Plate Tectonics:

- First ideas go back to early map makers

- Later suggested by various geological evidence (e.g., Frank Taylor (1908) showed geological evidence that the Atlantic Ocean had once been closed.

- Born as "Continental Drift" by Alfred Wegener (1912), who put the pieces together.

Plate Tectonics was both proved by and explains the evidence of:

1. Fit of Continents from a previous supercontinent.
2. Mountain ranges at the edges of continents.
3. Bimodal distribution of elevation of crustal surfaces.
4. Continuity of rock types across separate continents.
5. Continuity of fossils across separate continents.
6. Paleomagnetic “stripes” on the ocean sea floor.
7. The fact that the Earth’s mantle should be convecting (e.g., the Rayleigh number is high). First proposed by Arthur Holmes (1929).
8. Unusual features of the ocean sea floor bathymetry (ridges, parabolic increase in depth away from the ridge, guyots, transform faults, fracture zones)
9. Ocean heat flow, which is greatest near the ridges.
10. Distribution of earthquakes and volcanoes.
11. Gravity Anomalies (something is “pulling down” subduction zone regions).
12. GPS measurements, showing horizontal motions.

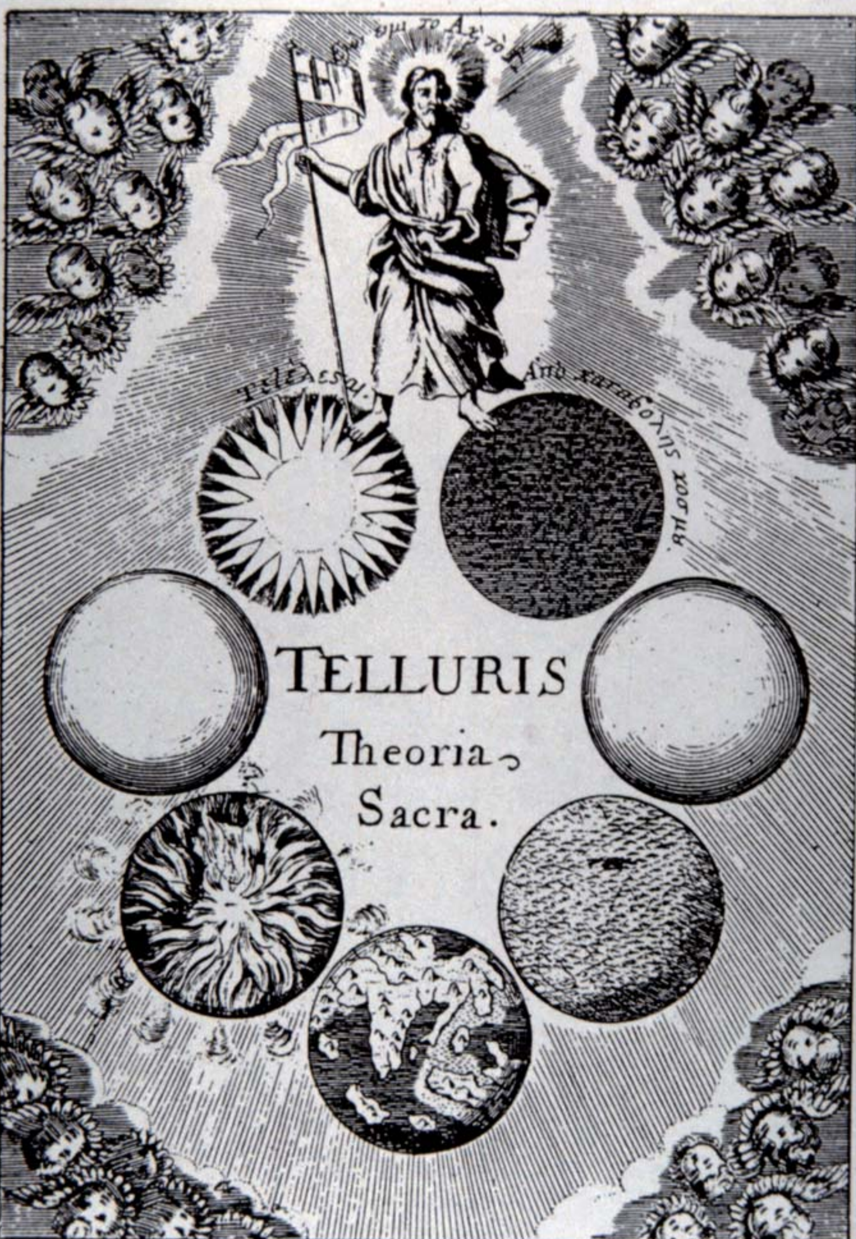


Figure 2.1
The frontispiece from the first edition of Thomas Burnet's *Telluris theoria sacra*, or *Sacred Theory of the Earth*.

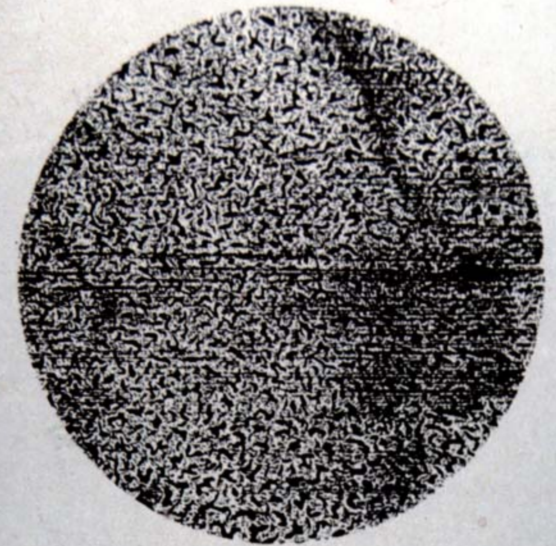


Figure 2.5
The chaos of the primeval earth as related in Genesis 1.
(From first edition.)

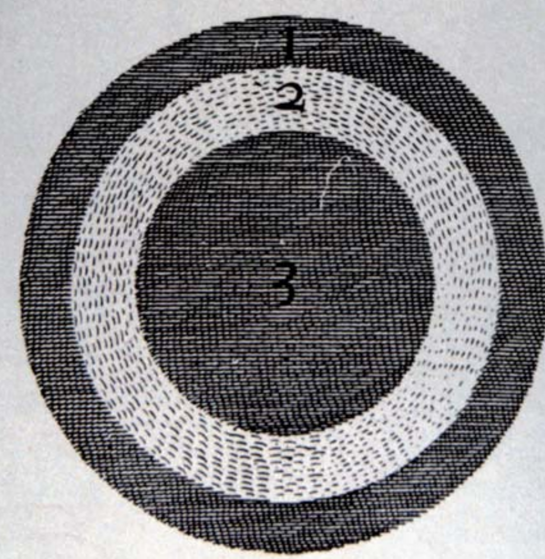


Figure 2.6
The perfect earth of the original paradise of Eden, arranged as concentric layers according to density after the descent of particles from primeval chaos. (From first edition.)

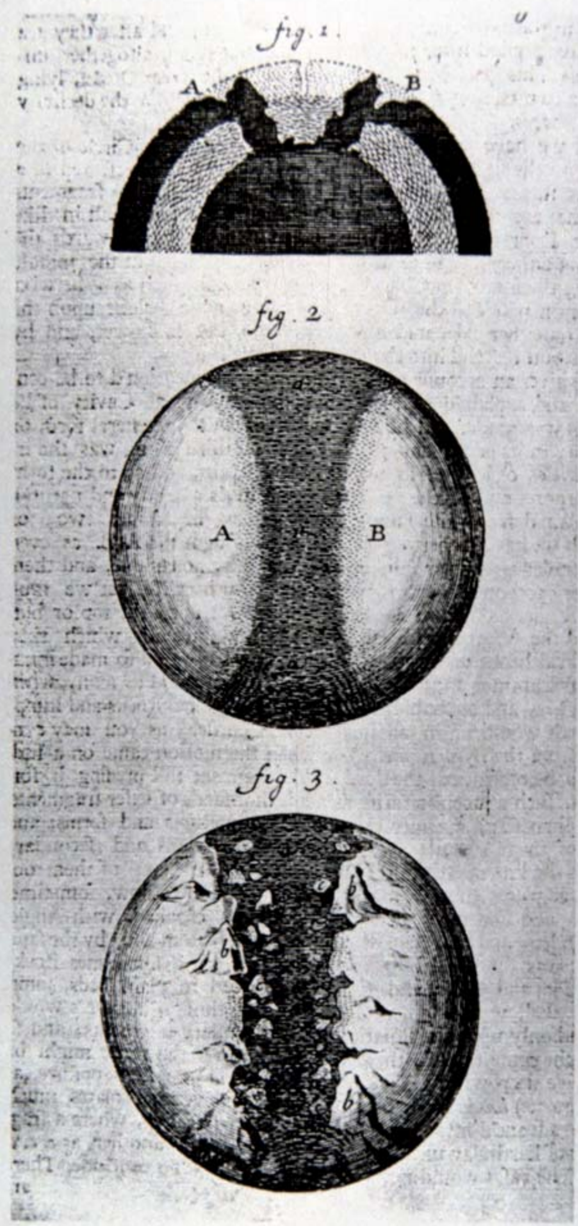
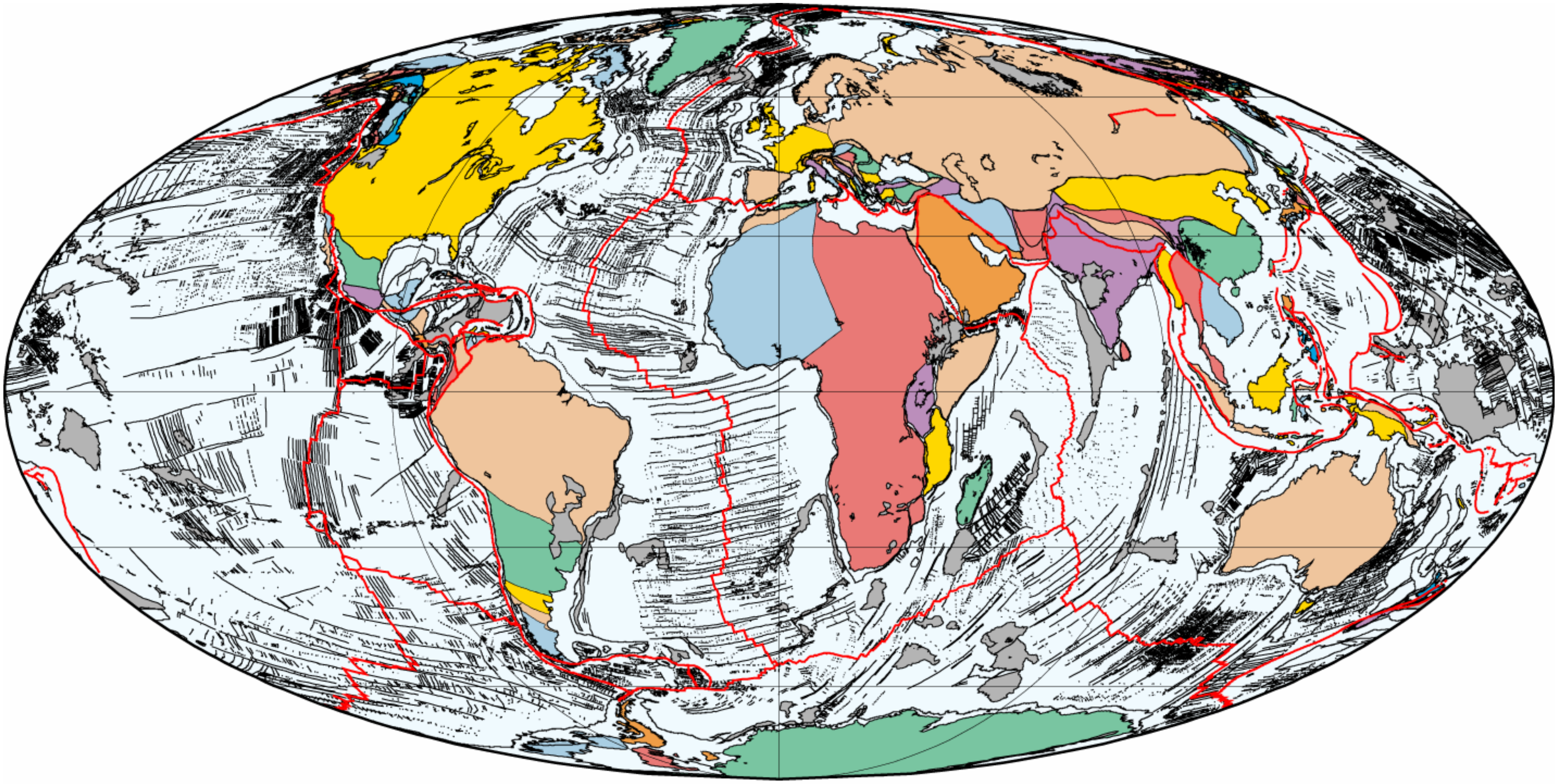


Figure 2.3

Burnet's physical cause of the deluge. The earth's crust cracks (fig. 1); water rises from its layer in the abyss to cover the earth (fig. 2), and then retreats again to leave modern continents (with mountains as edges of the cracked crust) and oceans. (From first English edition.)

In 1858, Antonio Snider-Pelligrini ("Creation and its Mysteries Revealed") explains the fit of the outlines of the continents as the result of Noah's Flood waters breaking apart the continents. (Had been previously been hinted at by Francis Bacon and others.)


SOUTH AMERICA
AFRICA
Overlap
Gap



0 Ma
Present Day

PLATES/UTIG
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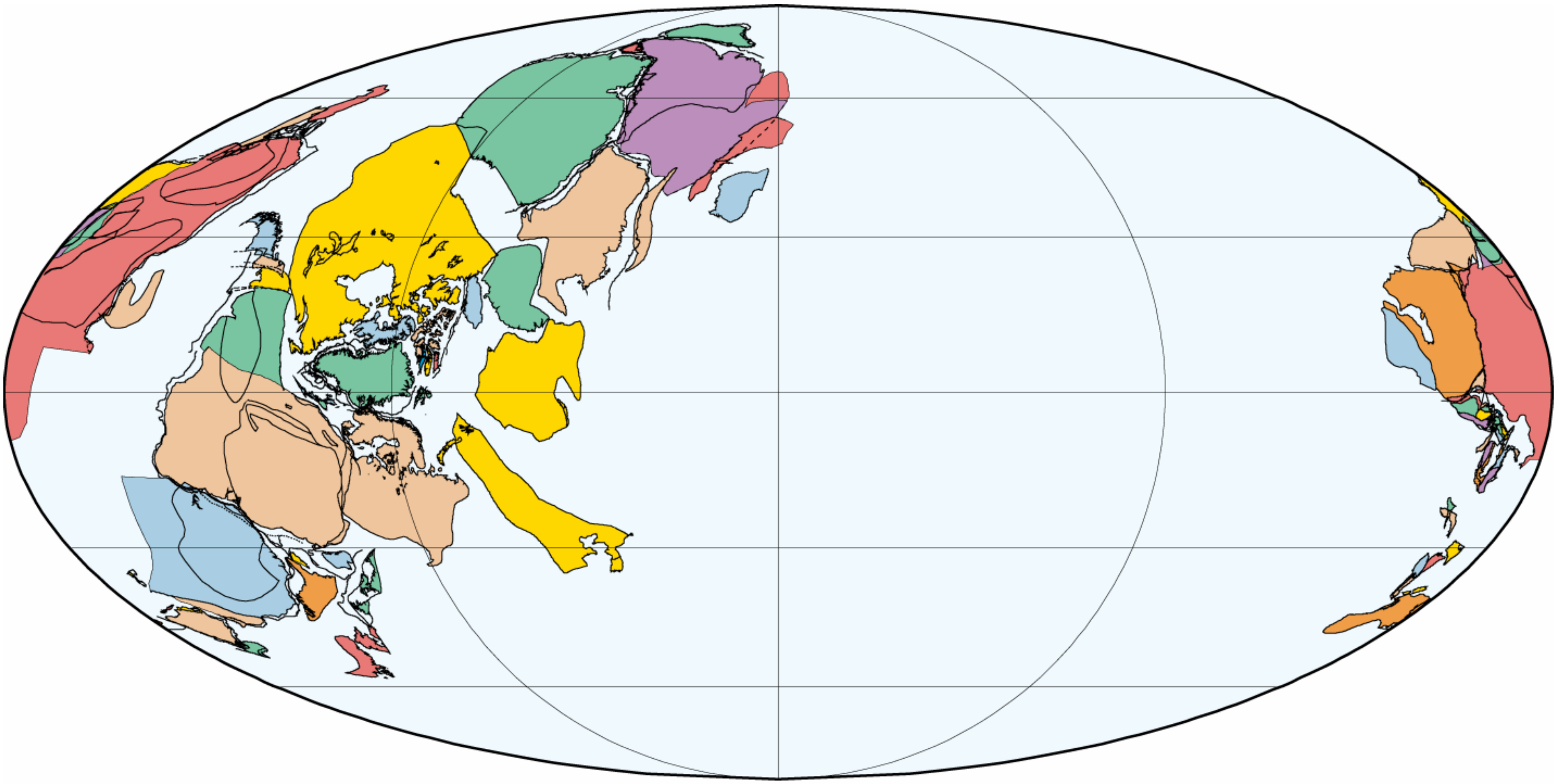

750 Ma
Late Proterozoic

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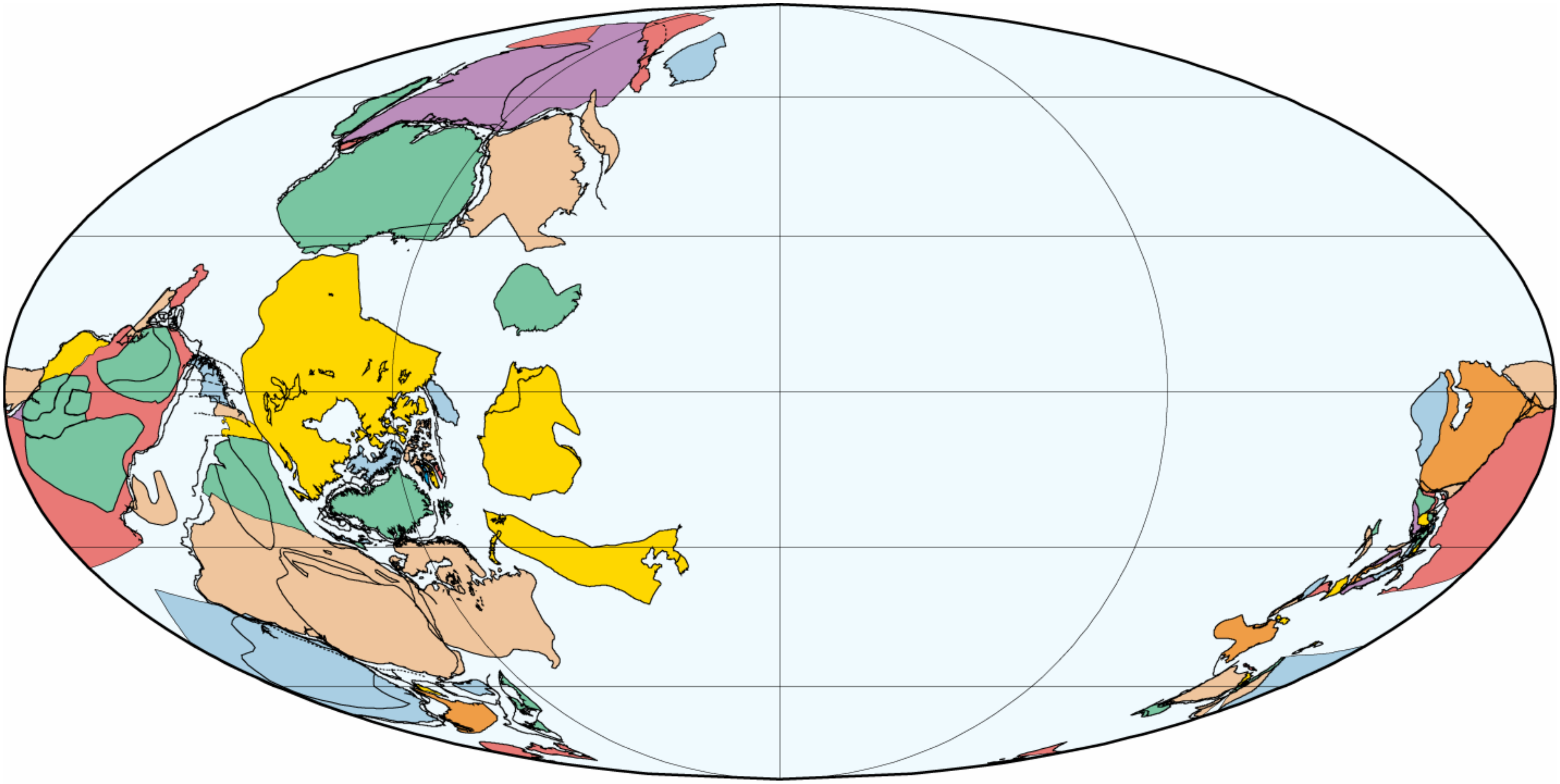

700 Ma

Late Proterozoic

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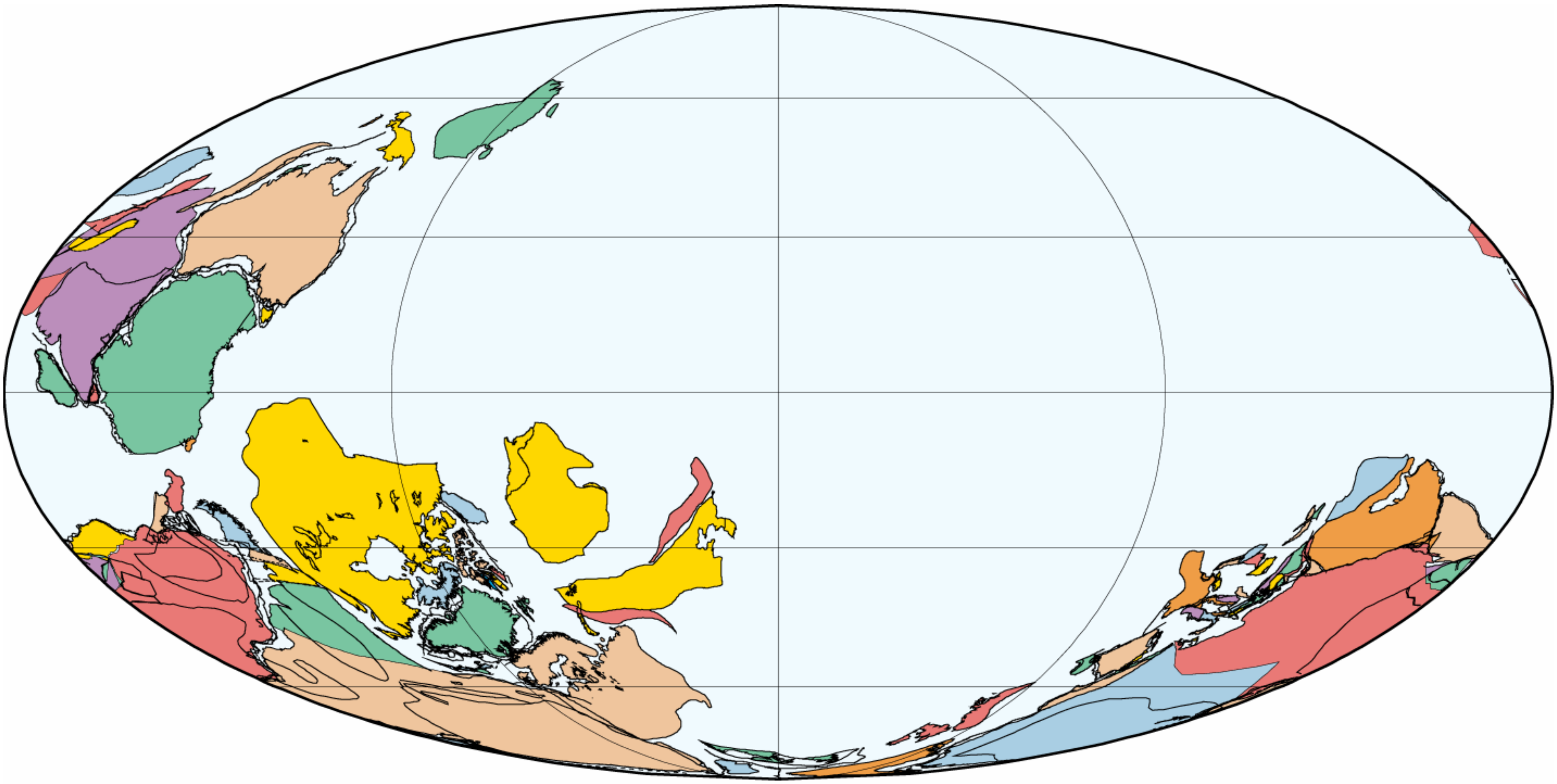

650 Ma

Late Proterozoic

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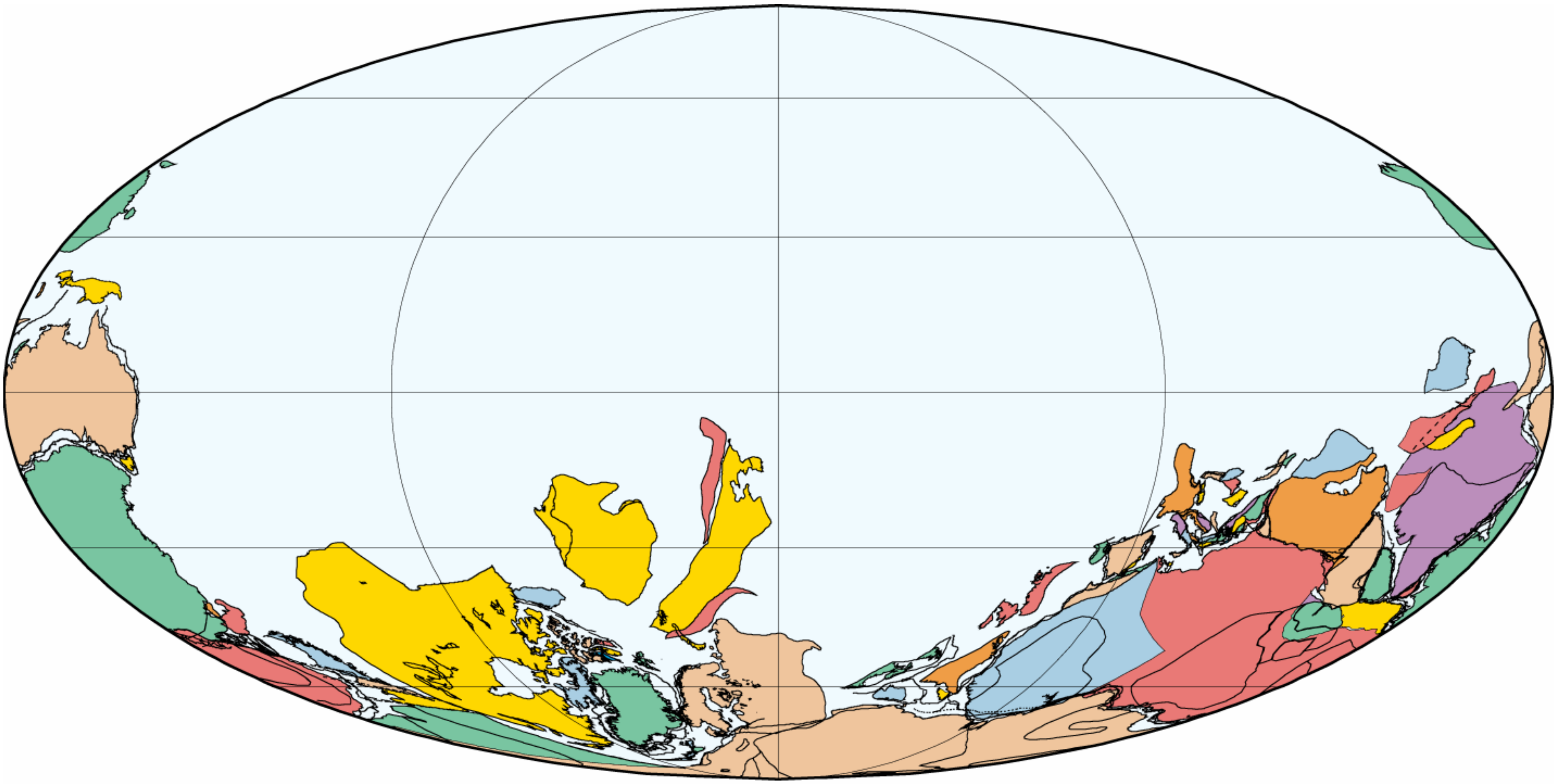

600 Ma

Late Proterozoic

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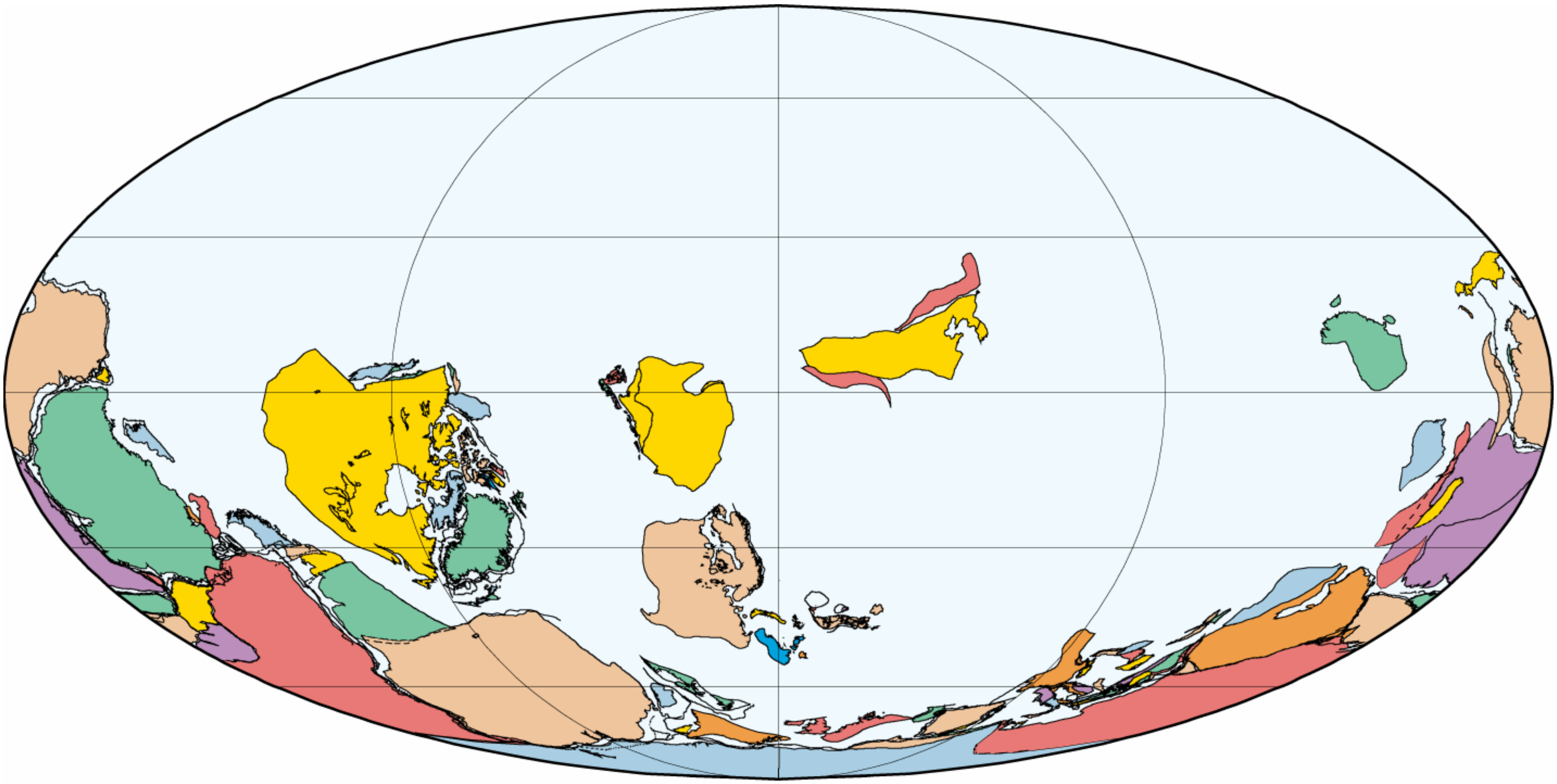

540 Ma

Nemakitian-Daldynian (Early Cambrian)

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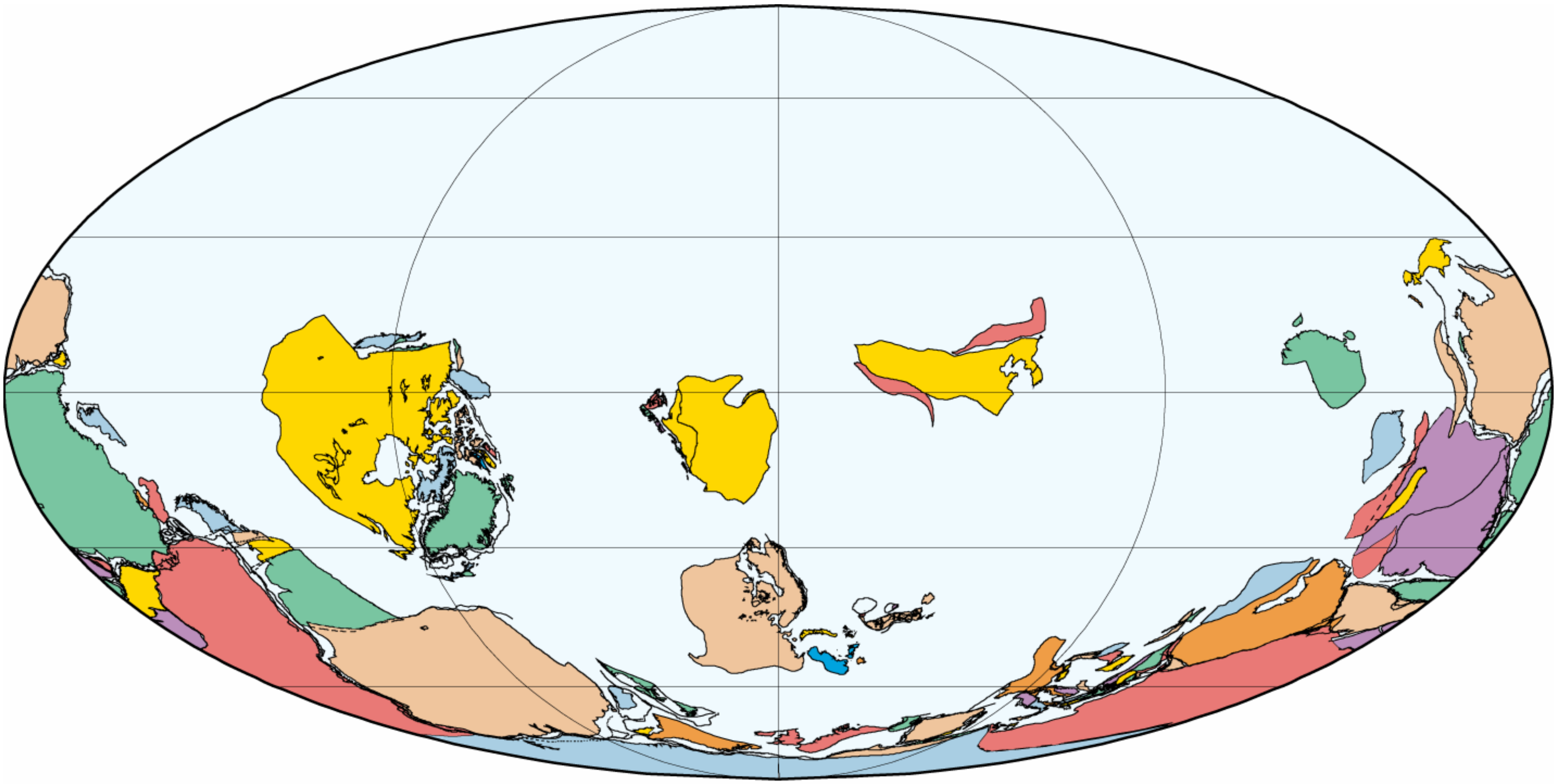

530 Ma

Late Tommotian/Early Atdabanian (Early Cambrian)

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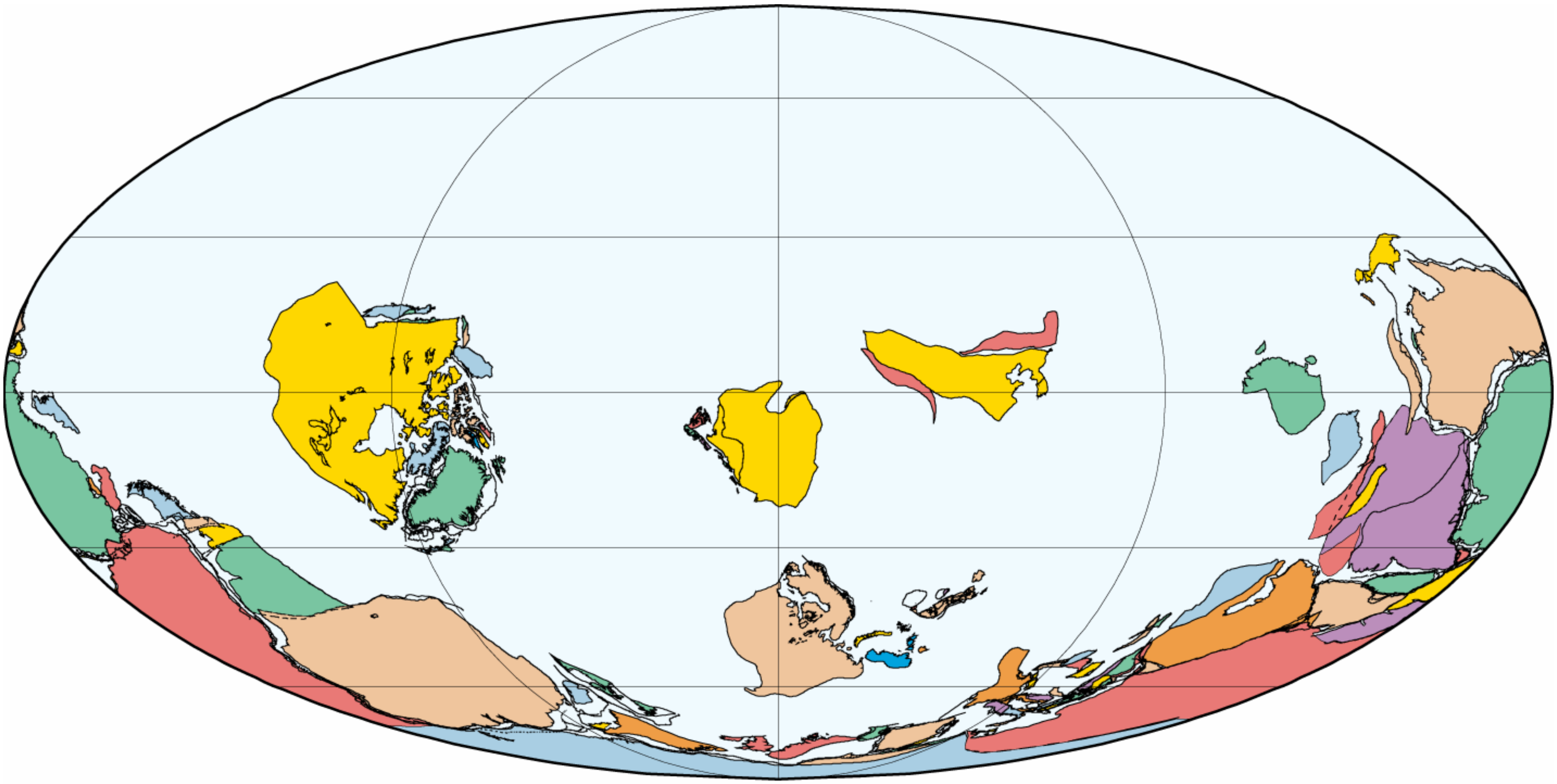

520 Ma

Lenian (Early Cambrian)

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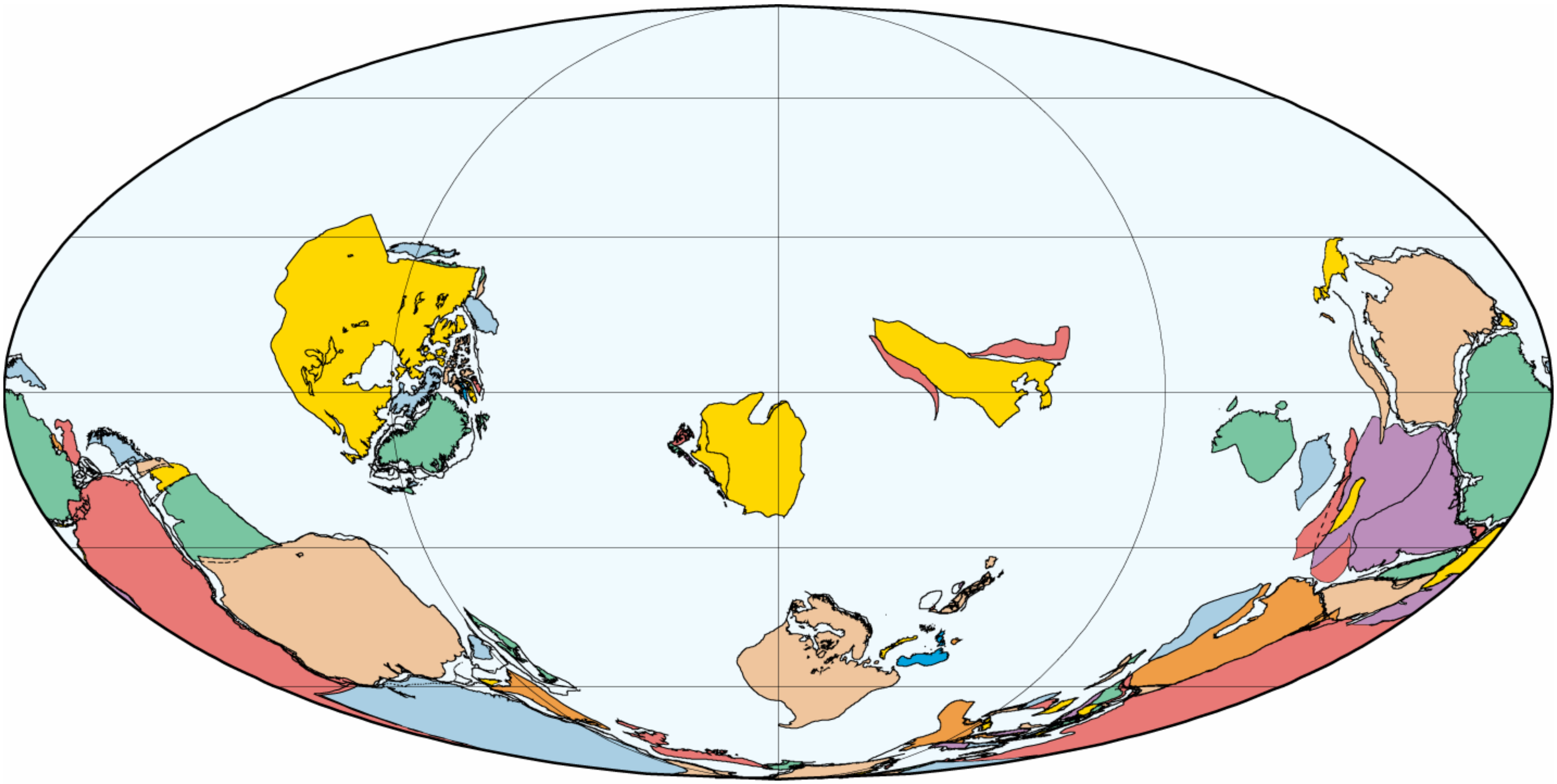

510 Ma
Middle Cambrian

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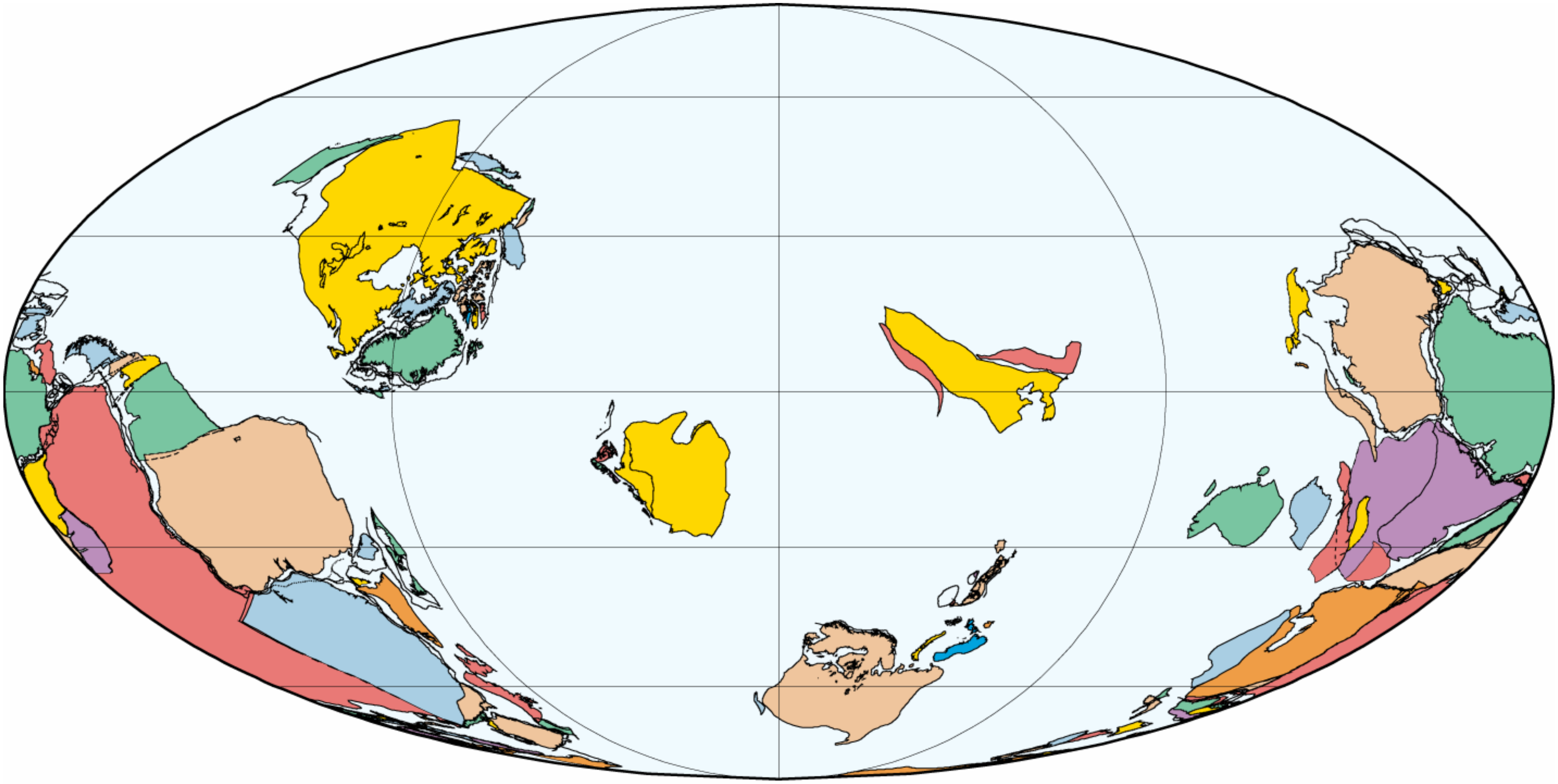

500 Ma
Late Cambrian

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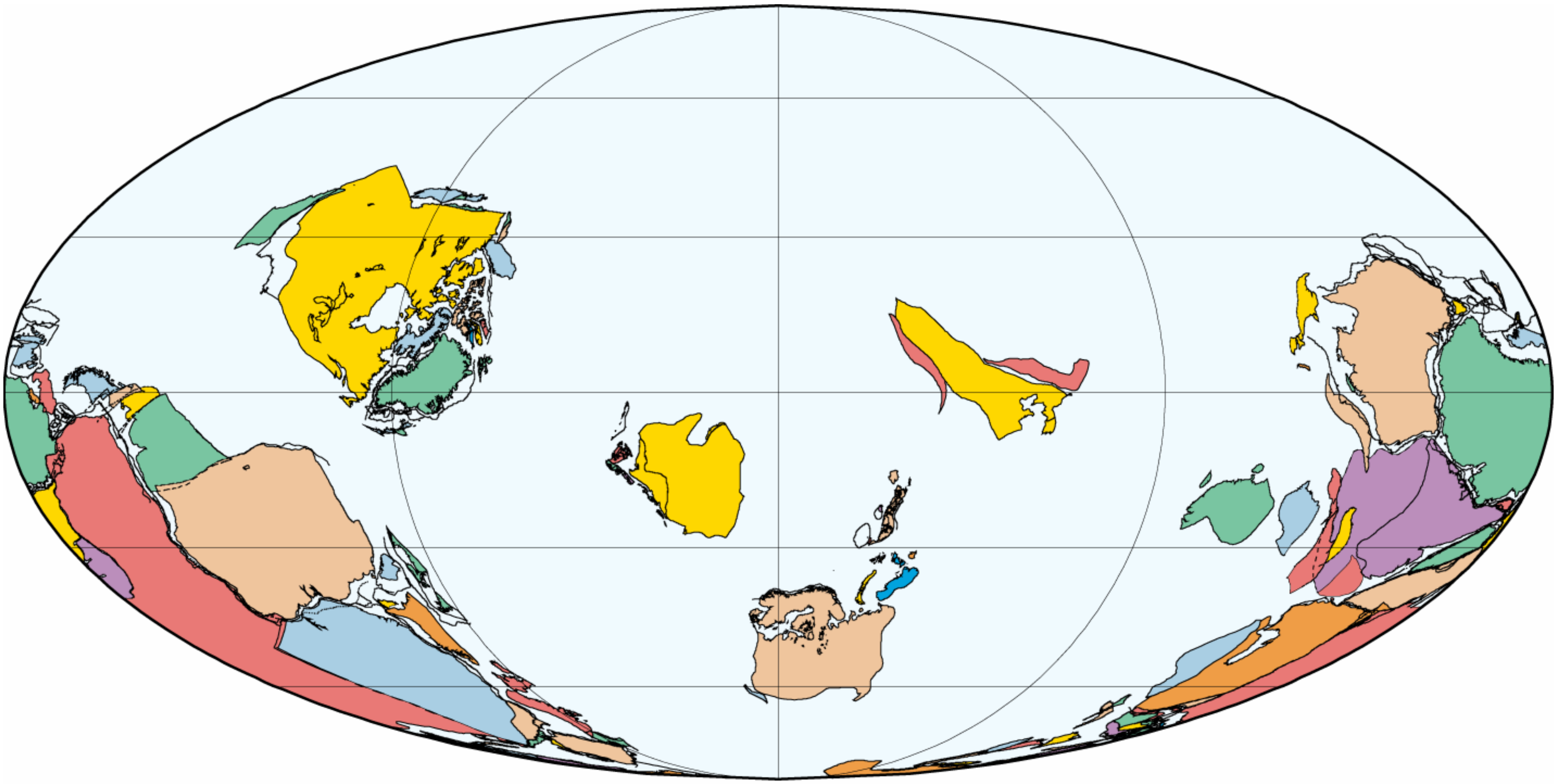

490 Ma

Tremadocian (Early Ordovician)

