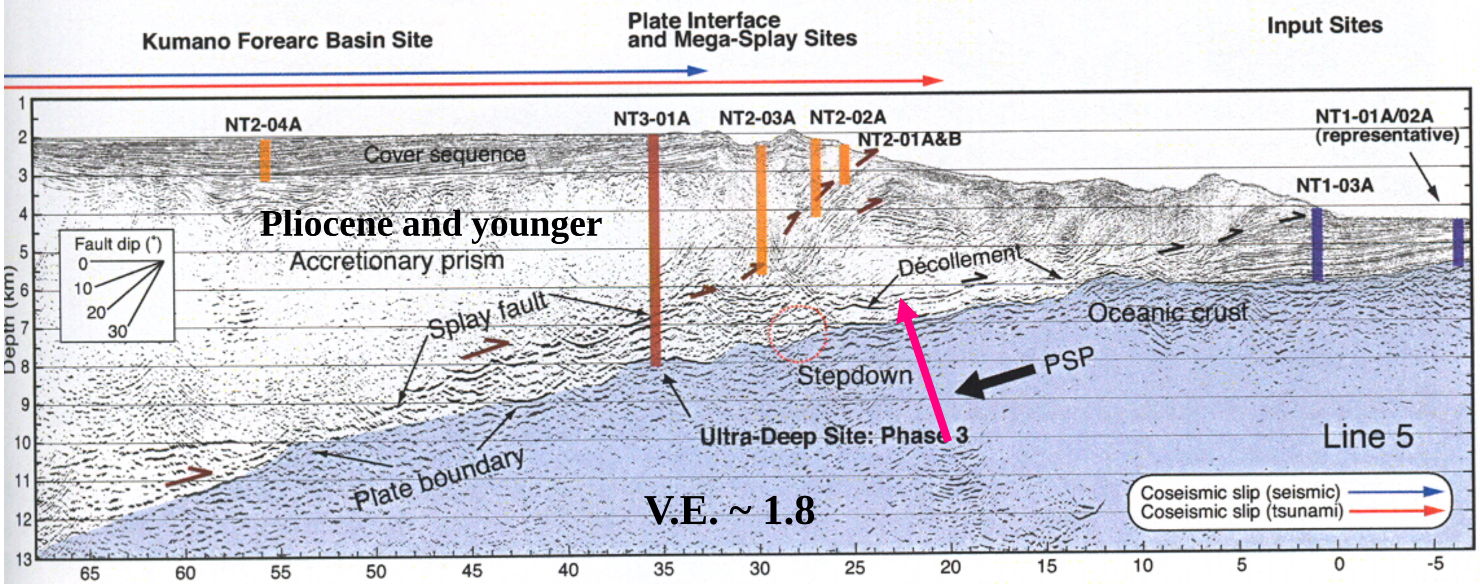
35° N
34°
33°
32°
31°
132° E
133°
134°
135°
136°
137°
Shikoku Island
Cape Muroto
Cape Ashizuri
1178
1175
1176
808
1174
1173
Muroto Transect
583
582
1177
Ashizuri Transect
KINAN SEAMOUNTS
-5100
-4000
-3000
-2000
-1000
0
500
1000
1600
Meters
km
0
50
100

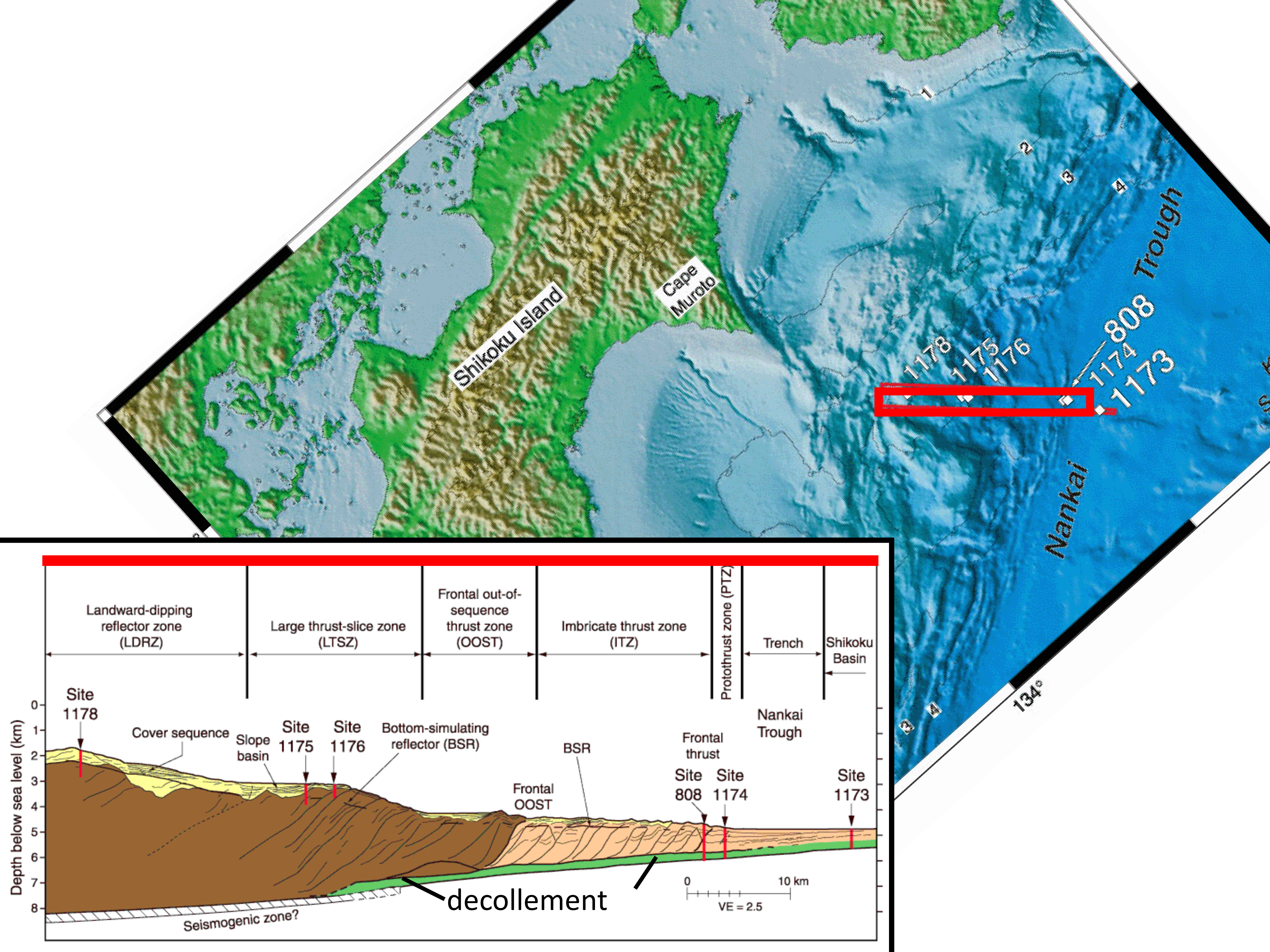
The accretionary wedge (prism) inland from the Nankai Trough continues onshore at Shikoku island. This figure shows only that part of the huge wedge that lies between the Trough and the island. The V.E. is about 2x (V:H). Most of this wedge is Pliocene and younger in age (≤ 6 Ma)! At a convergent rate of about 4 cm/year, this adds about 40 km of material per million years (before internal shortening).