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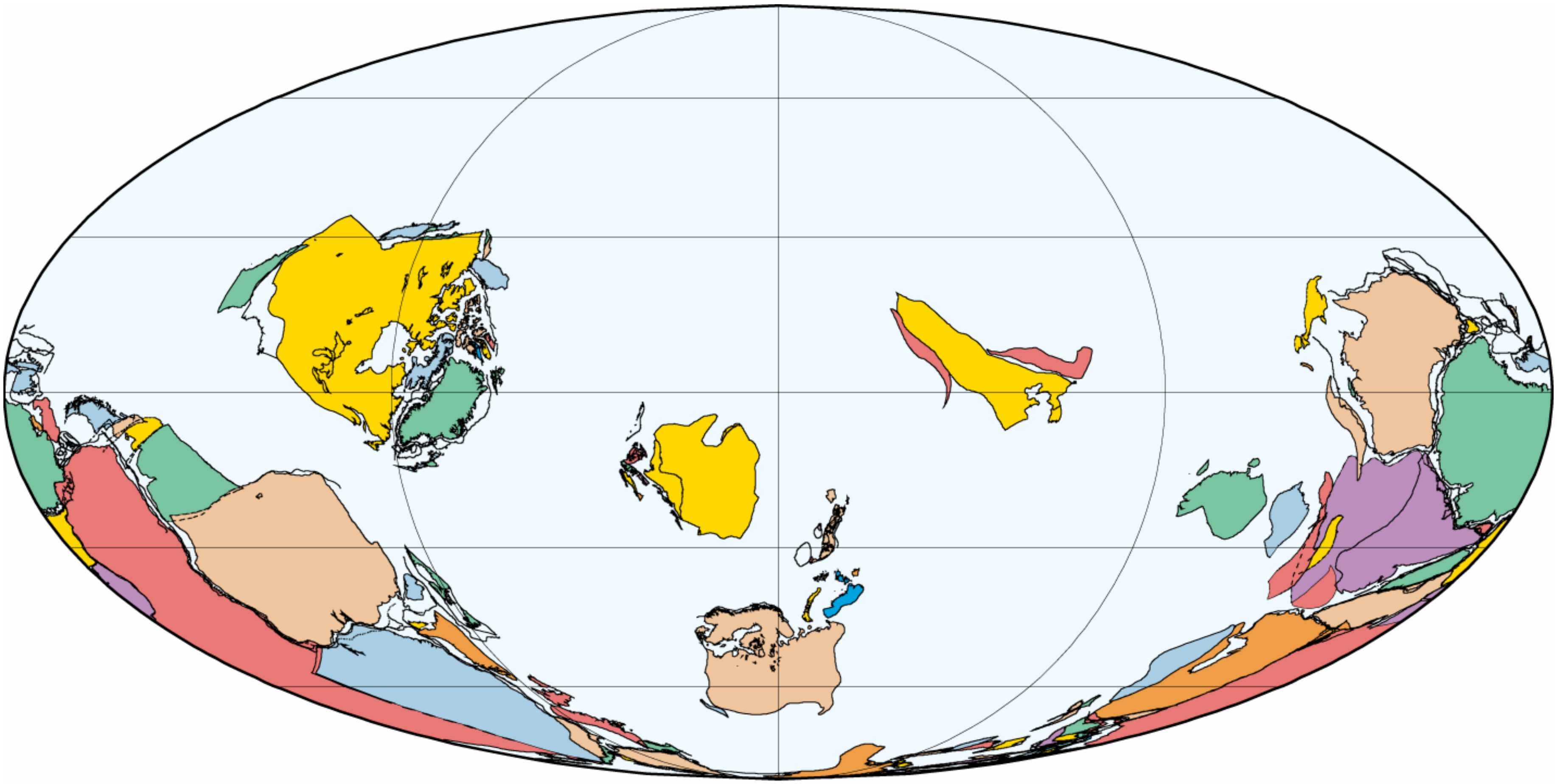

480 Ma

Arenigian (Early Ordovician)

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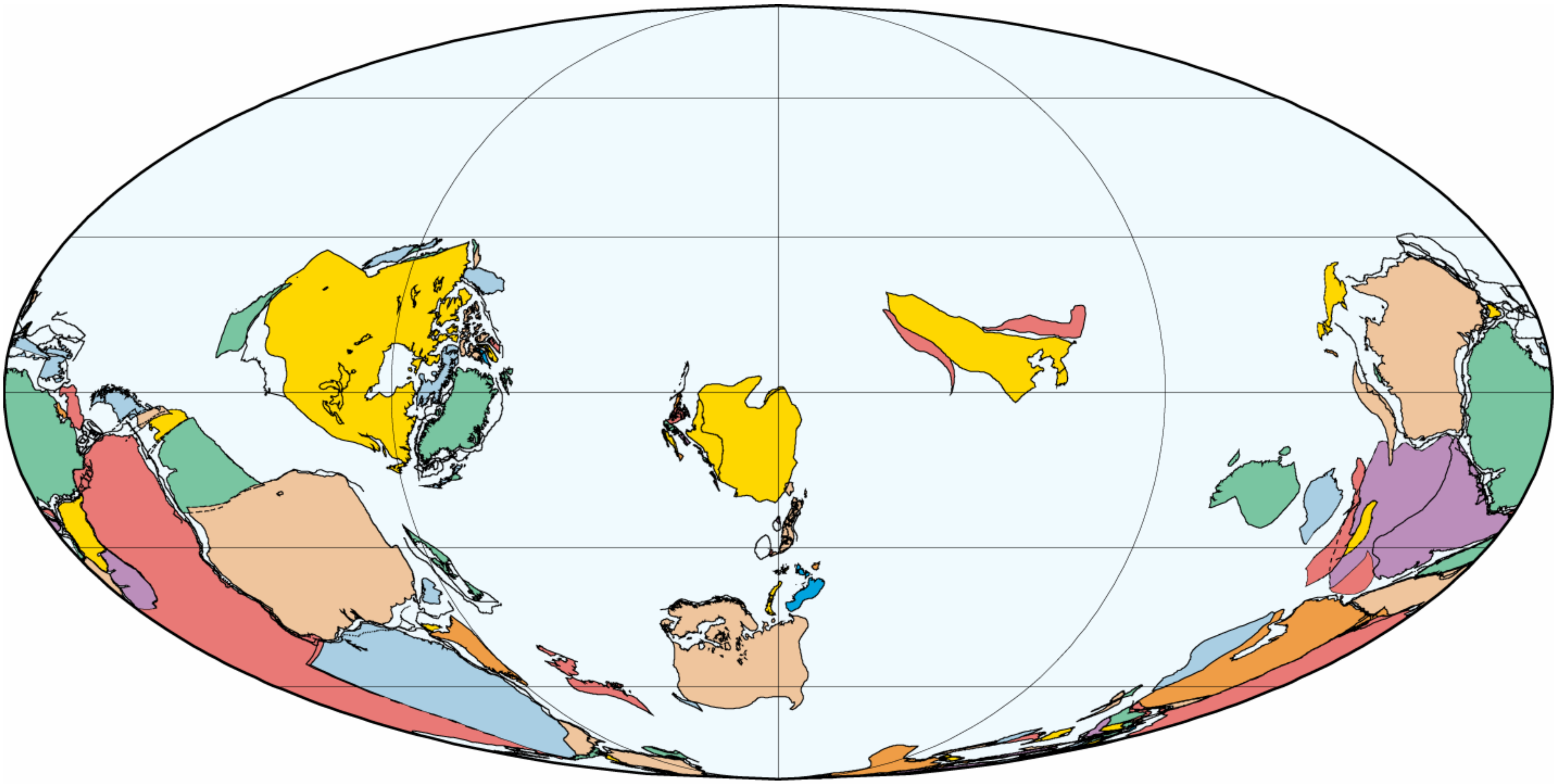

470 Ma

Late Arenigian/Early Llanvirnian (Early/Middle Ordovician)

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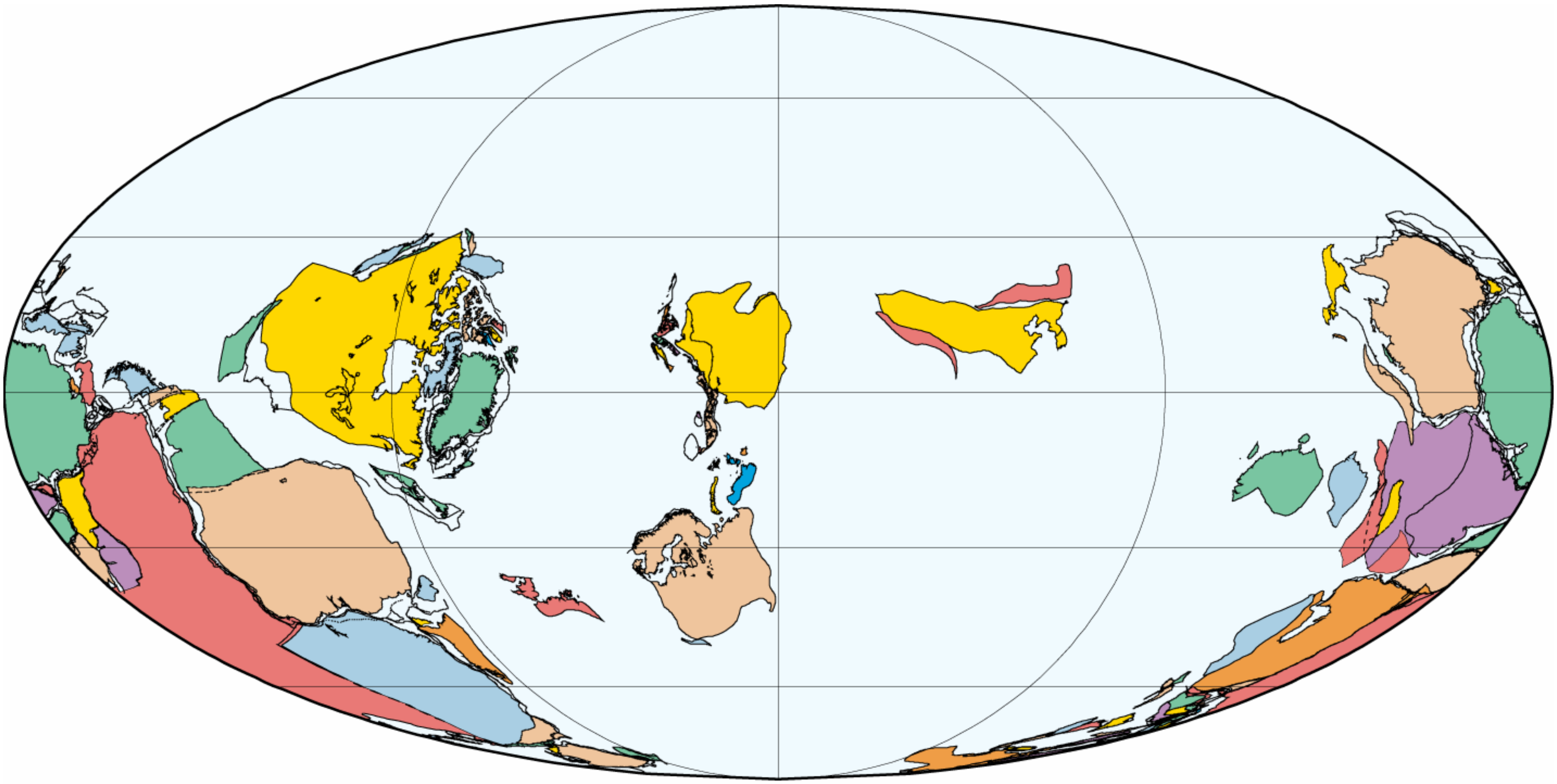

460 Ma

Llandeilan (Middle Ordovician)

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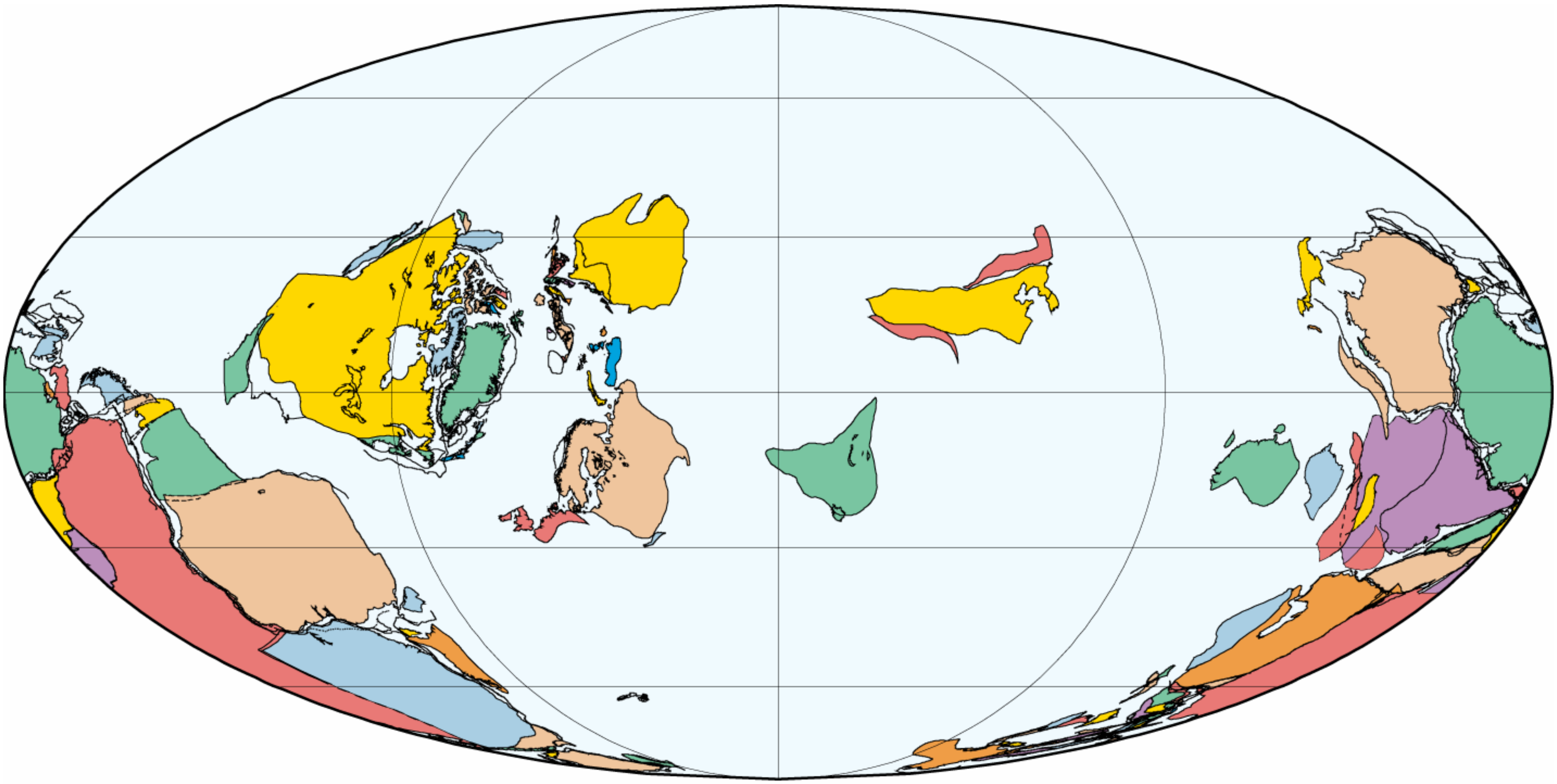

450 Ma

Caradocian (Late Ordovician)

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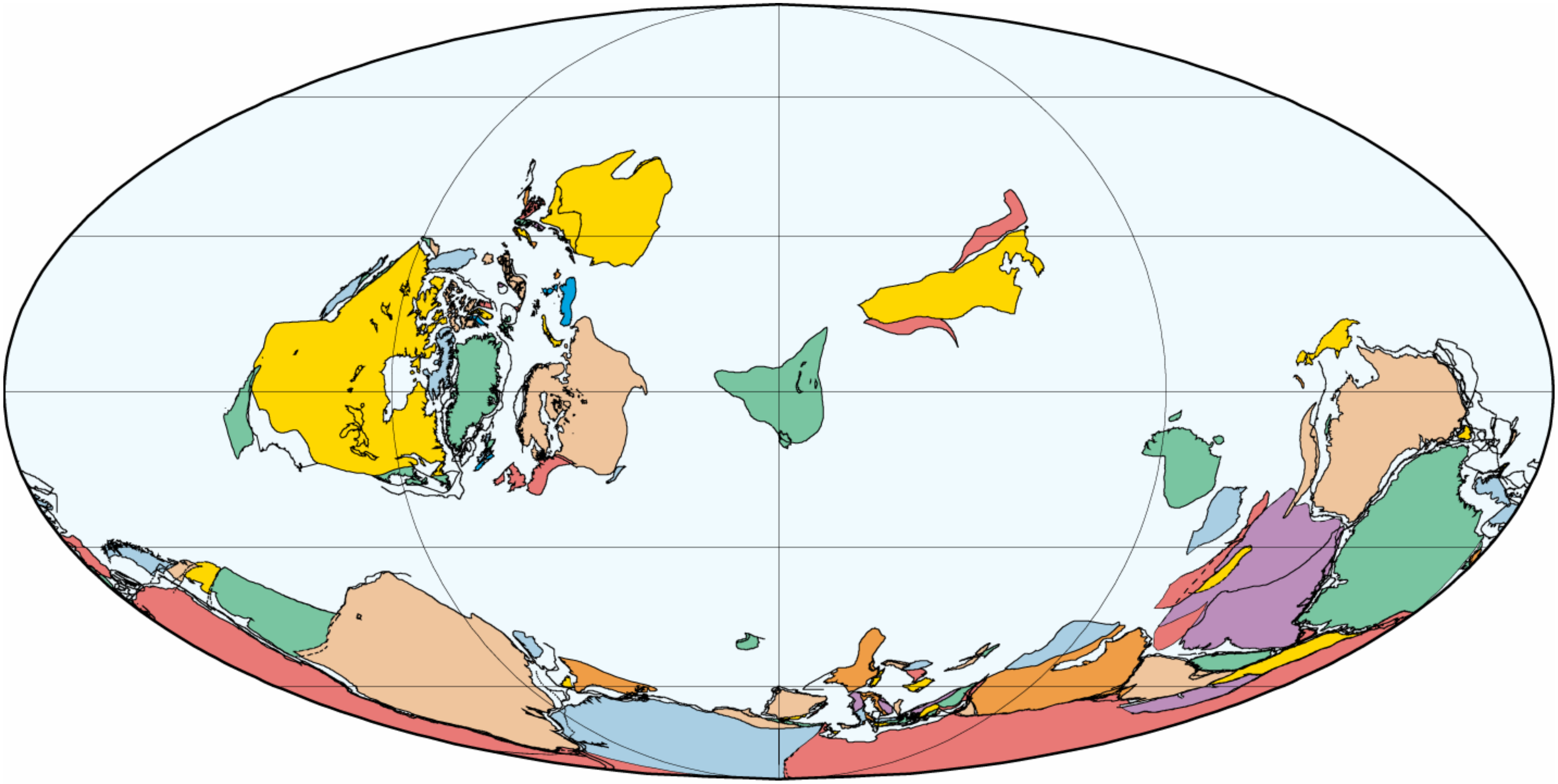

440 Ma

Early Llandoverian (Early Silurian)

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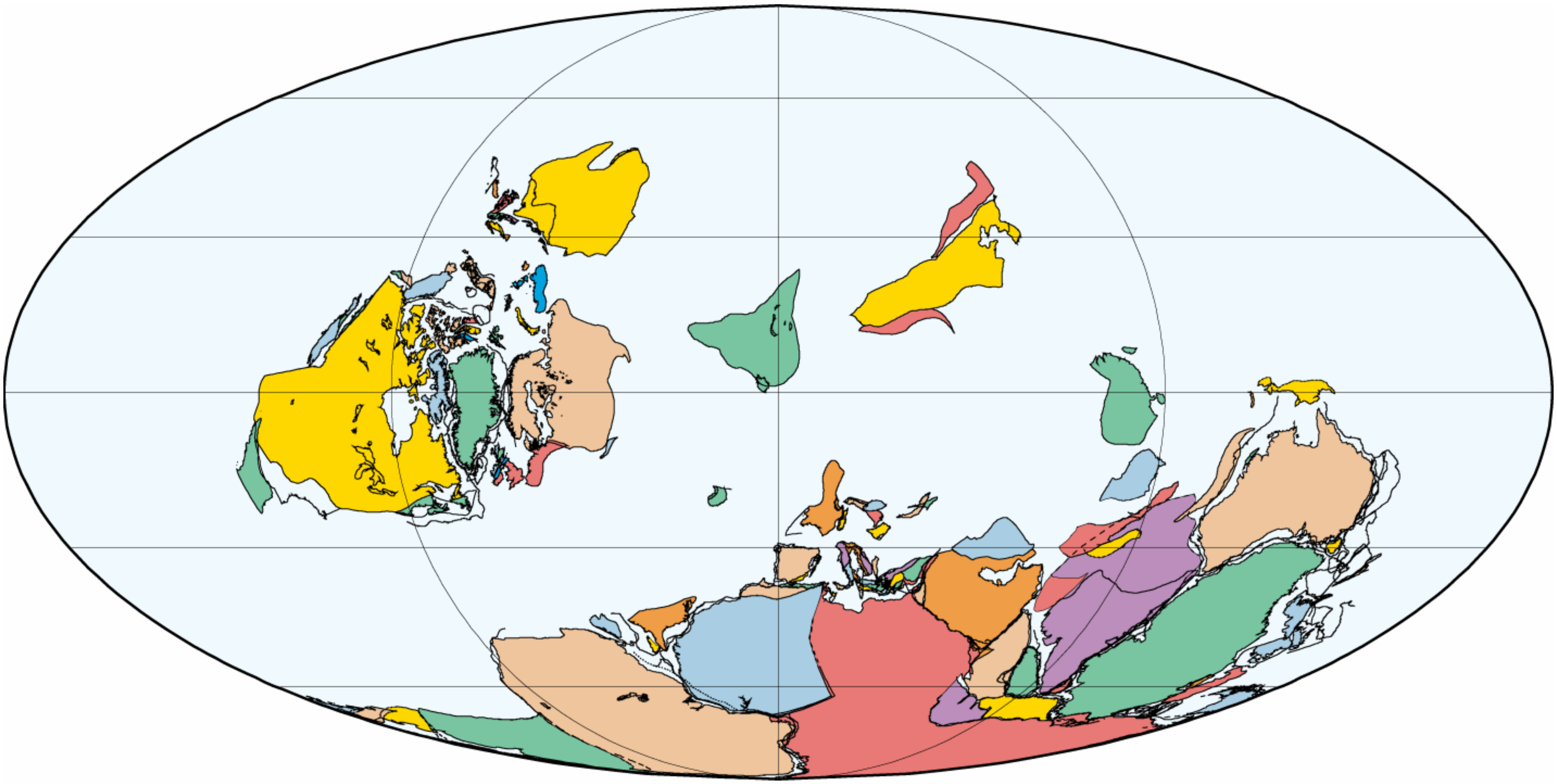

430 Ma

Late Llandoverian (Early Silurian)

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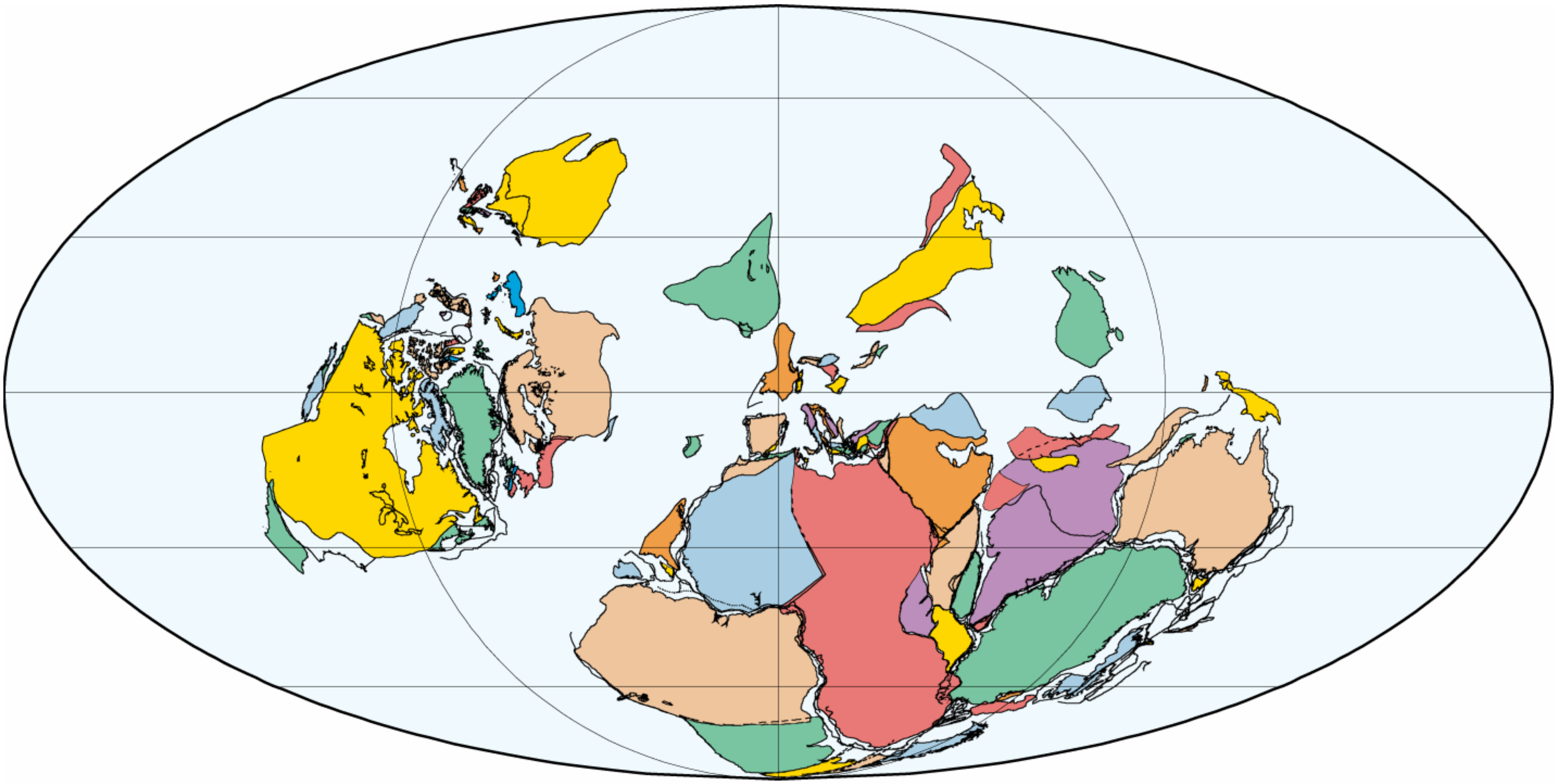

420 Ma

Ludlovian (Late Silurian)

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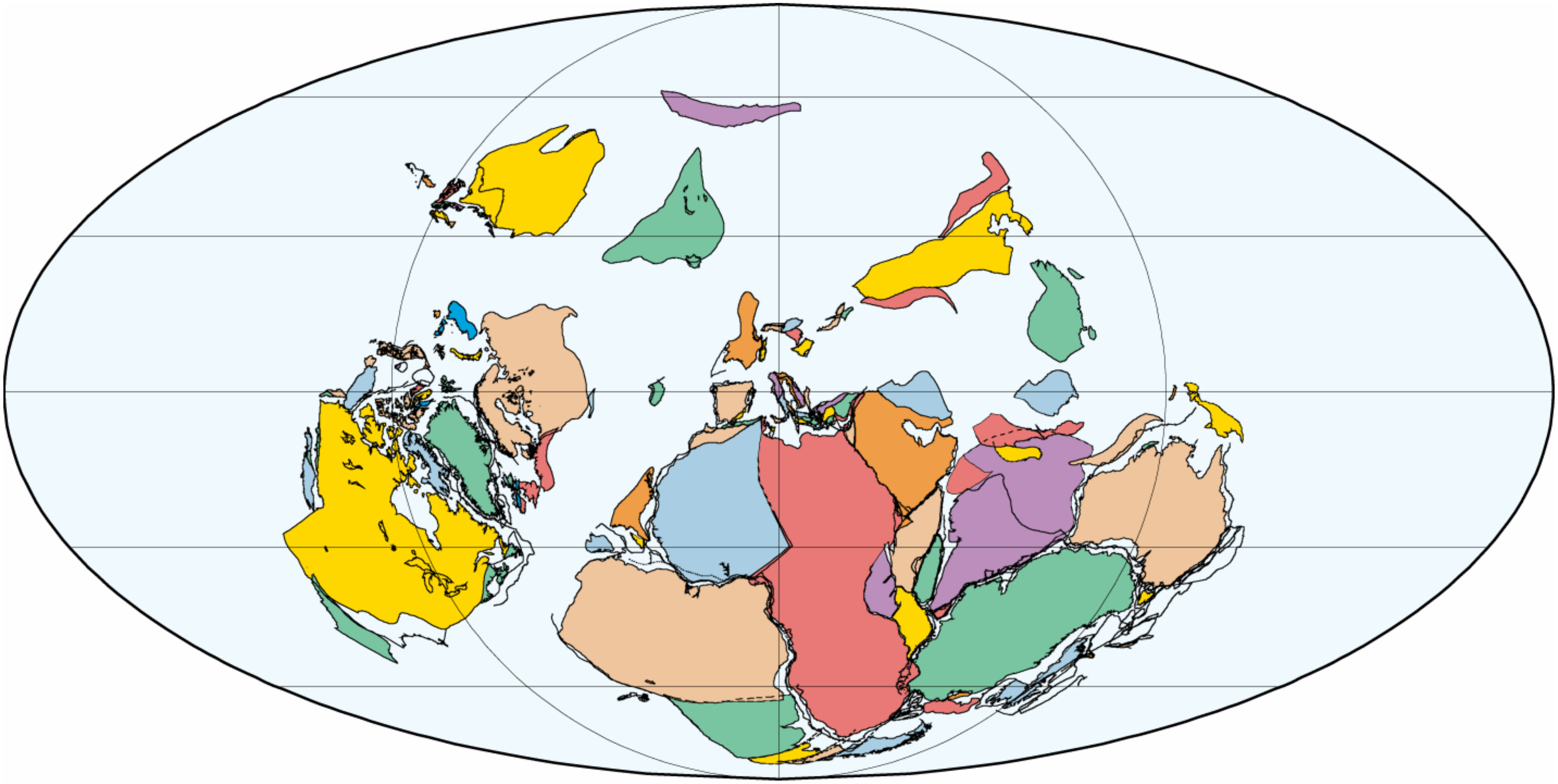

410 Ma
Early Praghian (Early Devonian)

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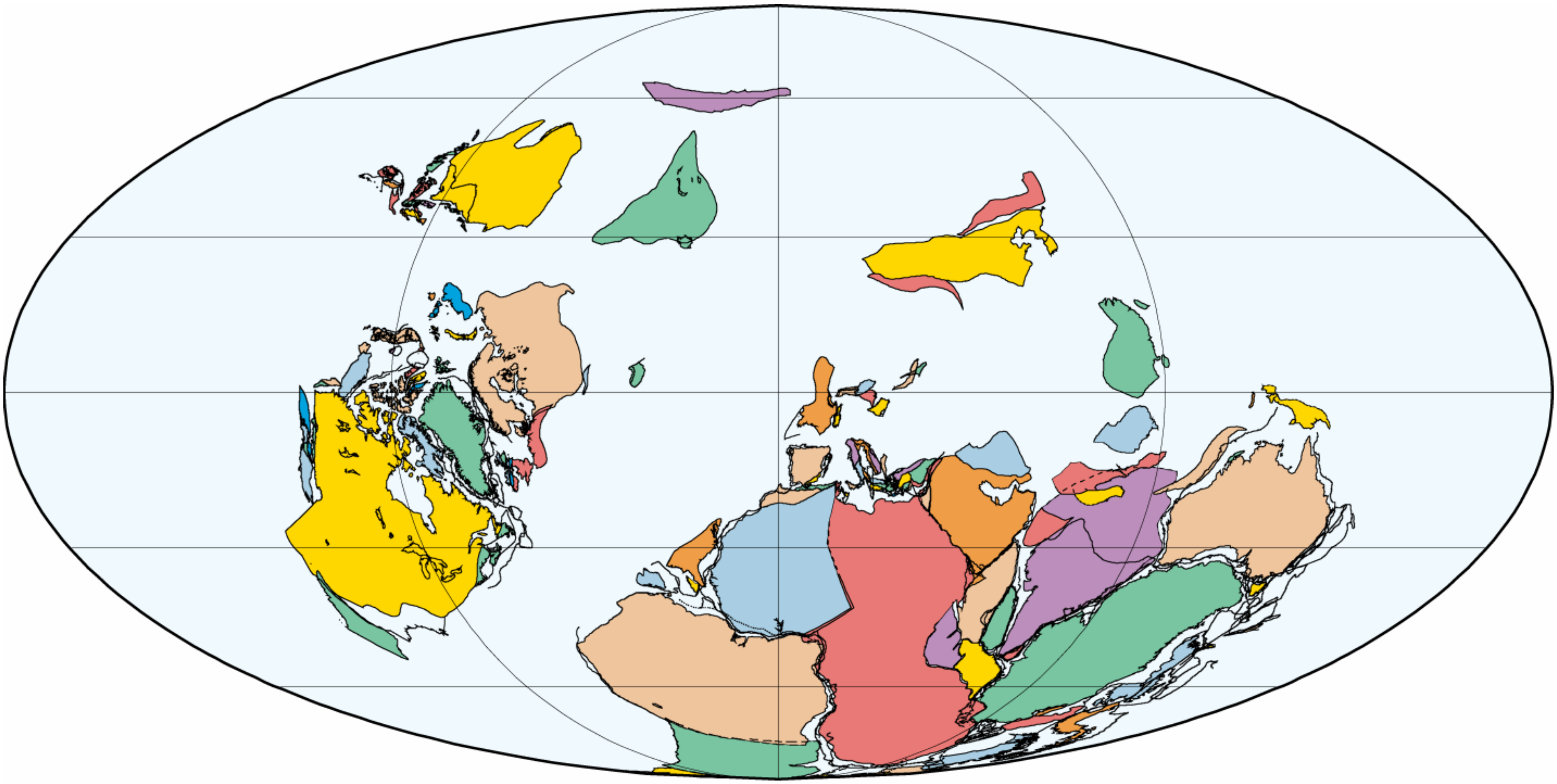

400 Ma

Late Praghian/Early Emsian (Early Devonian)

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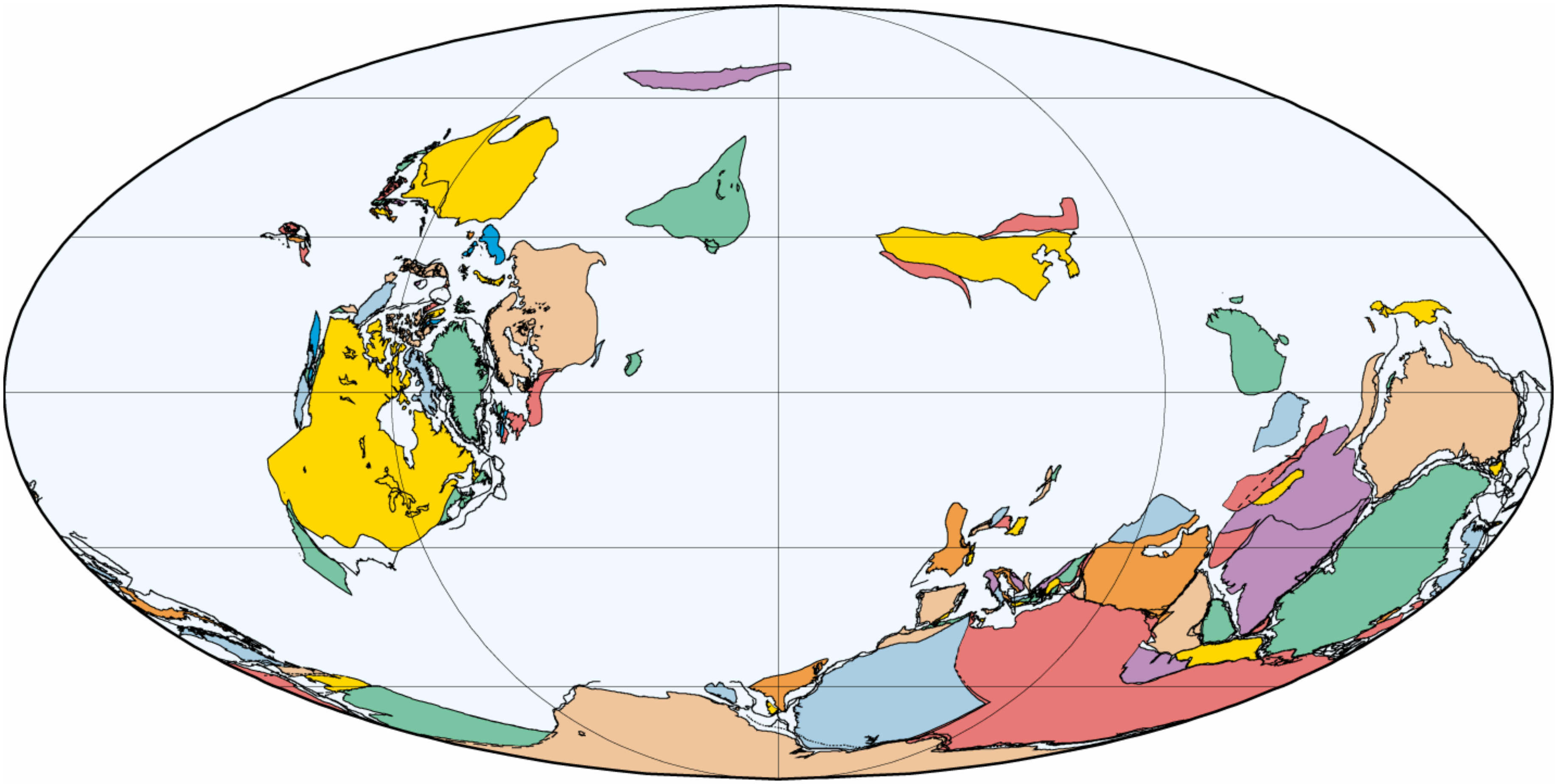

390 Ma

Early Eifelian (Early Devonian)

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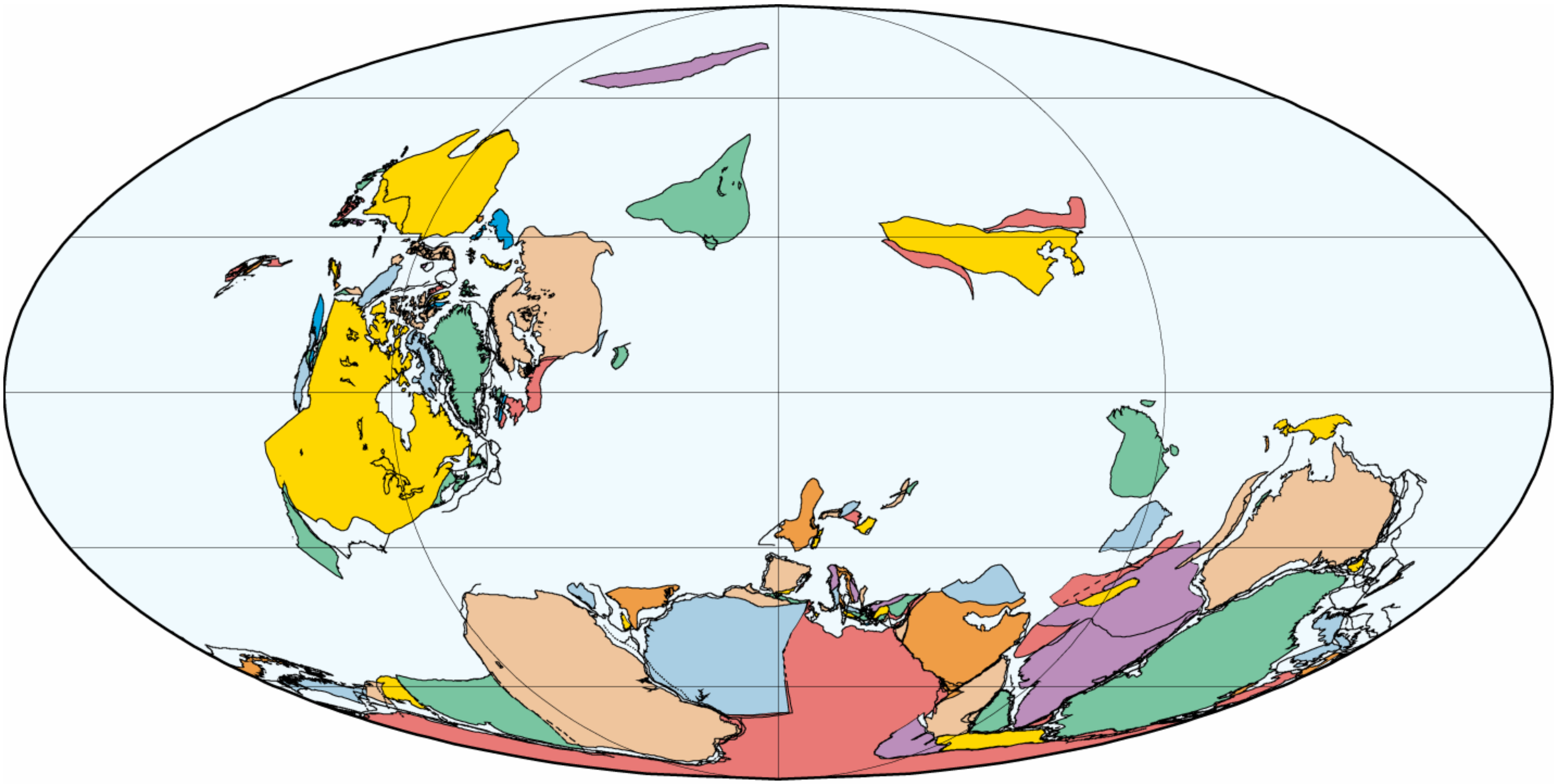

380 Ma

Late Eifelian/Early Givetian (Middle Devonian)

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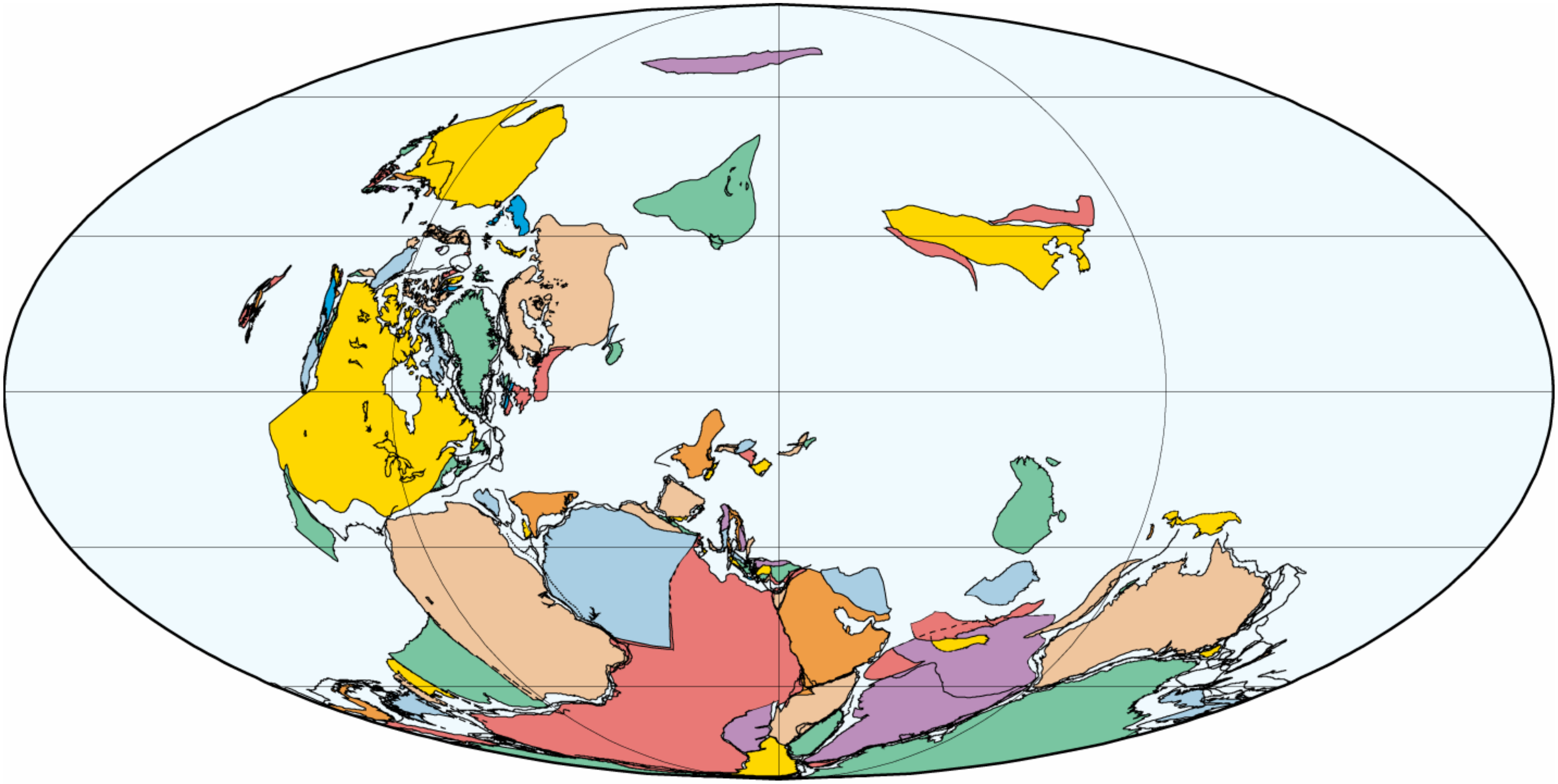

370 Ma

Late Givetian/Early Frasnian (Late Devonian)

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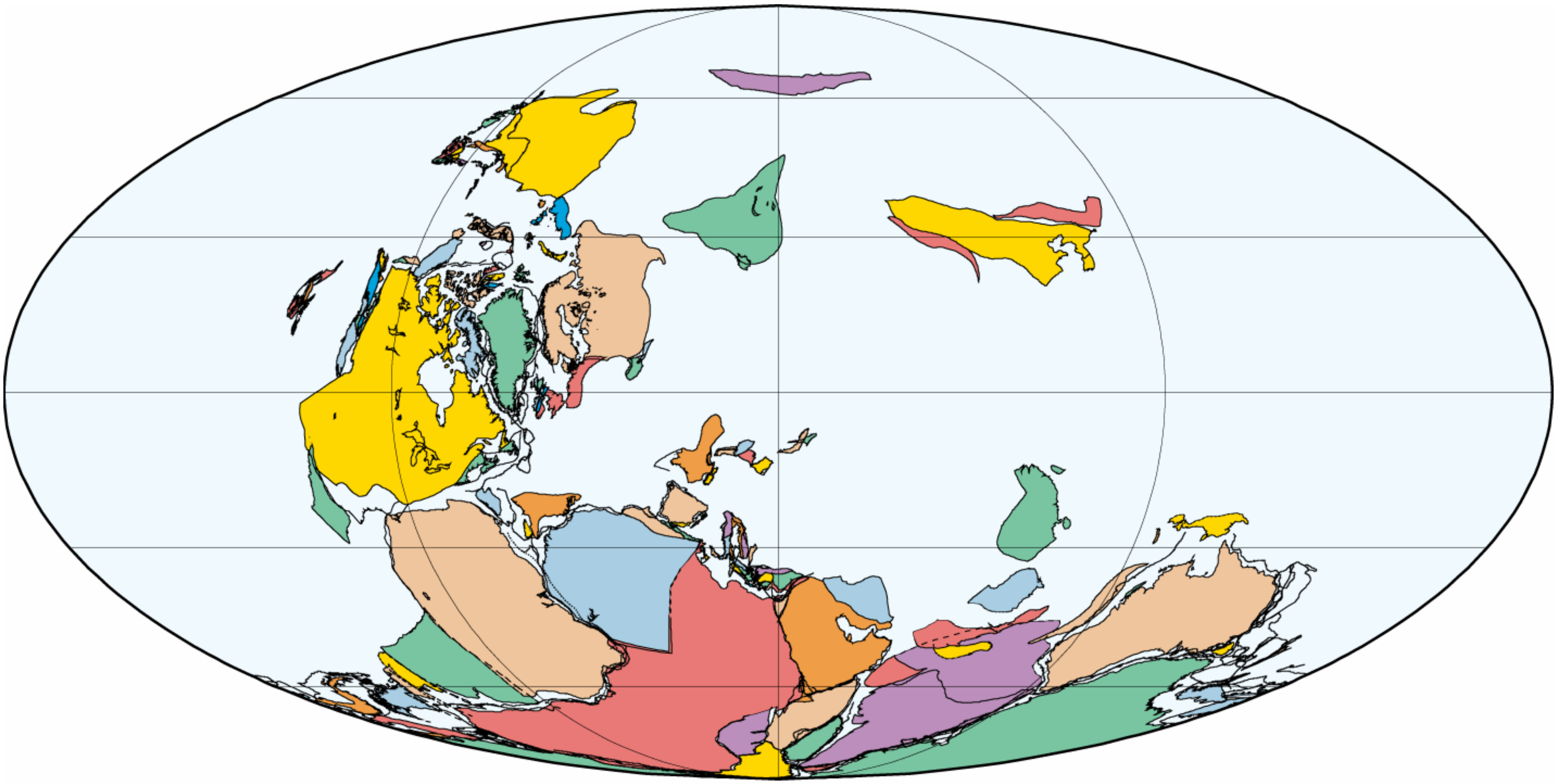