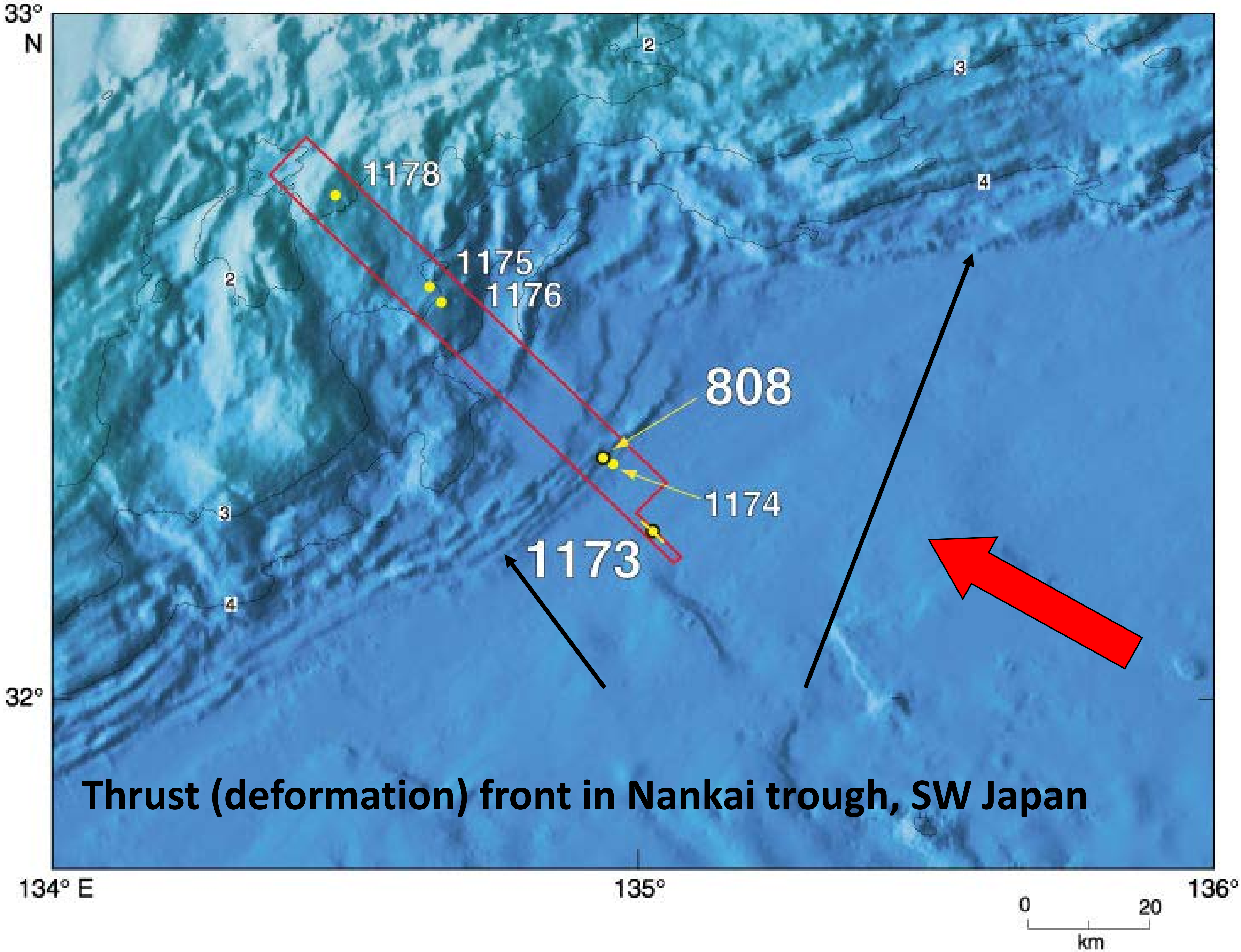


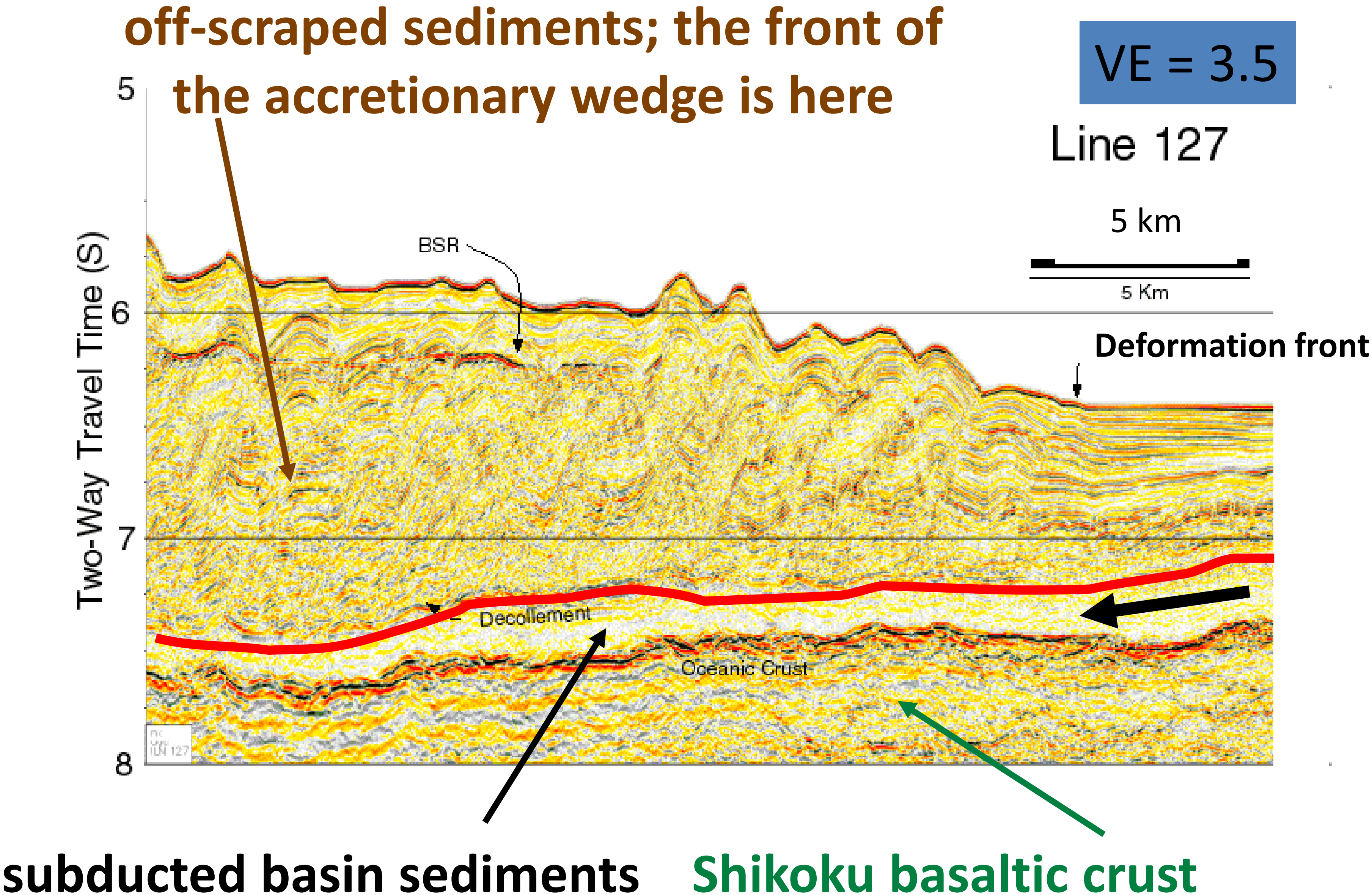


The Nankai Trough subduction zone (left) has been the site of numerous tsunamigenic megathrust great (M8+) earthquakes, most recently in 1944 and 1946. The red line shows the location of a deep-penetrating seismic reflection line (below) imaging the plate boundary fault system. Tsunami and earthquake inversion show that co-seismic slip propagated to shallow depth on the basal detachment and/or mega-splay fault system in 1944. In NanTroSEIZE, we plan for a series of boreholes accessing this interface at locations spanning the up-dip aseismic to seismic slip transition. Sampling, downhole experiments, and long-term monitoring are planned.