360 Ma
Famennian (Late Devonian)

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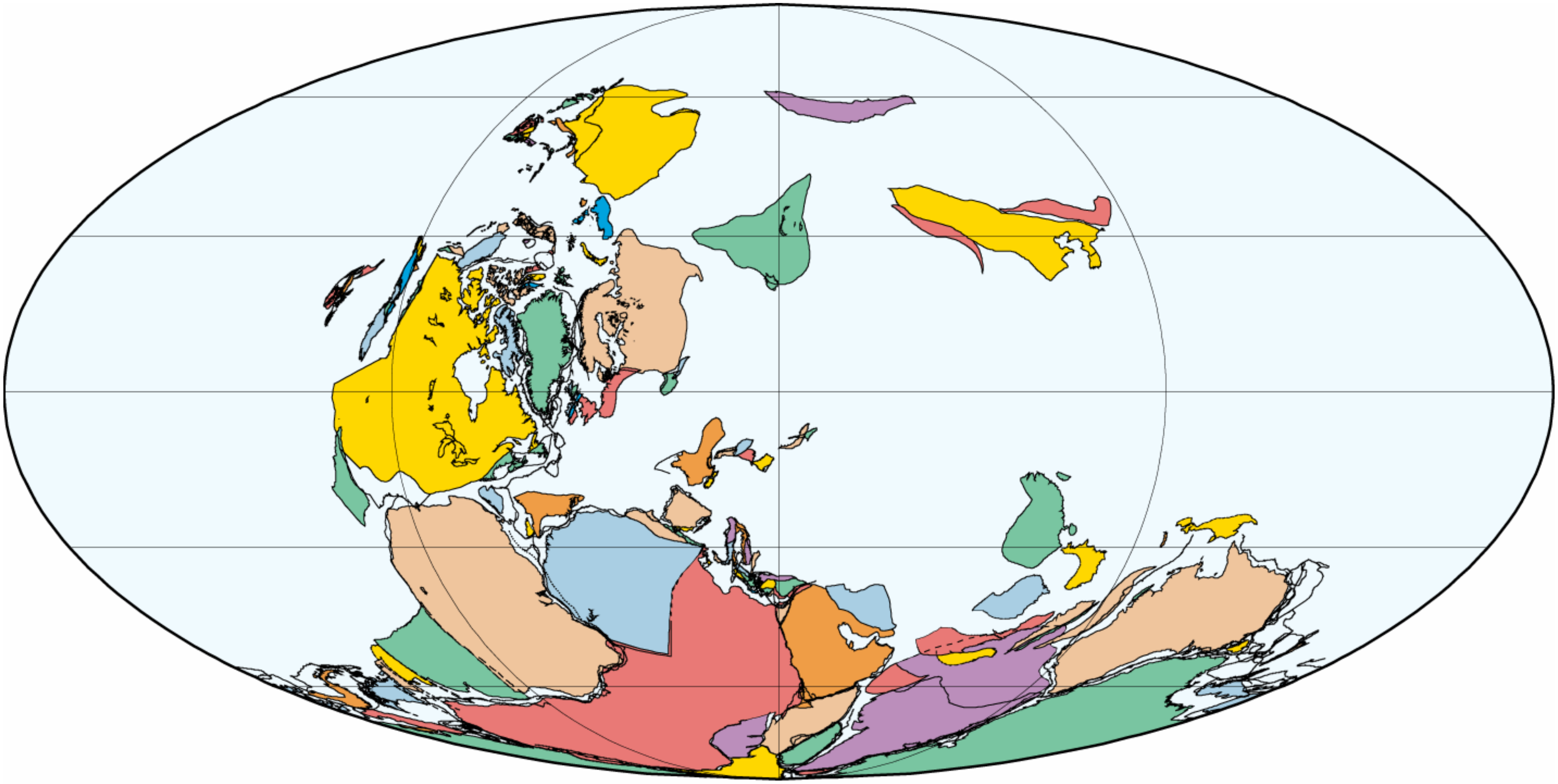

350 Ma

Tournaisian (Mississippian)

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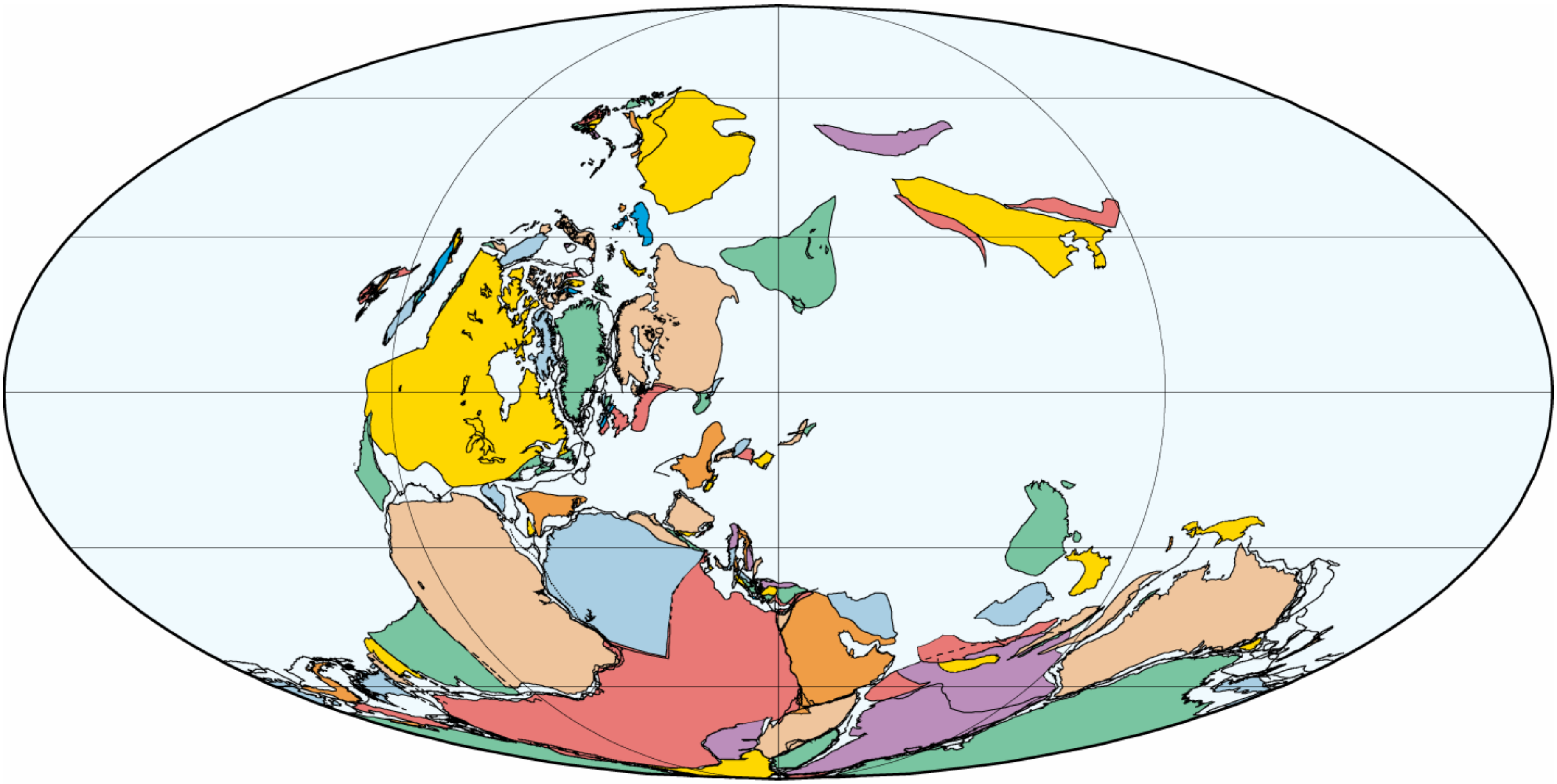

340 Ma

Early Visean (Mississippian)

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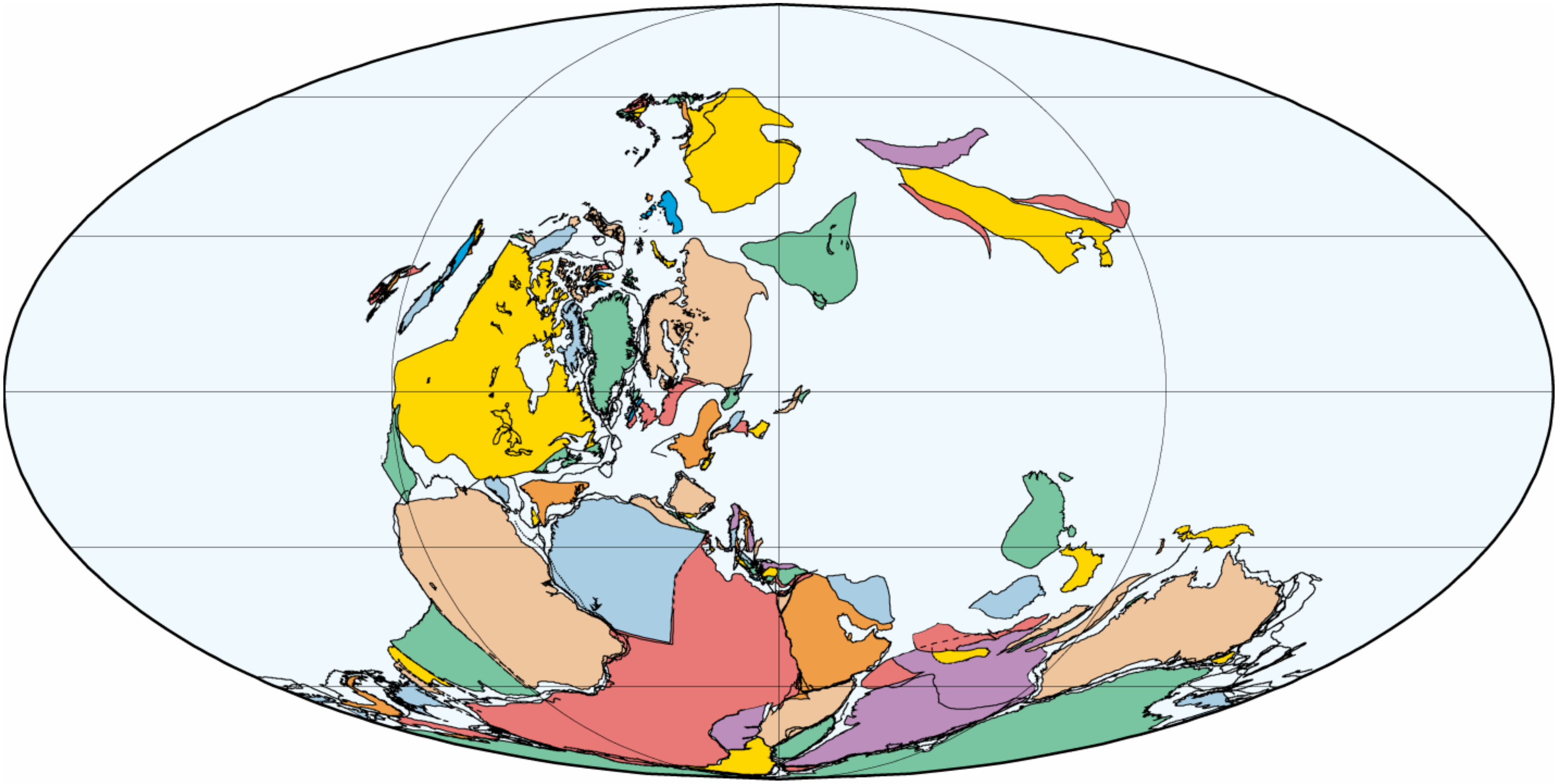

330 Ma
Late Visean (Mississippian)

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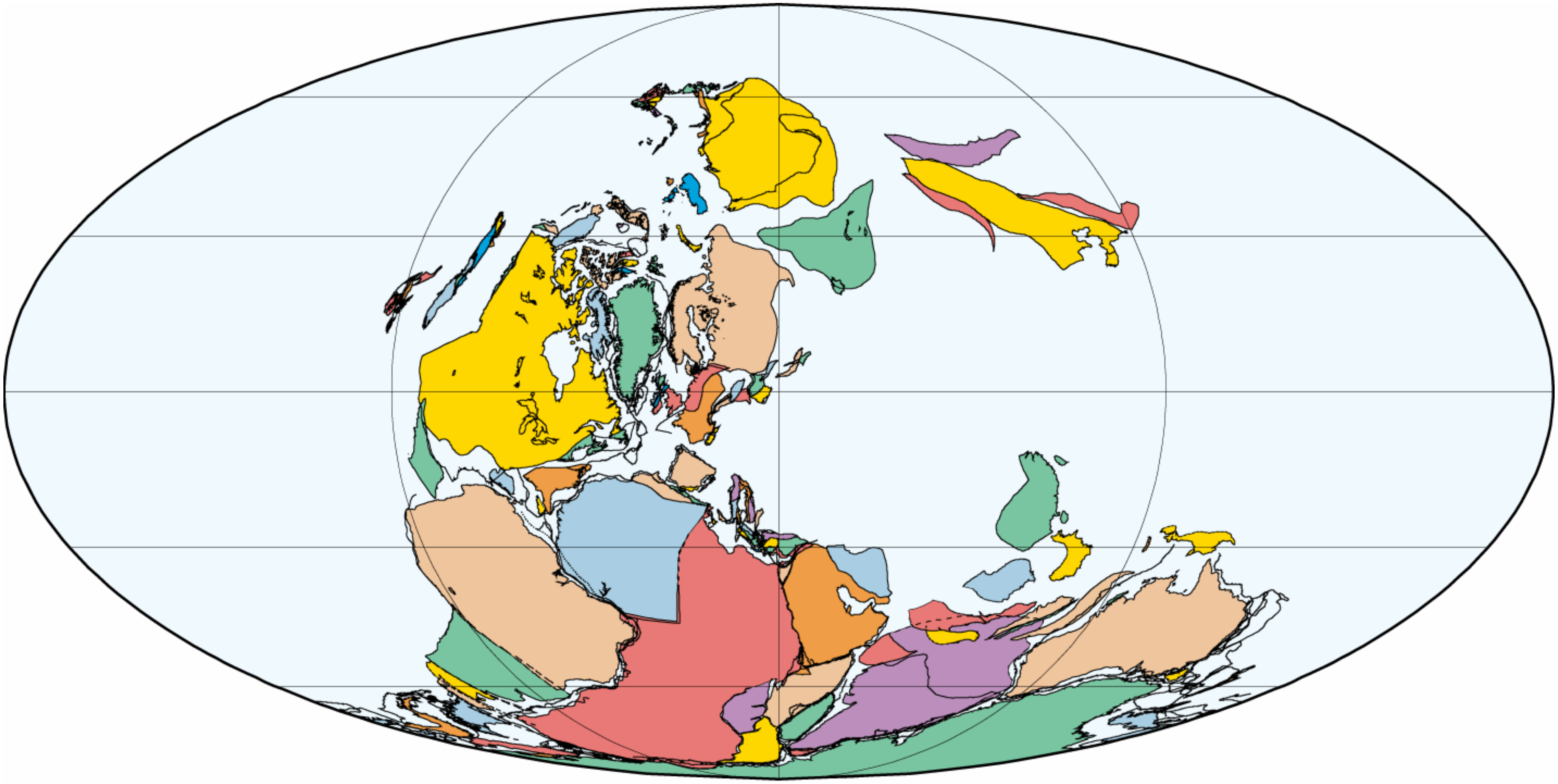

320 Ma

Bashkirian (Pennsylvanian)

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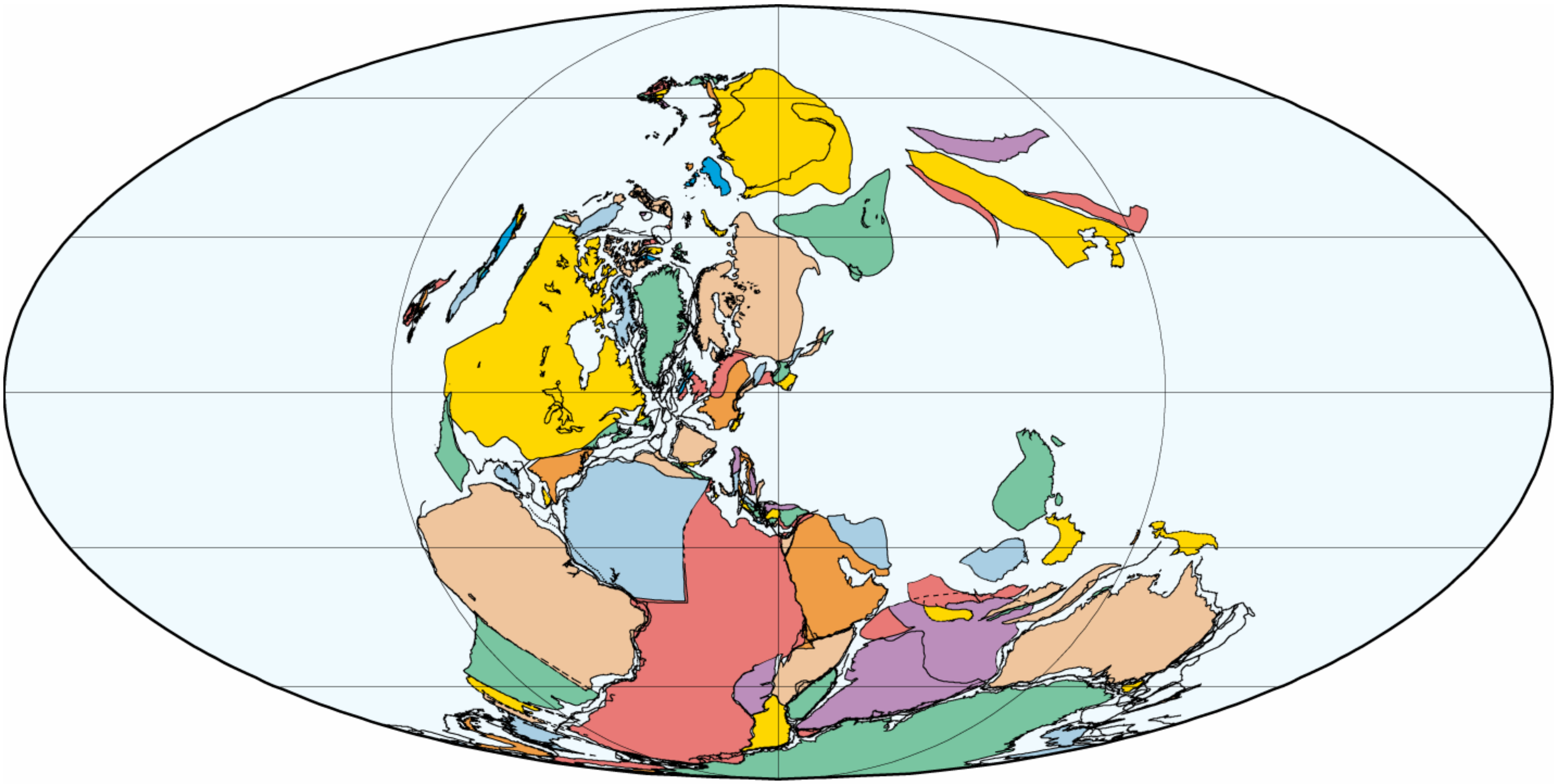

310 Ma

Moscovian (Pennsylvanian)

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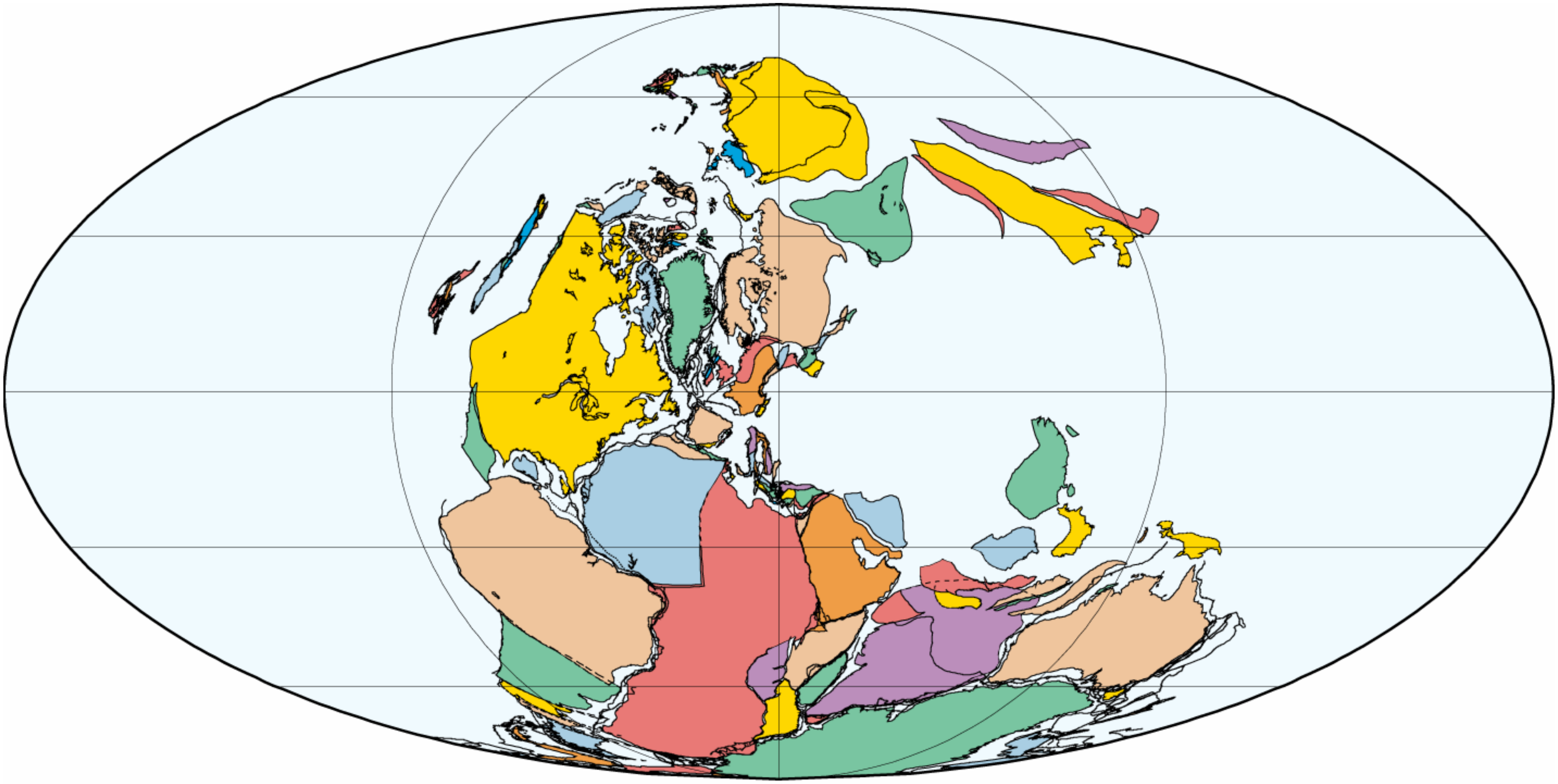

300 Ma
Kasimovian (Pennsylvanian)

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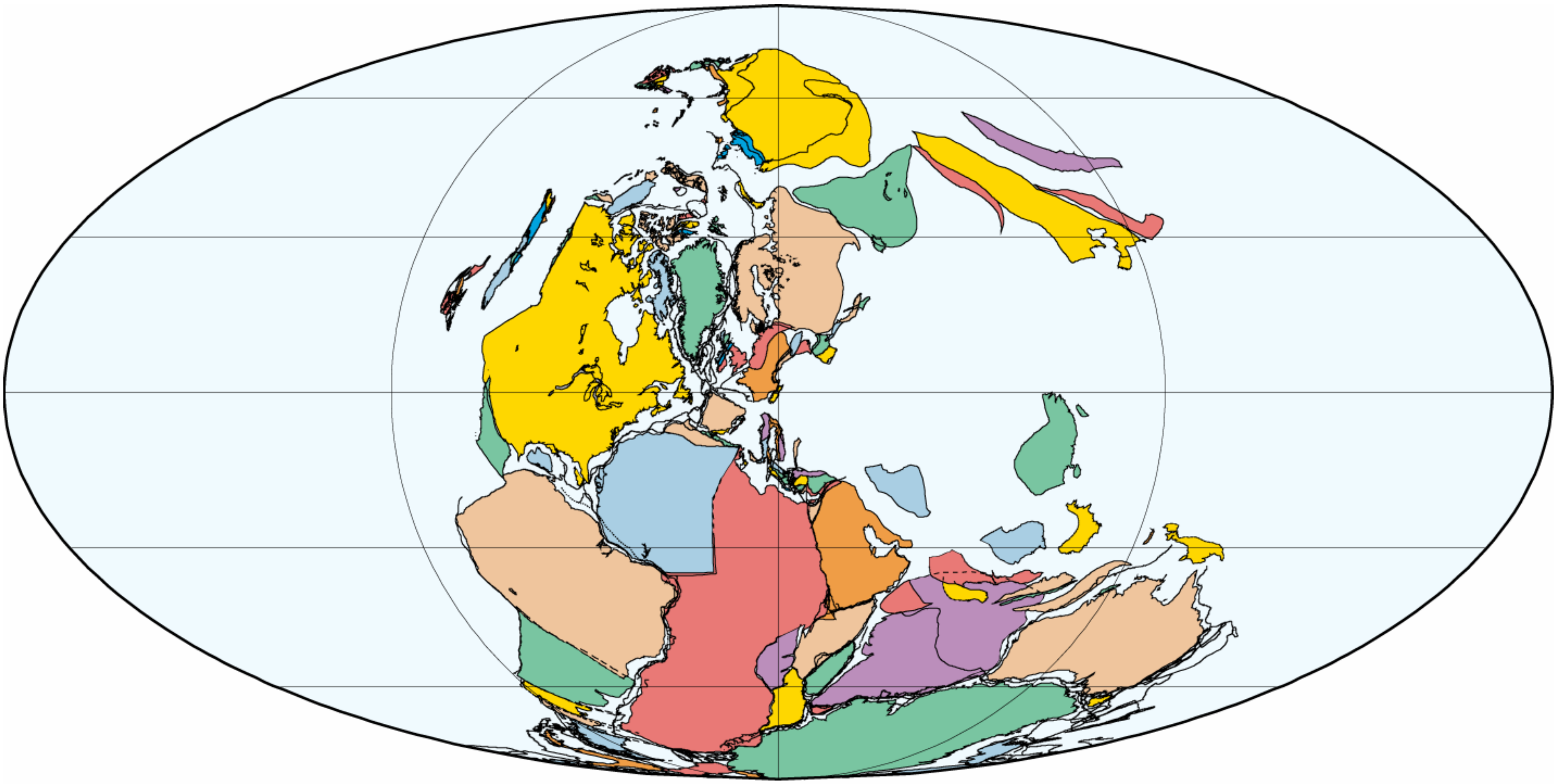

290 Ma

Late Gzelian/Early Asselian (Pennsylvanian/Permian)

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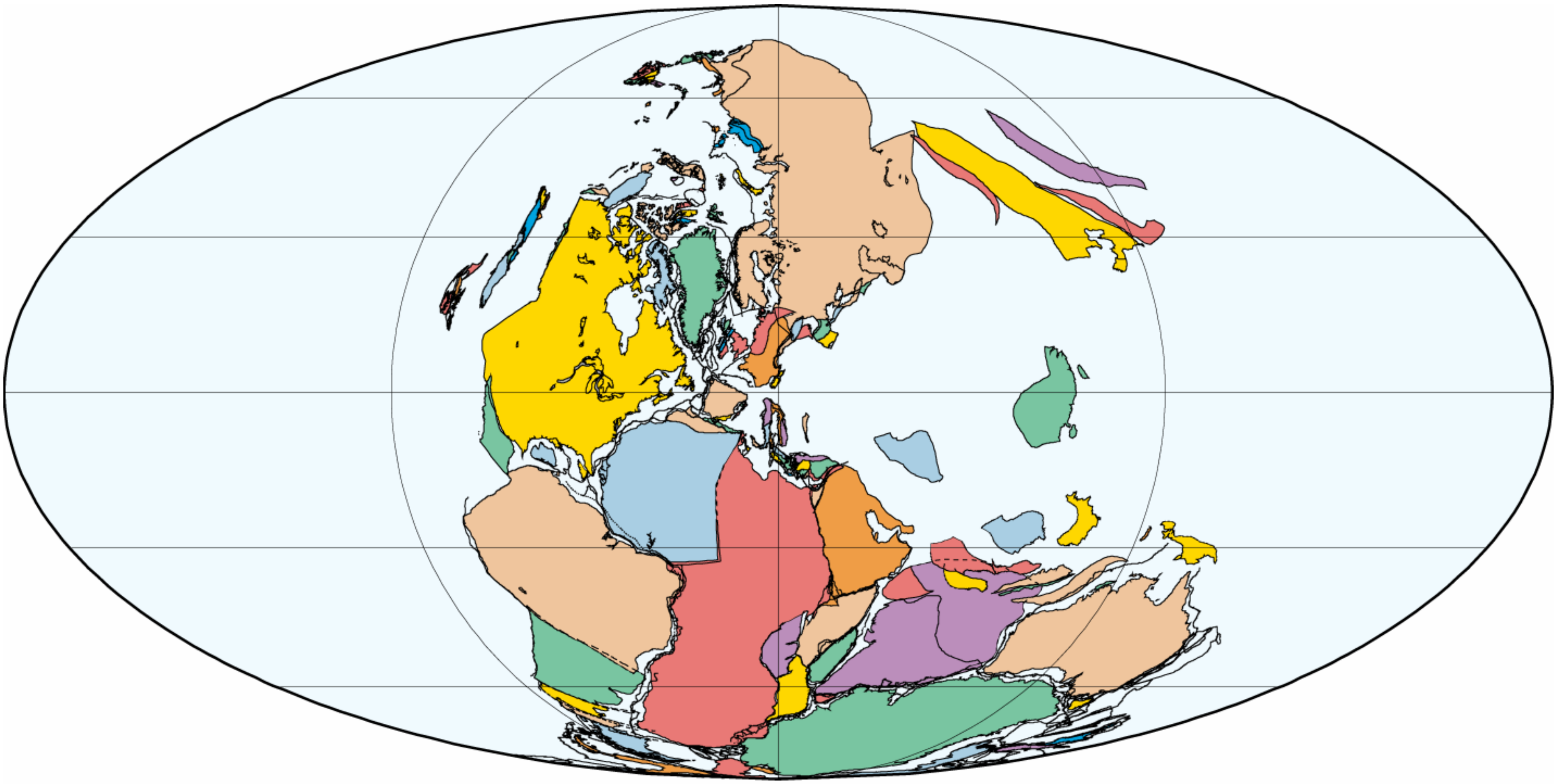

280 Ma

Early Sakmarian (Early Permian)

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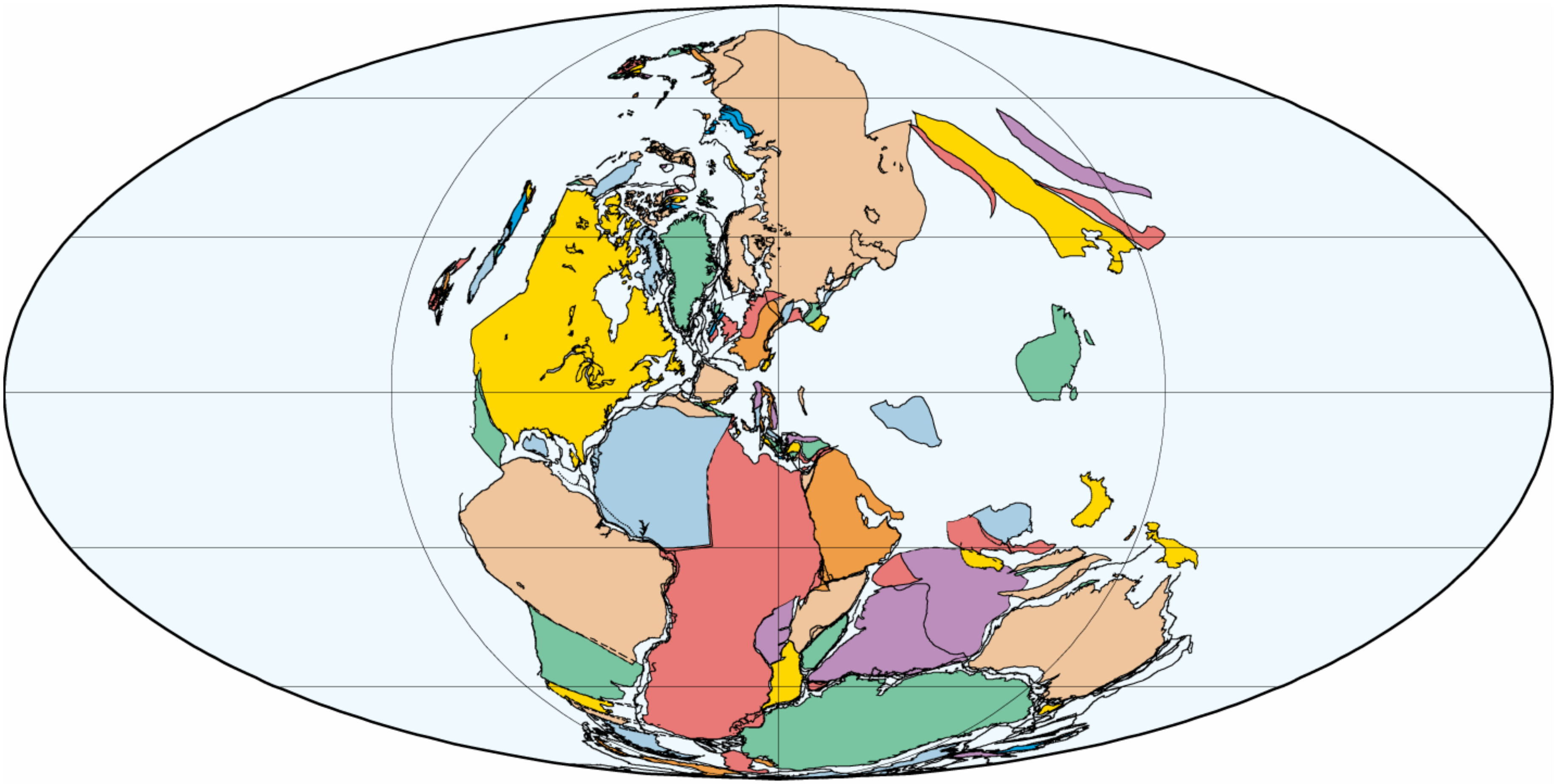

270 Ma
Late Sakmarian (Early Permian)

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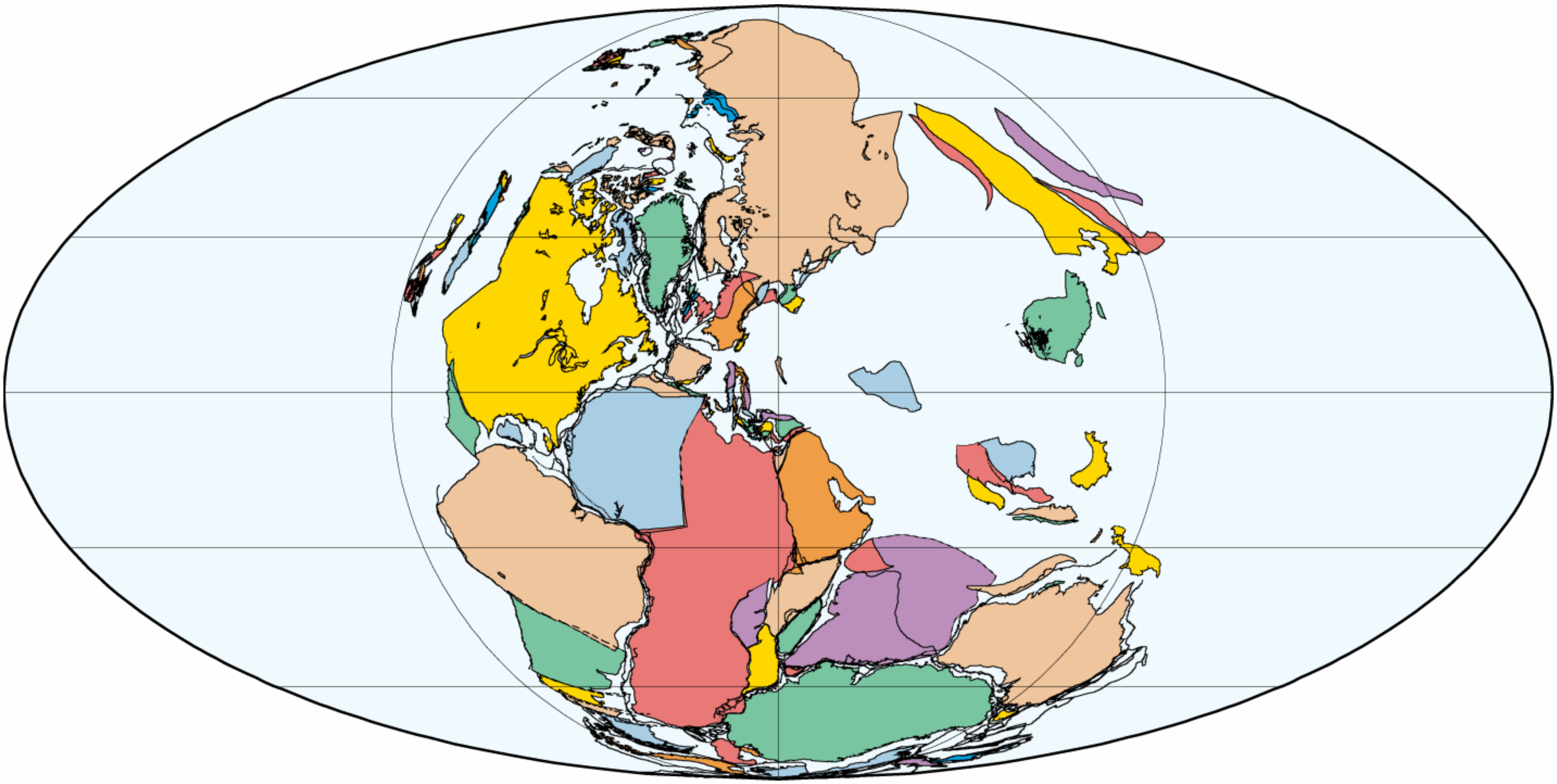

260 Ma

Late Artinskian/Early Kungurian (Early Permian)

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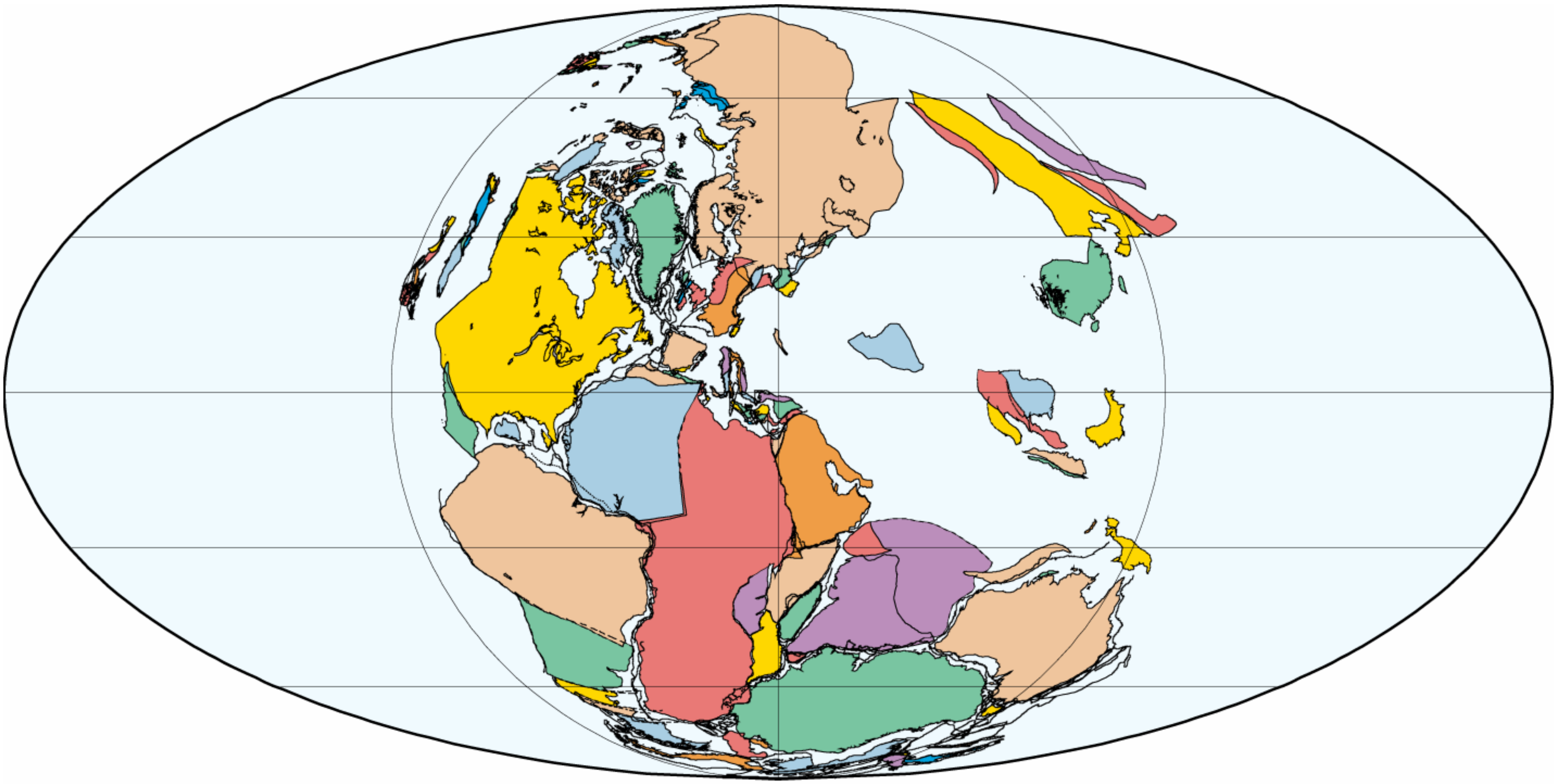

250 Ma

Tatarian (Late Permian)

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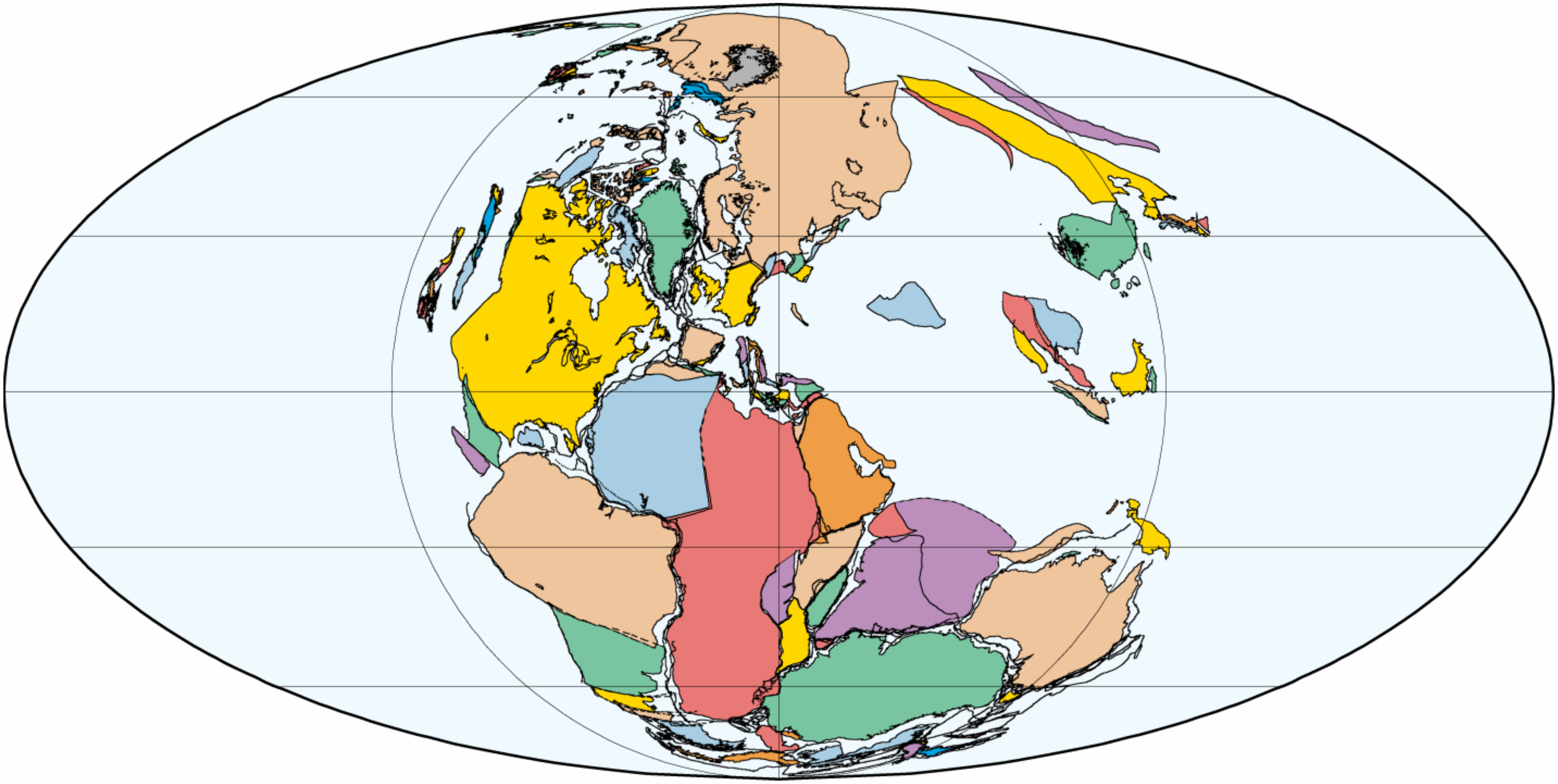

240 Ma
Anisian (Middle Triassic)

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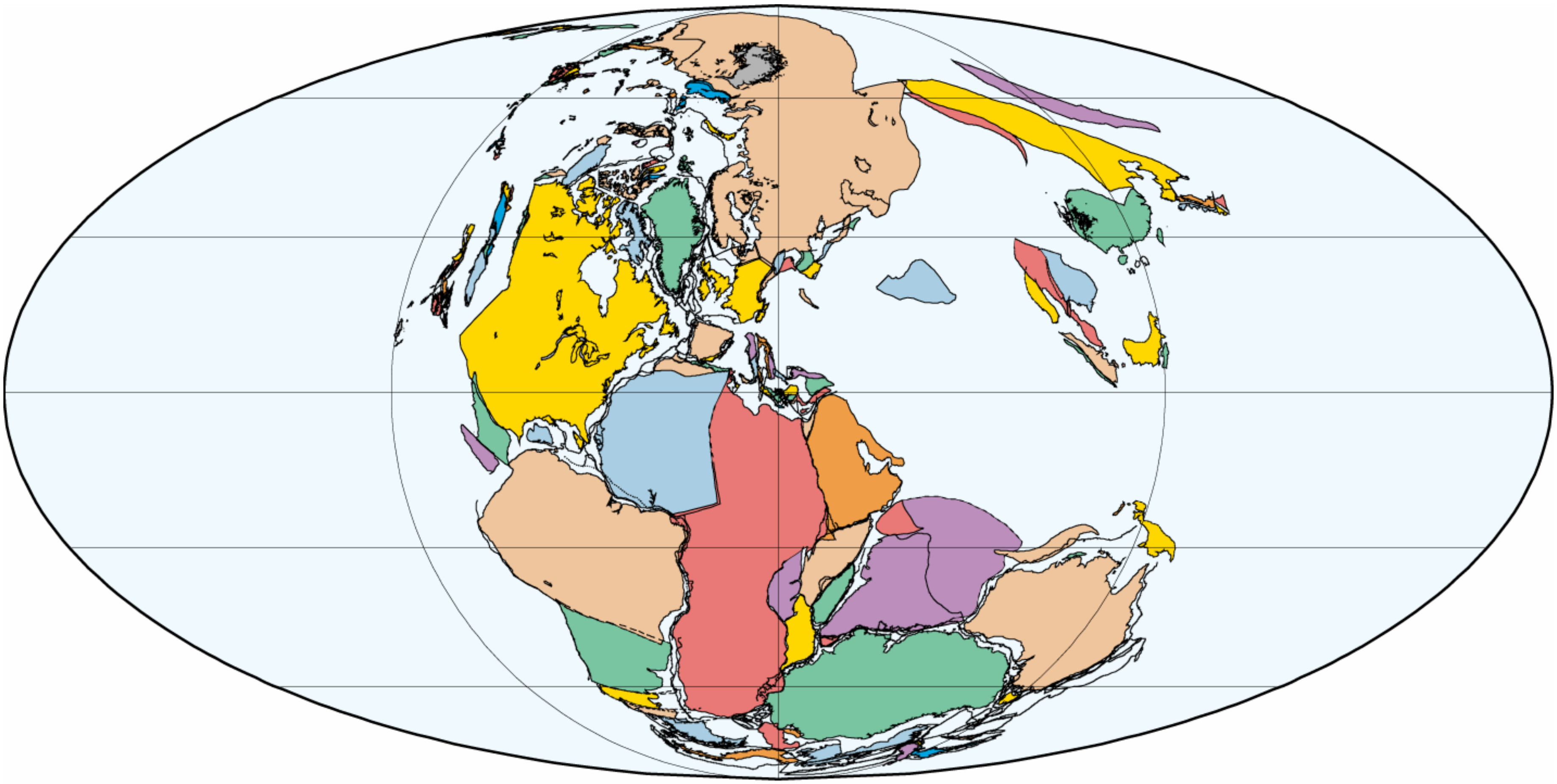
August 2002



230 Ma
Ladinian (Middle Triassic)

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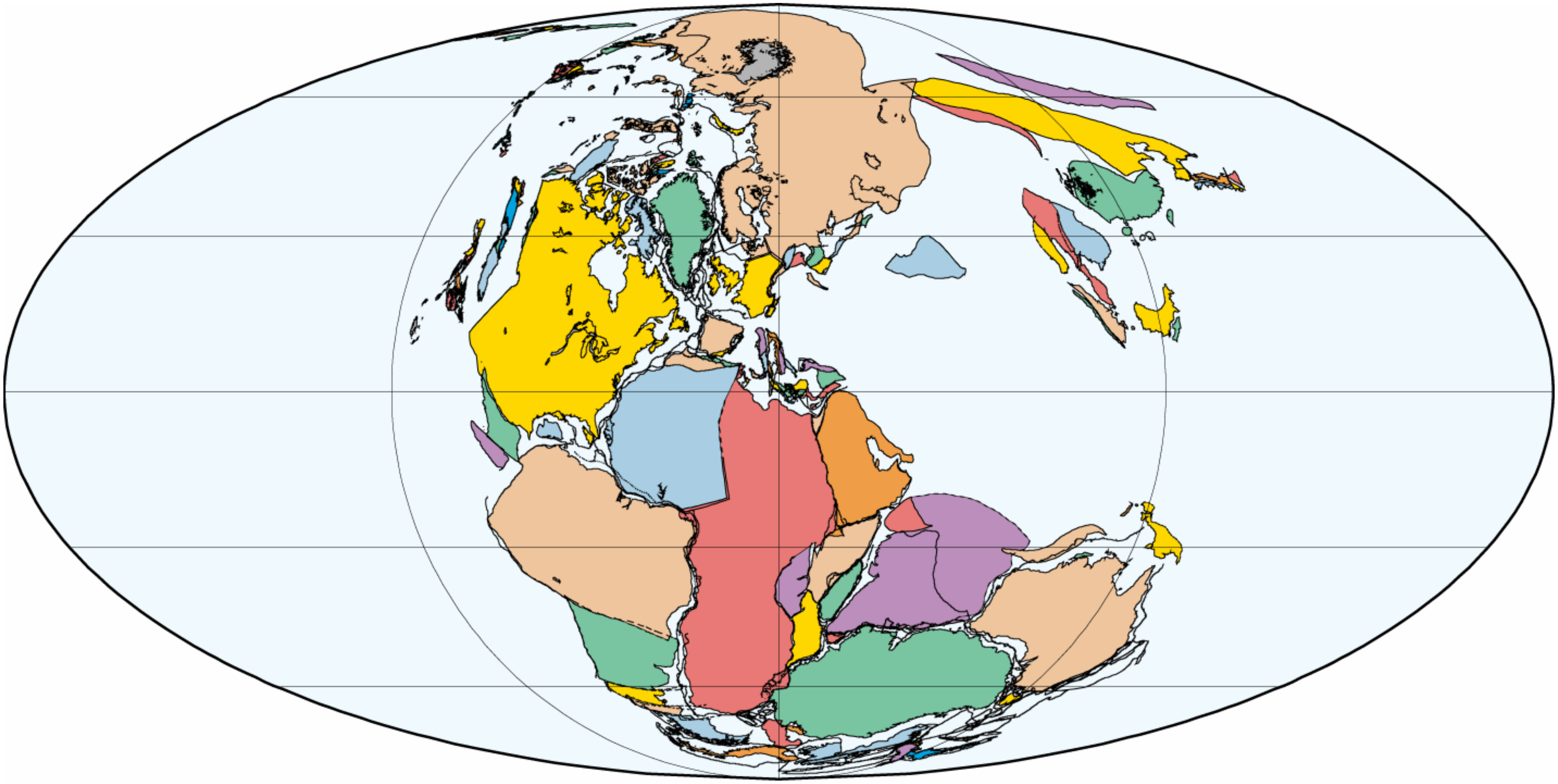

220 Ma

Early Norian (Late Triassic)

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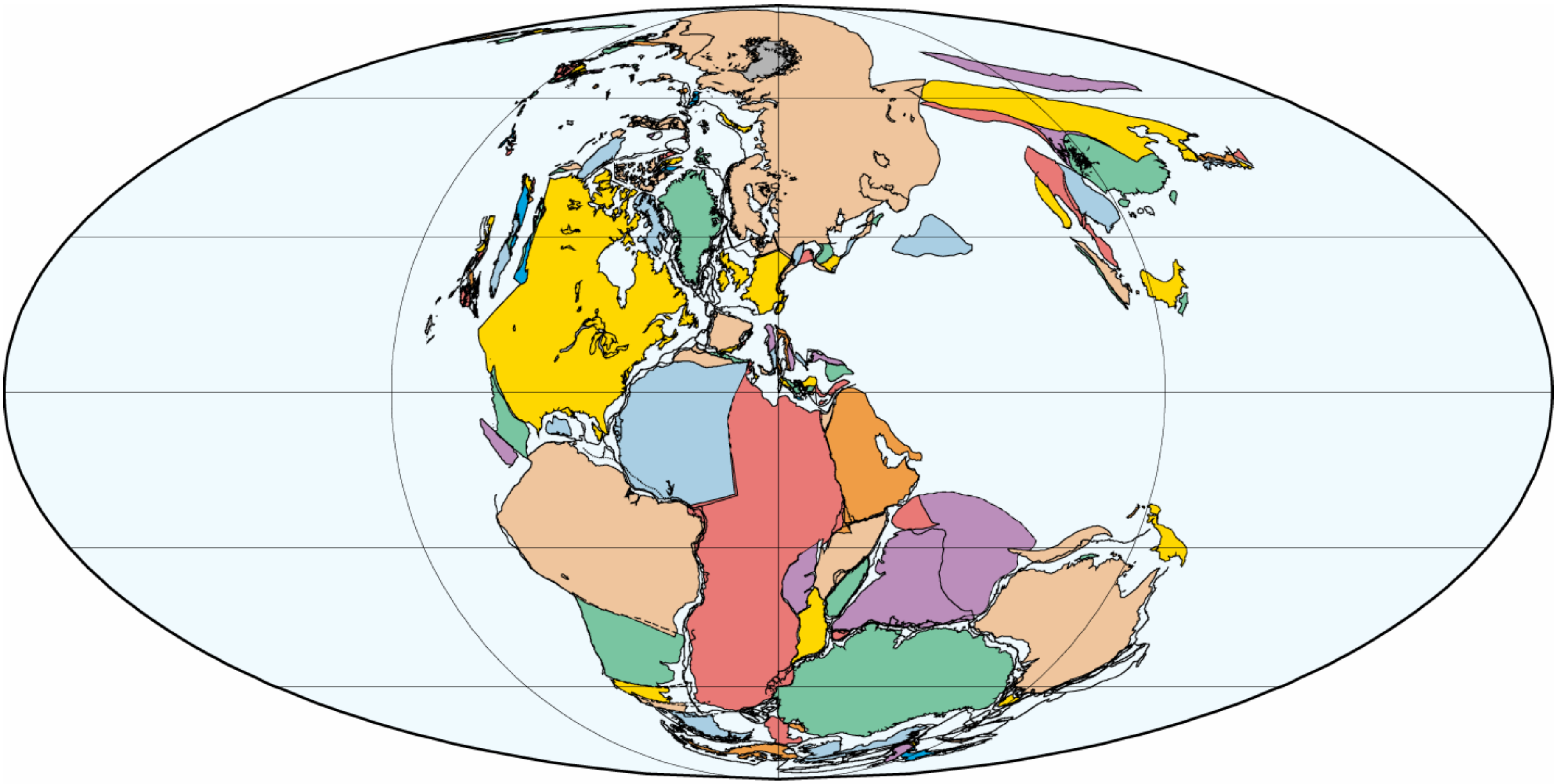

210 Ma

Late Norian (Late Triassic)

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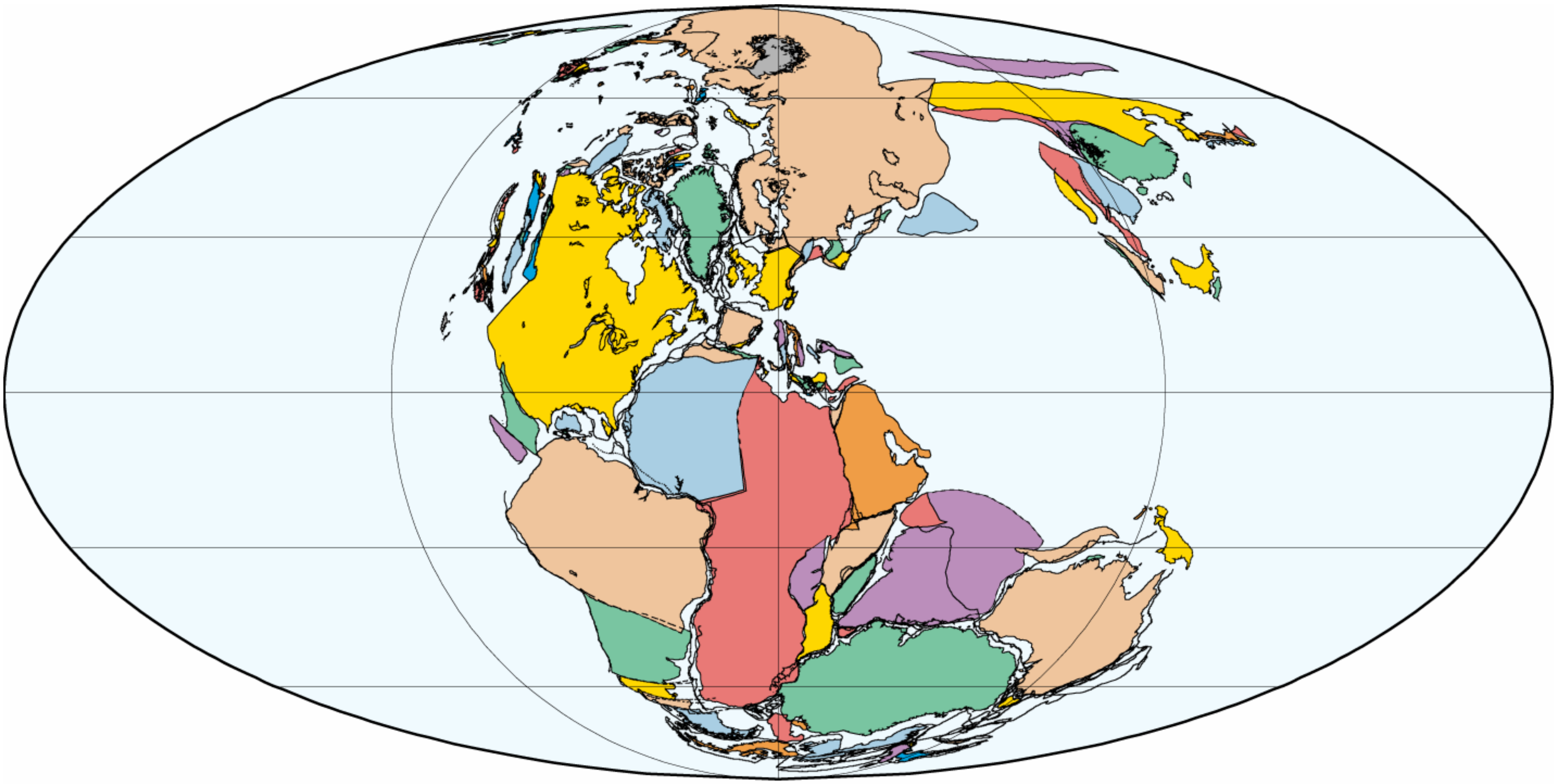
August 2002



200 Ma

Sinemurian (Early Jurassic)

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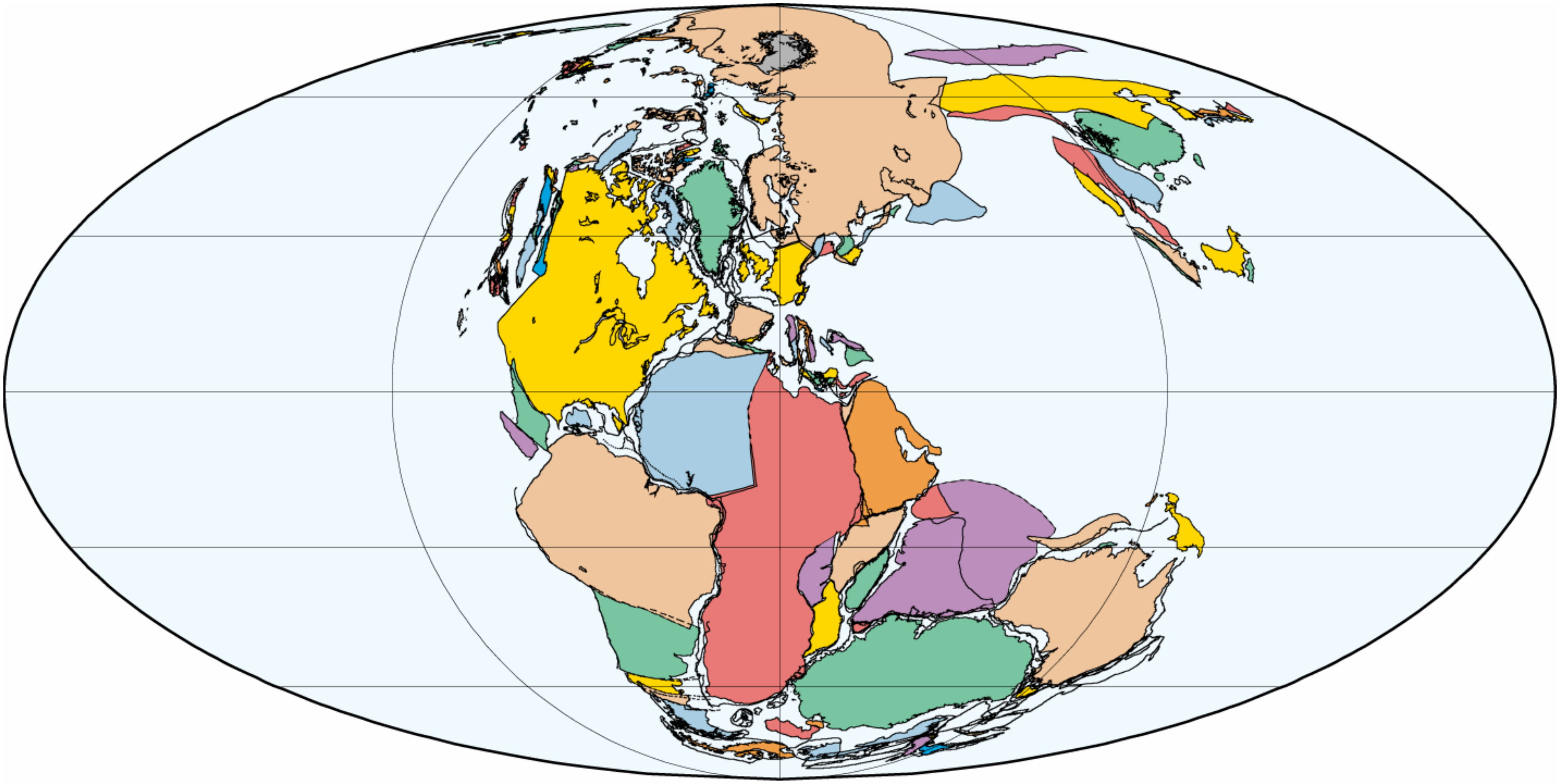

190 Ma

Pliensbachian (Early Jurassic)

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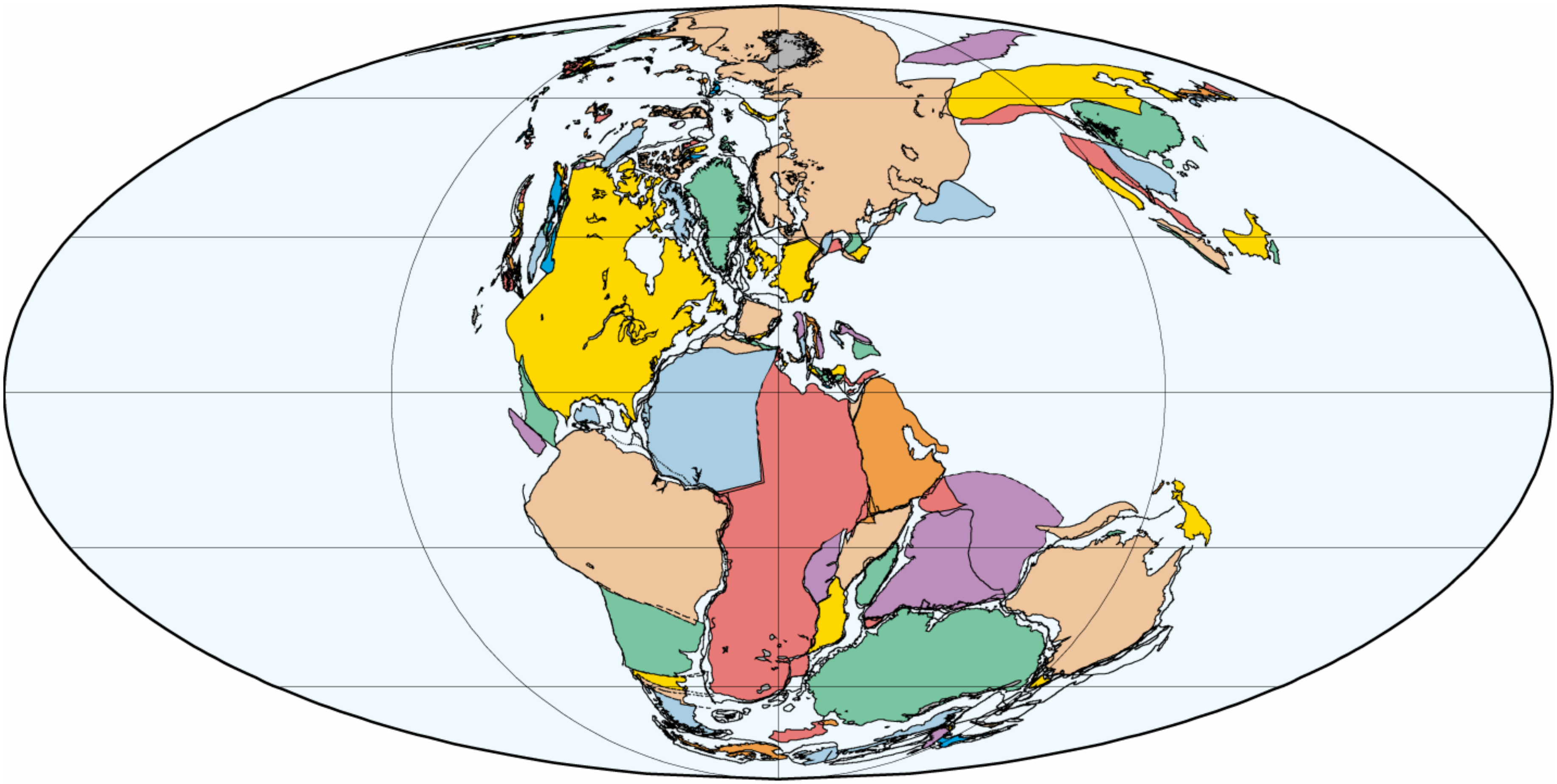

180 Ma

Aalenian (Middle Jurassic)

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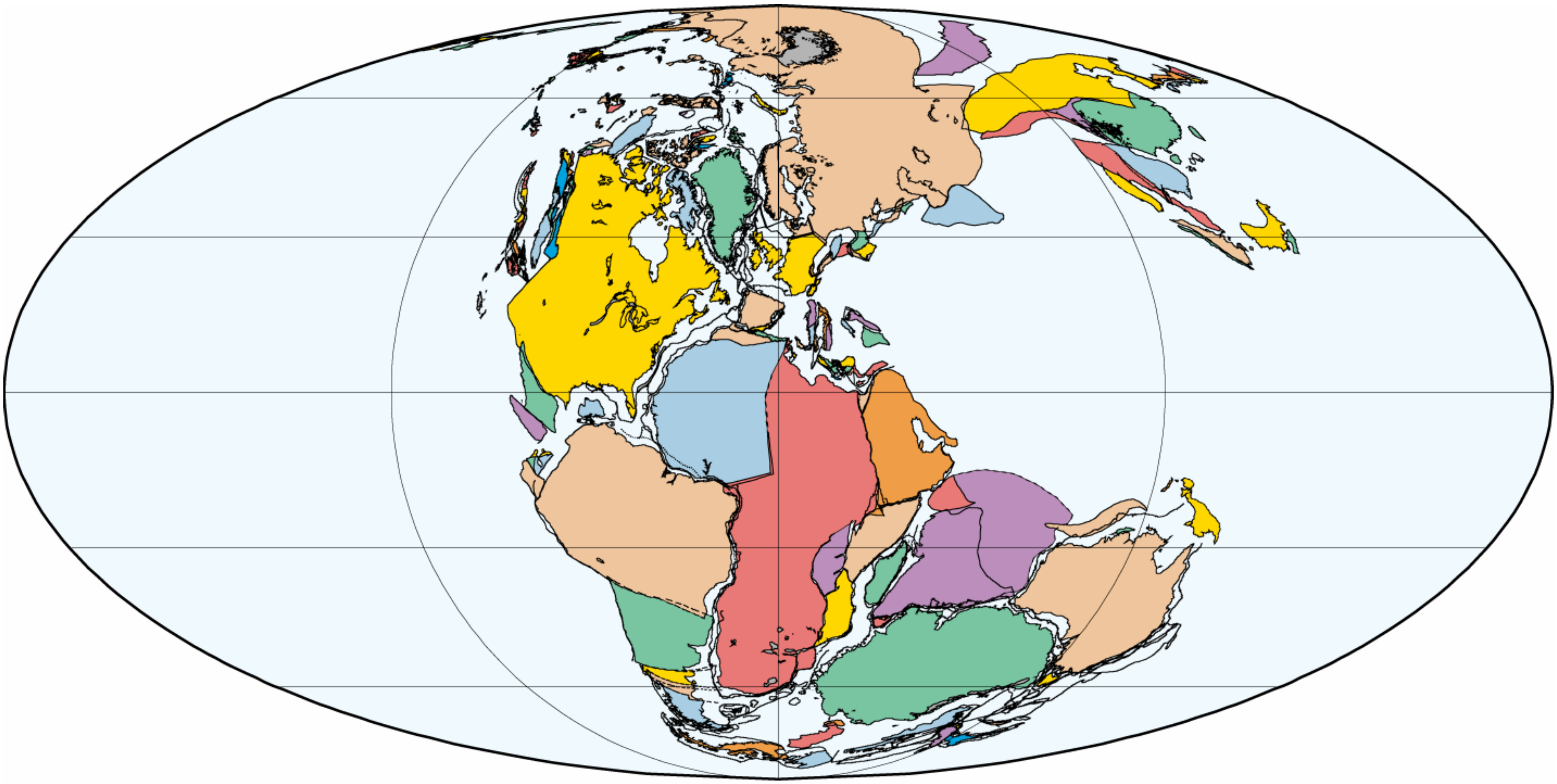

170 Ma
Bajocian (Middle Jurassic)

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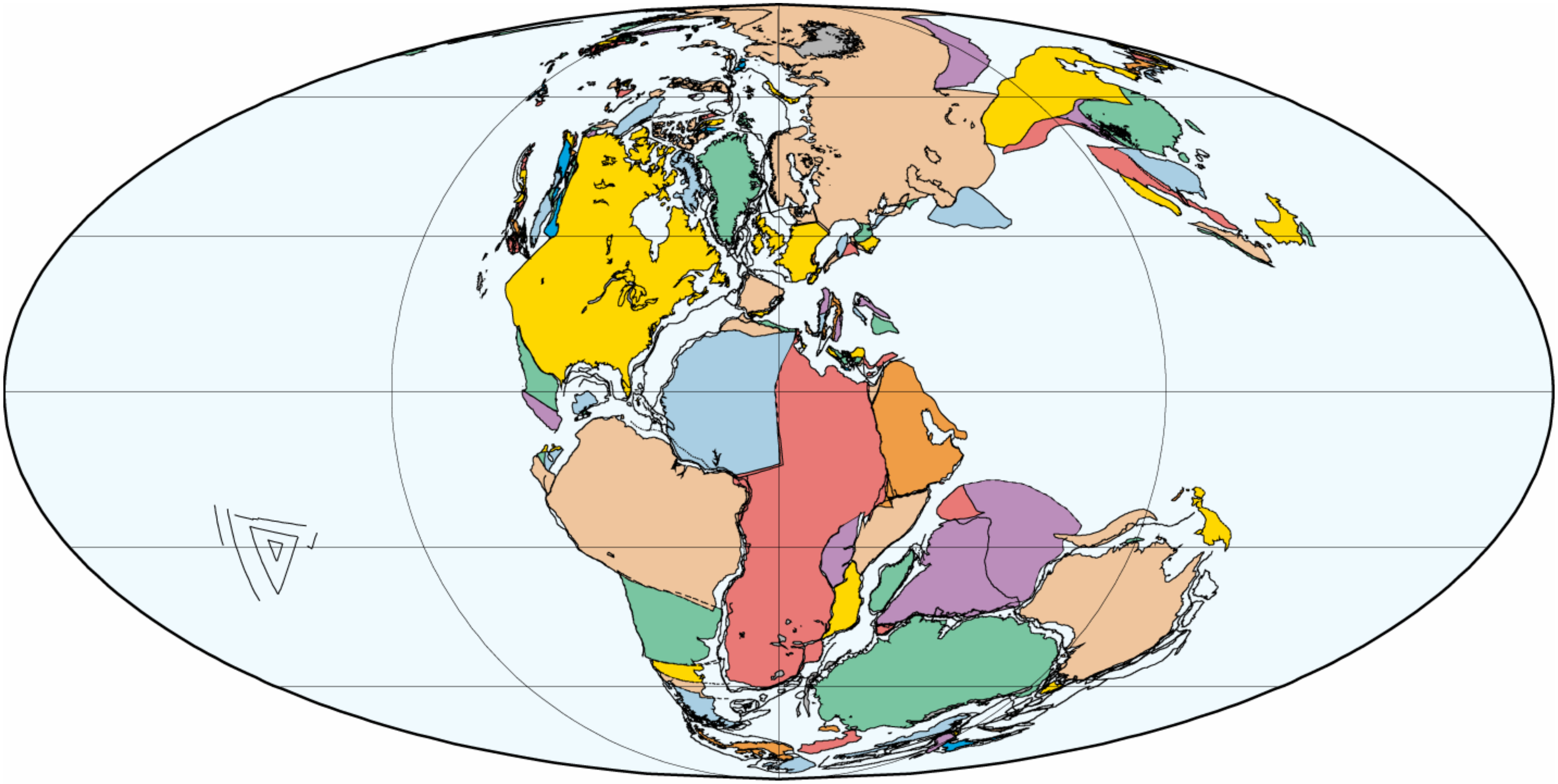

160 Ma

Callovian (Middle Jurassic)

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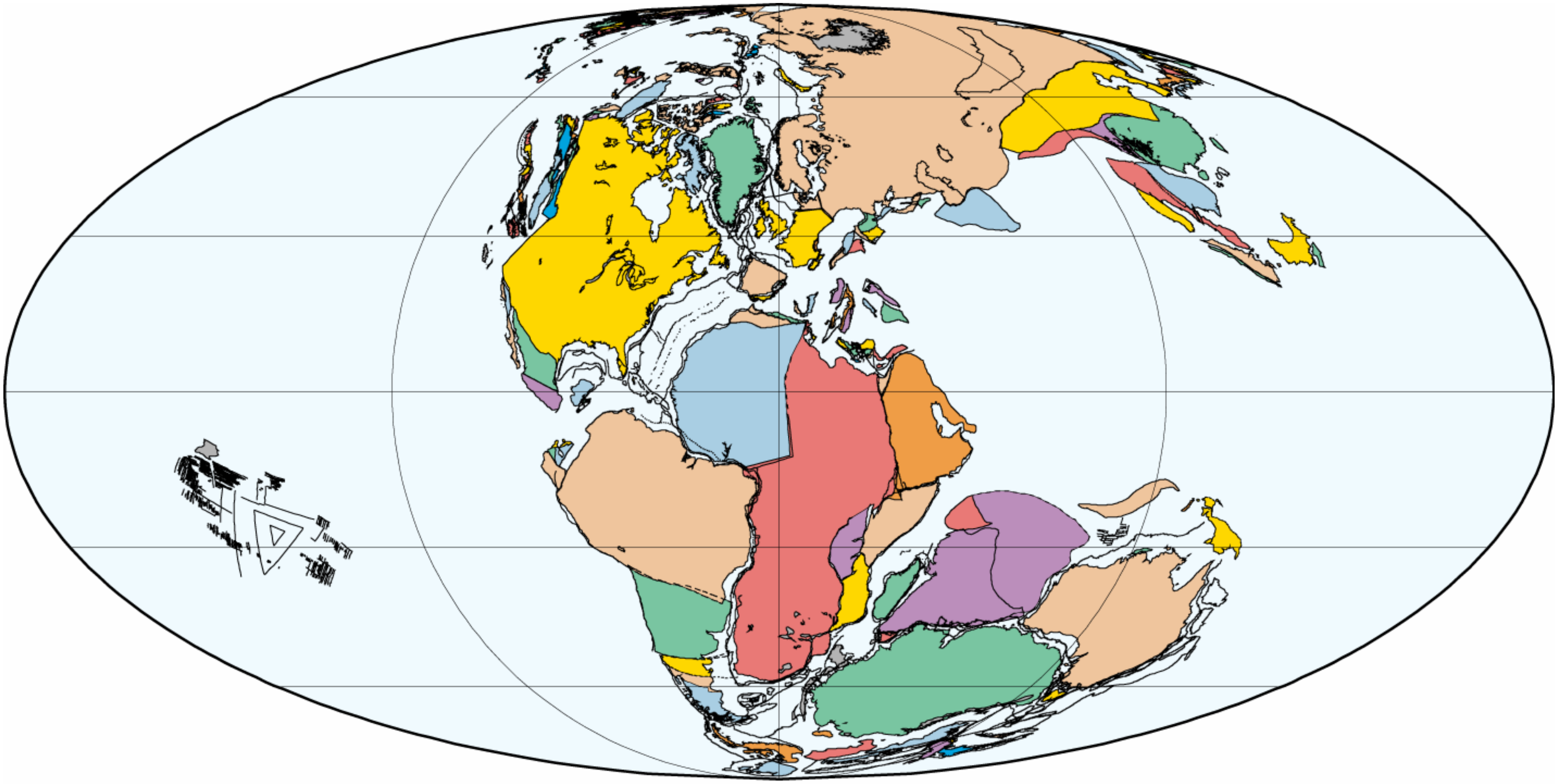
August 2002



150 Ma

Volgian (Late Jurassic)

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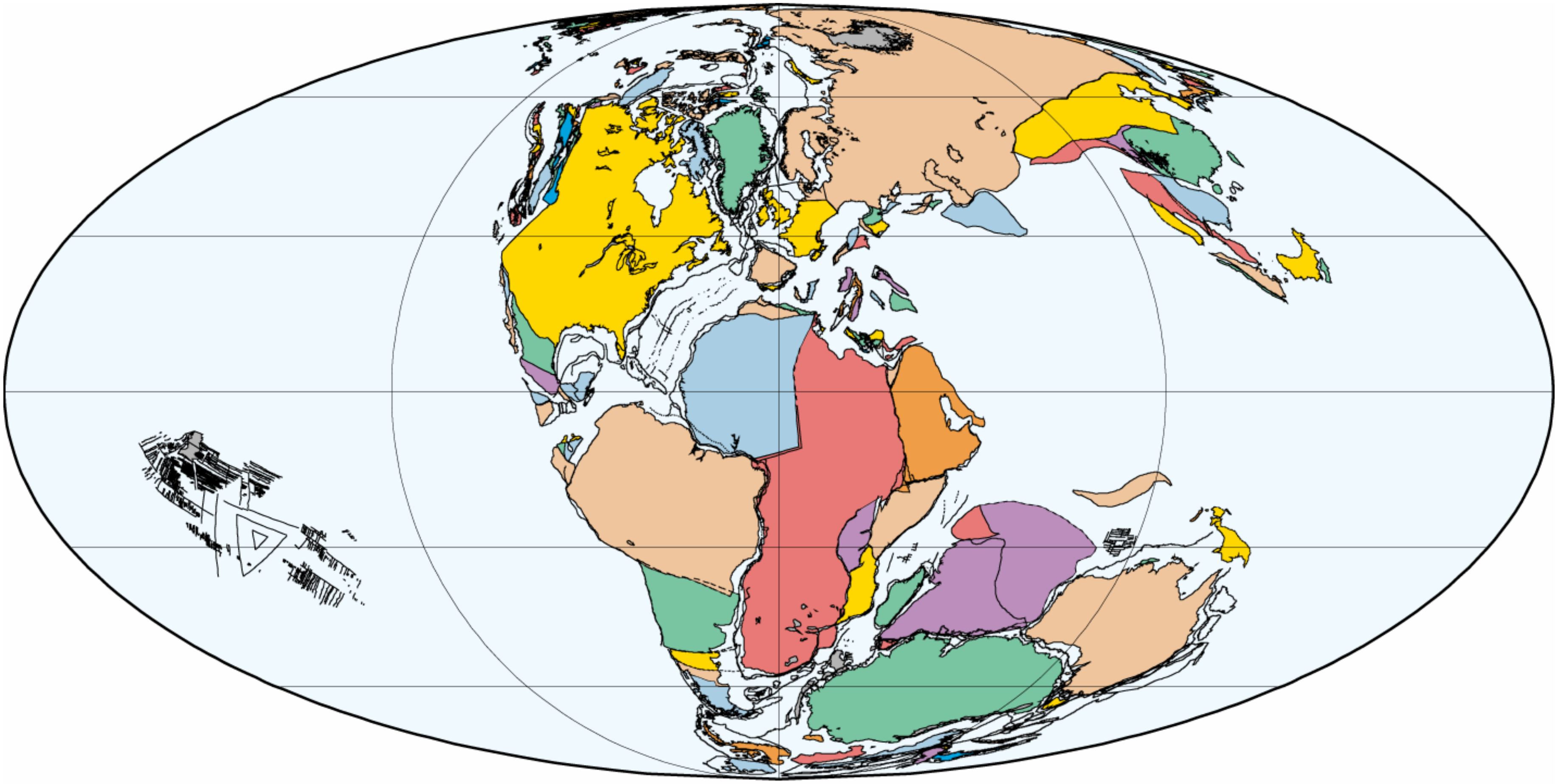
August 2002



140 Ma

Ryazanian (Early Cretaceous)

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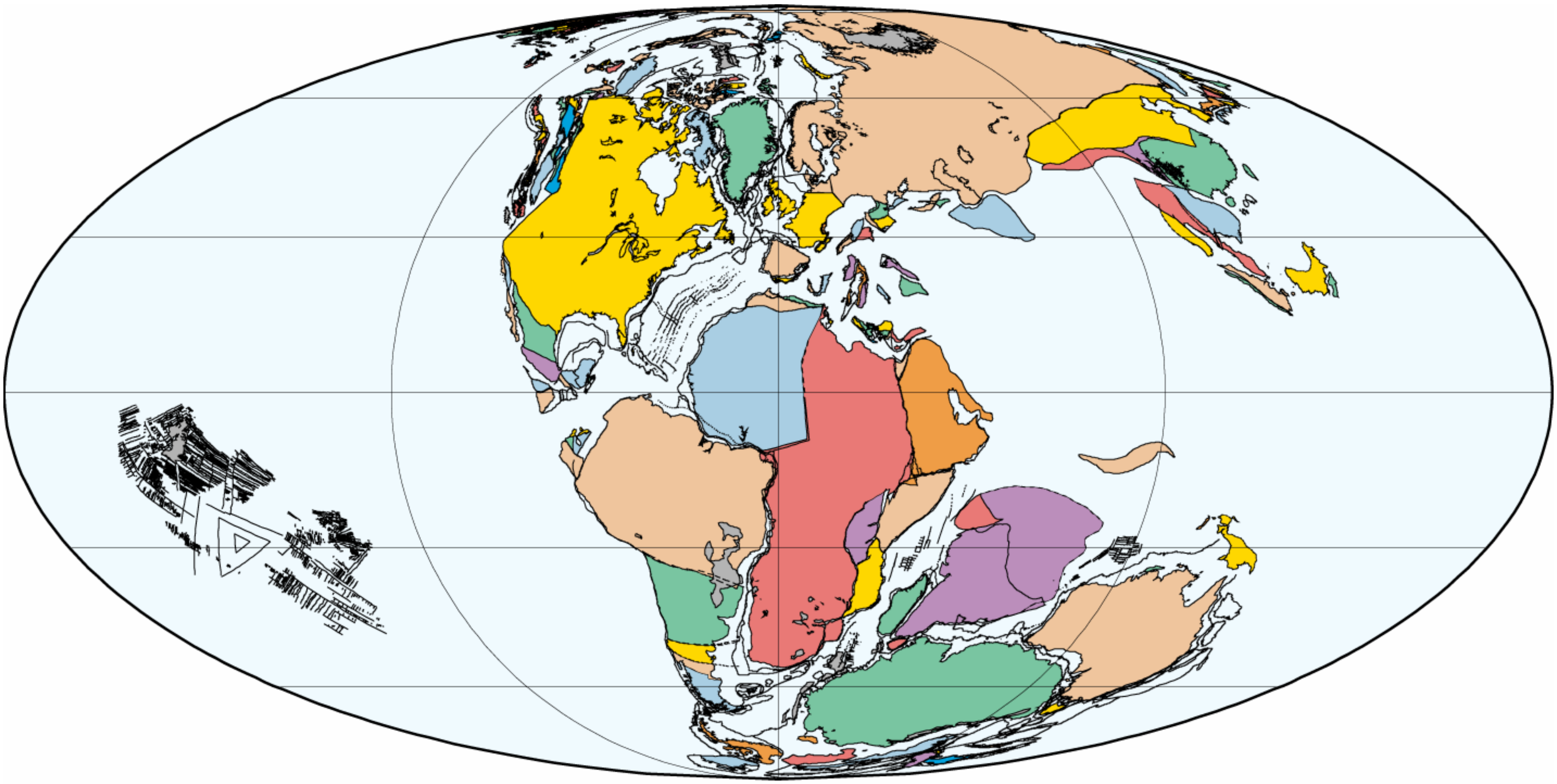

130 Ma

Hauterivian (Early Cretaceous)

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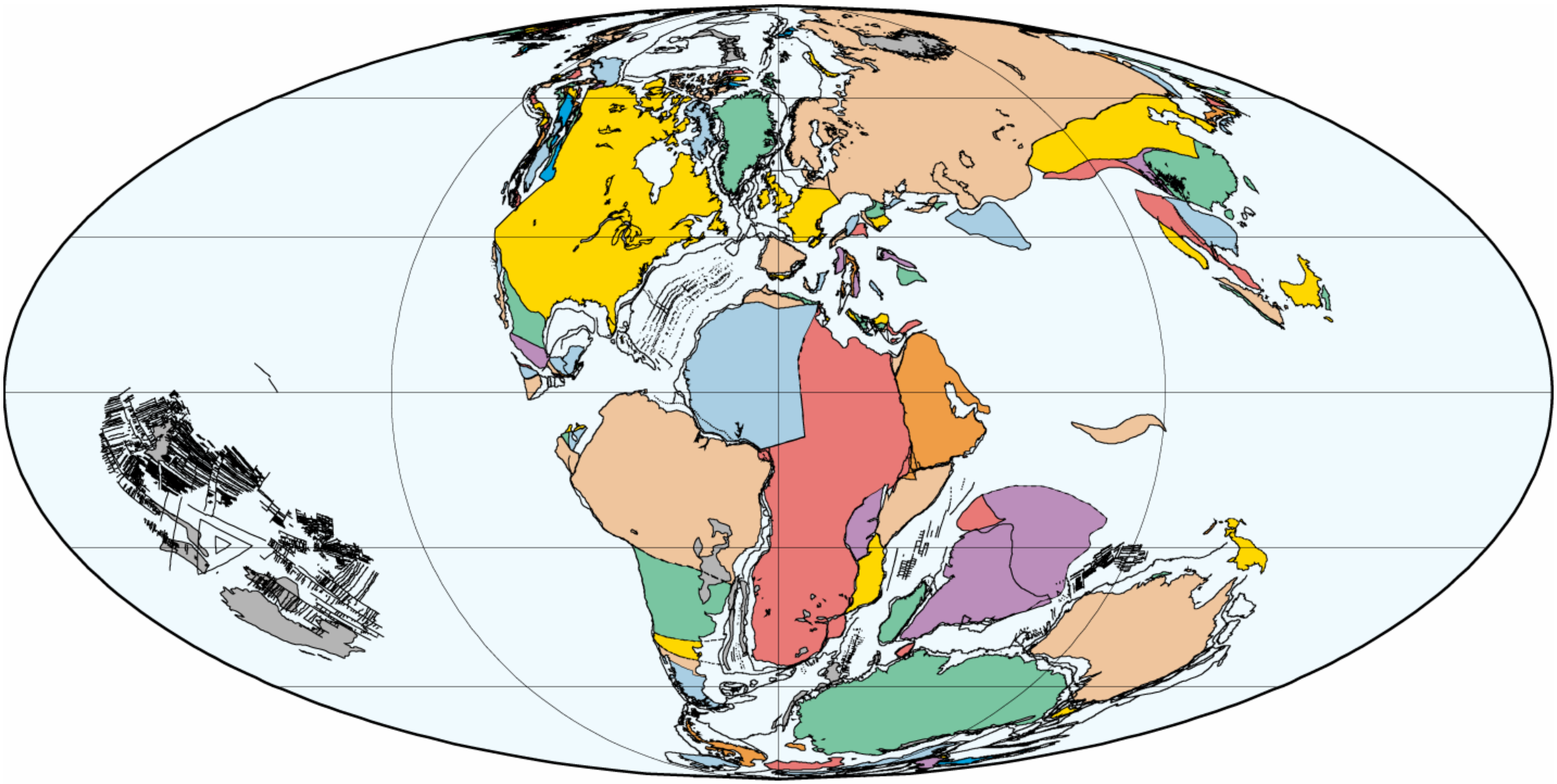
August 2002



120 Ma

Aptian (Early Cretaceous)

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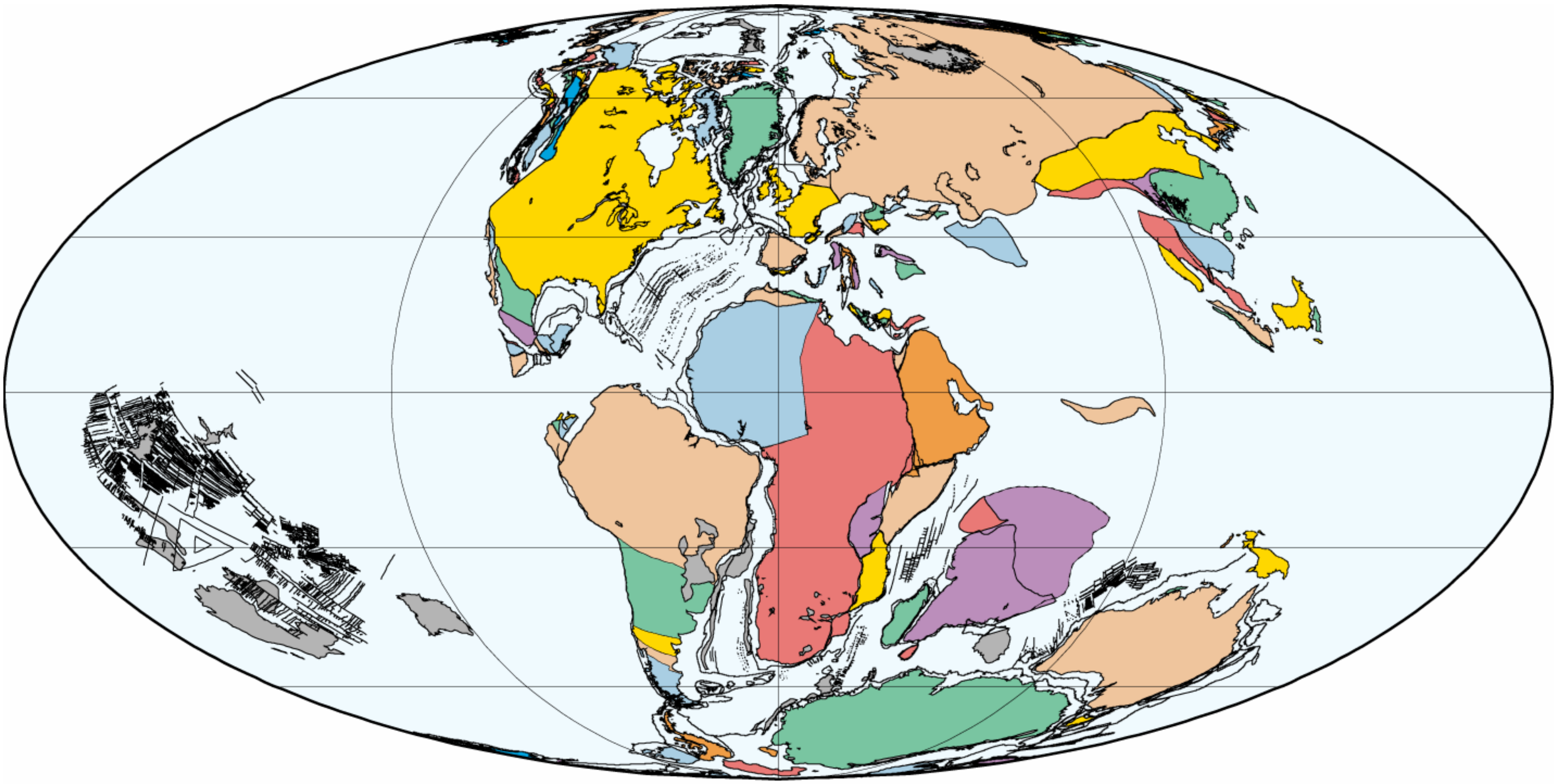

110 Ma

Early Albian (Early Cretaceous)

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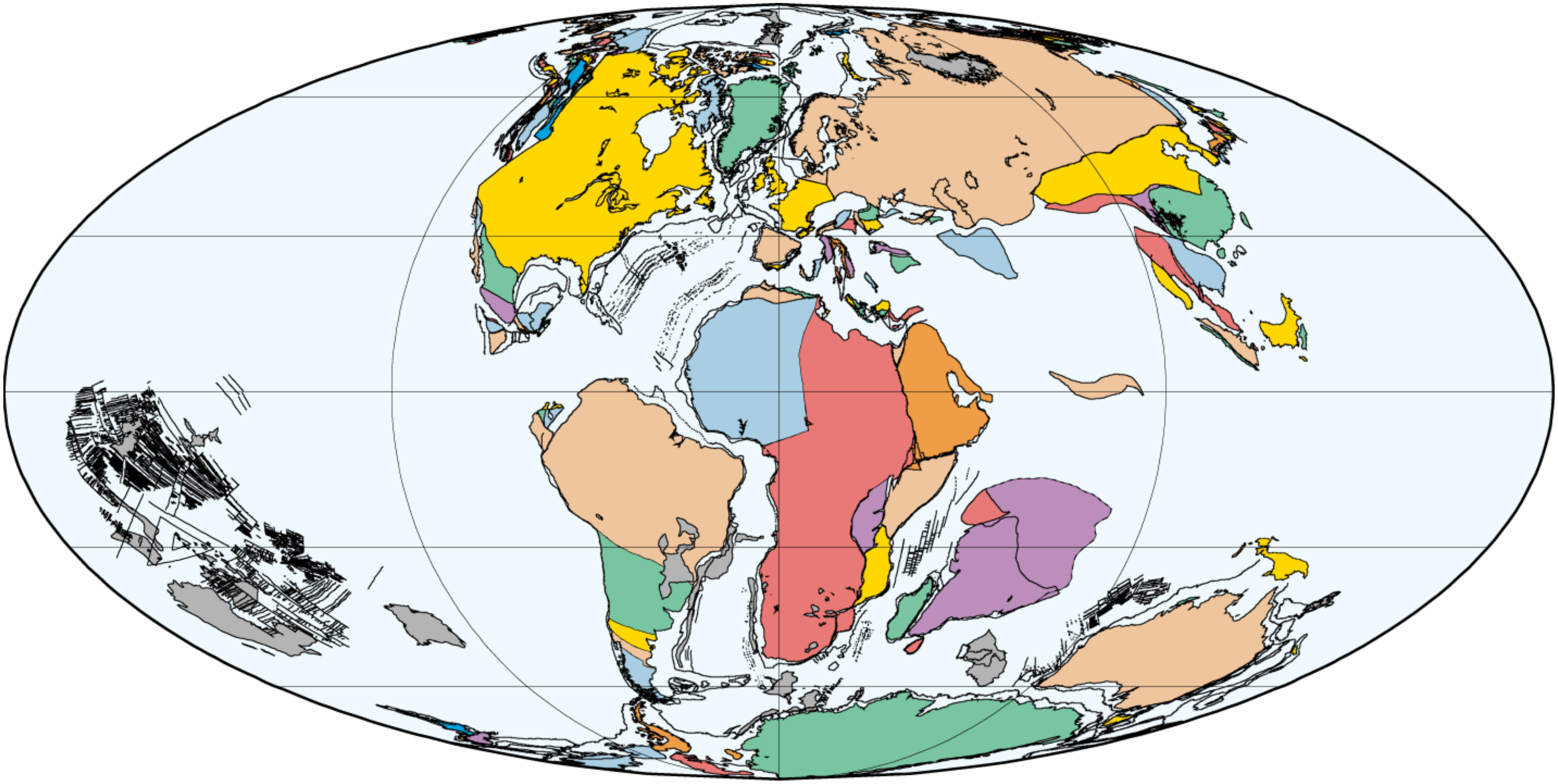

100 Ma
Late Albian (Early Cretaceous)

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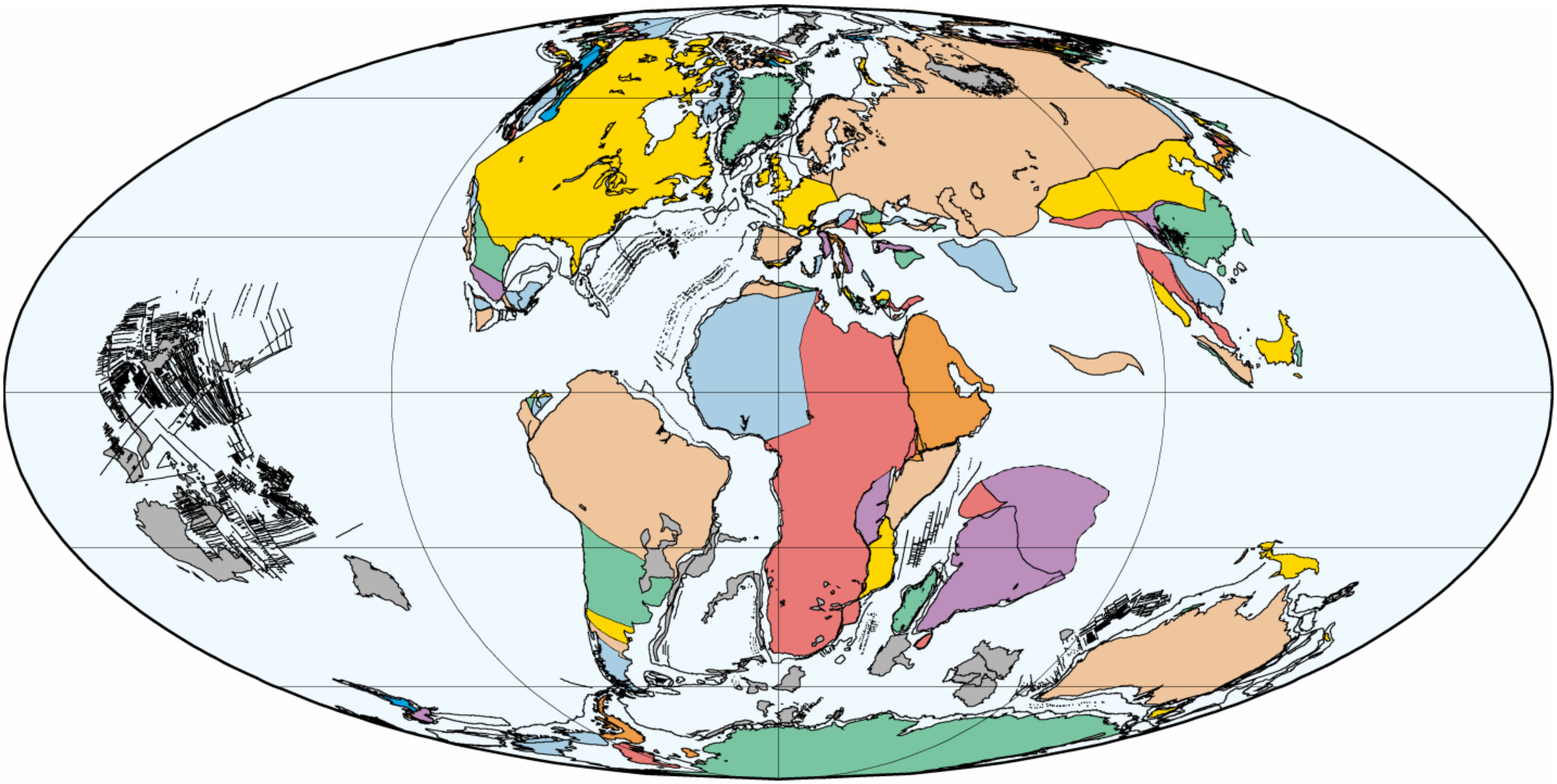

90 Ma

Turonian (Late Cretaceous)