Shikoku Island
Cape Muroto
Nankai
Trough
1178
1175
1176
808
1174
1173
134°
Landward-dipping reflector zone (LDRZ)
Large thrust-slice zone (LTSZ)
Frontal out-of-sequence thrust zone (OOST)
Imbricate thrust zone (ITZ)
Protothrust zone (PTZ)
Trench
Shikoku Basin
Depth below sea level (km)
Site 1178
Cover sequence
Slope basin
Site 1175
Site 1176
Bottom-simulating reflector (BSR)
BSR
Frontal OOST
Frontal thrust
Nankai Trough
Site 808
Site 1174
Site 1173
0
10 km
VE = 2.5
decollement
Seismogenic zone?


33°
N
1178
1175
1176
808
1174
1173
2
3
4
2
3
4
32°
134° E
135°
136°
0
20
km
Thrust (deformation) front in Nankai trough, SW Japan



off-scraped sediments; the front of the accretionary wedge is here
VE = 3.5
Line 127
5 km
5 Km
BSR
Deformation front
Two-Way Travel Time (S)
5
6
7
8
Decollement
Oceanic Crust
subducted basin sediments
Shikoku basaltic crust

Annu. Rev. Earth Planet. Sci. 1990. 18:55–99

CRITICAL TAPER MODEL OF FOLD-AND-THRUST BELTS AND ACCRETIONARY WEDGES

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INTRODUCTION

The fold-and-thrust belts and submarine accretionary wedges that lie along compressive plate boundaries are one of the best understood deformational features of the Earth's upper crust. Although there is considerable natural variation among the many fold-and-thrust belts and accretionary wedges that have been recognized and explored, several features appear to be universal. In cross section, fold-and-thrust belts and accretionary wedges occupy a wedge-shaped deformed region overlying a basal detachment or décollement fault; the rocks or sediments beneath this fault show very little deformation. The décollement fault characteristically dips toward the interior of the mountain belt or, in the case of a submarine wedge, toward the island arc; the topography, in contrast, slopes toward the toe or deformation front of the wedge. Deformation within the wedge is generally dominated by imbricate thrust faults verging toward the toe and related fault-bend folding.

Two North American fold-and-thrust belts that exhibit these features are shown in Figure 1. Neither of these two examples is tectonically active today; the southern Canadian fold-and-thrust belt was active during the late Jurassic and Cretaceous (150–100 Ma), whereas the southern Appalachians were deformed during the late Carboniferous to Permian Alleghenian orogeny (300–250 Ma). Figure 2 shows two examples that are currently active: the Taiwan fold-and-thrust belt, produced by the subduction of the Eurasian plate beneath the Philippine Sea plate (Suppe 1981, 1987); and the Barbados accretionary wedge, produced by the sub-

Fig. 16. Cross sections of the Himalayan fold-and-thrust belt and various active submarine accretionary wedges. Heavy dashed lines are best fitting linear profiles used to infer the fluid pressure ratios $\lambda = \lambda_b$, which are also shown.

True scale geometries of various accretionary wedges (and the Himalayan thrust belt)

Japan (Nankai)

Barbados

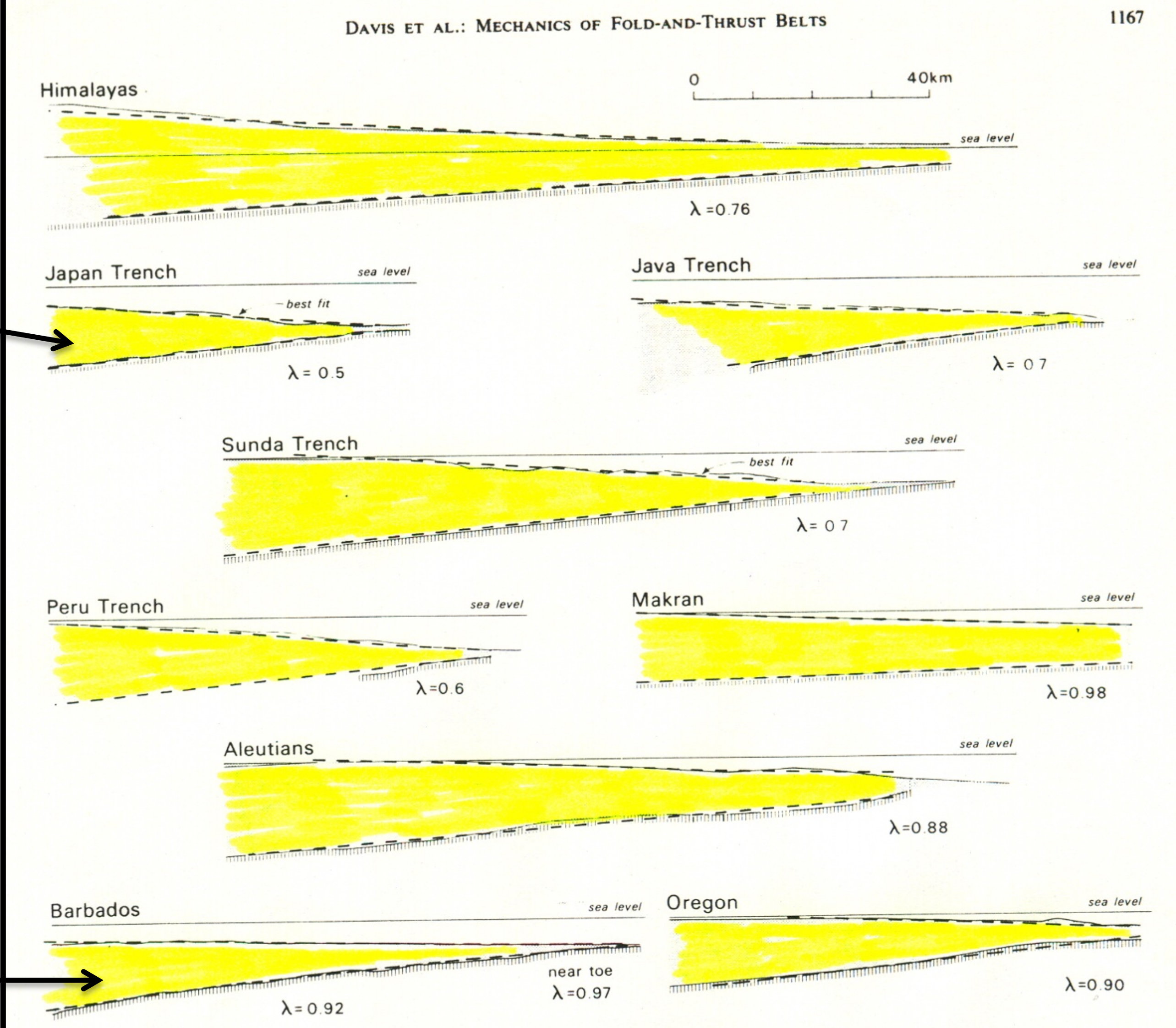
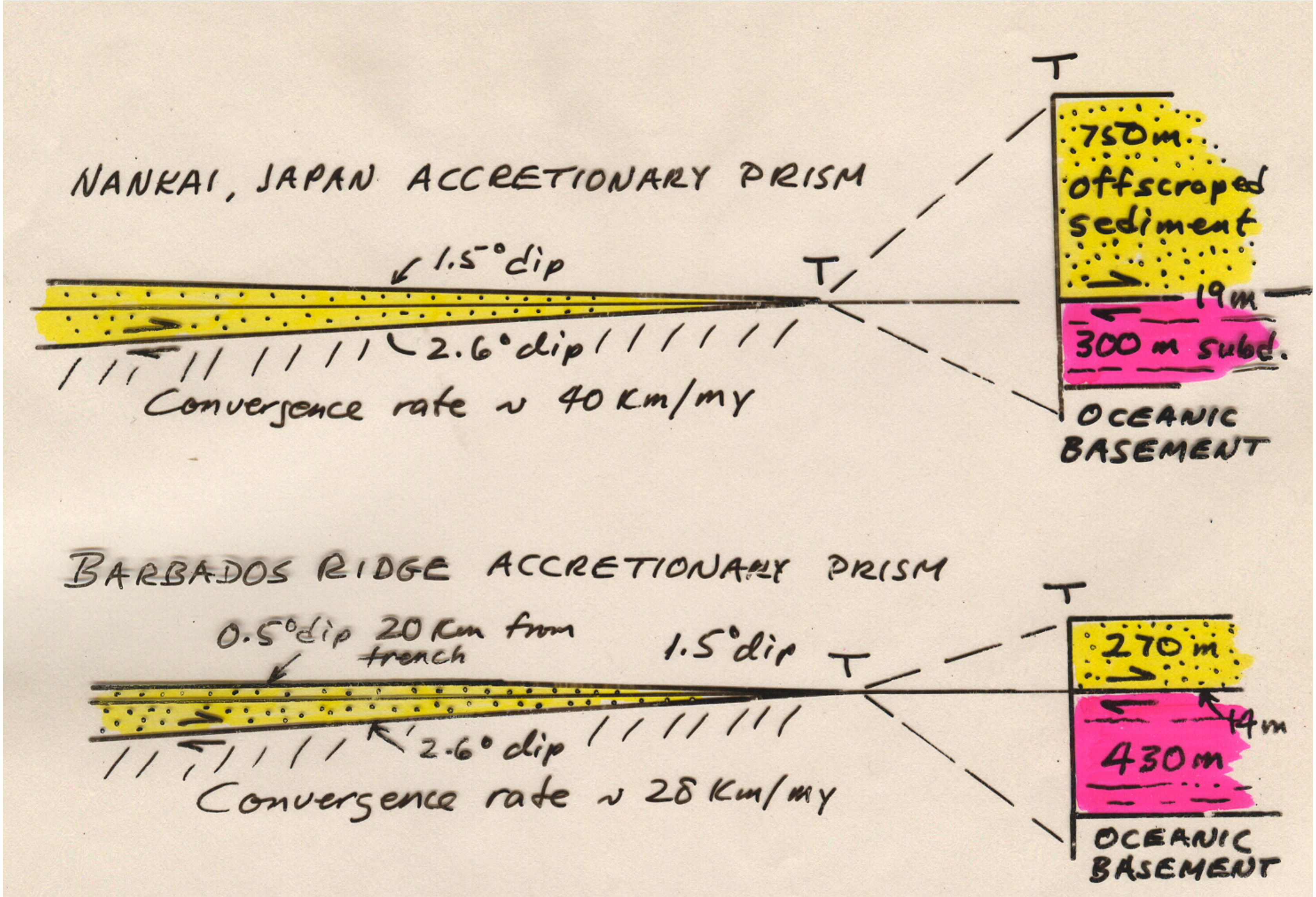