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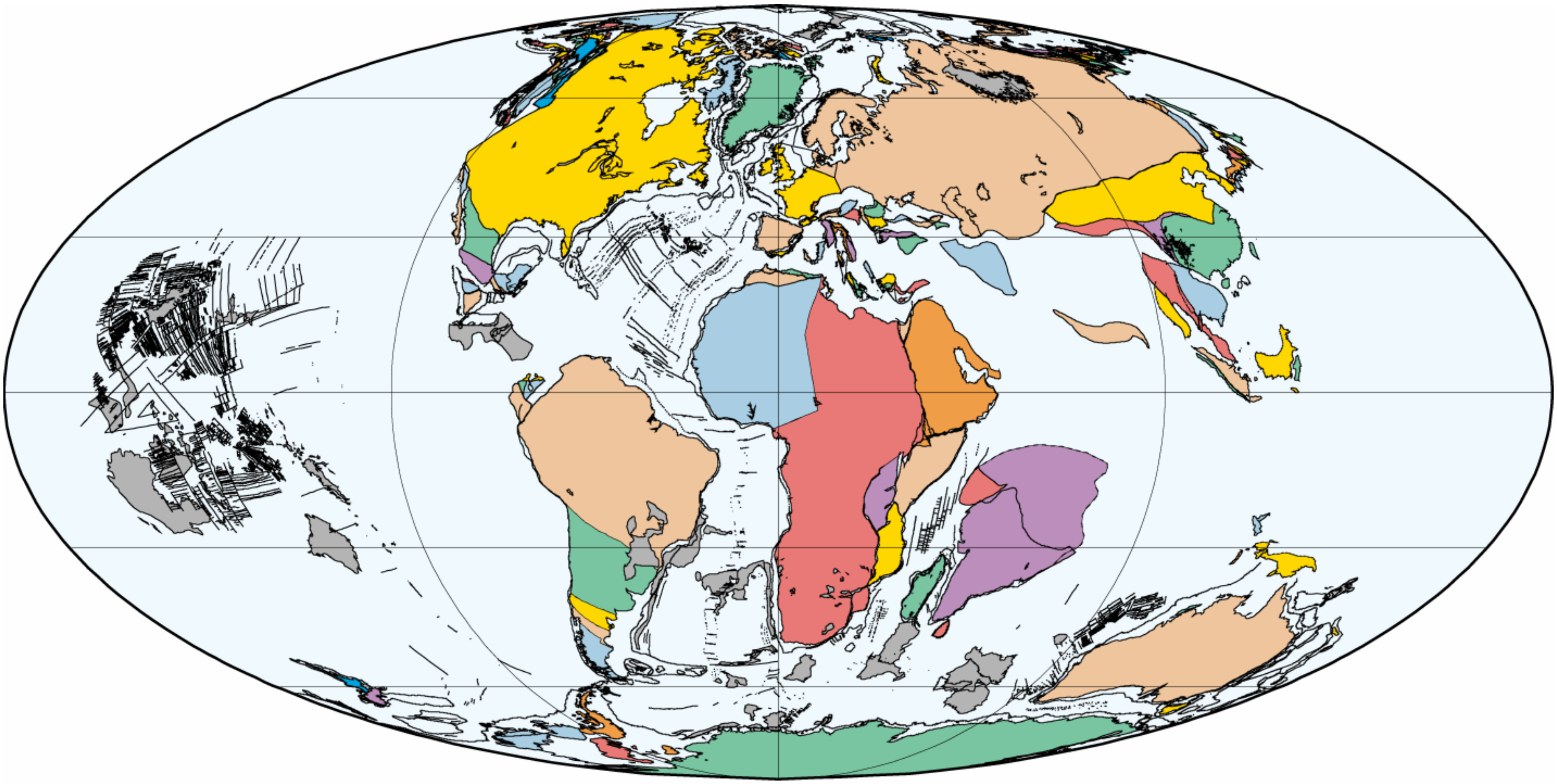

80 Ma
Campanian (Late Cretaceous)

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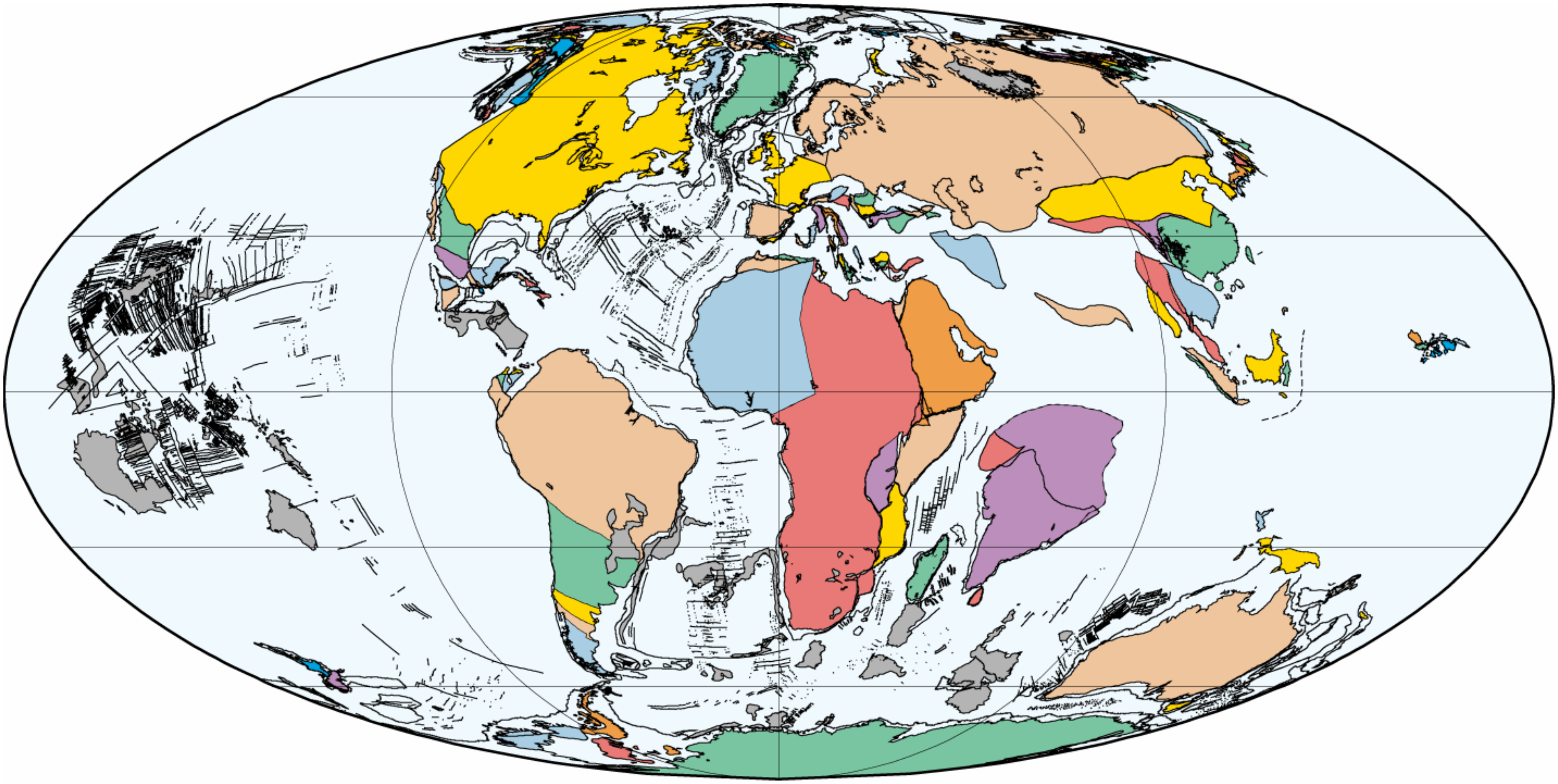

70 Ma

Maastrichtian (Late Cretaceous)

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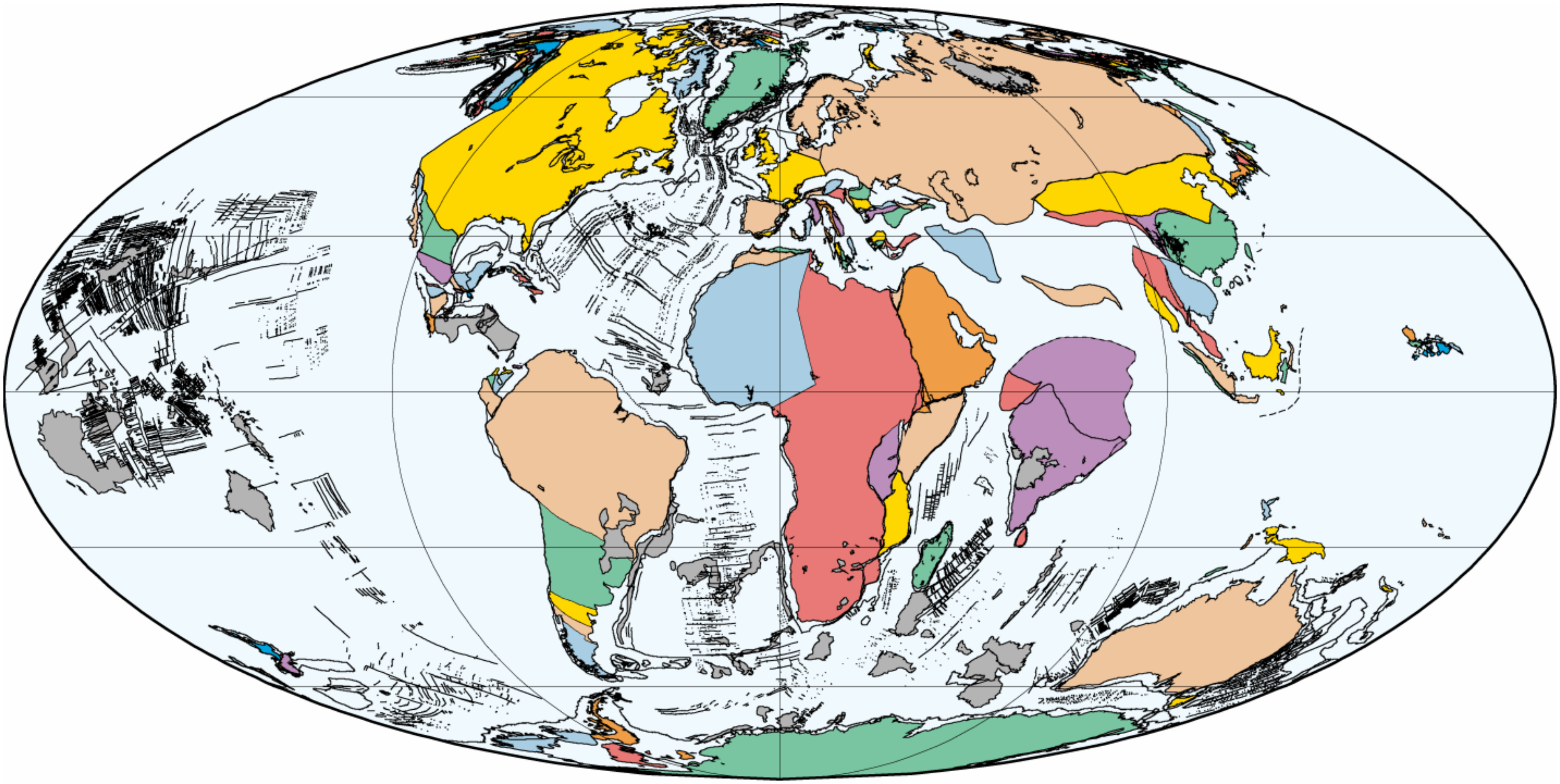

60 Ma
Late Paleocene

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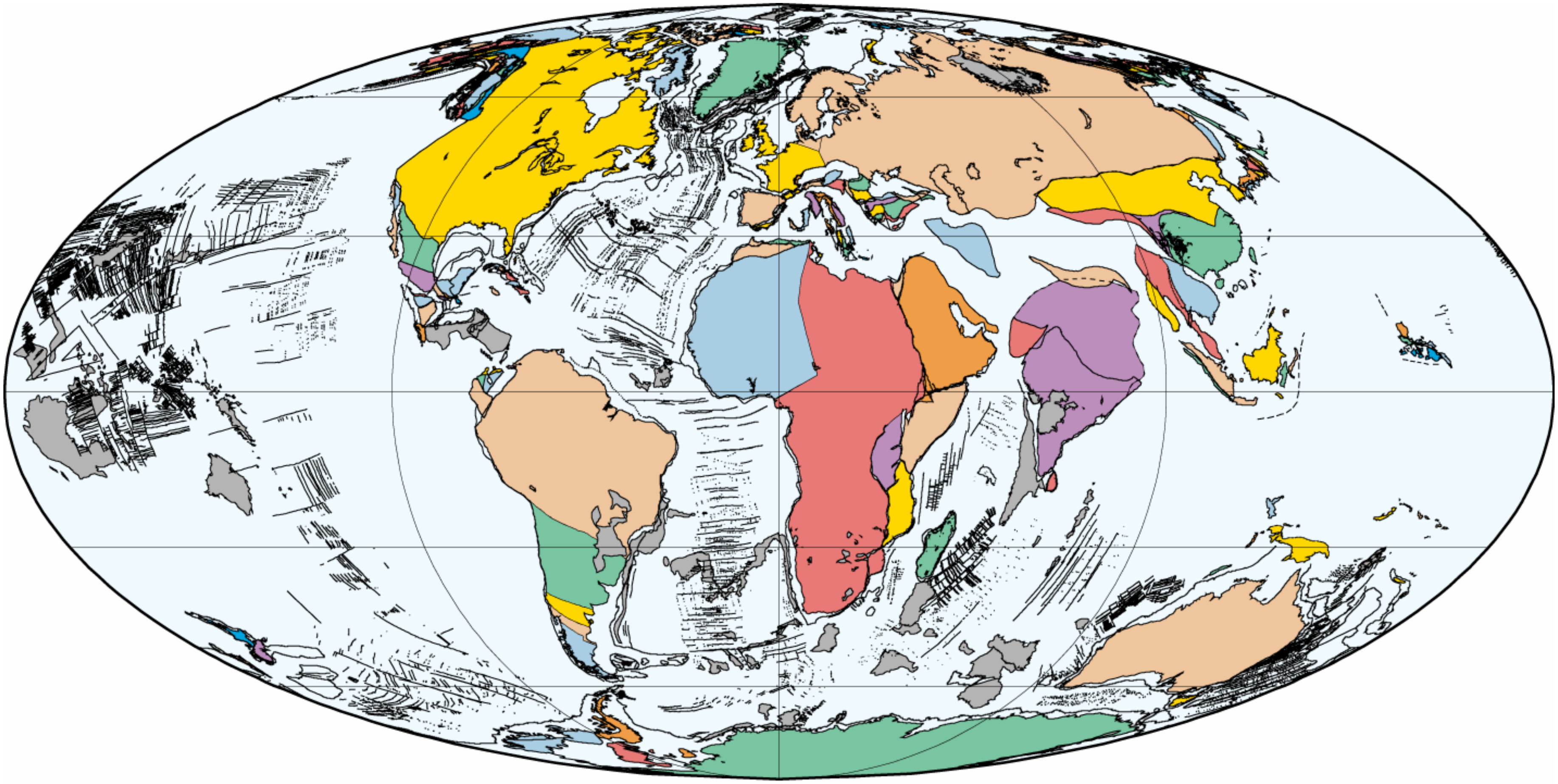
August 2002

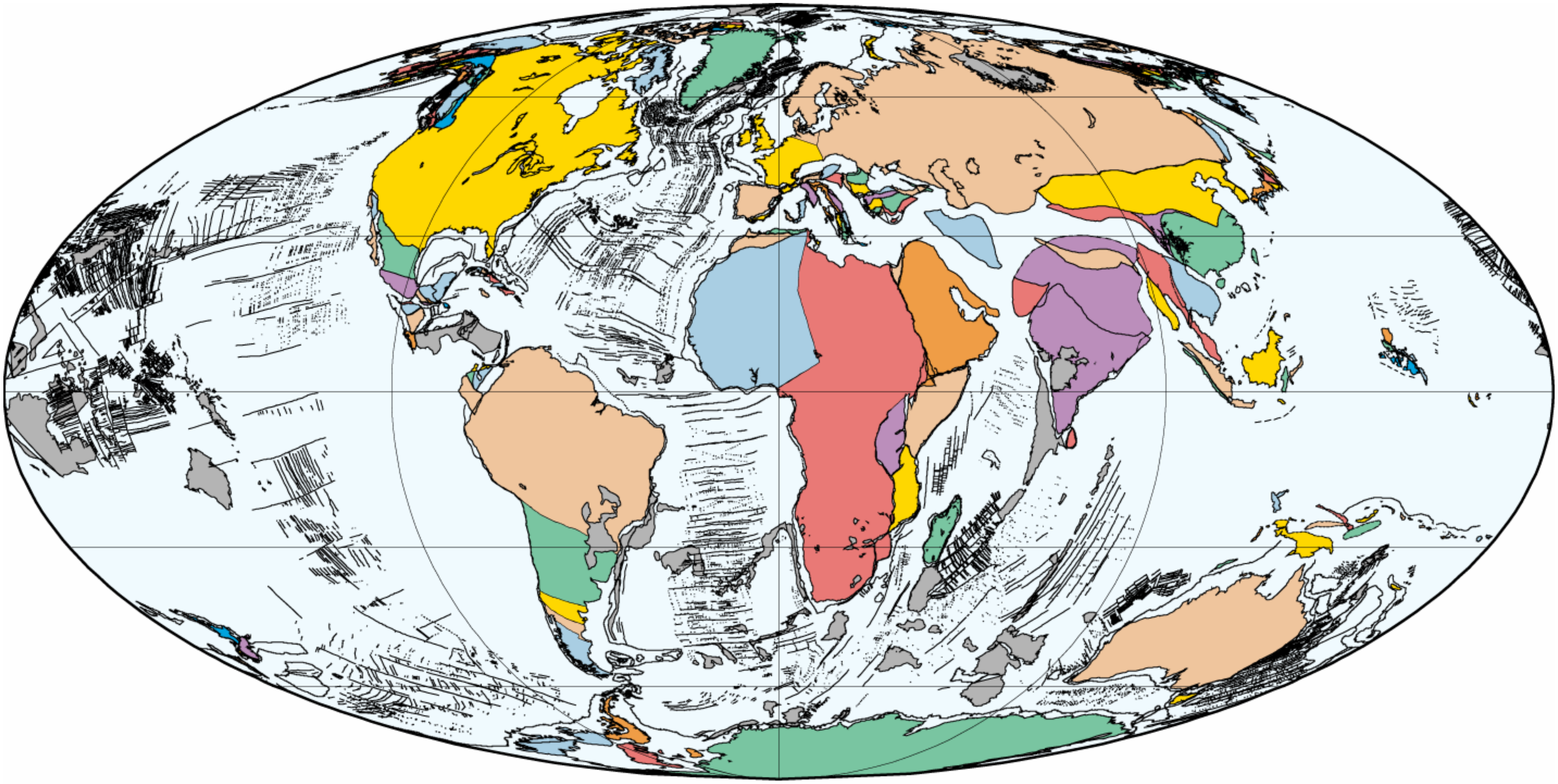


50 Ma

Early Eocene

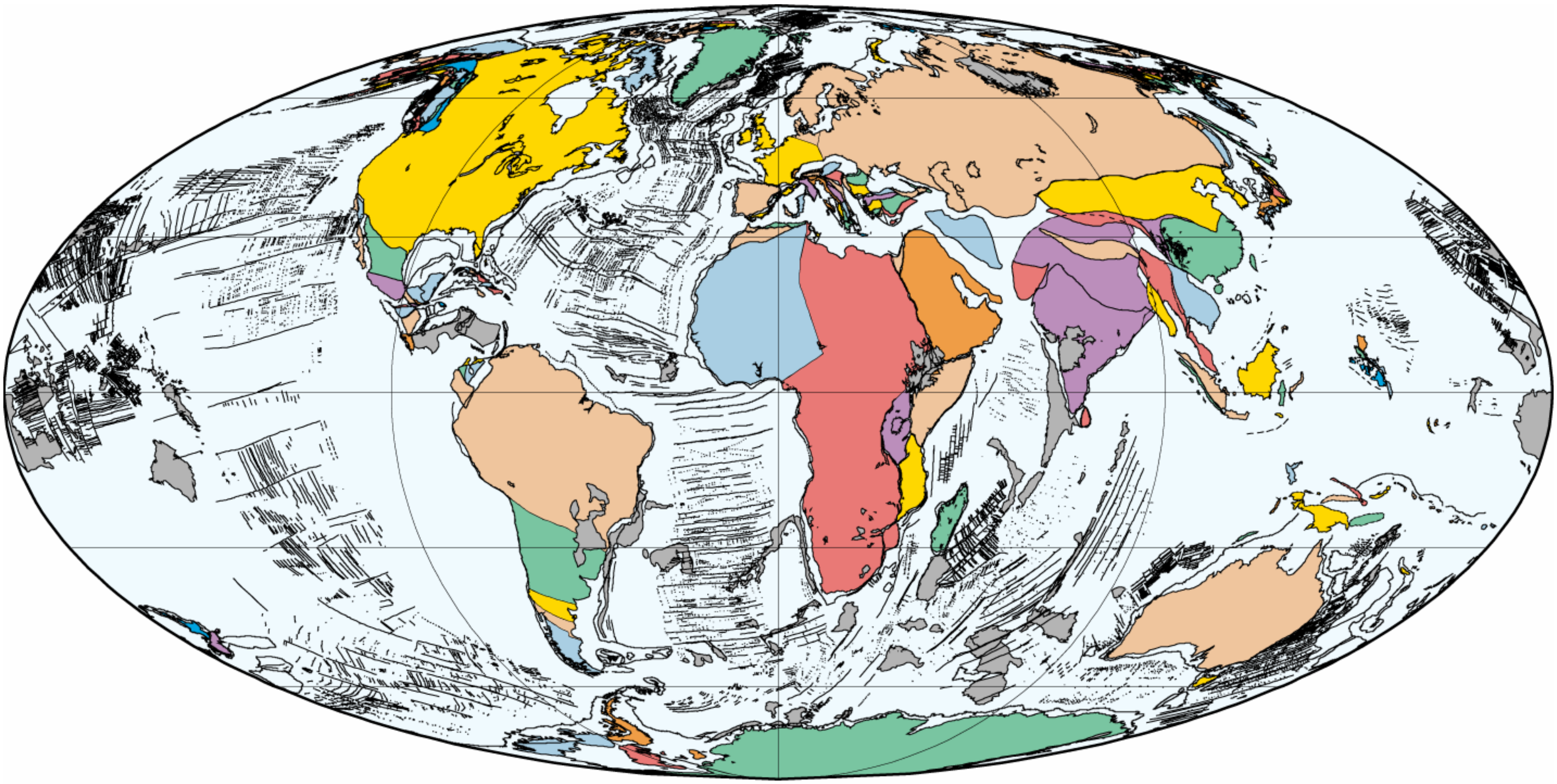
PLATES/UTIG

August 2002



40 Ma
Middle Eocene

PLATES/UTIG
August 2002

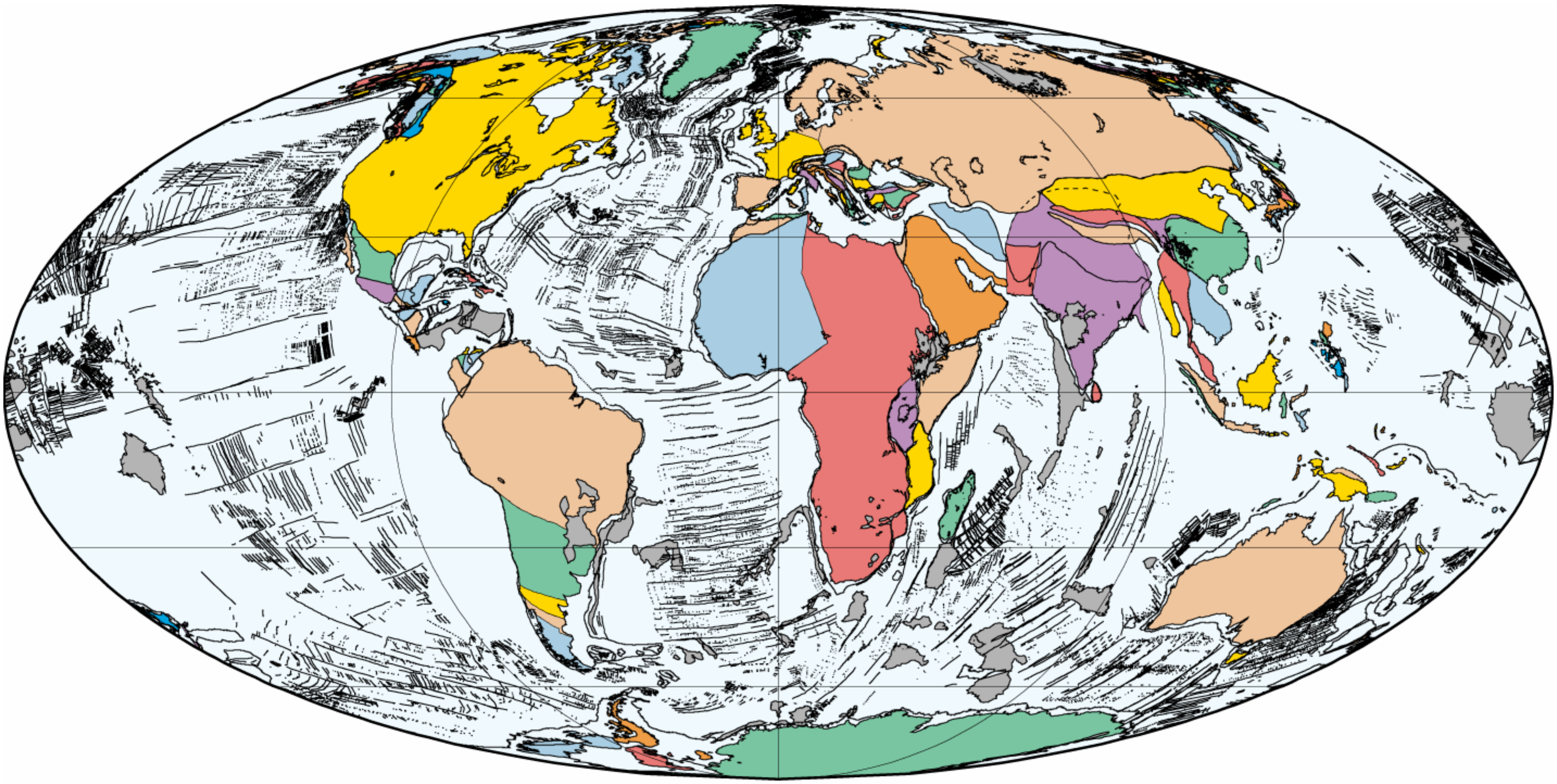


30 Ma

Early Oligocene

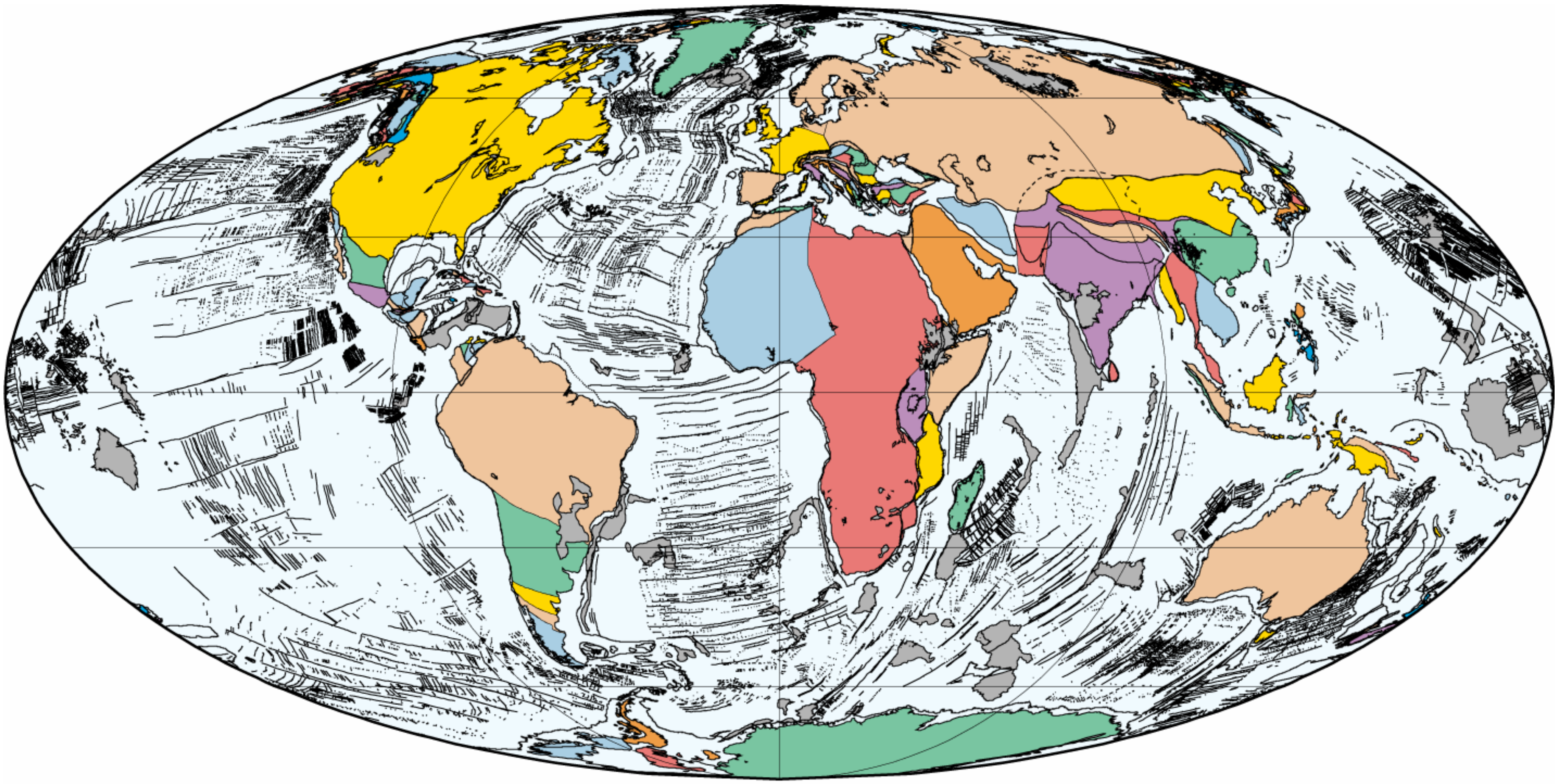
PLATES/UTIG

August 2002



20 Ma
Early Miocene

PLATES/UTIG
August 2002

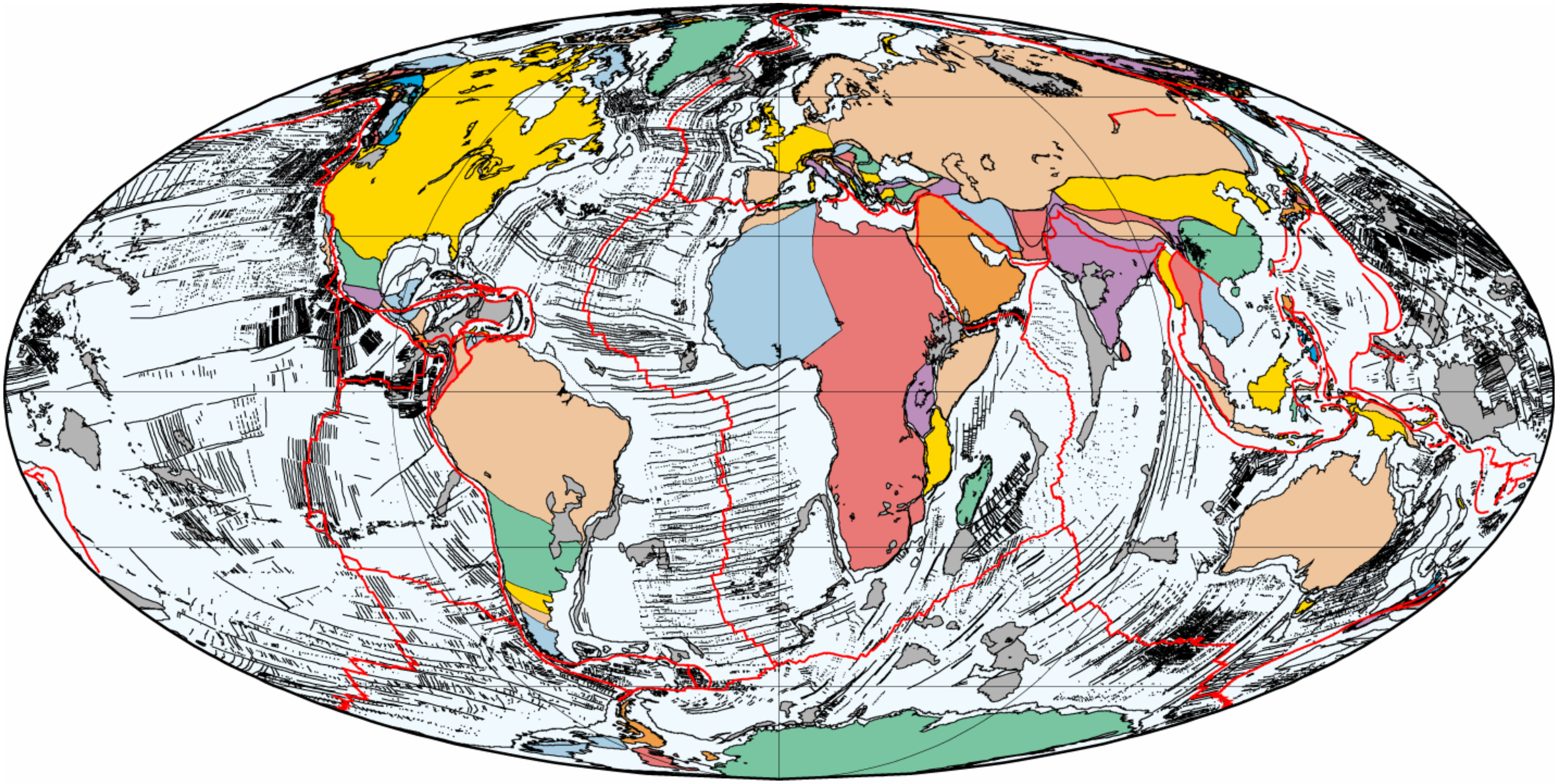


10 Ma

Late Miocene

PLATES/UTIG

August 2002



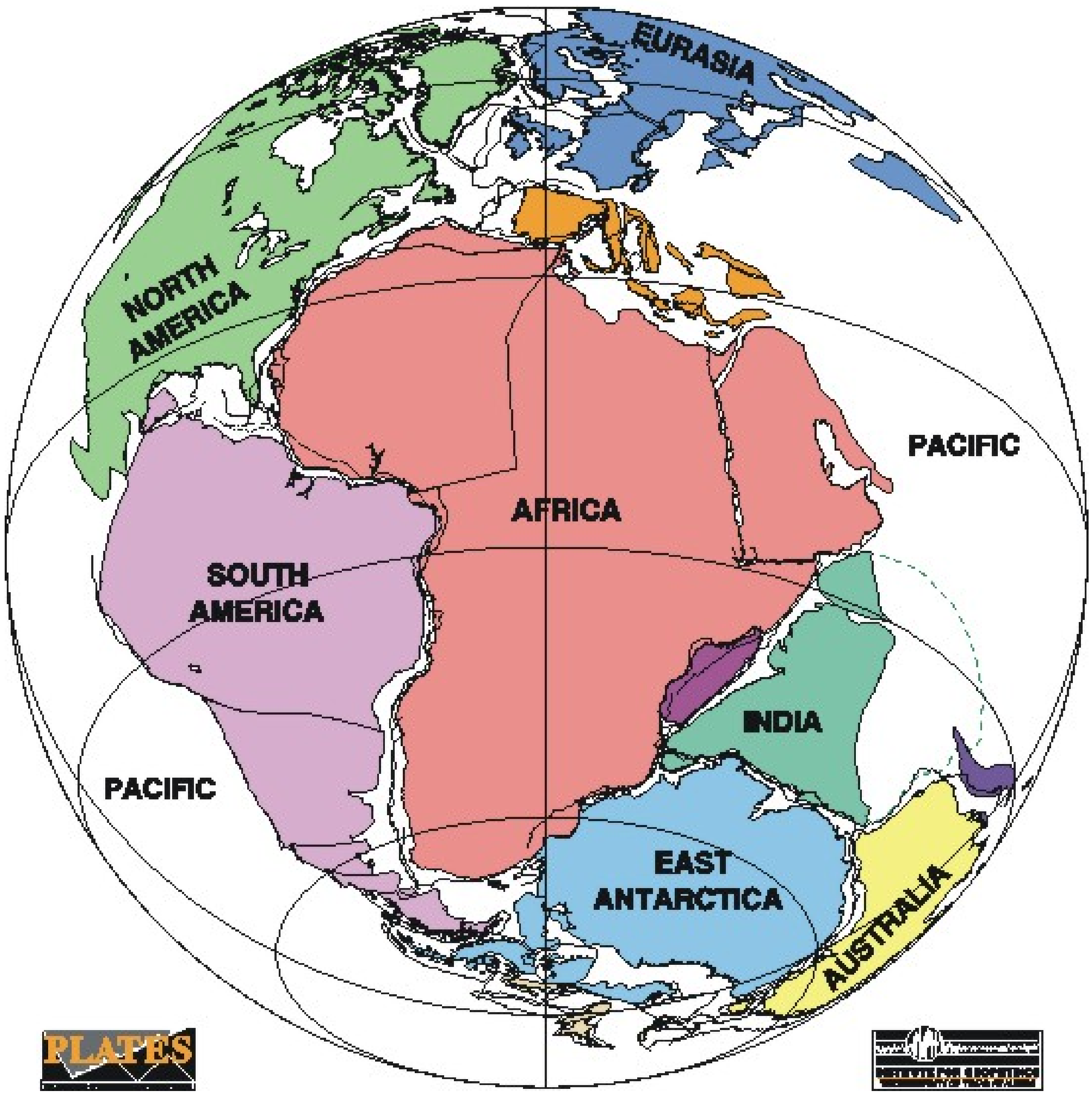
0 Ma
Present Day

PLATES/UTIG
August 2002

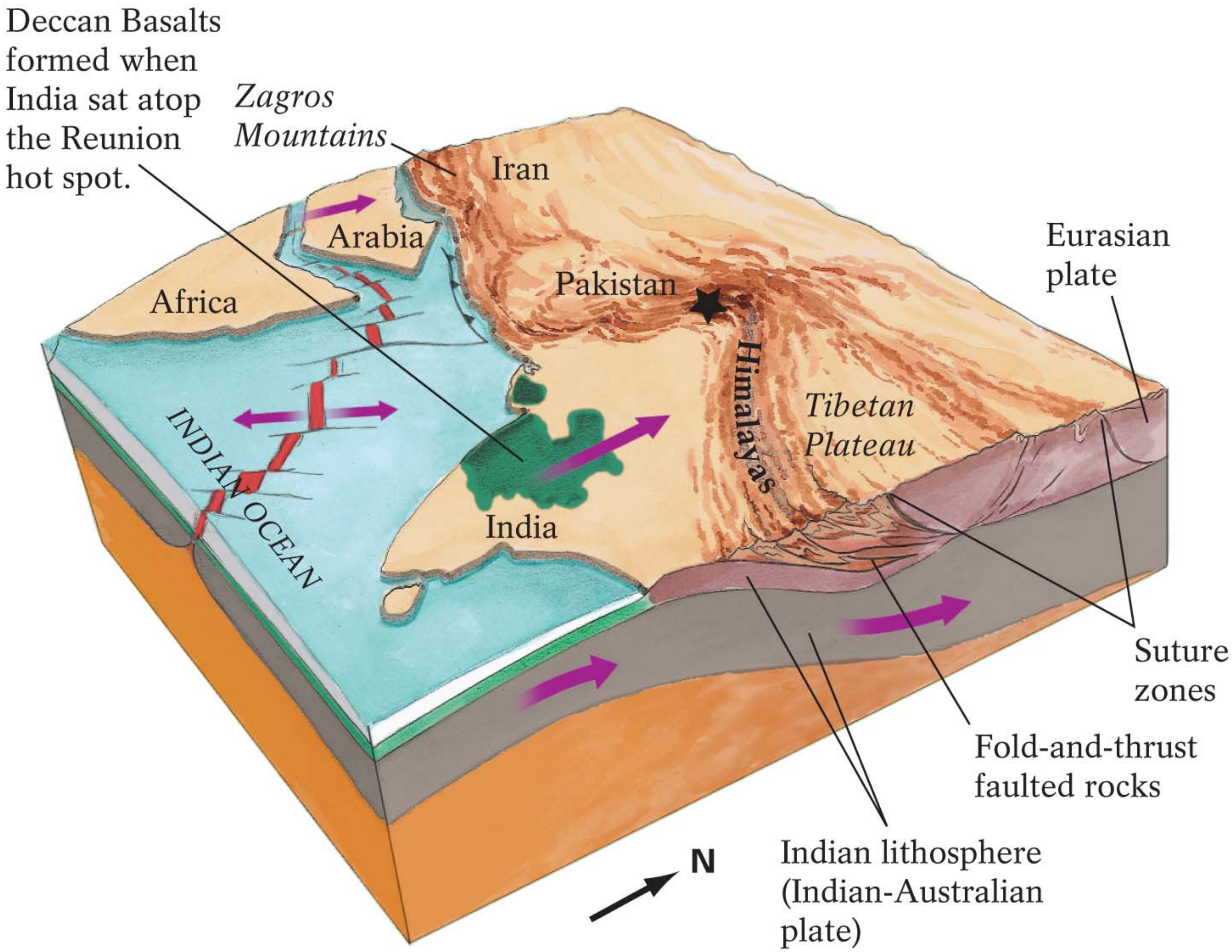
PANGEA

Pangea: Proposed by A. Wegener as part of hypothesis of Continental Drift.

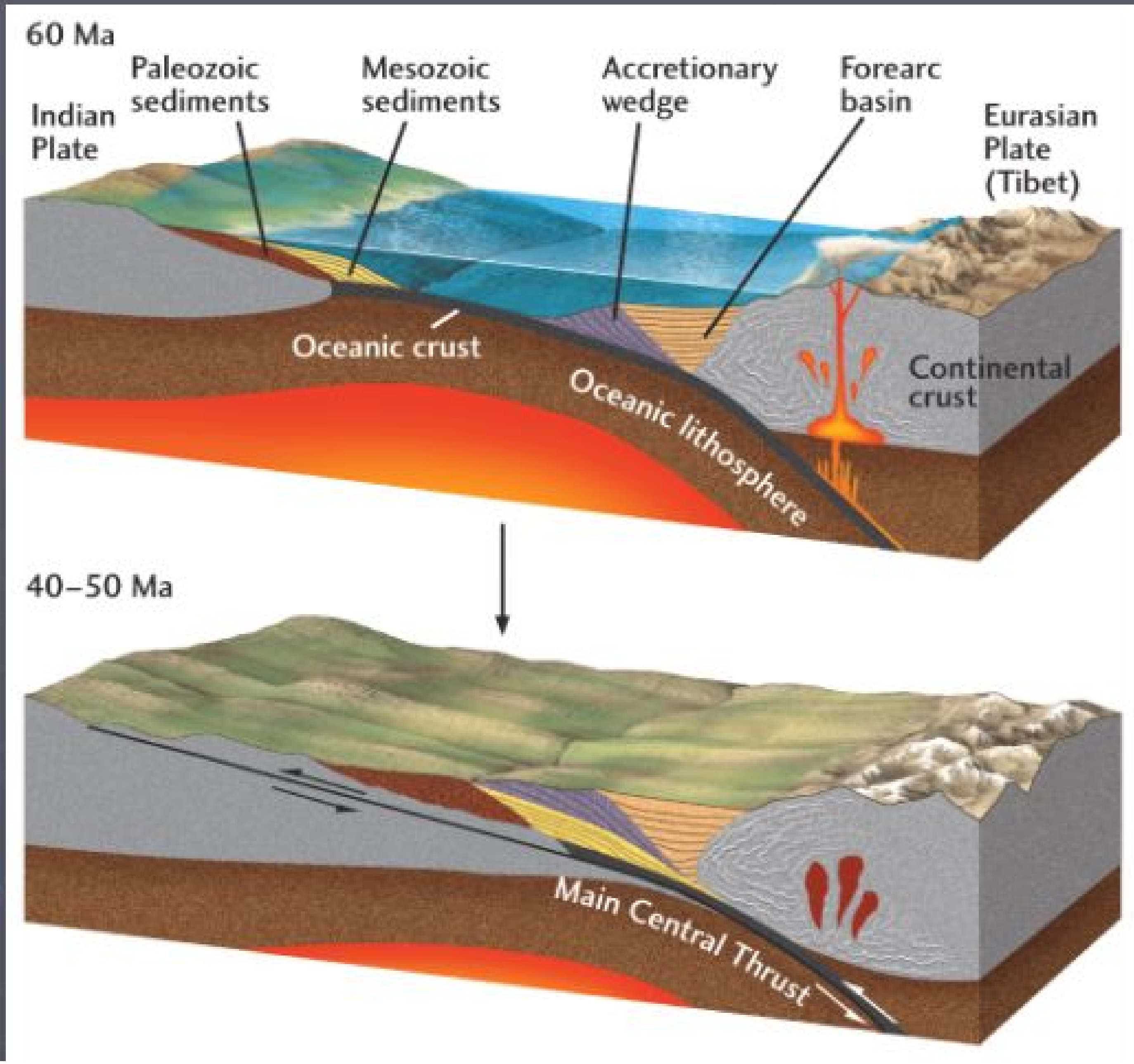
Problem – Wegener couldn't explain why plates moved, and geologists refused to listen to a weatherman. (though never rejected in Southern Hemisphere)



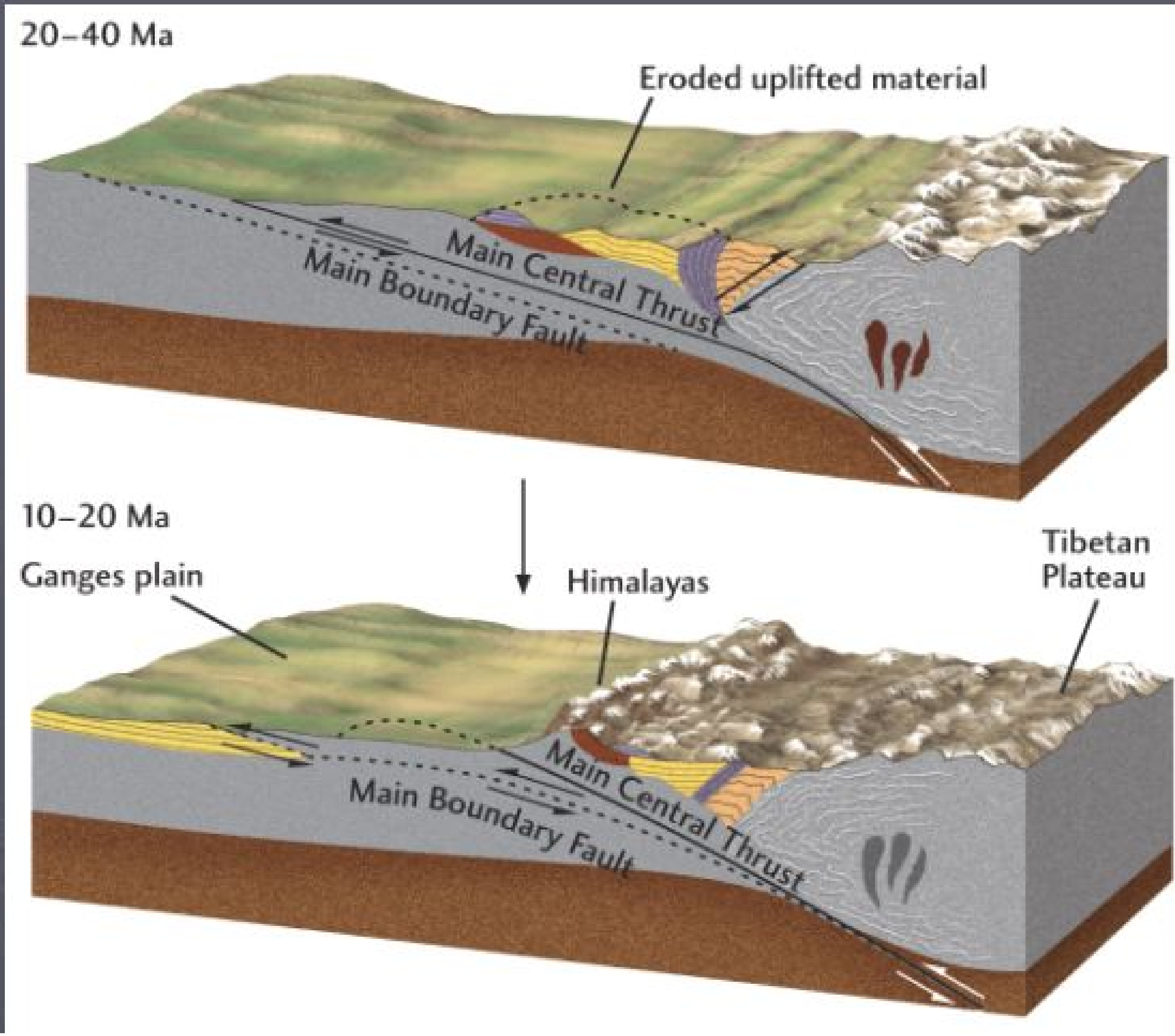
Formation of Himalayas

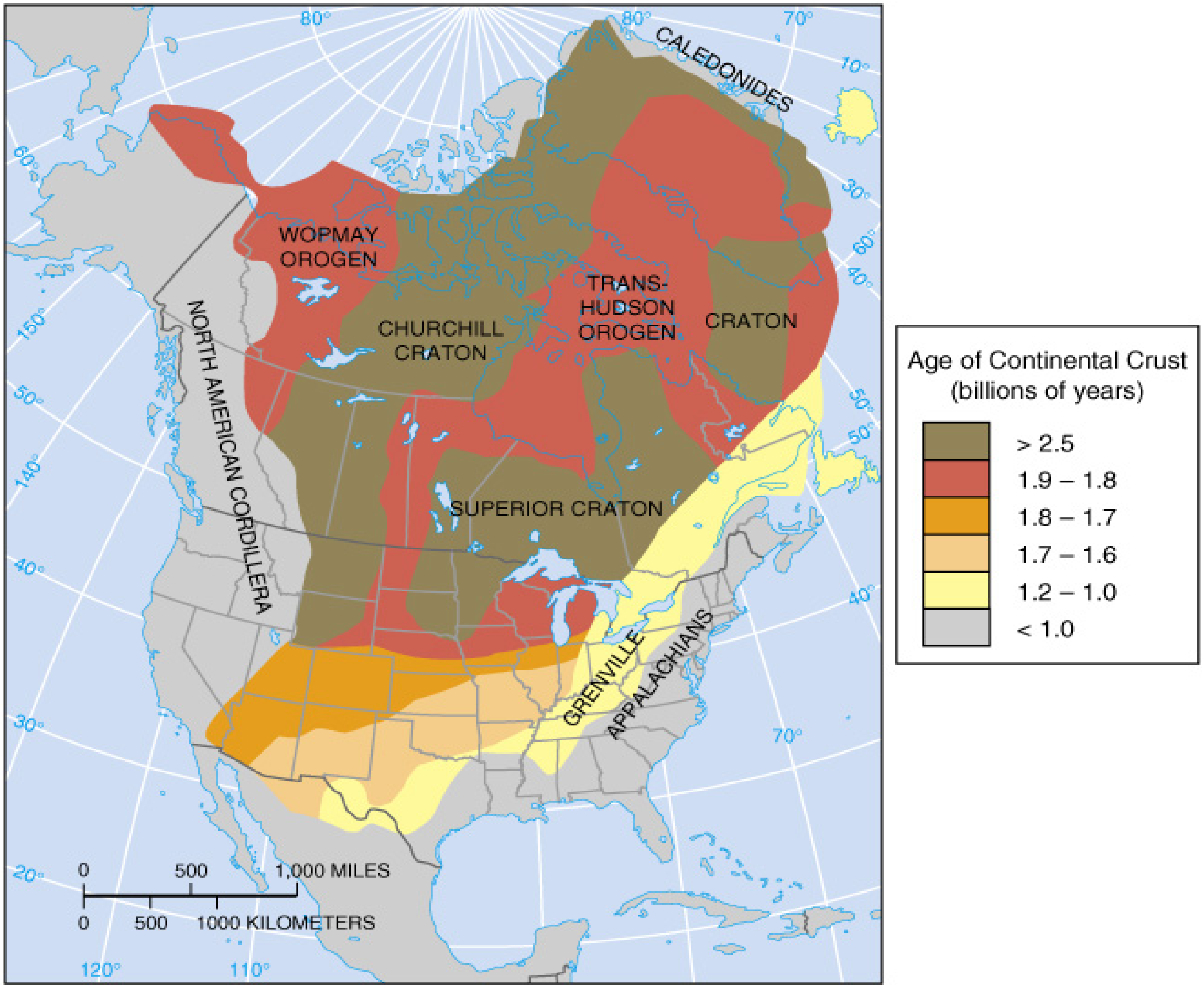


Formation of Himalayas I



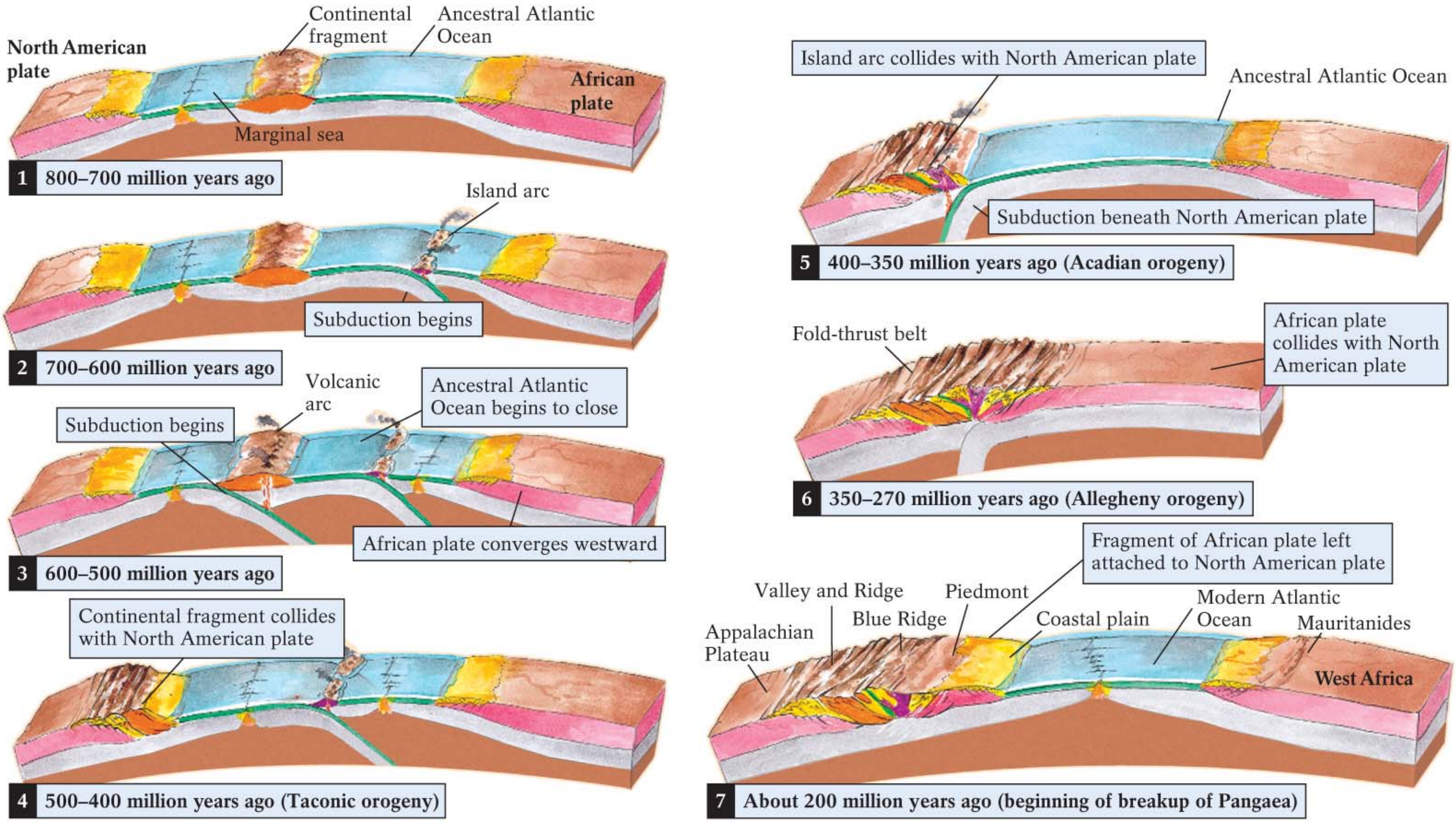
Formation of Himalayas II



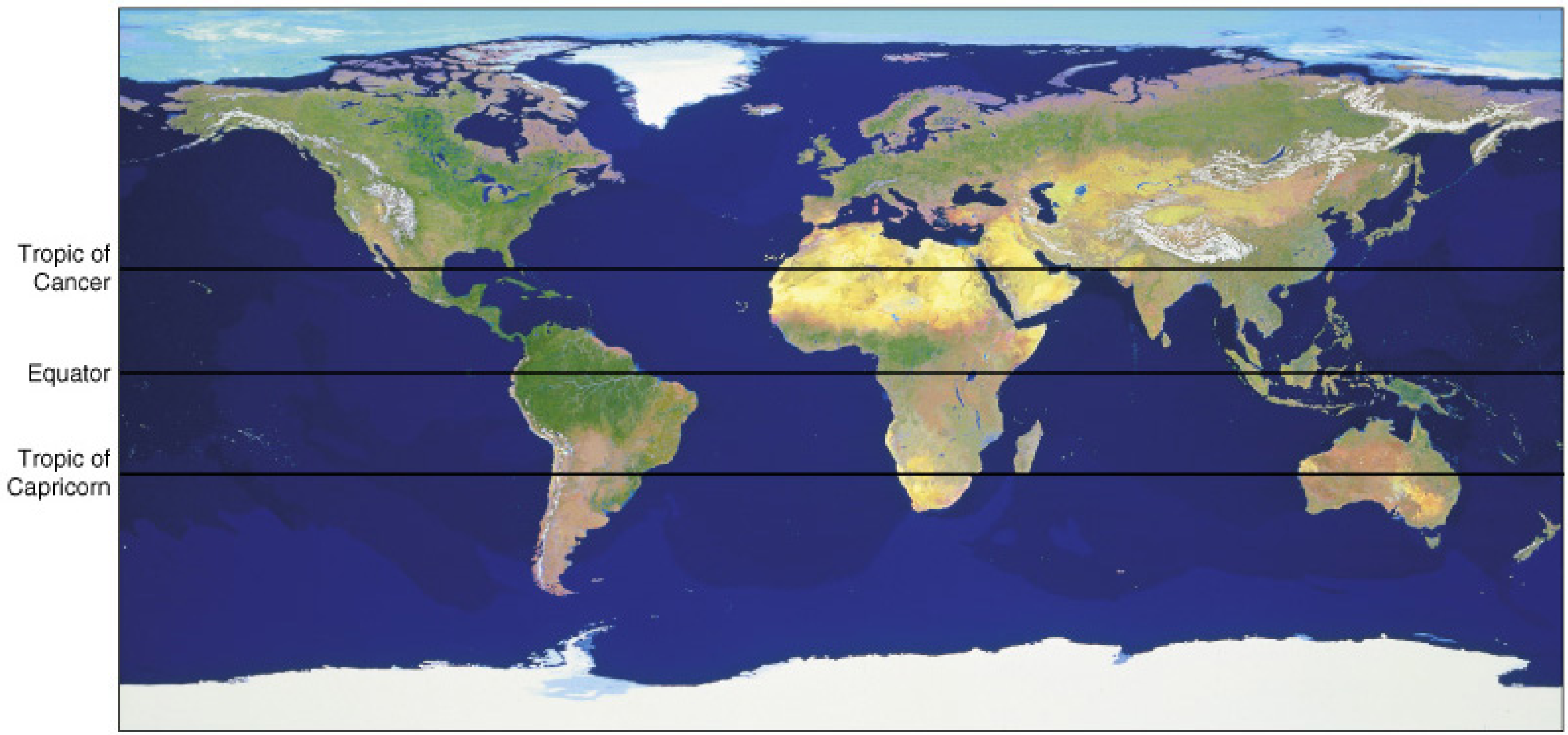


CALEDONIDES
WOPMAY
OROGEN
CHURCHILL
CRATON
TRANS-
HUDSON
OROGEN
CRATON
SUPERIOR CRATON
NORTH AMERICAN CORDILLERA
GRENVILLE
APPALACHIANS
0
500
1,000 MILES
0
500
1000 KILOMETERS
Age of Continental Crust
(billions of years)
> 2.5
1.9 – 1.8
1.8 – 1.7
1.7 – 1.6
1.2 – 1.0
< 1.0

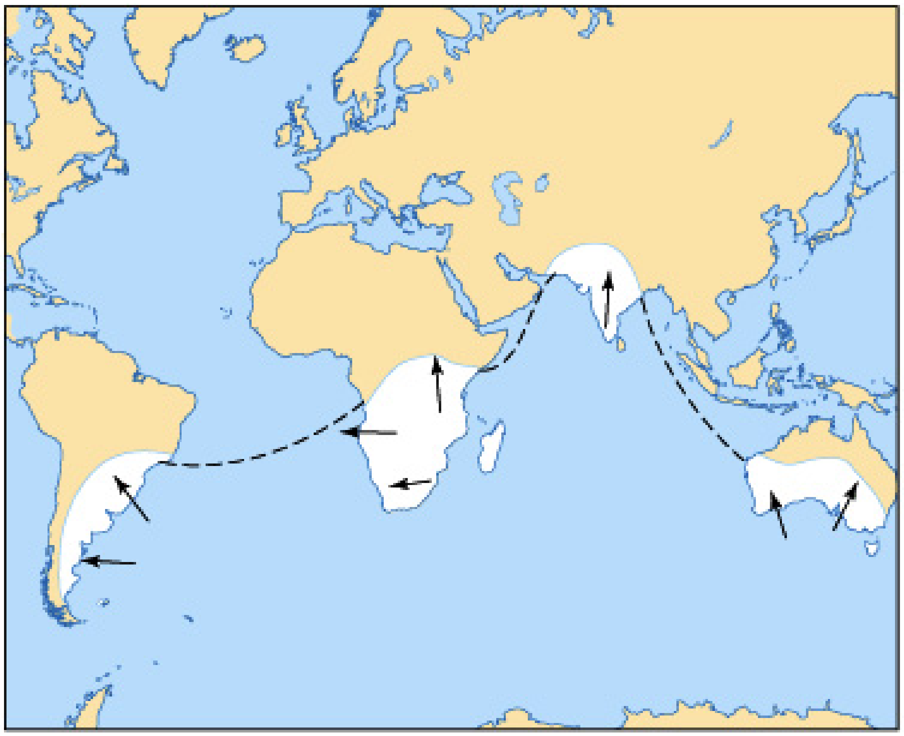
Growth of the Appalachians

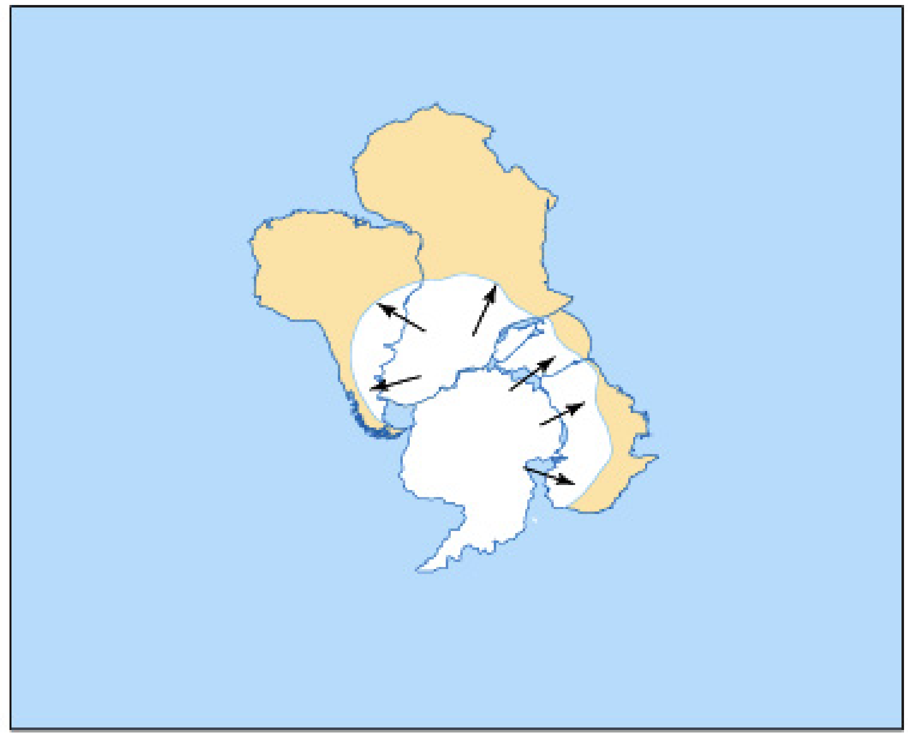


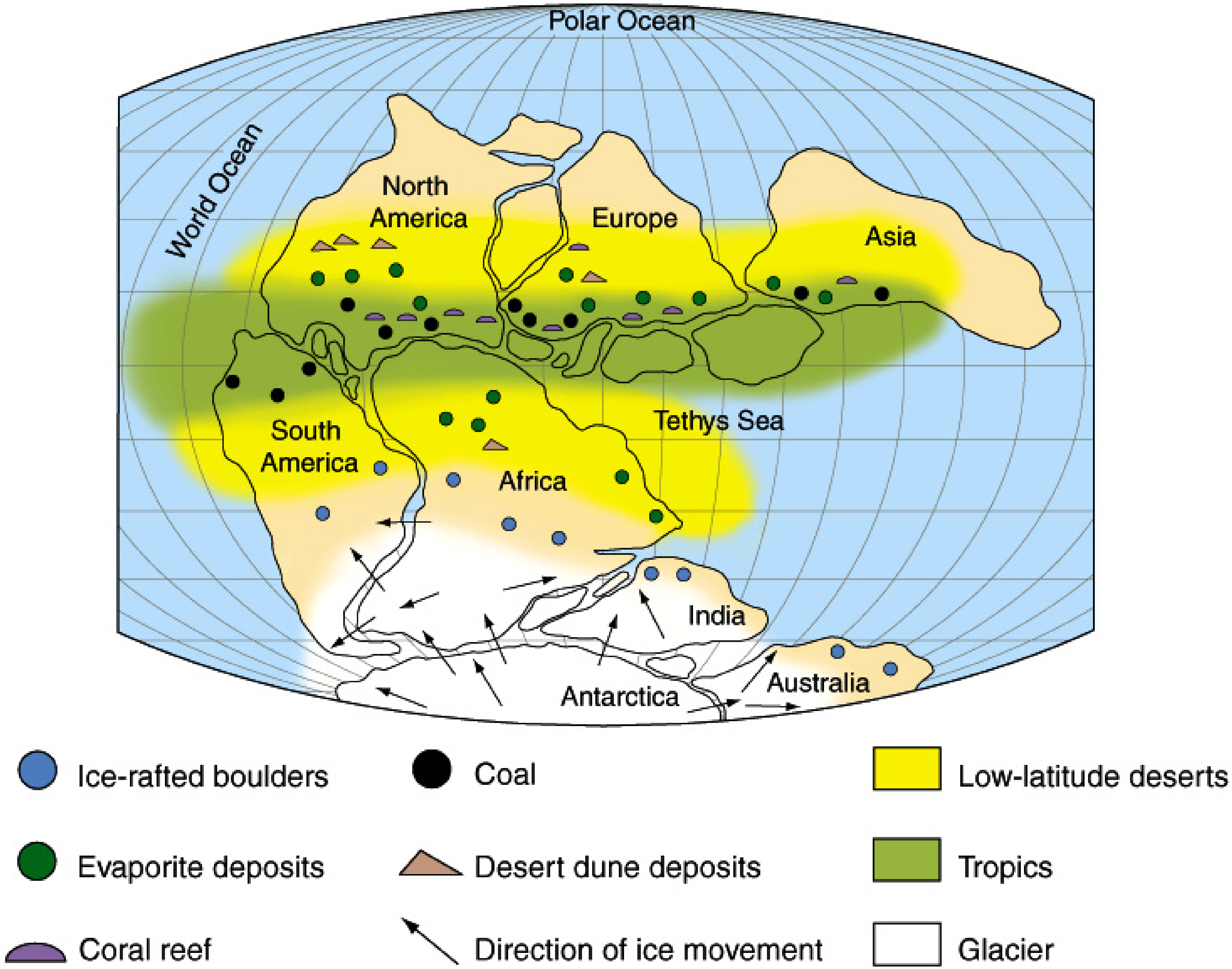
Locations of deserts and tropical climates are largely a function of latitude.

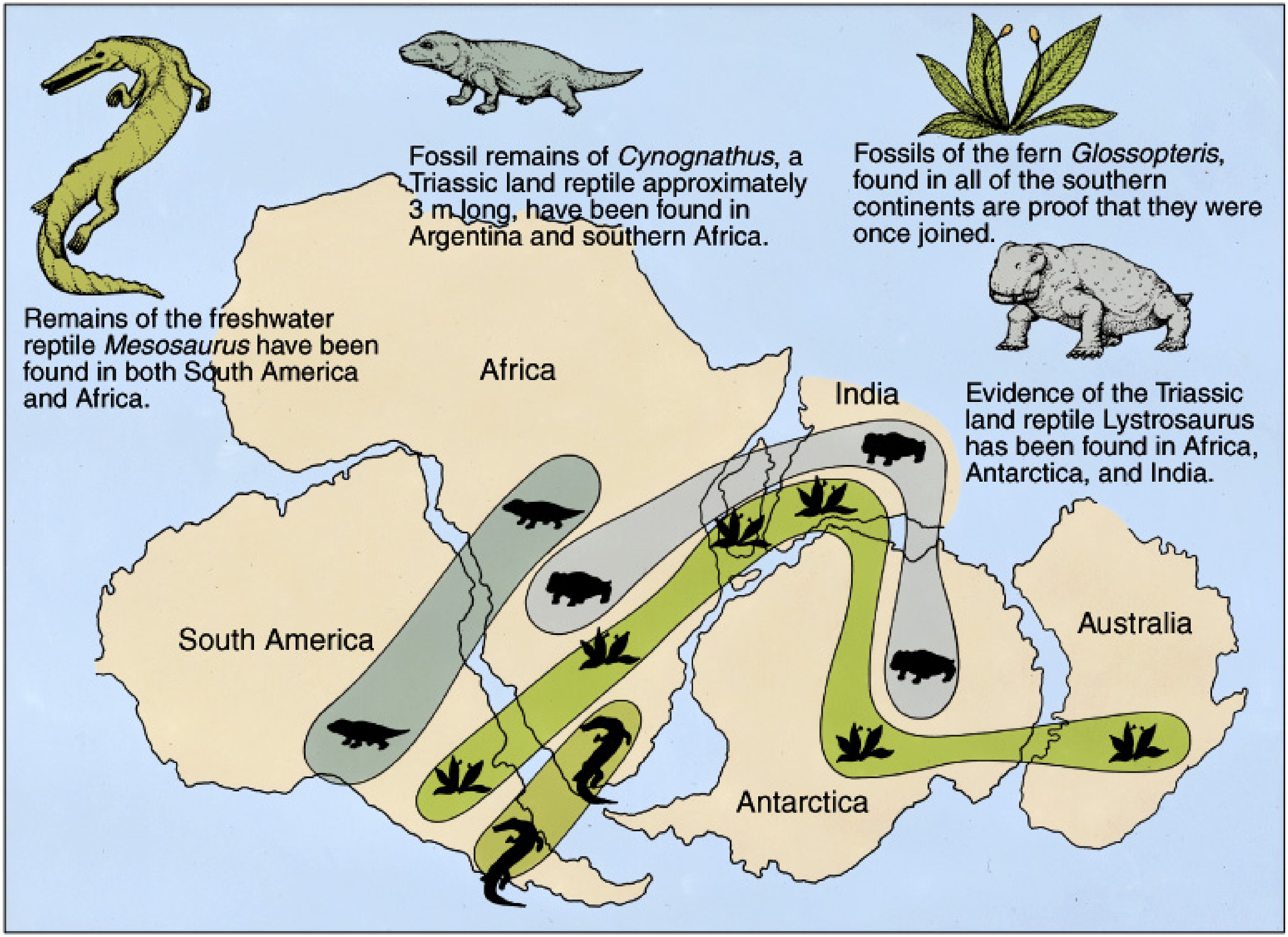


Places that are now warm show previous evidence of glaciation.

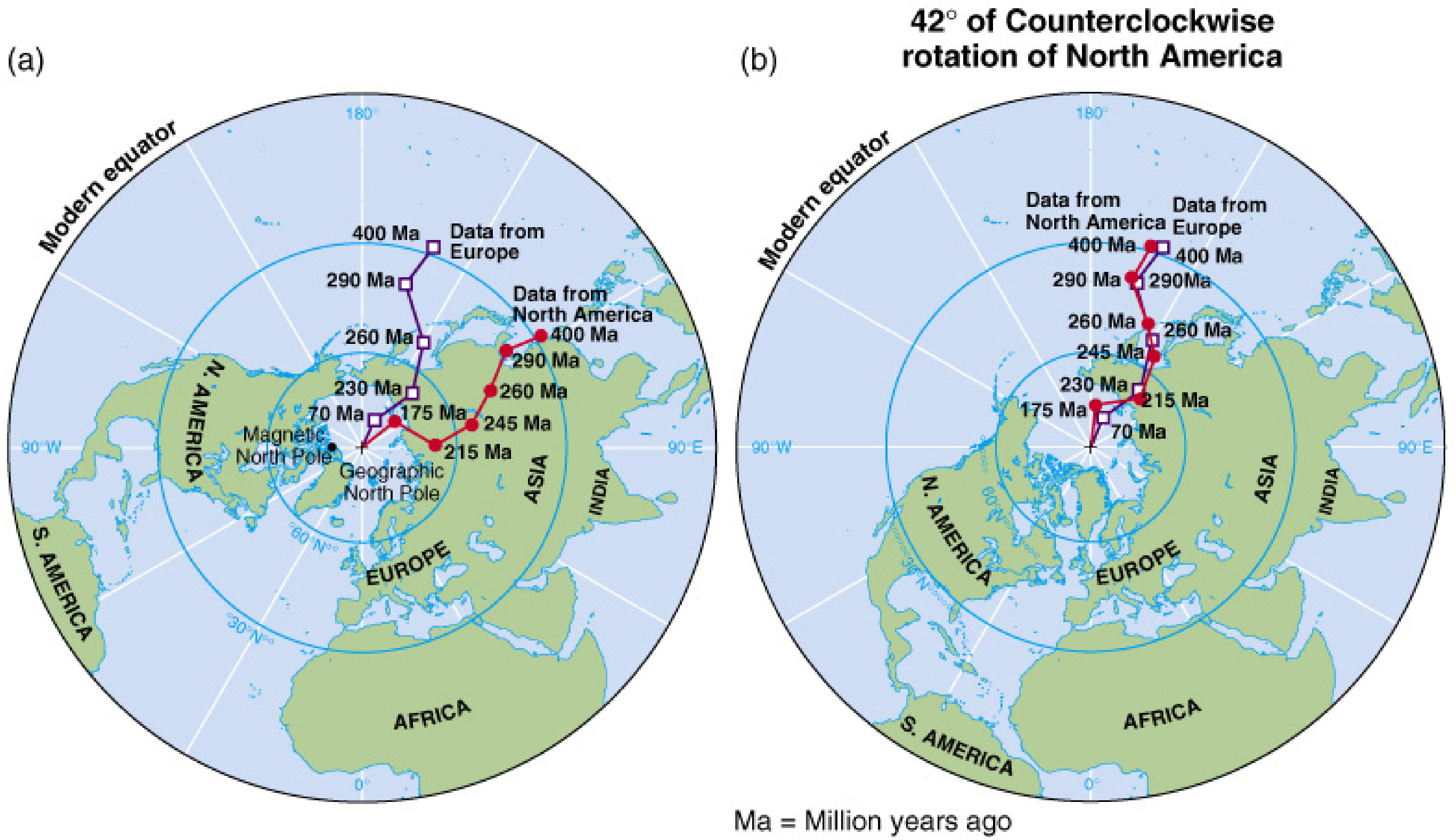





Polar Ocean
World Ocean
North America
Europe
Asia
South America
Africa
Tethys Sea
India
Australia
Antarctica
Ice-rafted boulders
Coal
Low-latitude deserts
Evaporite deposits
Desert dune deposits
Tropics
Coral reef
Direction of ice movement
Glacier

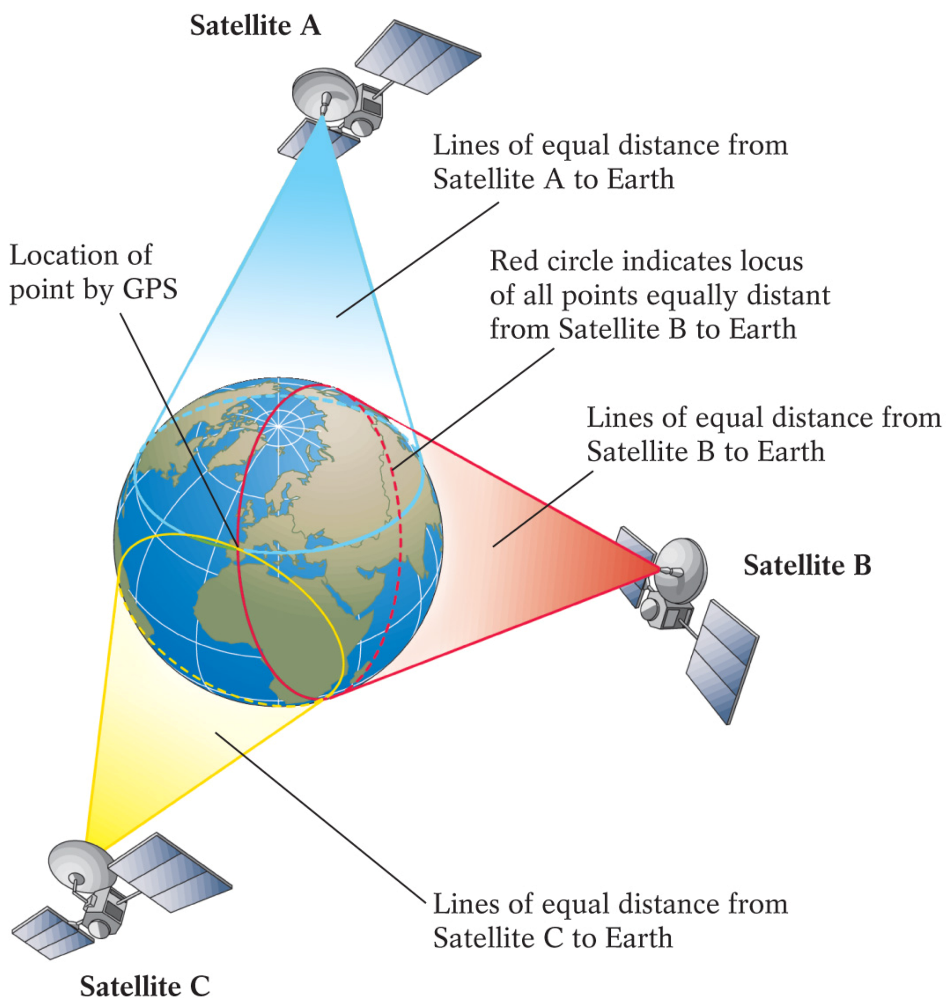

Remains of the freshwater reptile *Mesosaurus* have been found in both South America and Africa.
Fossil remains of *Cynognathus*, a Triassic land reptile approximately 3 m long, have been found in Argentina and southern Africa.
Fossils of the fern *Glossopteris*, found in all of the southern continents are proof that they were once joined.
Evidence of the Triassic land reptile Lystrosaurus has been found in Africa, Antarctica, and India.
Africa
India
South America
Australia
Antarctica

The apparent magnetic pole moves if a continent moves. Different continents have moved differently, so their apparent magnetic poles seem to be different. If you account for the previous plate motions, the poles line up.



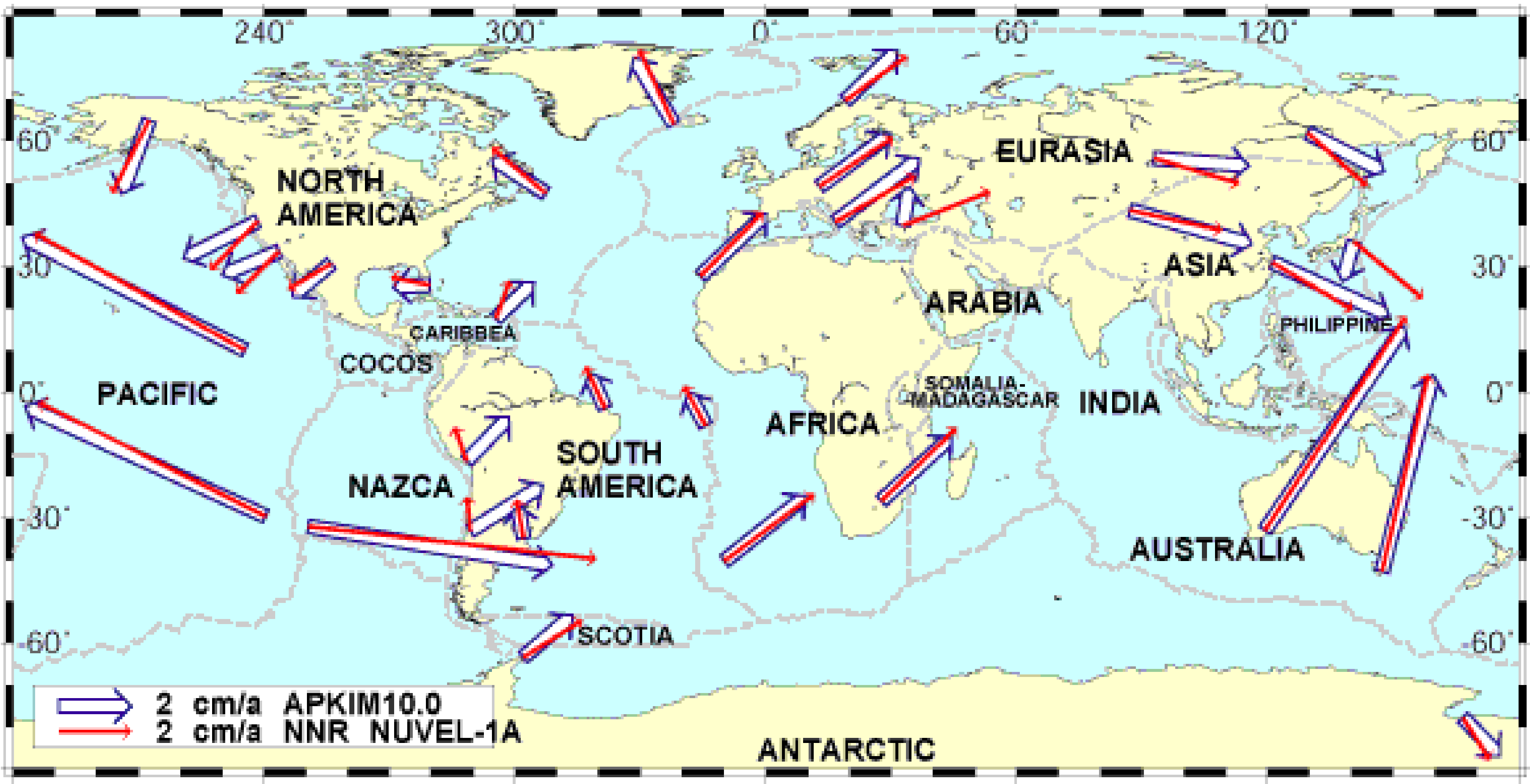
Determining Plate Velocity

- Satellite positioning
  - Global positioning system
- Hot-spot tracking
- Seafloor magnetic stripes



Measures
absolute plate velocity

GPS sensors help give us the exact velocities (direction and speed) of plates. Today's velocities (from GPS) are the same as those averaged over the past 5 million years (from paleomagnetism and earthquake faulting).



Determining Plate Velocity

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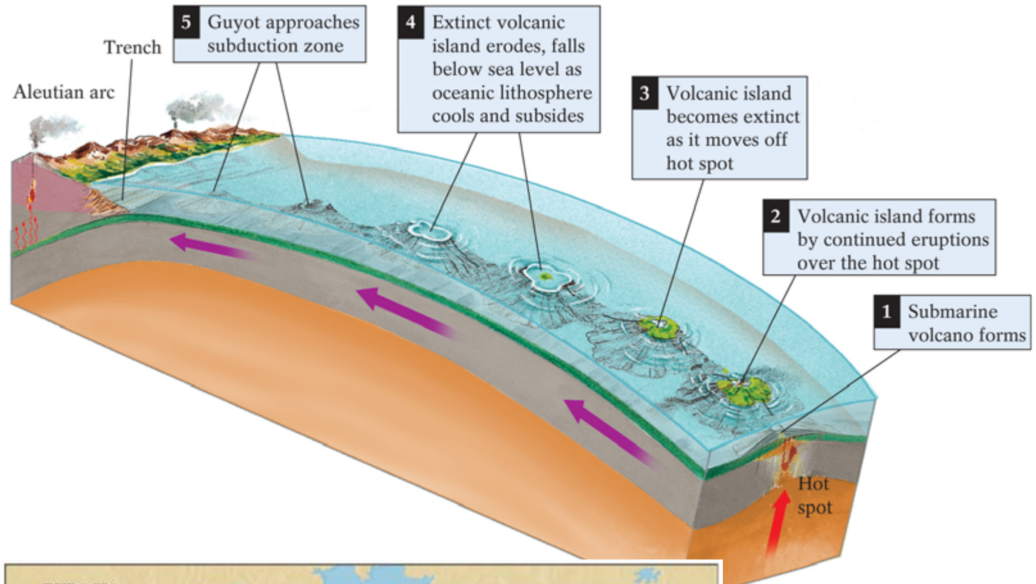
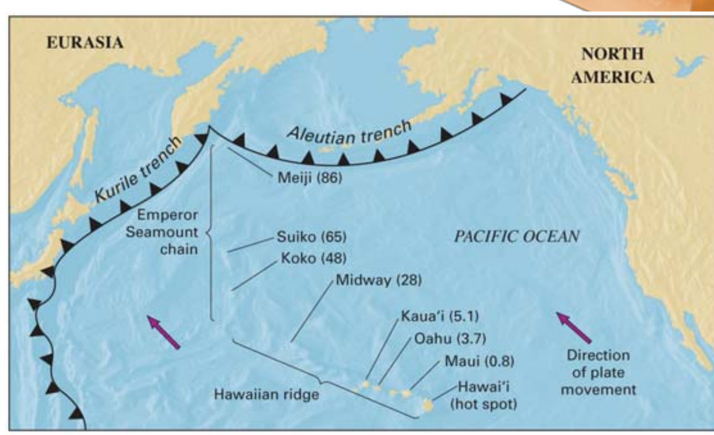


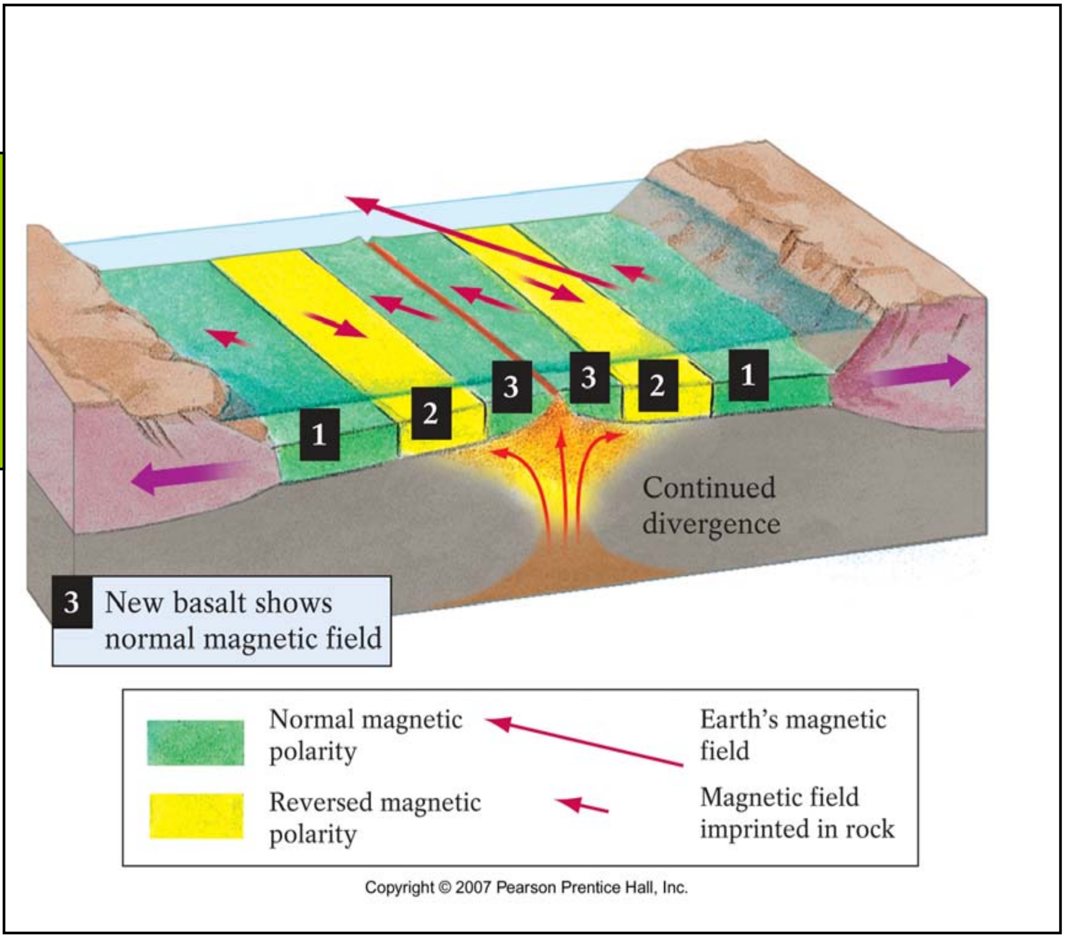


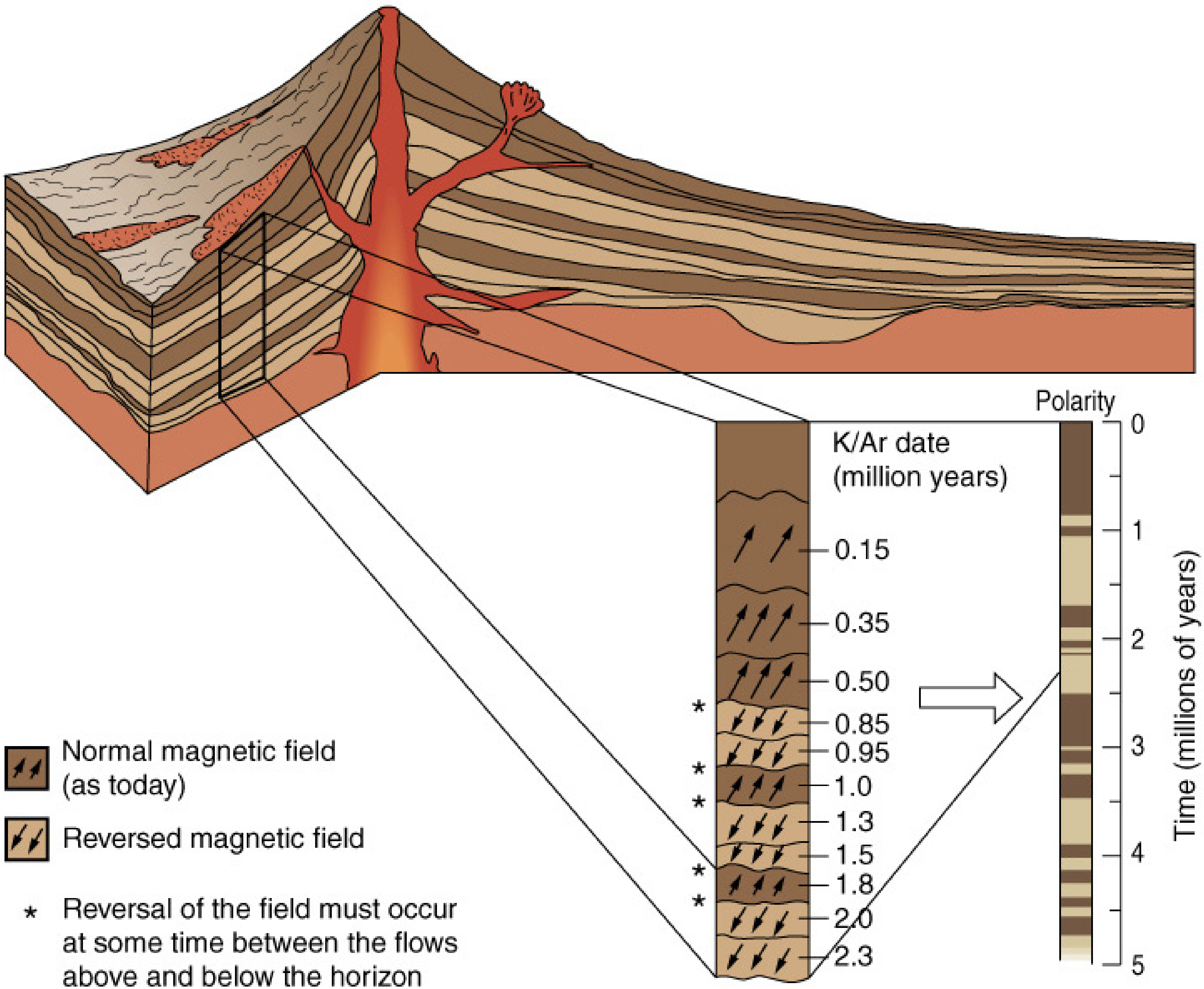
Measures
absolute plate velocity

Determining Plate Velocity

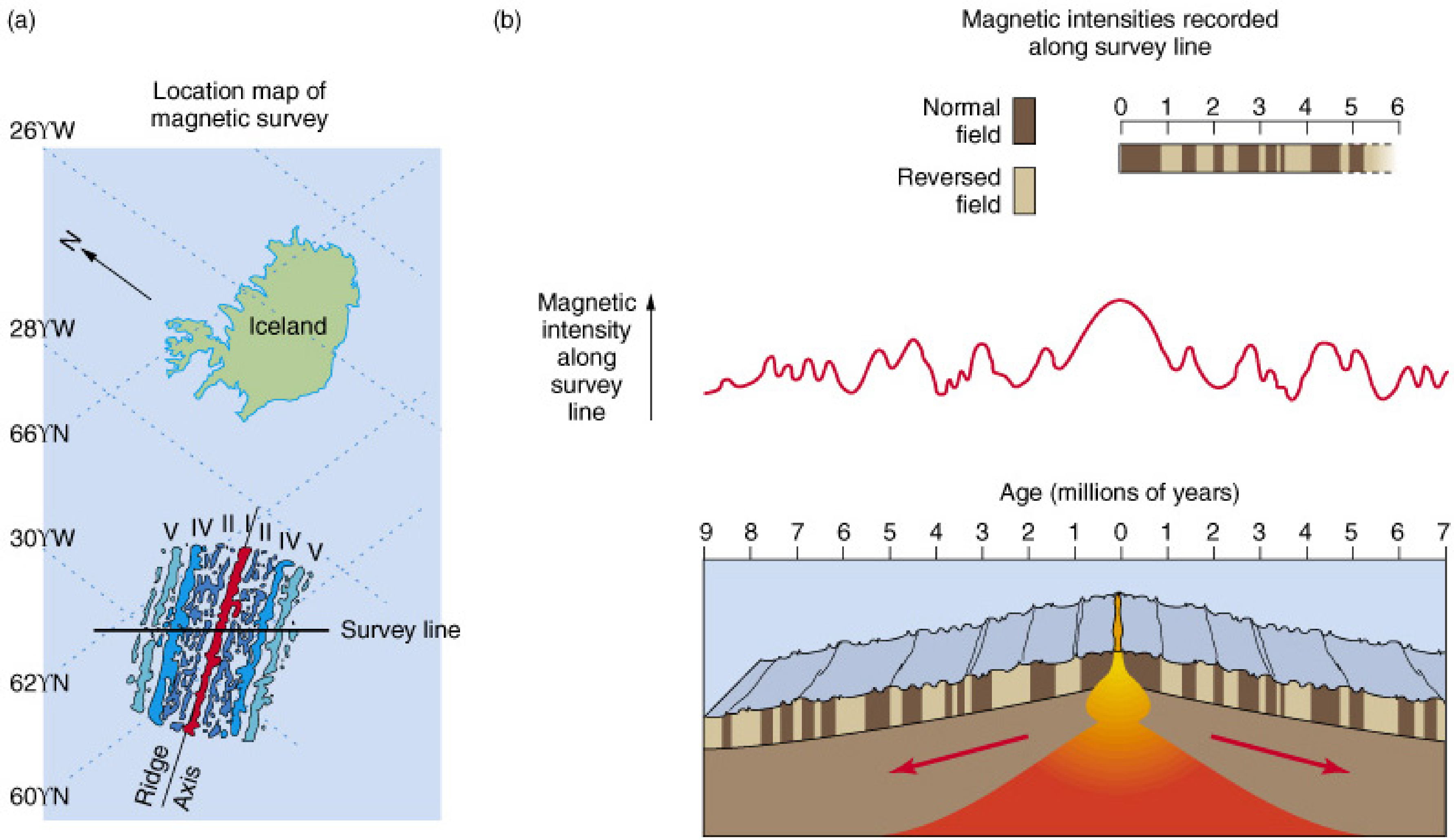
- Satellite positioning
  Global positioning system
- Hot-spot tracking
- Seafloor magnetic stripes

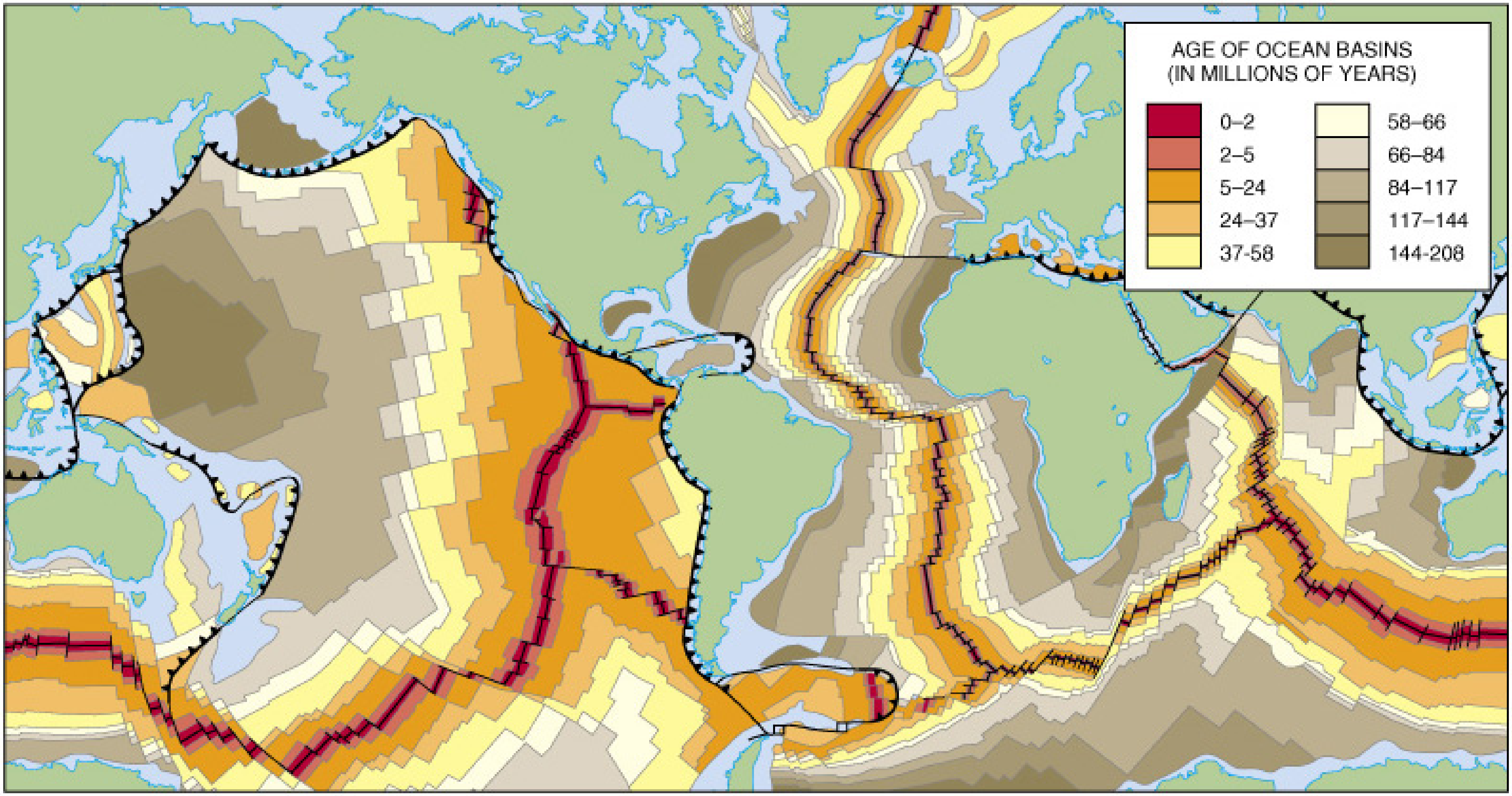
Measures
relative plate velocity



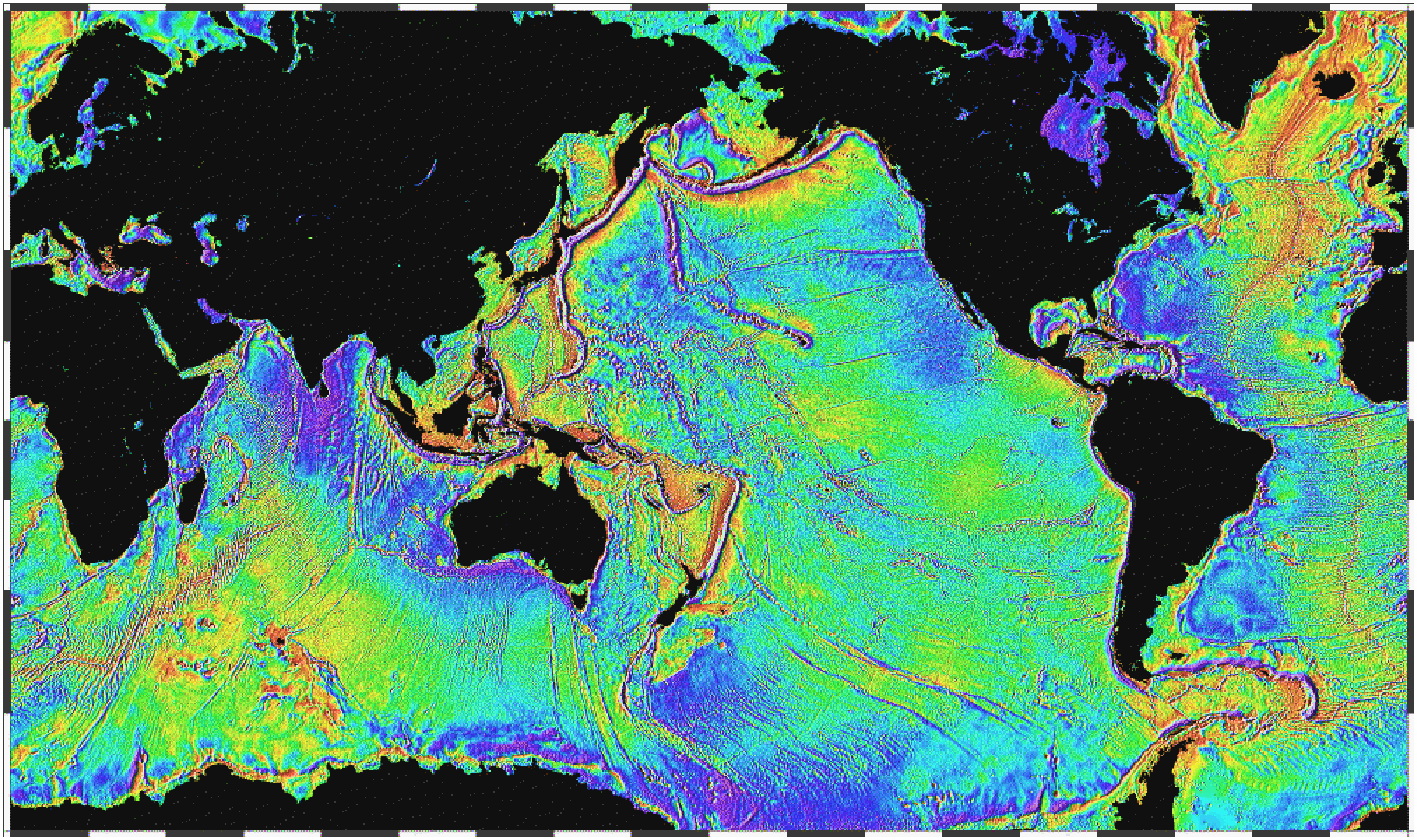


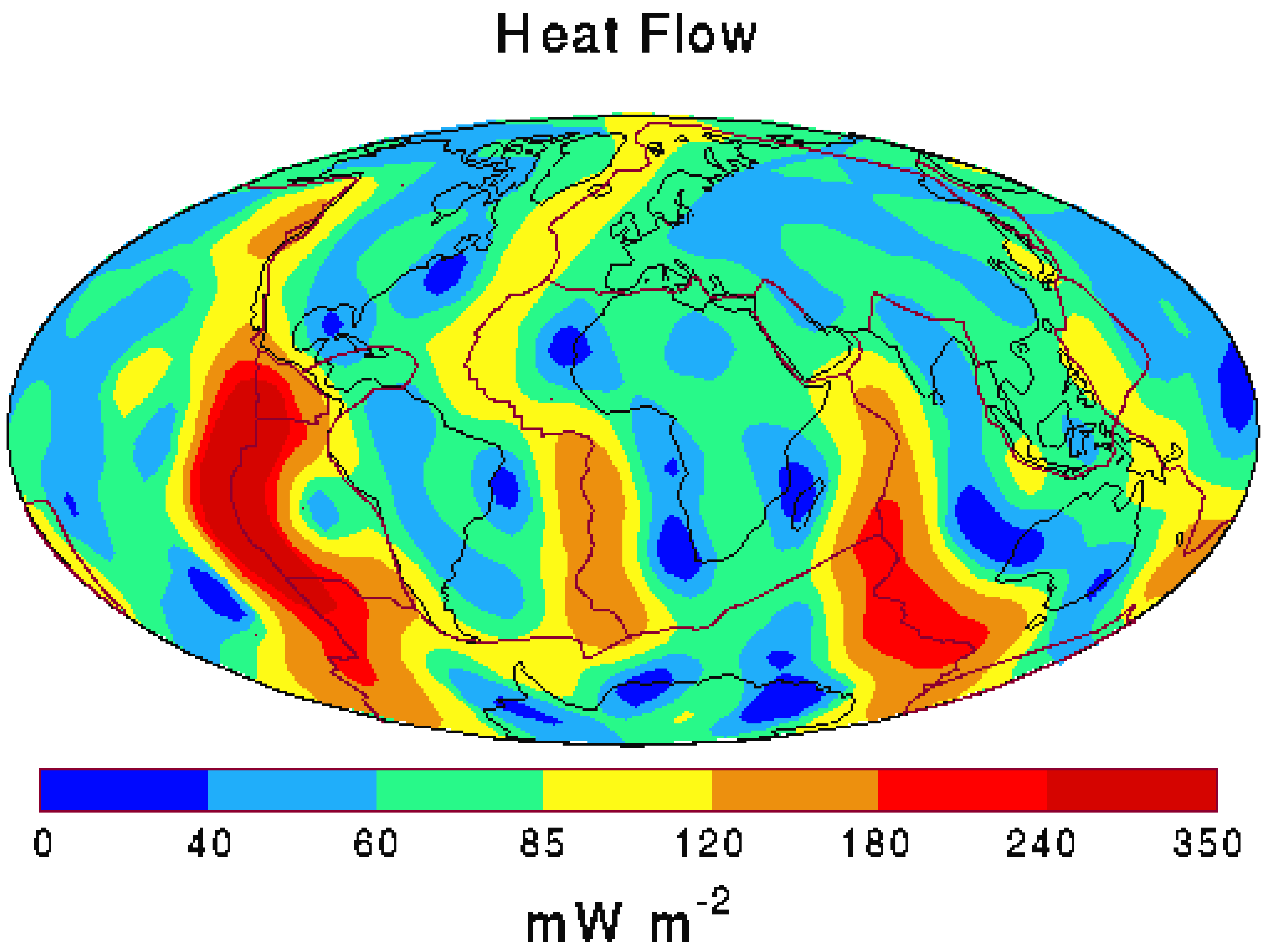
Polarity
K/Ar date
(million years)
0.15
0.35
0.50
0.85
0.95
1.0
1.3
1.5
1.8
2.0
2.3
0
1
2
3
4
5
Time (millions of years)
Normal magnetic field
(as today)
Reversed magnetic field
* Reversal of the field must occur at some time between the flows above and below the horizon