Fig. 16. Cross sections of the Himalayan fold-and-thrust belt and various active submarine accretionary wedges. Heavy dashed lines are best fitting linear profiles used to infer the fluid pressure ratios $\lambda = \lambda_b$, which are also shown.

Nankai and Barbados Accretionary Wedges



Snow plow tectonics — the plow (the backstop) advances over the snow-covered road …. and snow accumulates in front of it

Accretionary wedge tectonics — the sediment-covered subducting plate advances towards the backstop … and off-scraped sediment accumulates in front of it

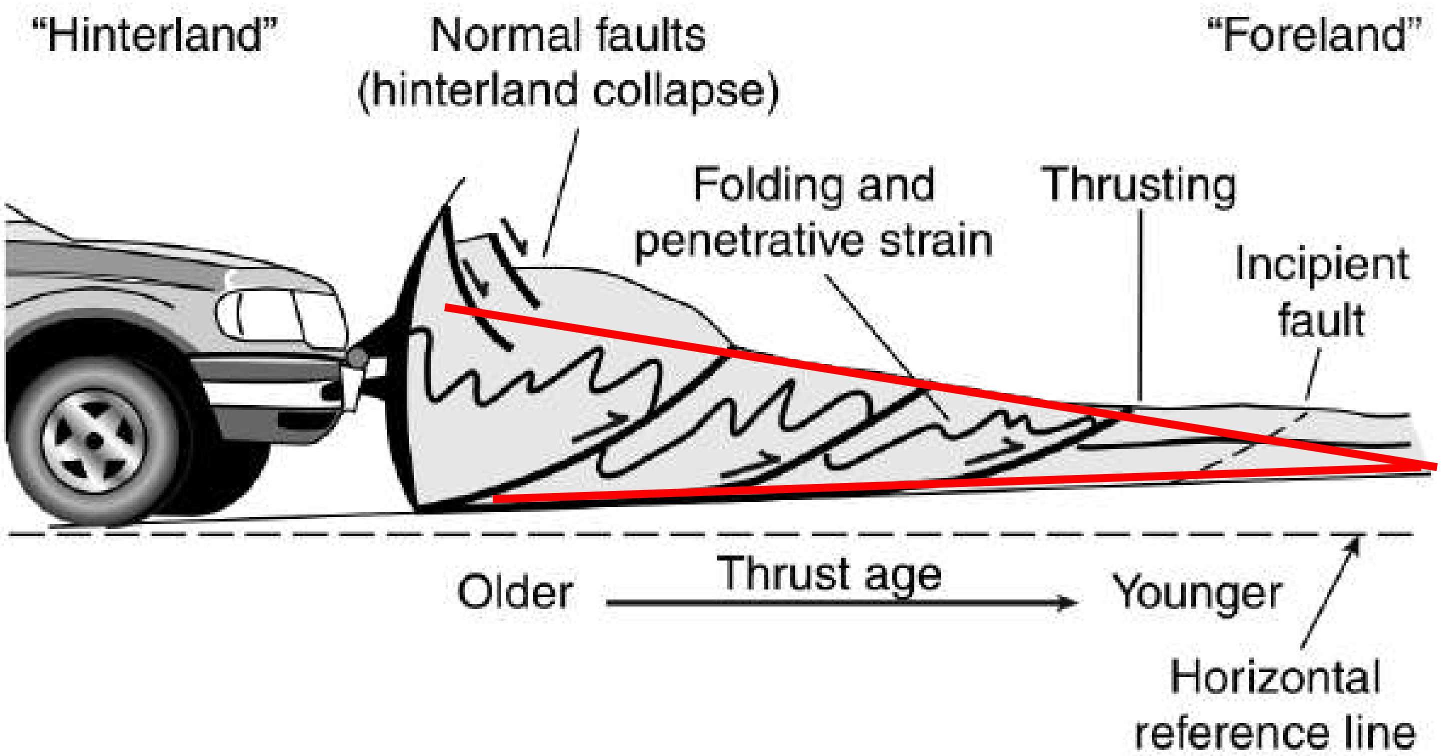


FIGURE 18.32 Snowplow analogy for fold-thrust belt development. The wedge of snow widens with continued shortening; younger thrusts generally initiate in a hinterland to foreland progression. While new thrusts are adding material at the toe of the wedge, the hinterland portions are developing penetrative strain, normal faults, and slump features.