(a)
Location map of magnetic survey
26YW
28YW
66YN
30YW
62YN
60YN
N
Iceland
V IV II I II IV V
Survey line
Ridge Axis
(b)
Magnetic intensities recorded along survey line
Normal field
Reversed field
0 1 2 3 4 5 6
Magnetic intensity along survey line
Age (millions of years)
9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7

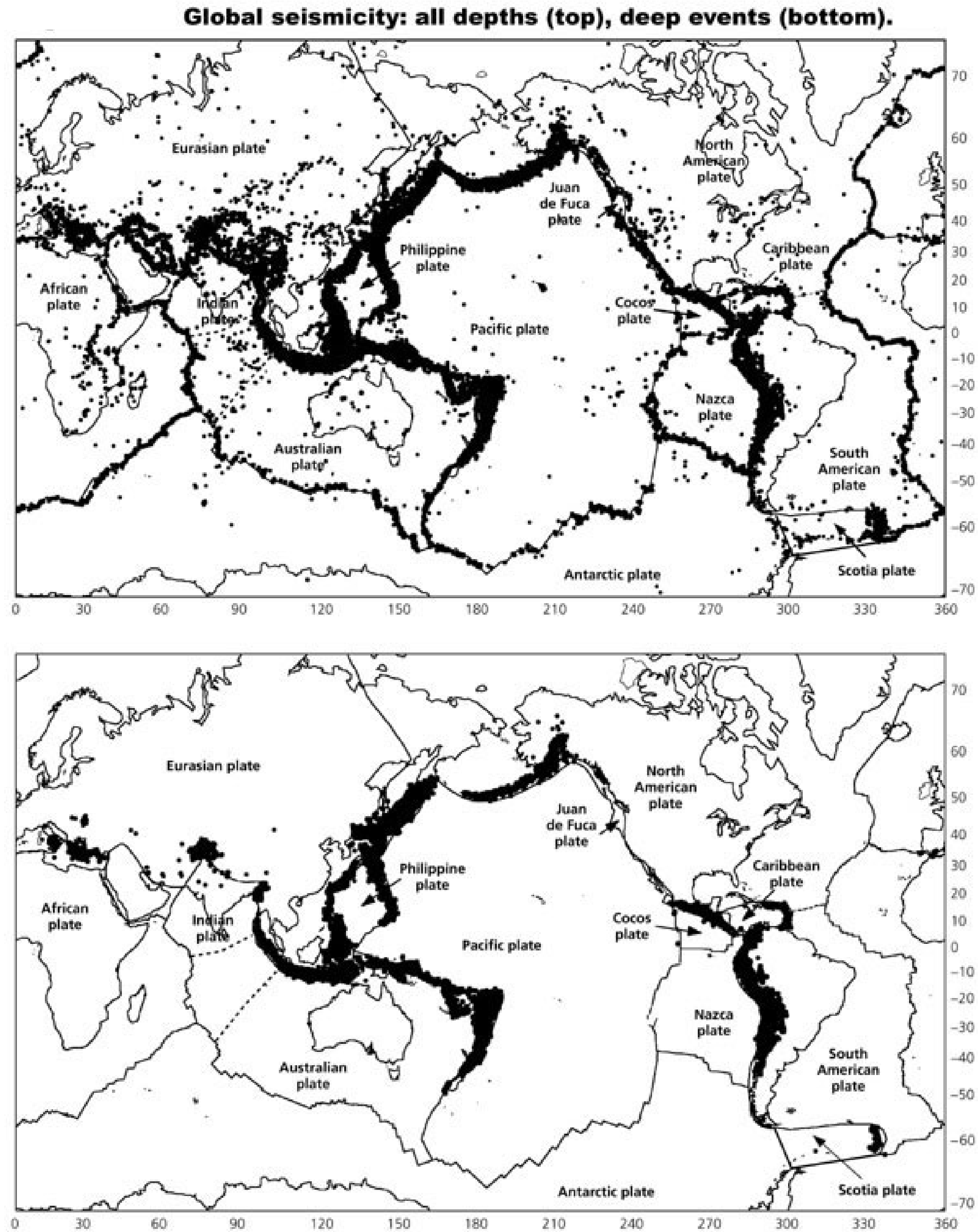

AGE OF OCEAN BASINS
(IN MILLIONS OF YEARS)
0–2
2–5
5–24
24–37
37-58
58–66
66–84
84–117
117–144
144-208

Map of Ocean Seafloor from Laser Altimetry



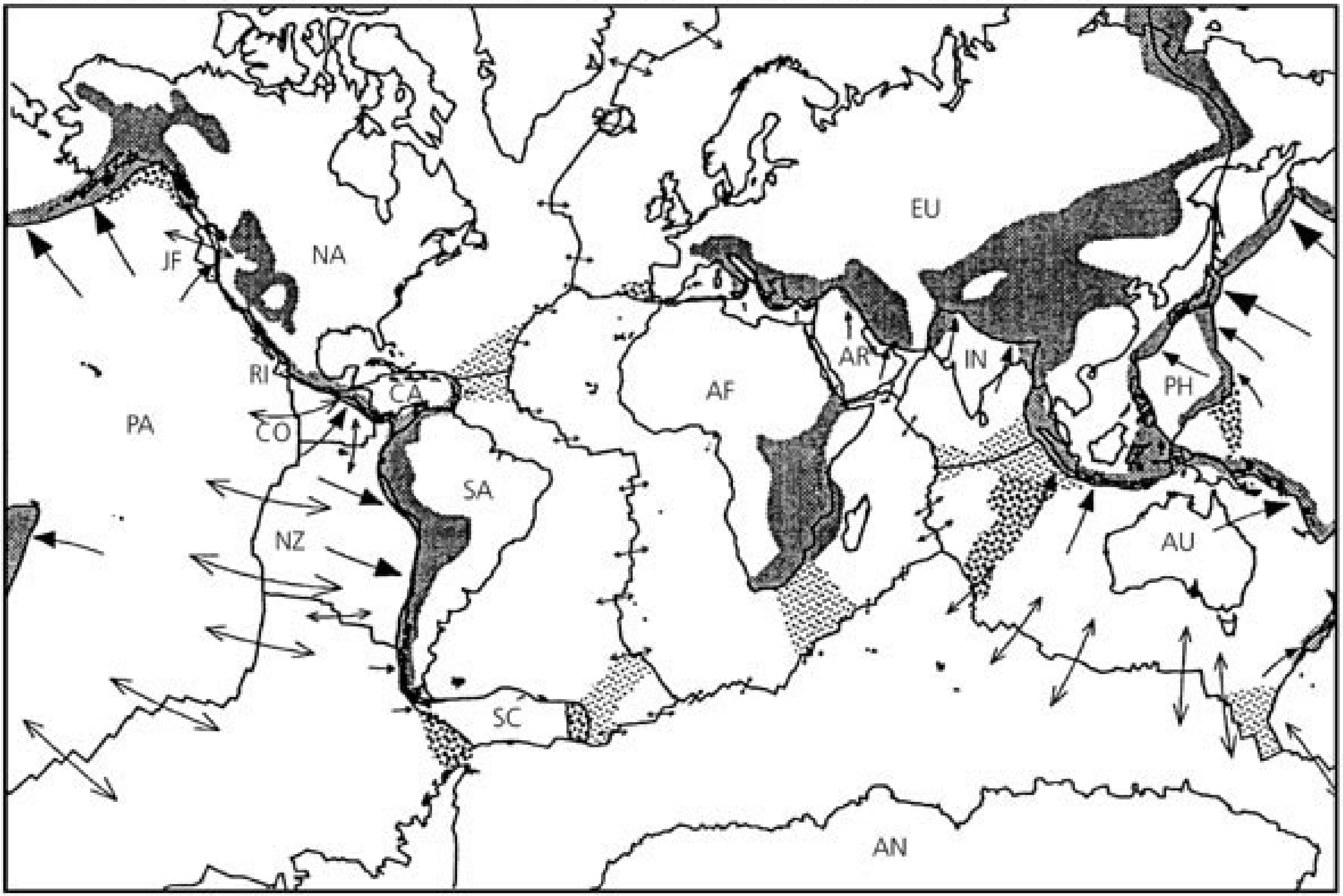

Heat Flow
0
40
60
85
120
180
240
350
mW m-2

1. Most earthquakes are at plate boundaries.
2. All deep earthquakes are at subduction zones

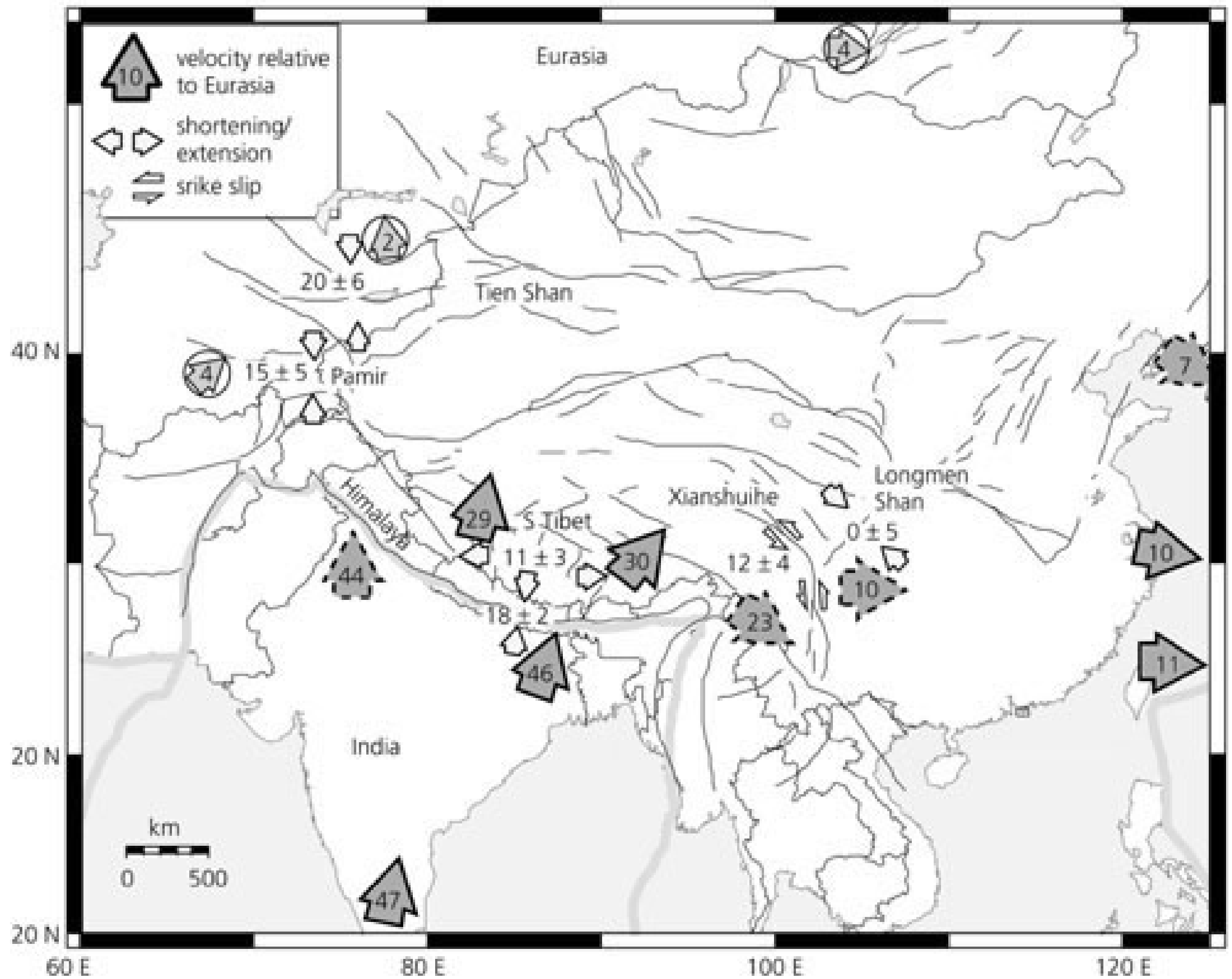


The plates are NOT entirely rigid – about 15% of the Earth's surface is deforming. You can think of these as diffuse plate boundaries.

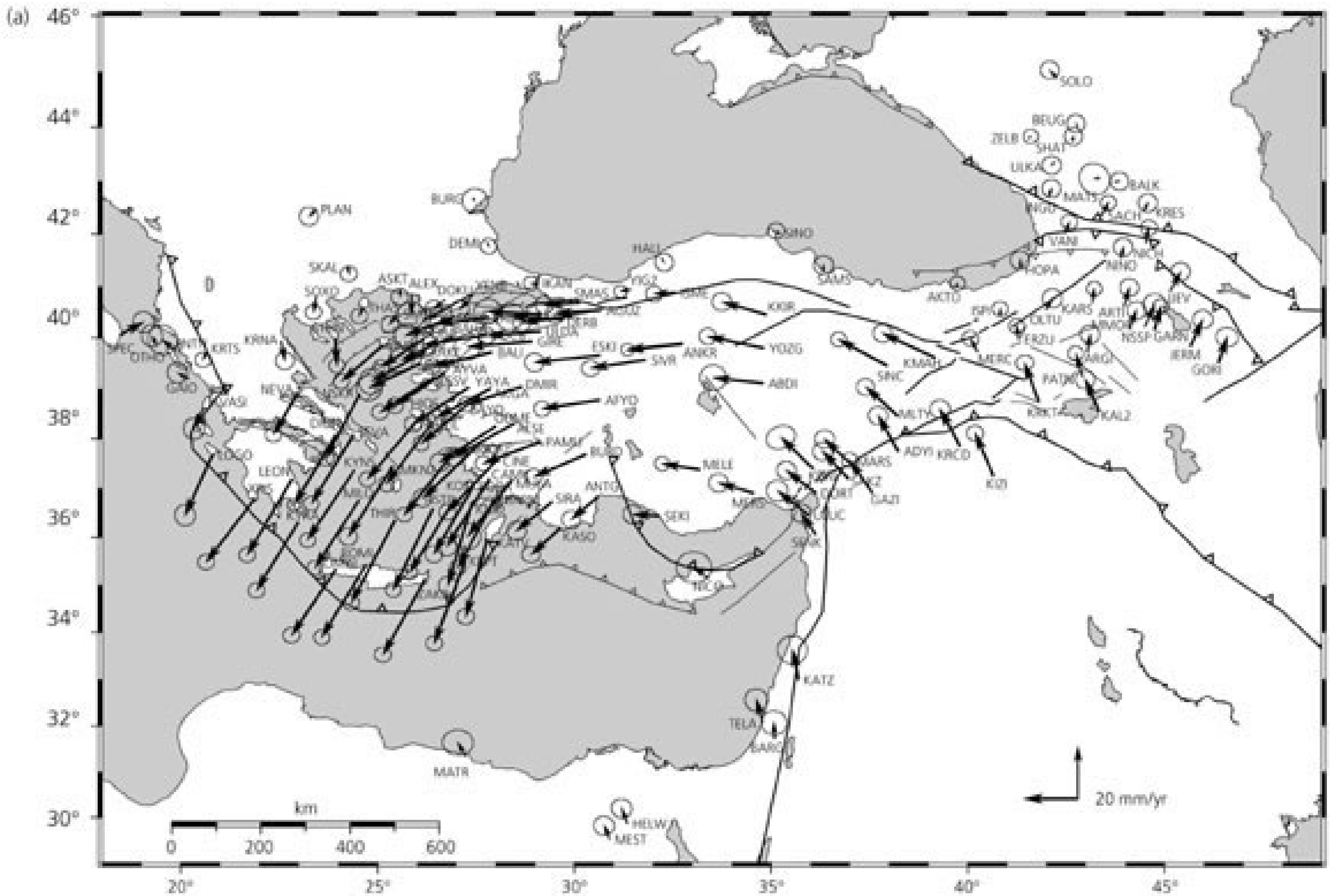
Relative plate motions and diffuse plate boundary zones.



Crustal deformations associated with the India-Eurasia palte



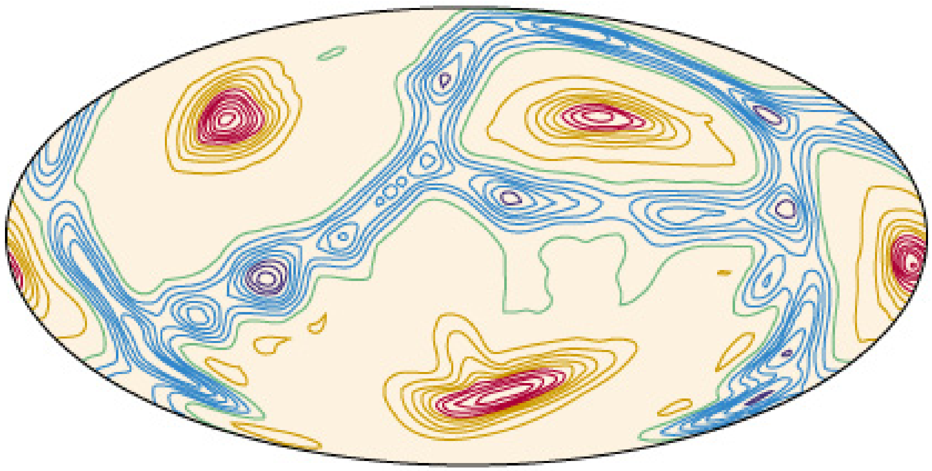
GPS motions for a portion of the Africa-Arabia-Eurasia plate



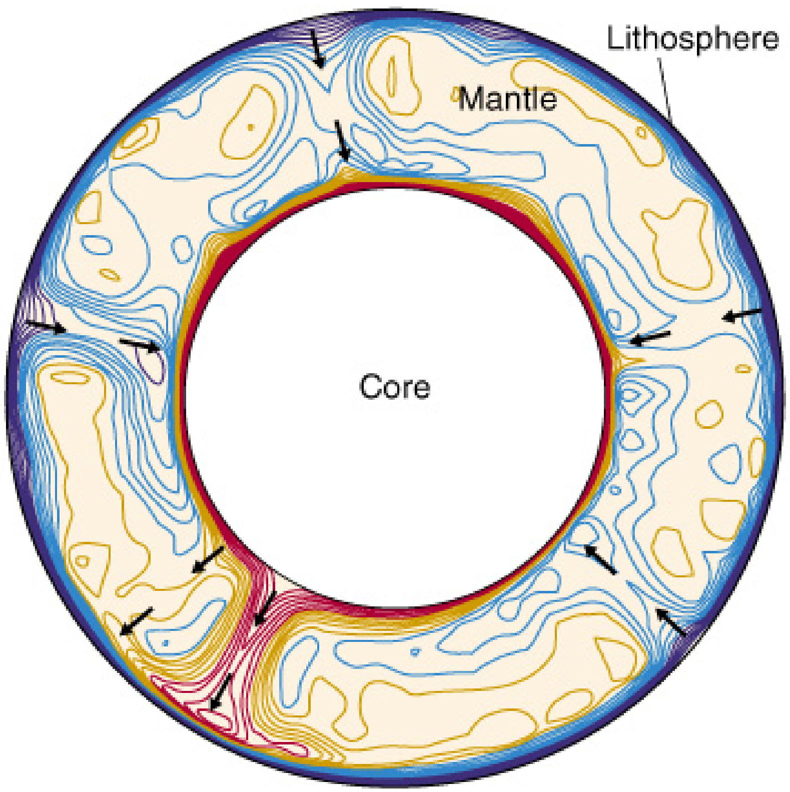
Q. Why are the plates moving?

Q. Why are the plates moving?

A. Mantle Convection. Plate tectonics can be viewed as the surface expression of mantle convection.



(i)



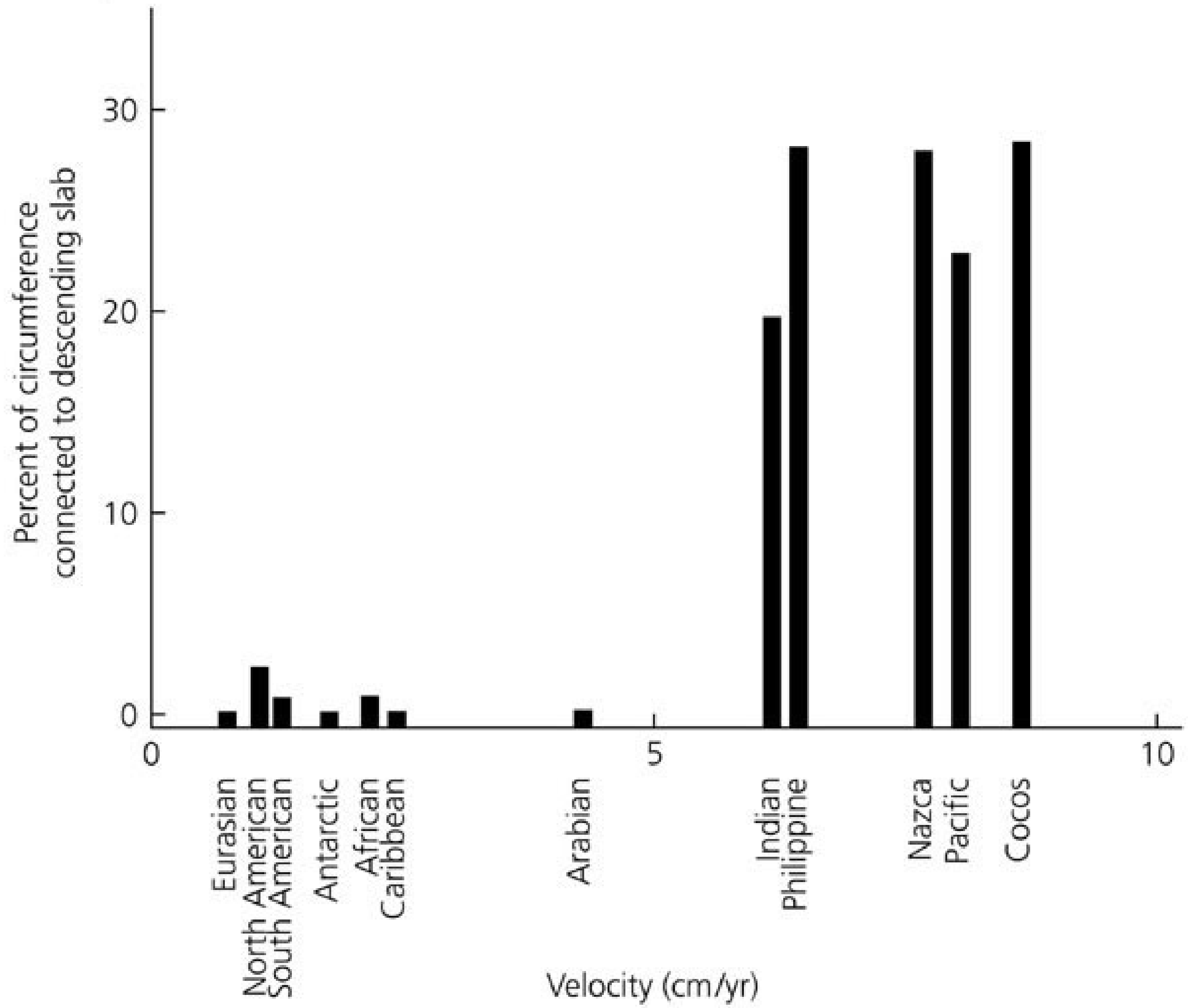
(ii)

Q. What are the forces that directly move the plates?

Q. What are the forces that directly move the plates?

A. Primarily “slab pull,” but there are other forces involved.

Plate velocity as a function of the amount of subducting lithosphere.



The important forces moving plates are:

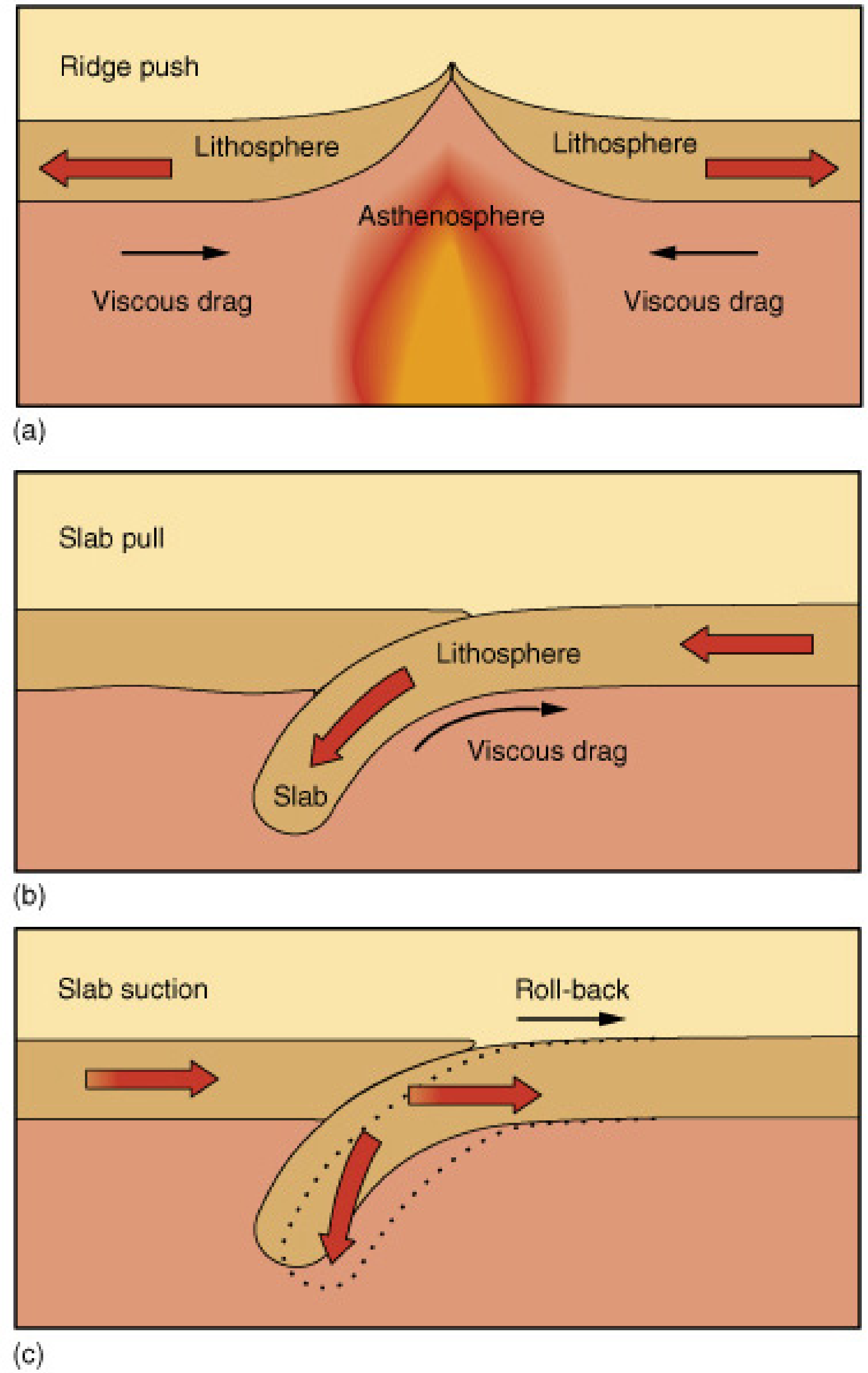
Slab Pull – most important

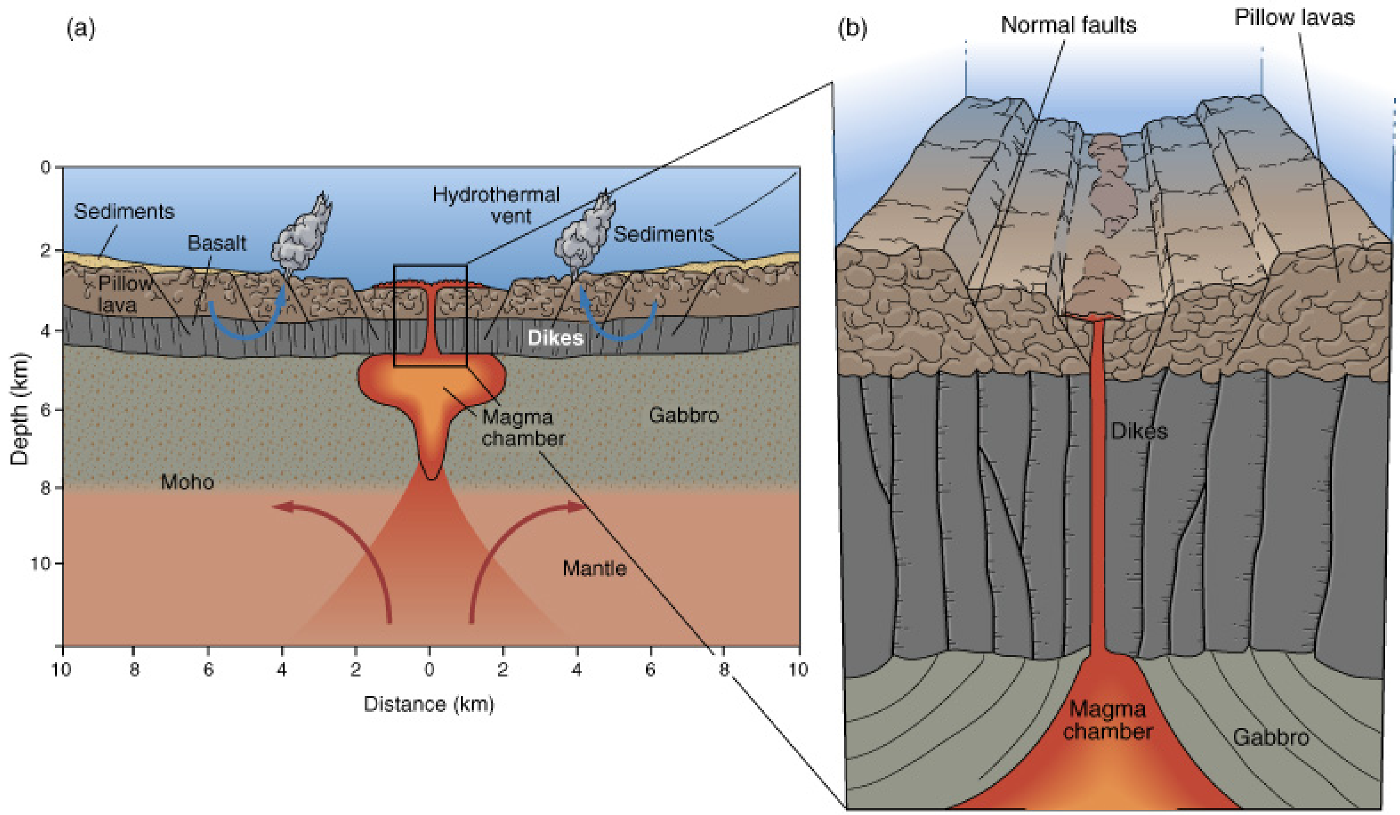
Ridge Push – like surfing

Viscous Drag

Slab Resistance

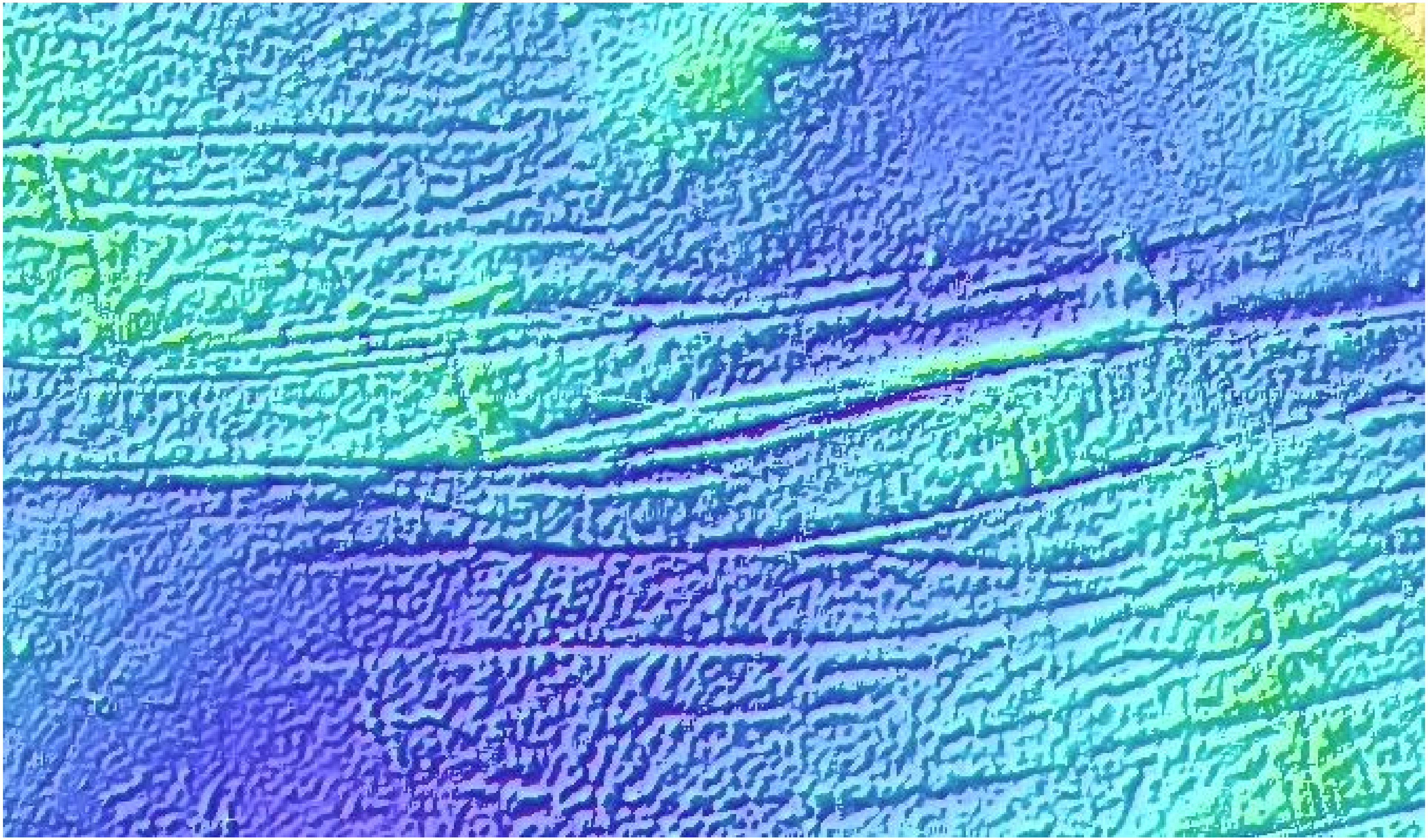
Subducting plates accelerate until viscous resistance equals slab pull ("terminal velocity')



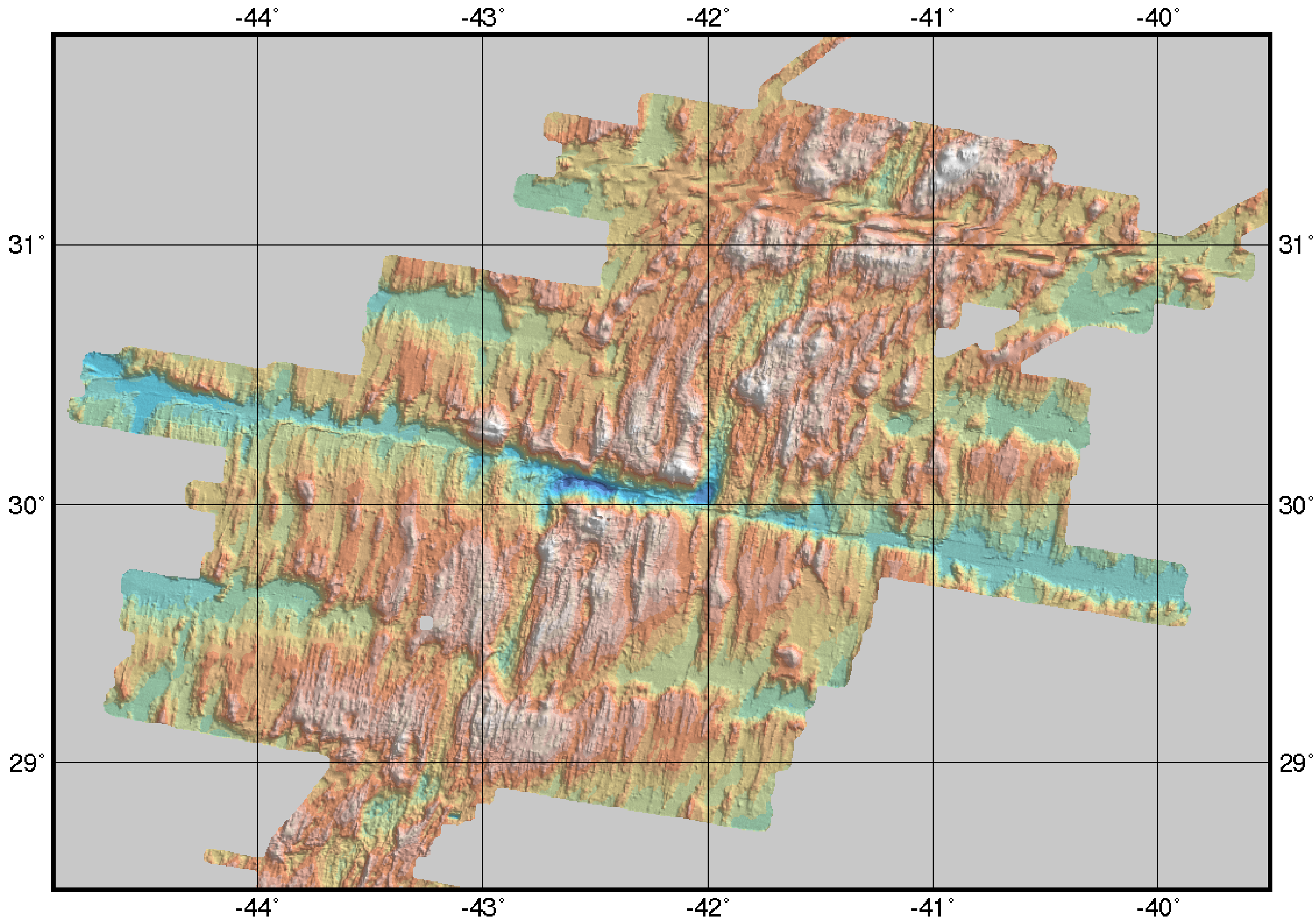


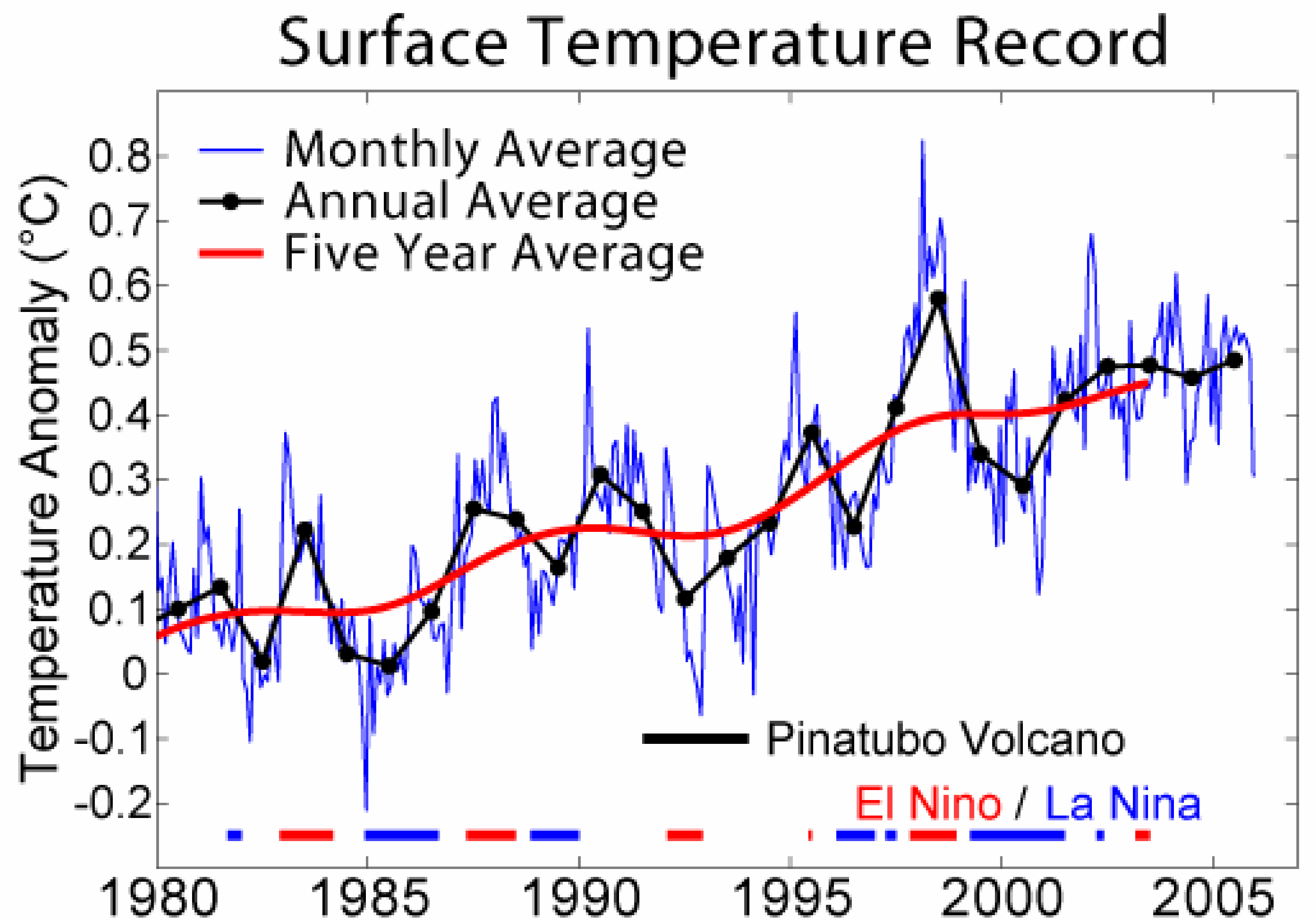
Remember: Even the “magma chamber” is mostly solid. The Earth’s mantle is solid rock, even though it moves a lot.

A Portion of the Mid-Atlantic Ridge System

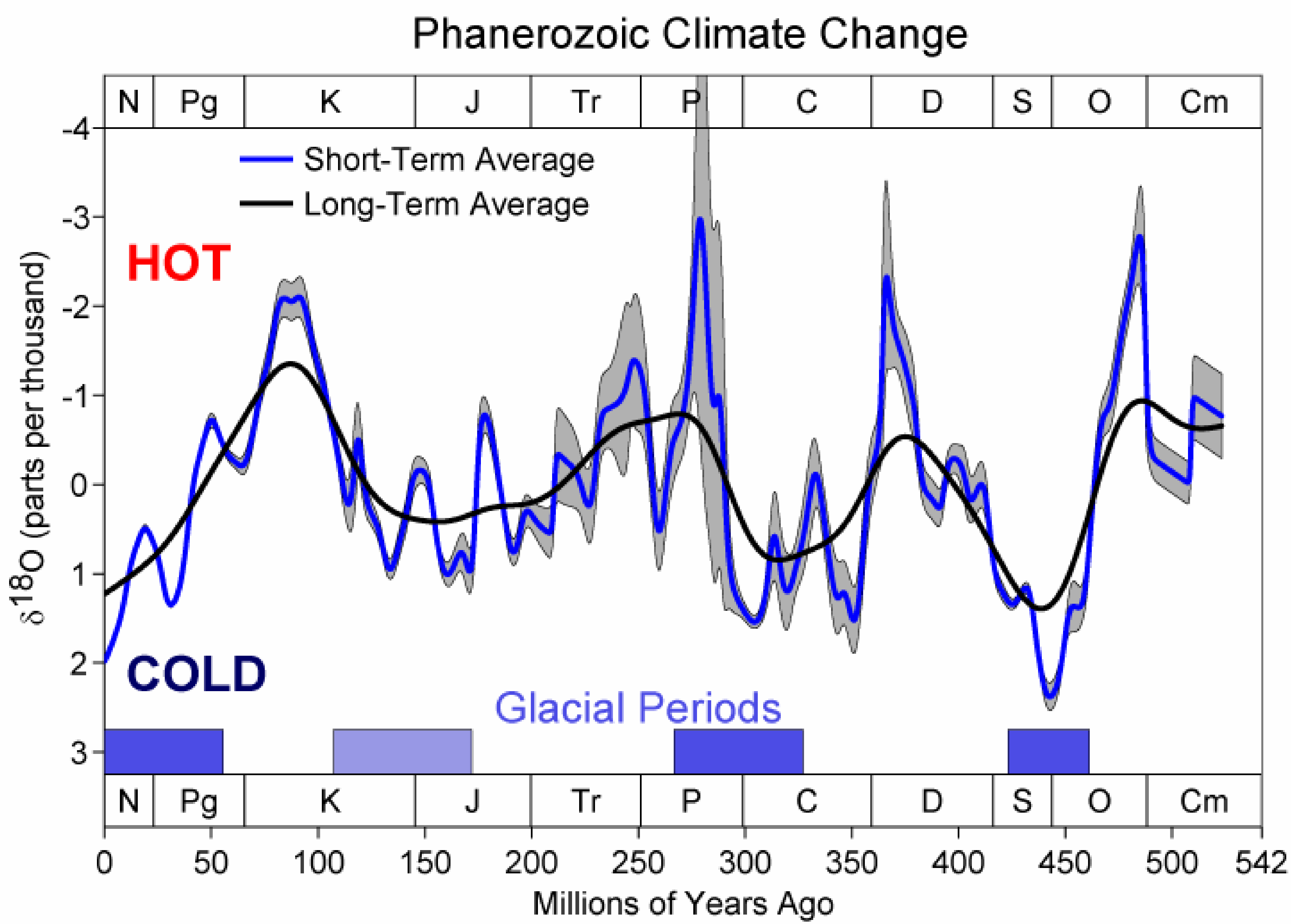


A Portion of the Mid-Atlantic Ridge System





Surface Temperature Record
Monthly Average
Annual Average
Five Year Average
Temperature Anomaly (°C)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
Pinatubo Volcano
El Nino / La Nina
1980
1985
1990
1995
2000
2005



Phanerozoic Climate Change
N
Pg
K
J
Tr
P
C
D
S
O
Cm
Short-Term Average
Long-Term Average
HOT
COLD
Glacial Periods
δ18O (parts per thousand)
-4
-3
-2
-1
0
1
2
3
0
50
100
150
200
250
300
350
400
450
500
542
Millions of Years Ago

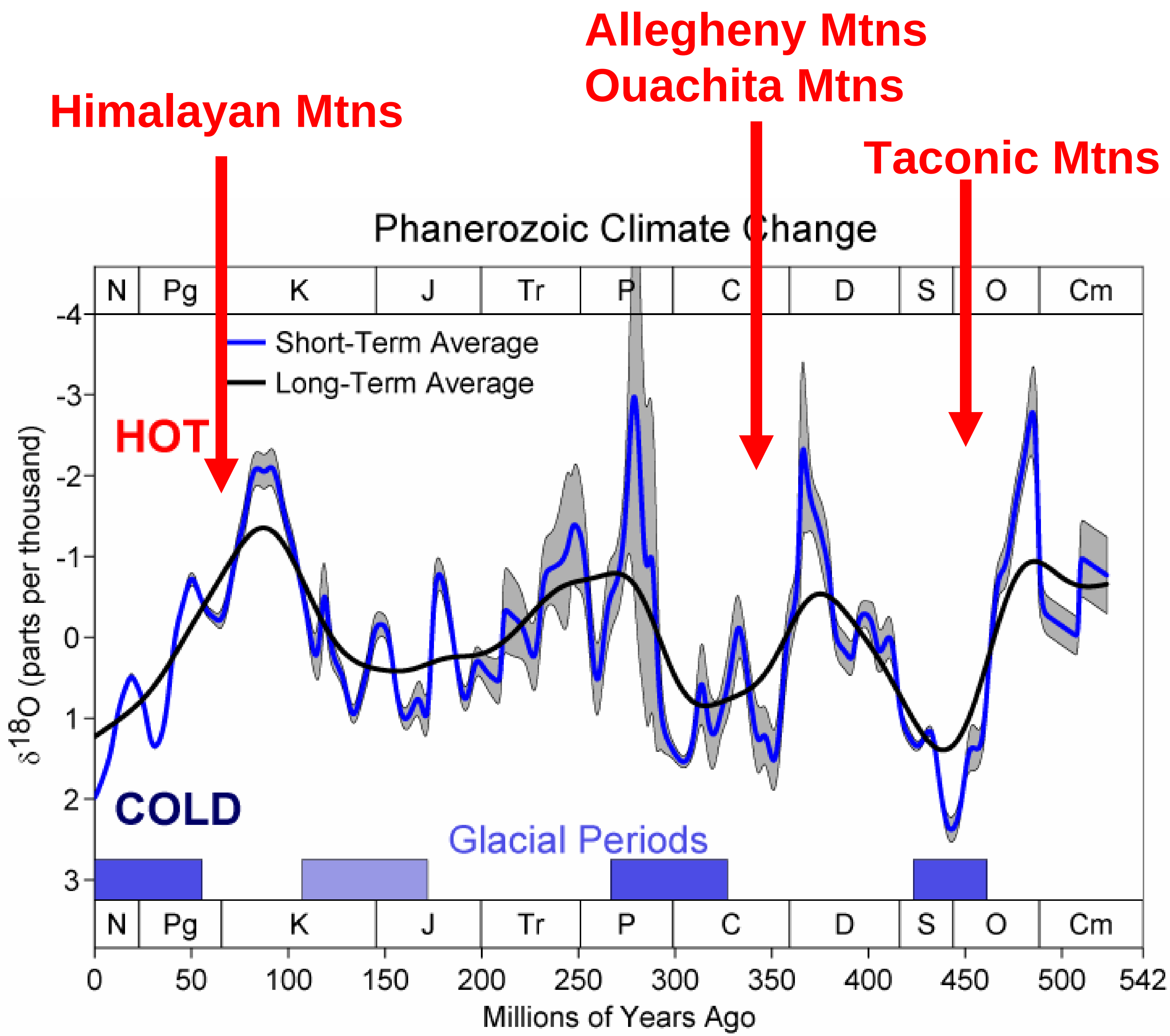
Mountains!!