*(**only** if the wedge thickens above critical taper angle!)*

Critical Taper Theory

FIGURE 18.33 The critical taper theory of fold-thrust belt mechanics. The critical taper (ϕ_c) is defined as the sum of the surface slope angle (α_1) and the detachment slope angle (β). (a) Stress acting on a wedge is partly a horizontal boundary load caused by the backstop (σ_{bs}) and is partly caused by gravity (σ_g). (b) If the backstop moves, the wedge thickens, so the surface slope increases, and the taper (ϕ) eventually exceeds ϕ_c. (c) The wedge slides toward the foreland and new material is added to the toe, and extension of the wedge occurs so that surface slope decreases. (d, e) If the surface slope becomes too small, thrusting at the toe stops, and the wedge thickens by penetrative strain or out-of-sequence thrusting.

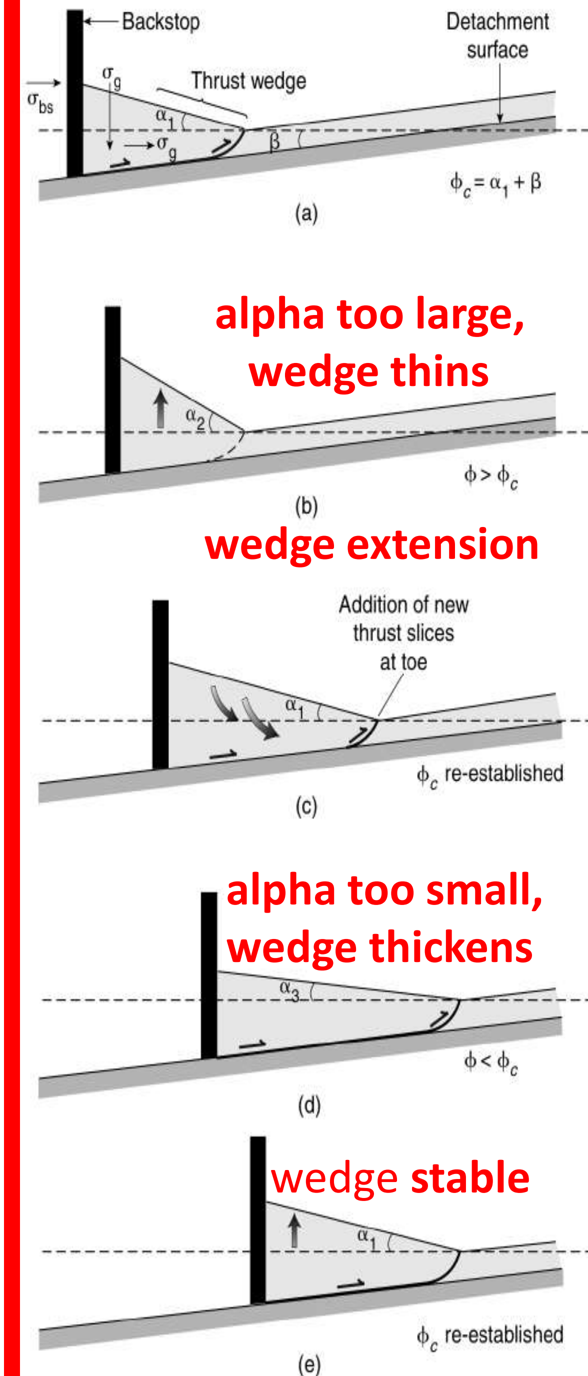
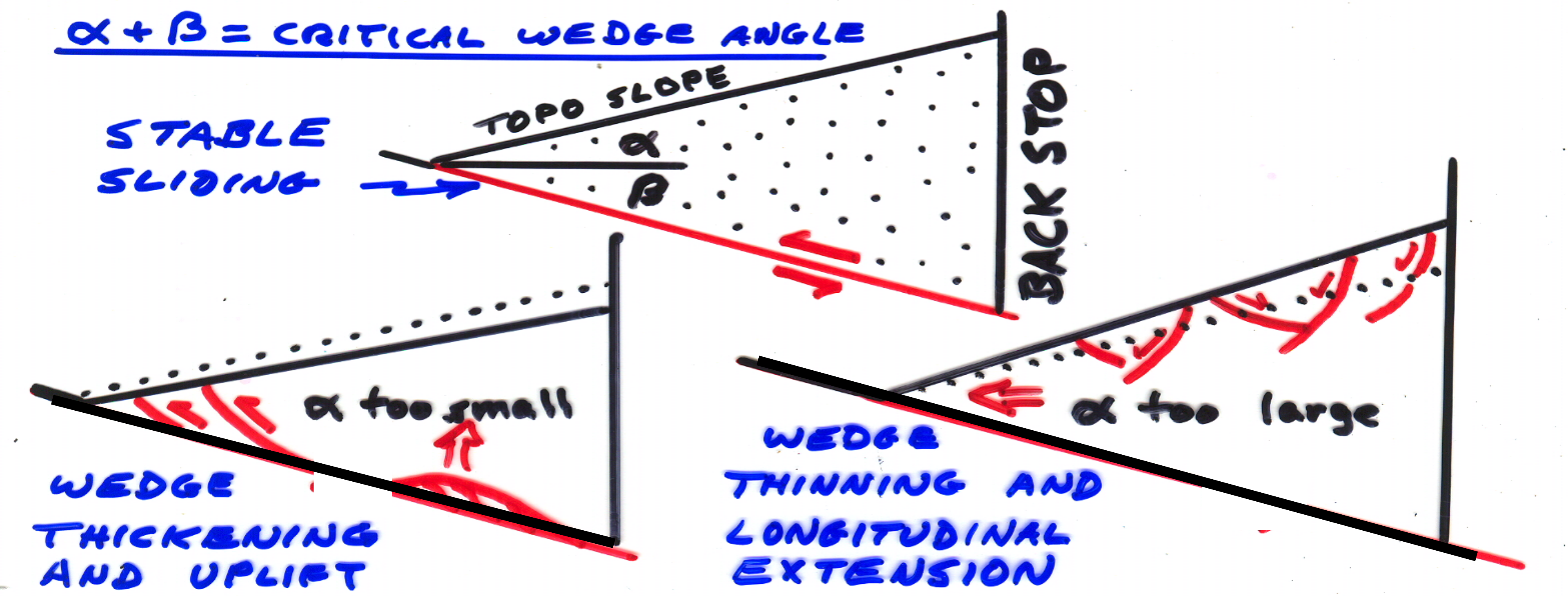
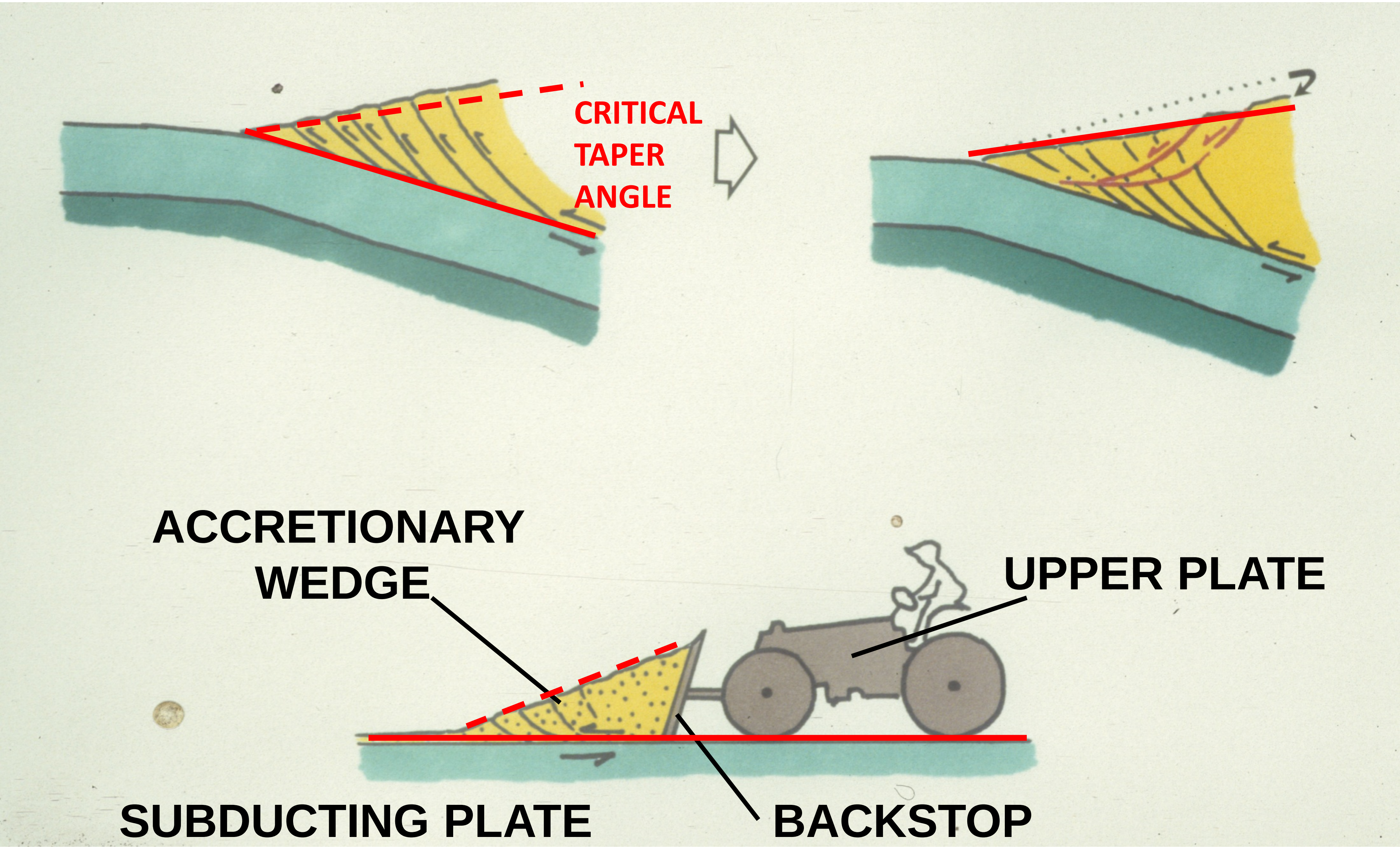


FIGURE 18.33 The critical taper theory of fold-thrust belt

The critical wedge angle must be maintained for stable sliding or displacement between the wedge and its basal slip surface.!




CRITICAL
TAPER
ANGLE
ACCRETIONARY
WEDGE
UPPER PLATE
SUBDUCTING PLATE
BACKSTOP

- End of 3-hour lecture here

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