→ **Erosion (Carbonic Acid)**

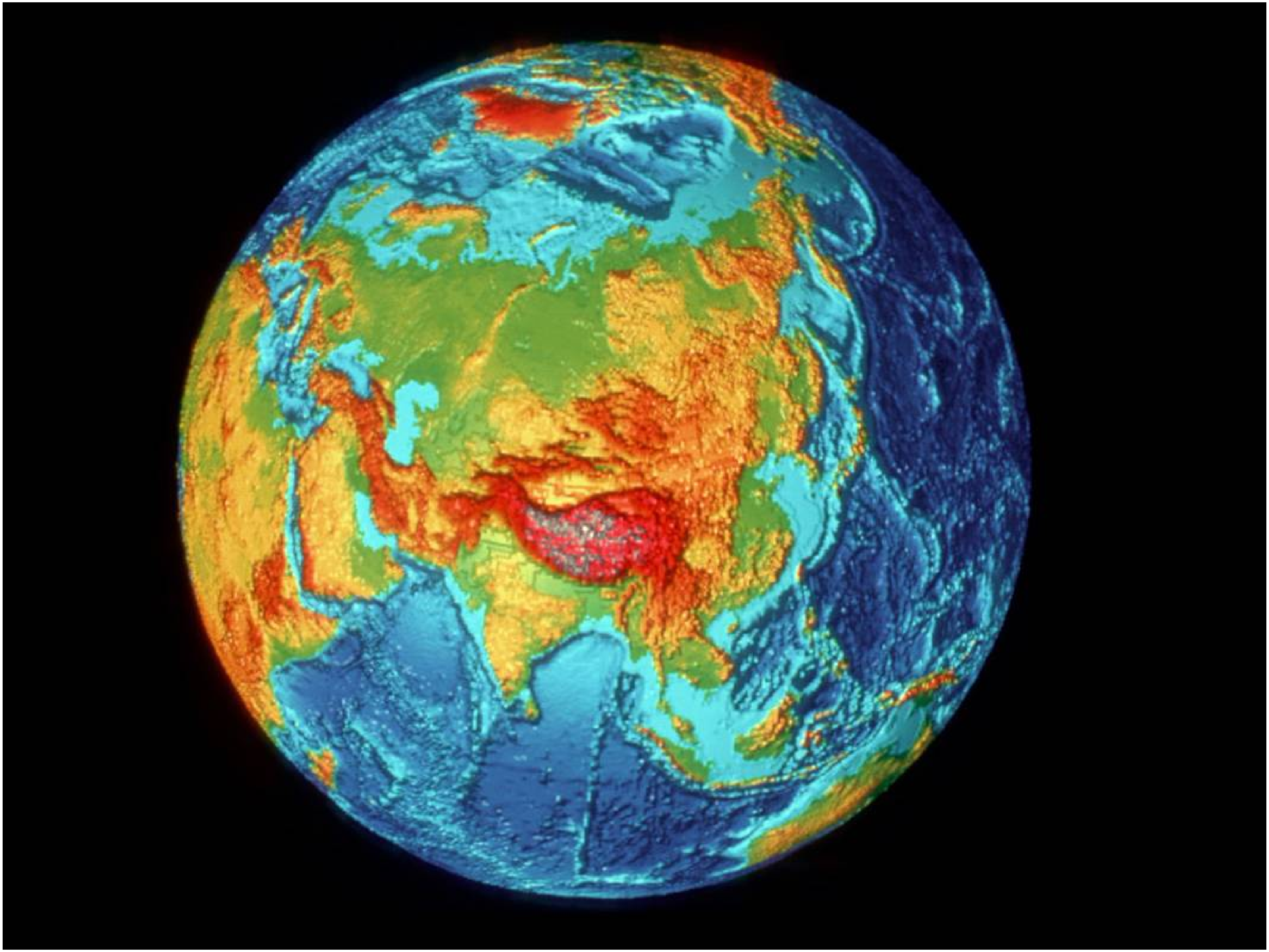
→ **Deposition of Carbonates in the Oceans**

→ **Reduced CO_2 in Atmosphere**

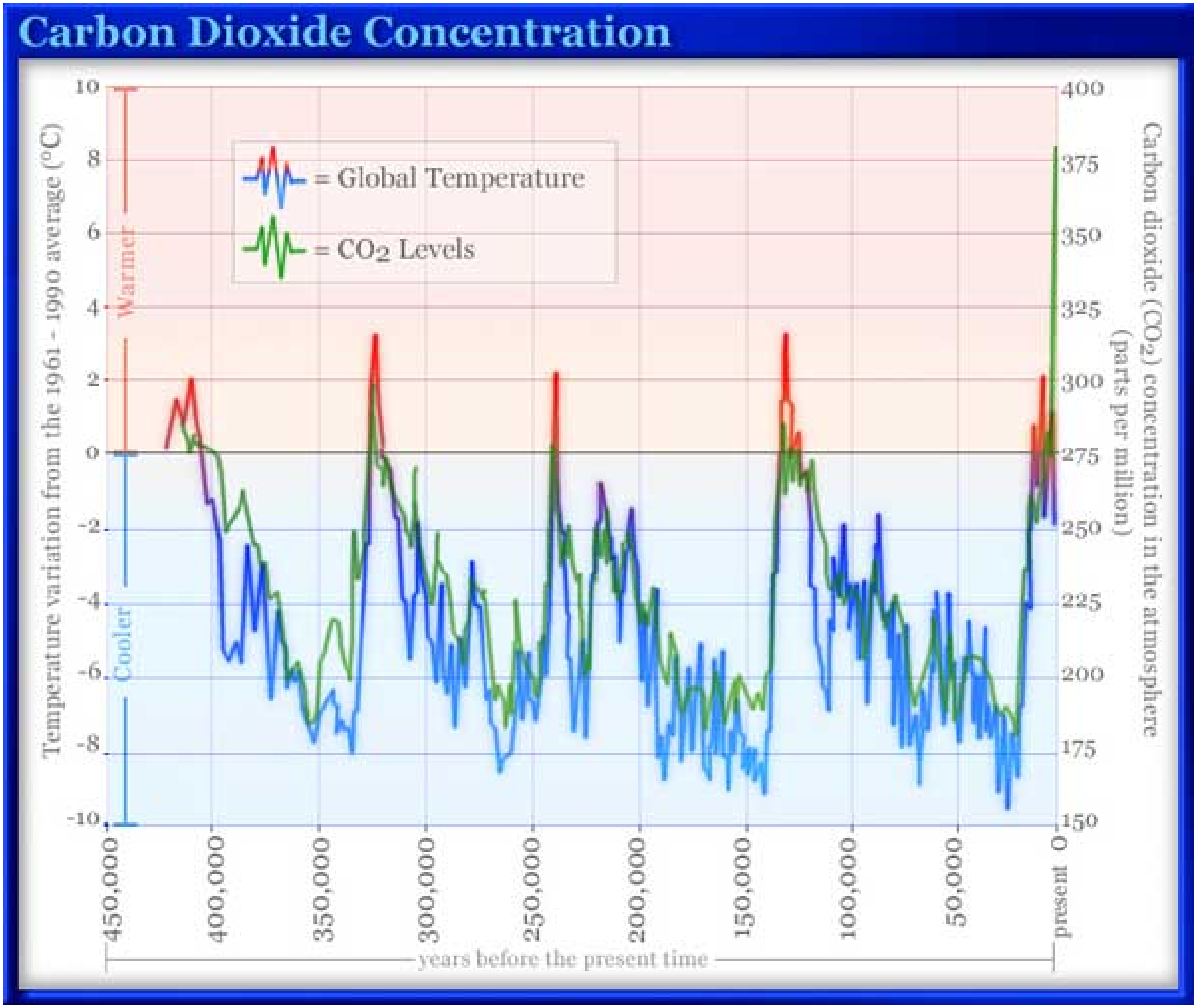
→ **Global Cooling**



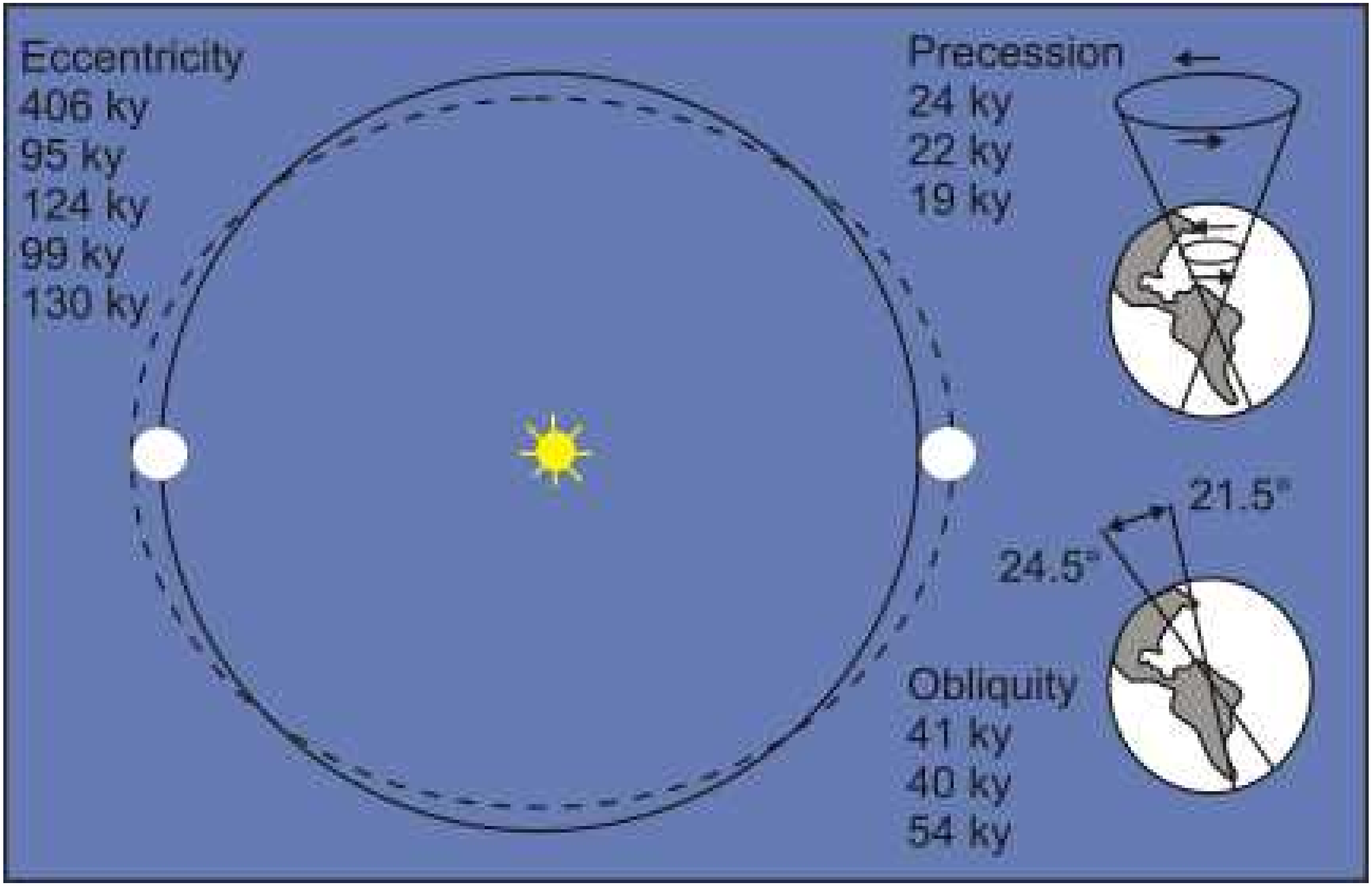
Himalayan Mtns
Allegheny Mtns
Ouachita Mtns
Taconic Mtns
Phanerozoic Climate Change
N Pg K J Tr P C D S O Cm
Short-Term Average
Long-Term Average
HOT
COLD
Glacial Periods
δ18O (parts per thousand)
-4 -3 -2 -1 0 1 2 3
0 50 100 150 200 250 300 350 400 450 500 542
Millions of Years Ago



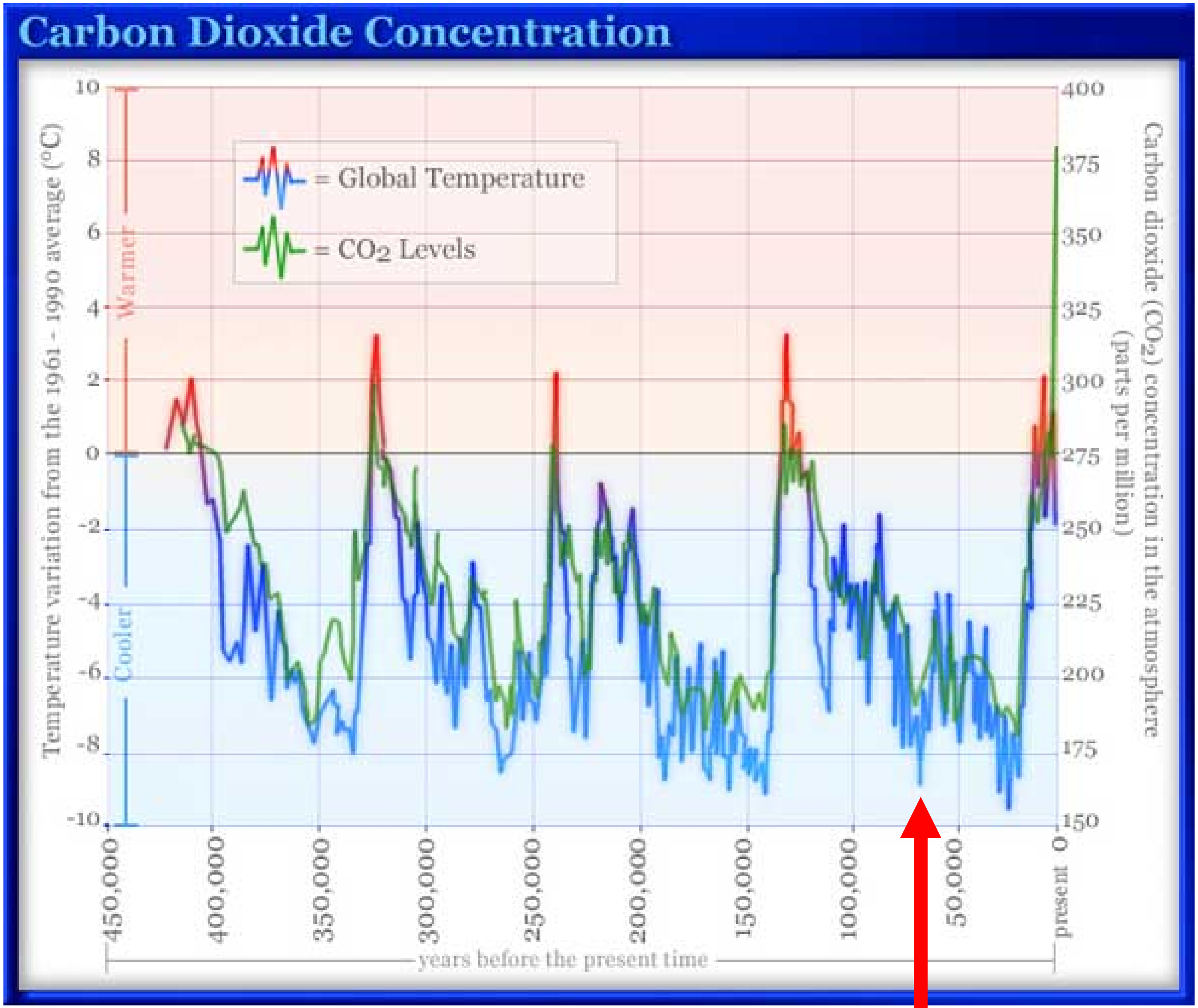
What drives the intermediate-term temperature changes? (20,000 – 400,000 years)



Fluctuations in Earth's Orbit (Milankovich Cycles)



What about some of the narrow, sharp spikes?



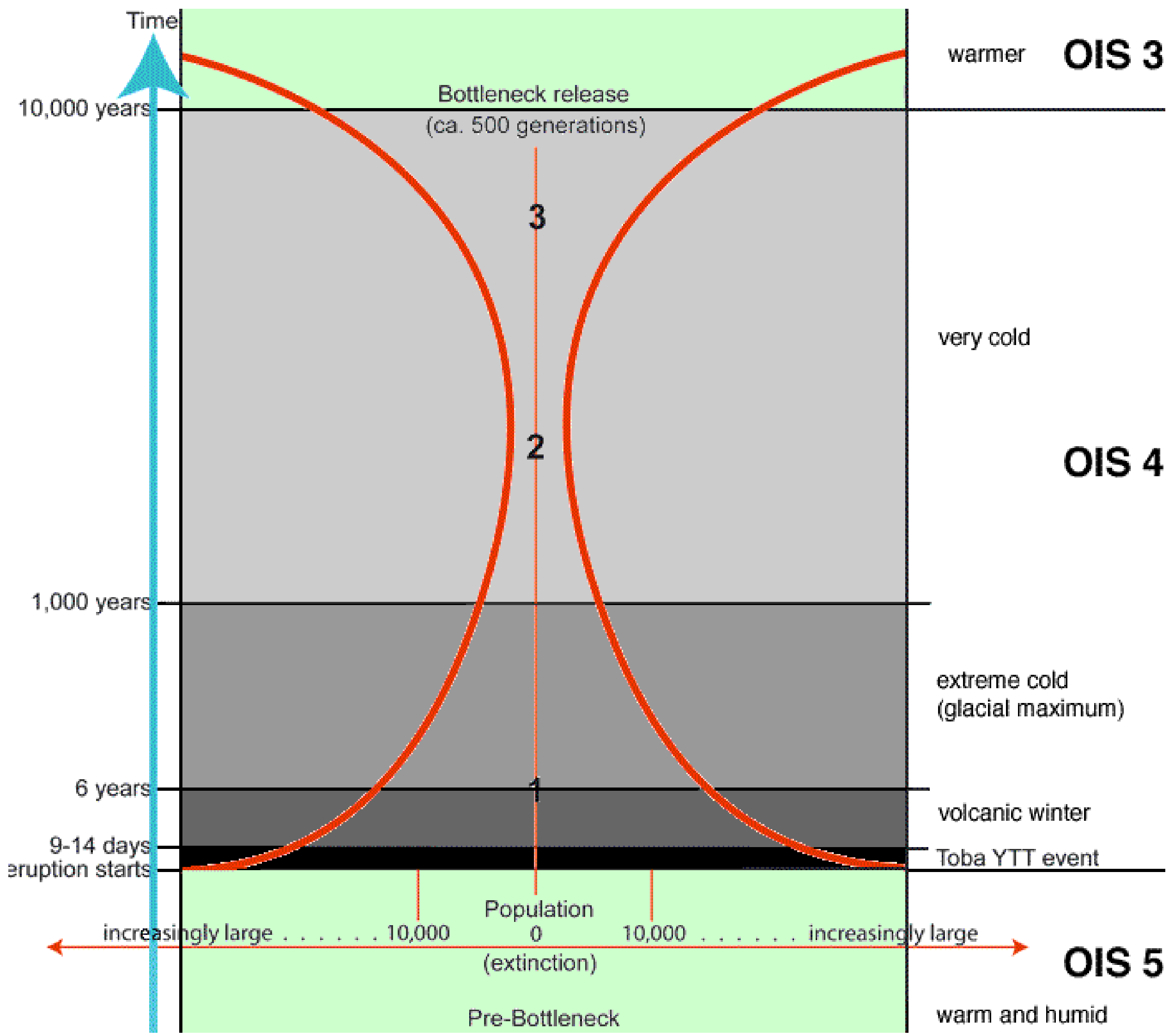
71,000 years ago

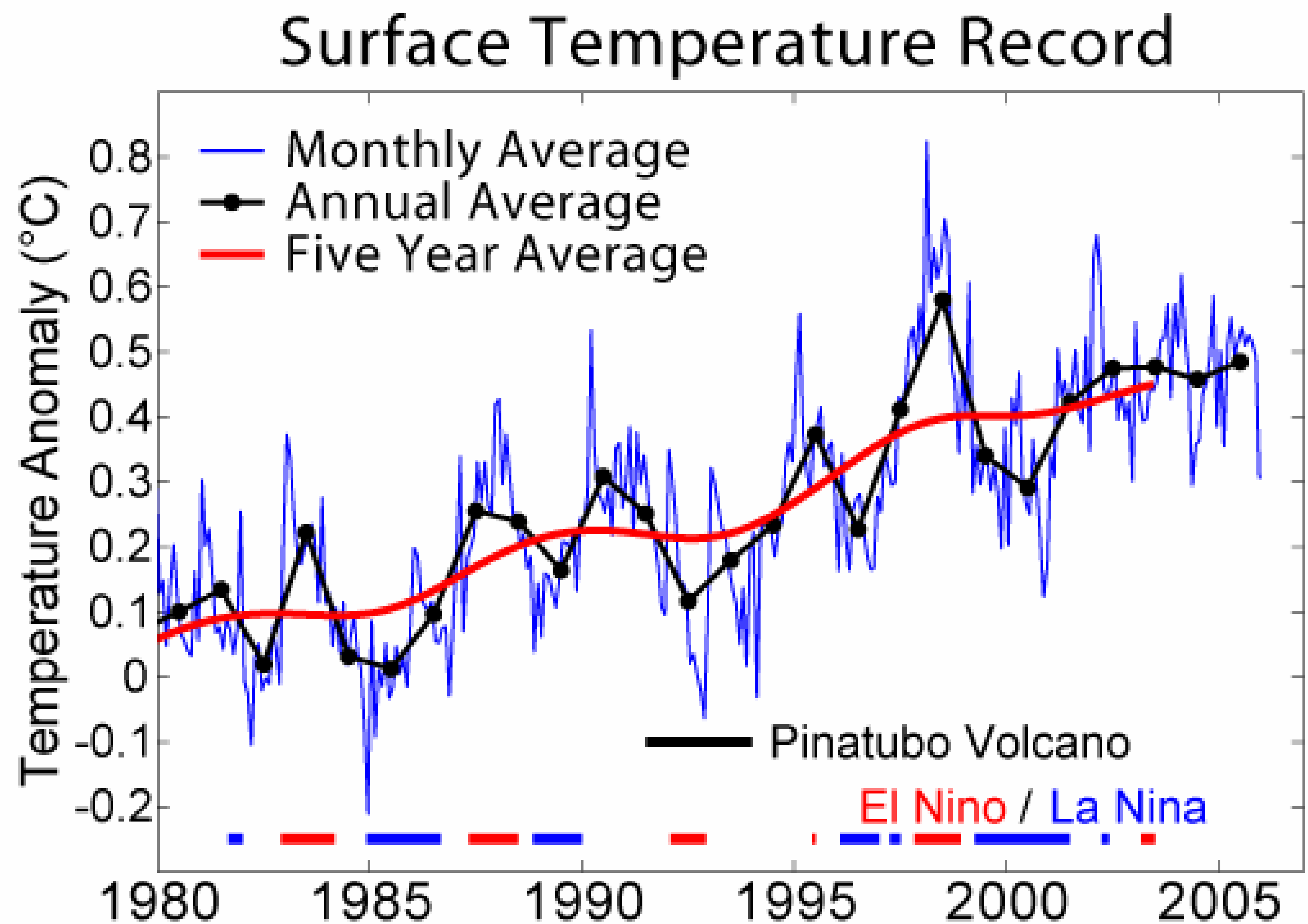
Toba Volcano – 72,000 years ago

→ 280,000 km^3 ejected!

→ 1 gigaton tnt explosion!

Based on genetic diversity, it is estimated that all modern humans evolved from only 1000-10,000 individuals following the Toba eruption.





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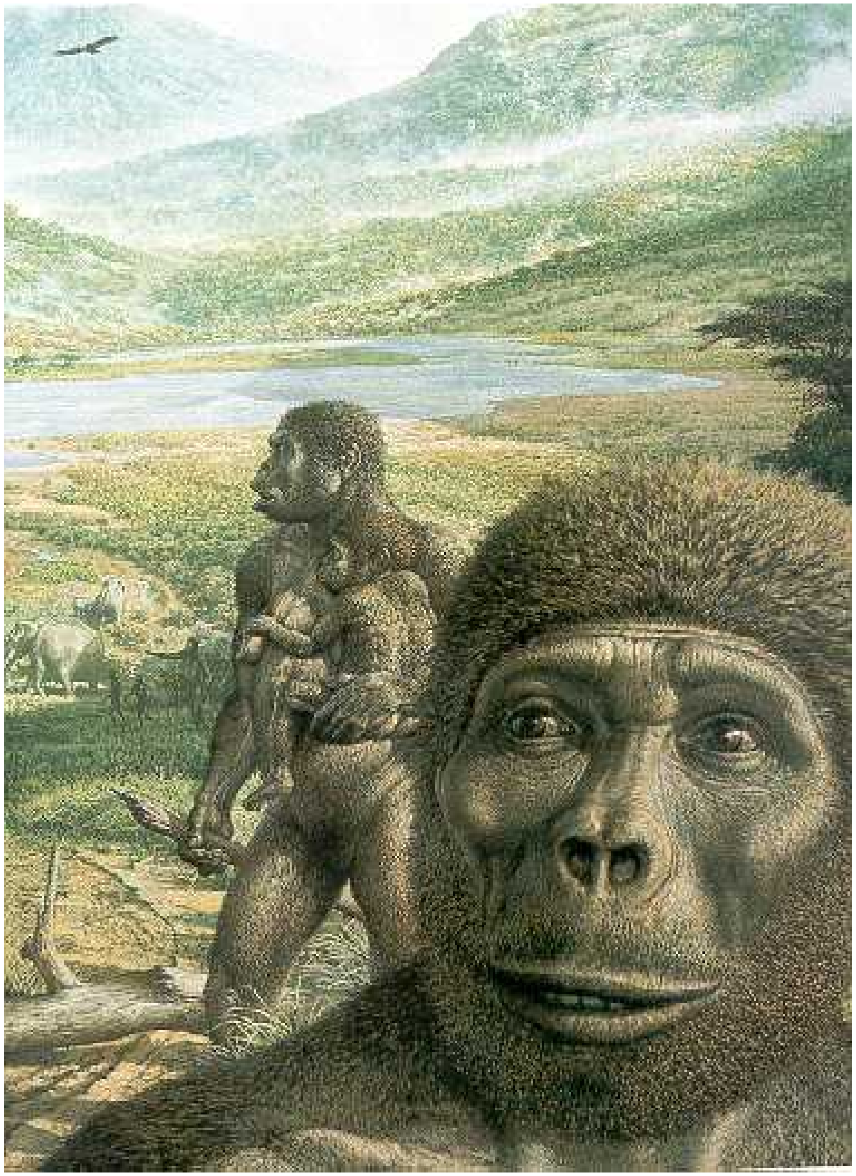
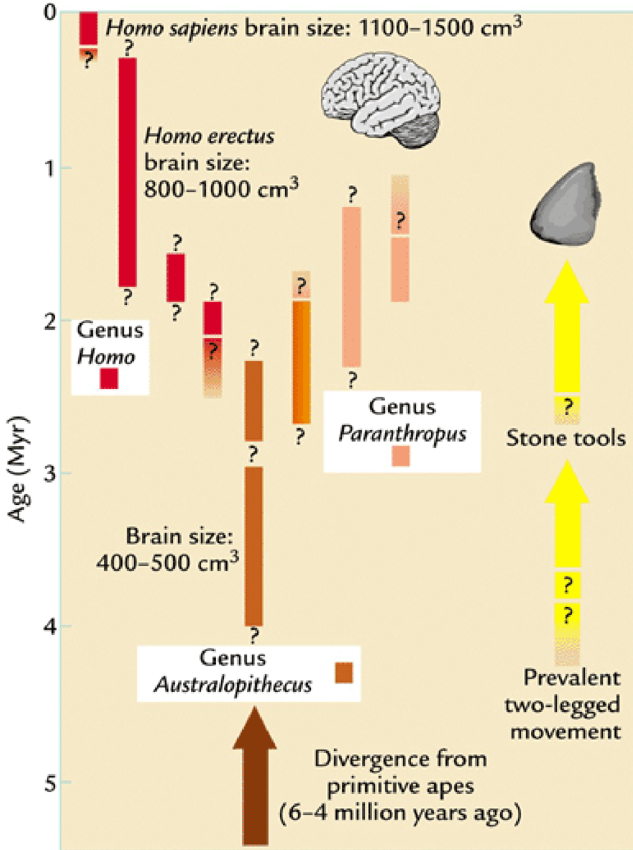
0.2
0.1
0
-0.1
-0.2
Pinatubo Volcano
El Nino / La Nina
1980
1985
1990
1995
2000
2005

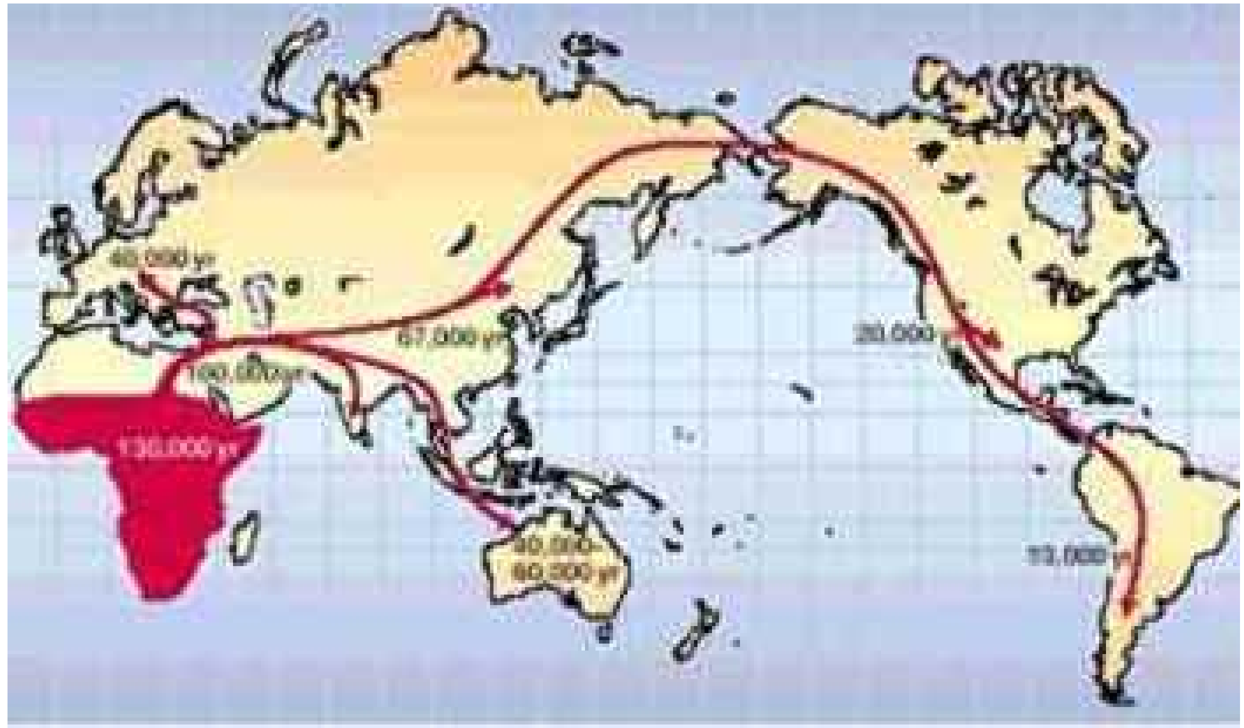
About 5 million years ago our ancestors became increasingly bipedal.

Why?



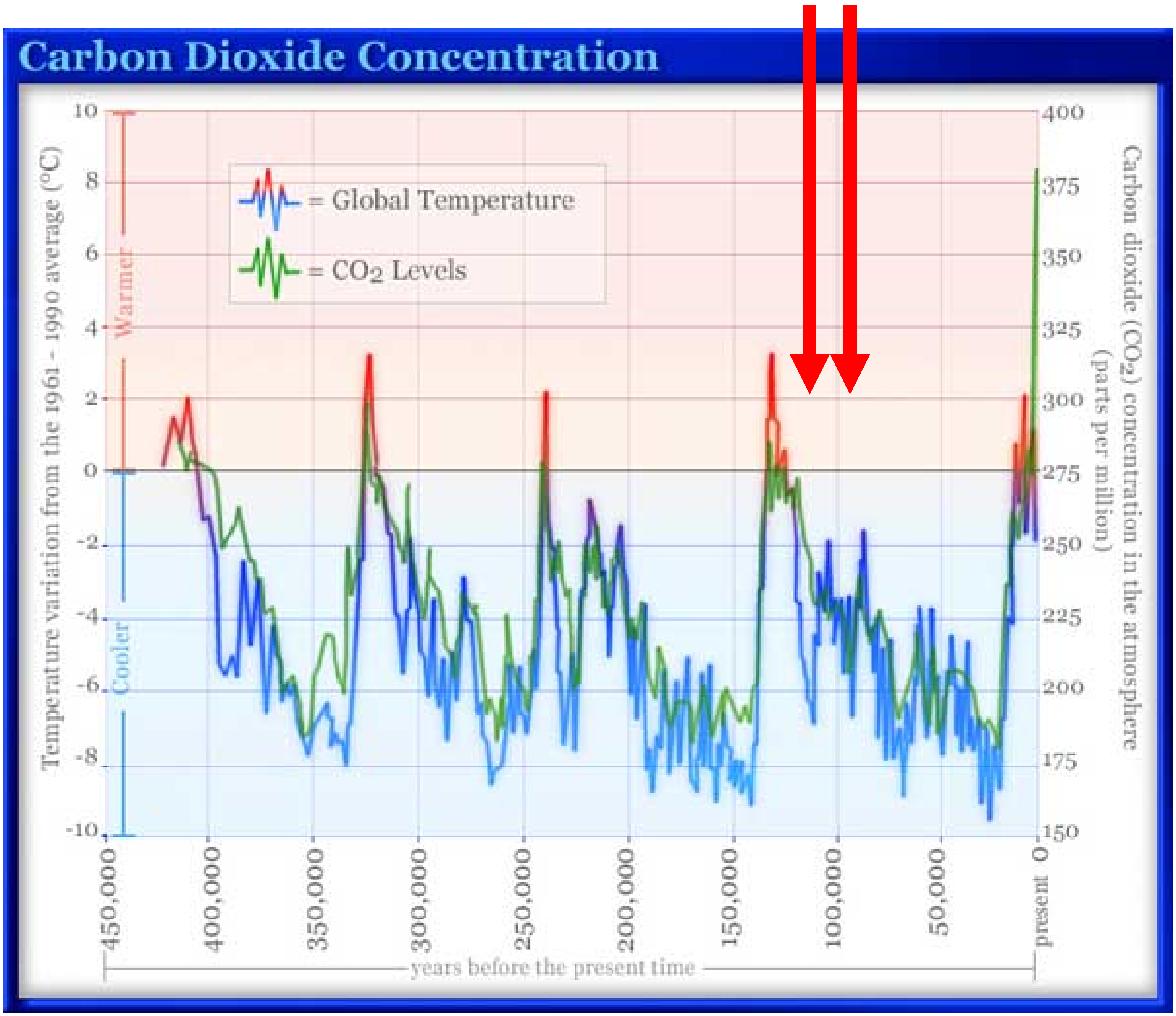
→ **A major cooling trend changed forests to savannas??**





By 100,000 years ago, Homo Sapiens was emerging as dominant hominid. Why?

?? Selection for large brains during strong Ice Ages that occurred 120,000-90,000 years ago??



The Natural History Museum

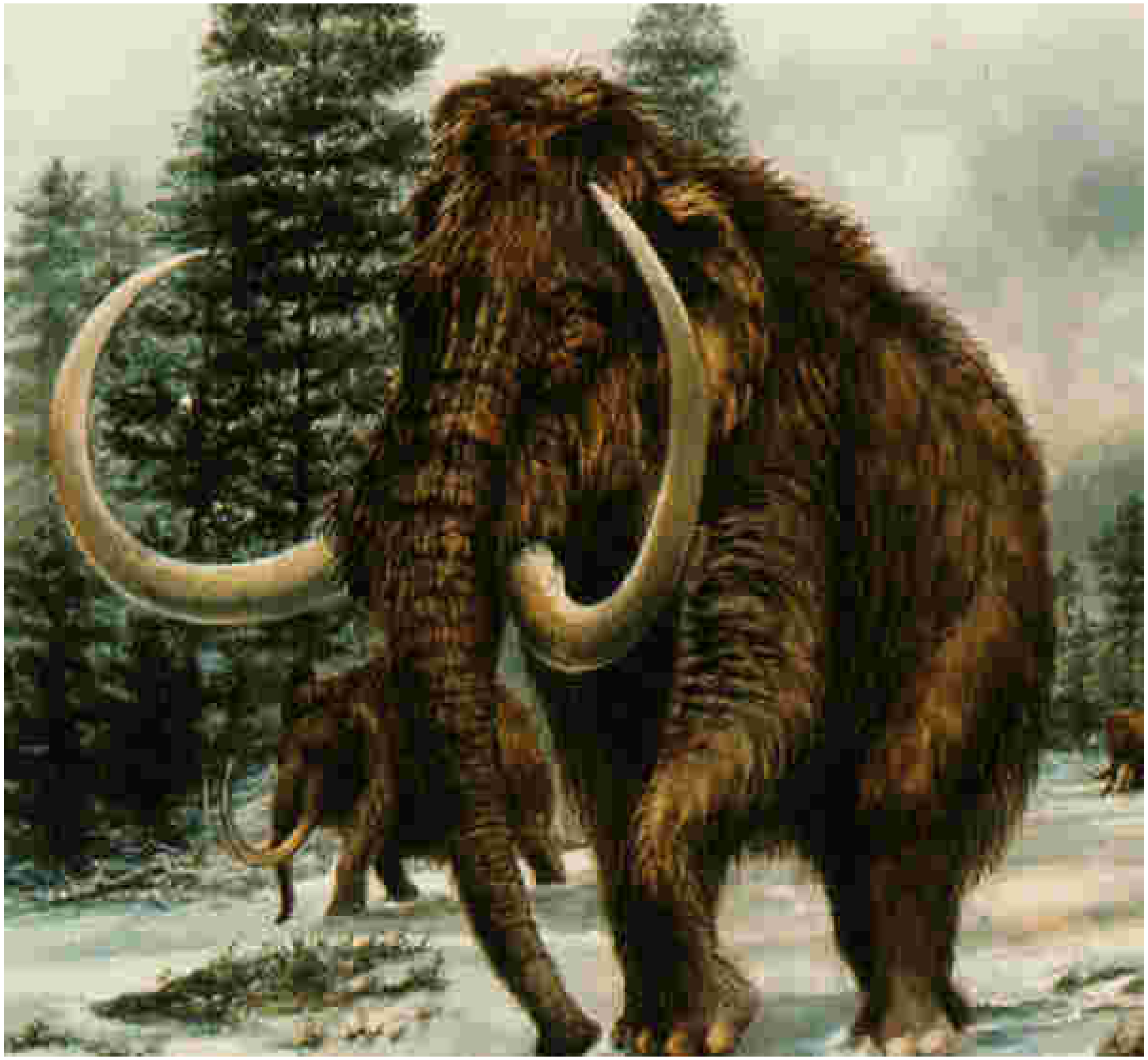
50,000-40,000 years ago there was a cultural explosion in Europe.

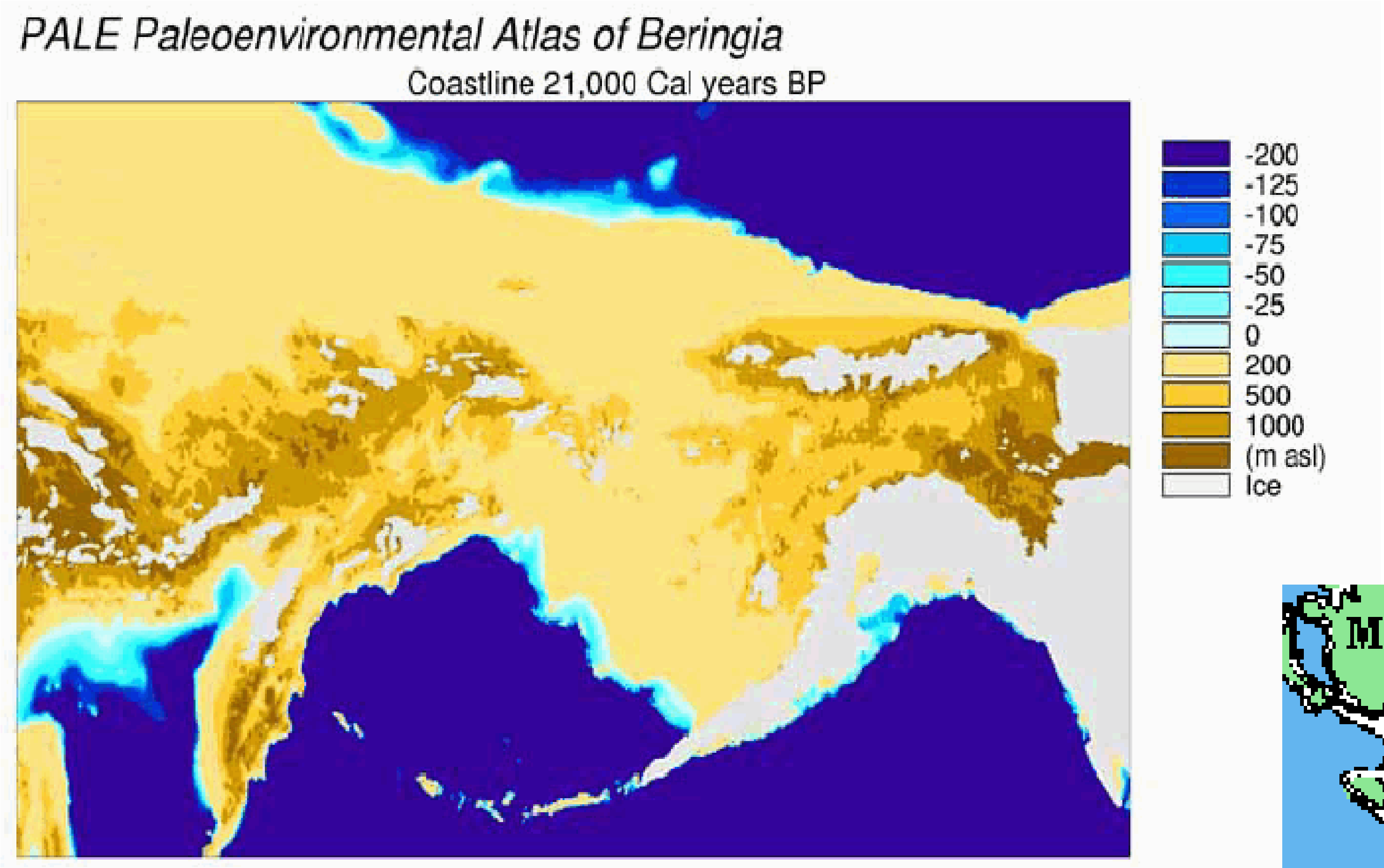
Why?

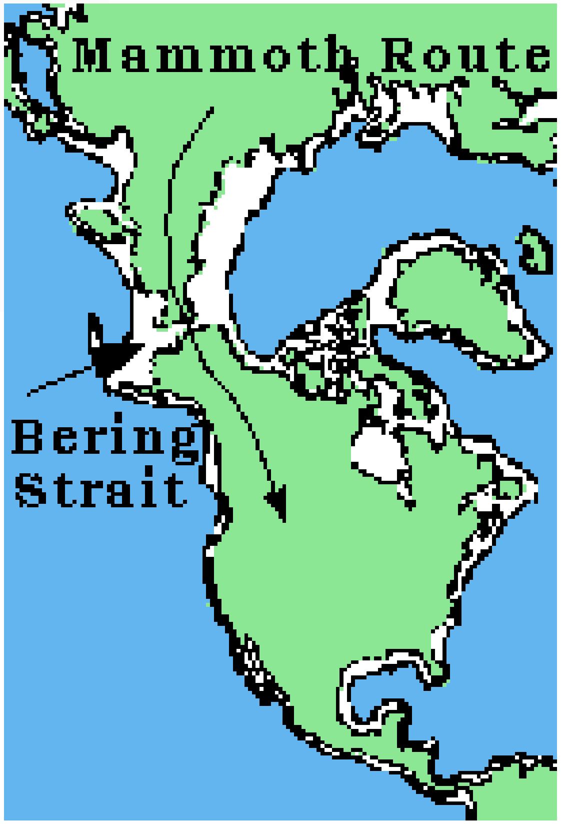
Warming trend in Europe.

Life was easier?

North American Mammoths evolved in Asia.
How did they get here 20,000 years ago?



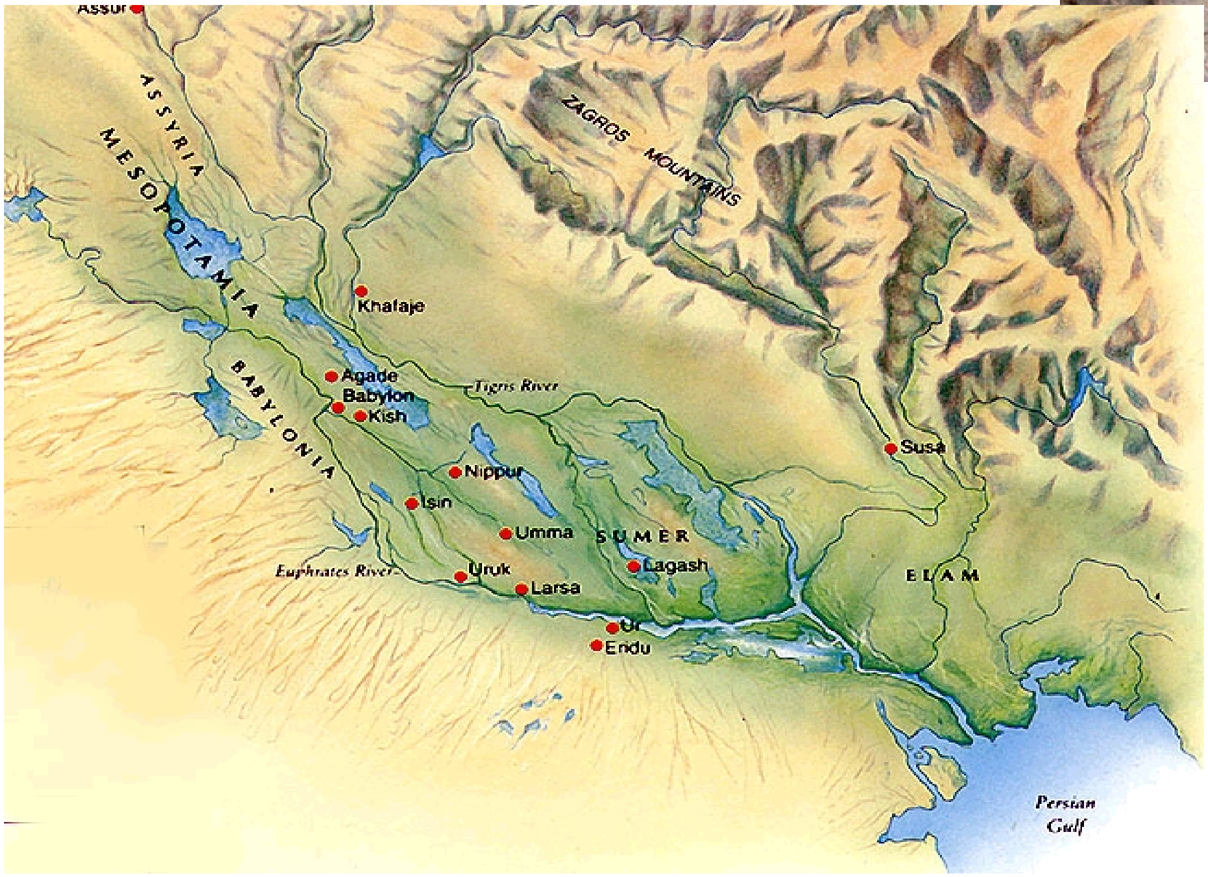




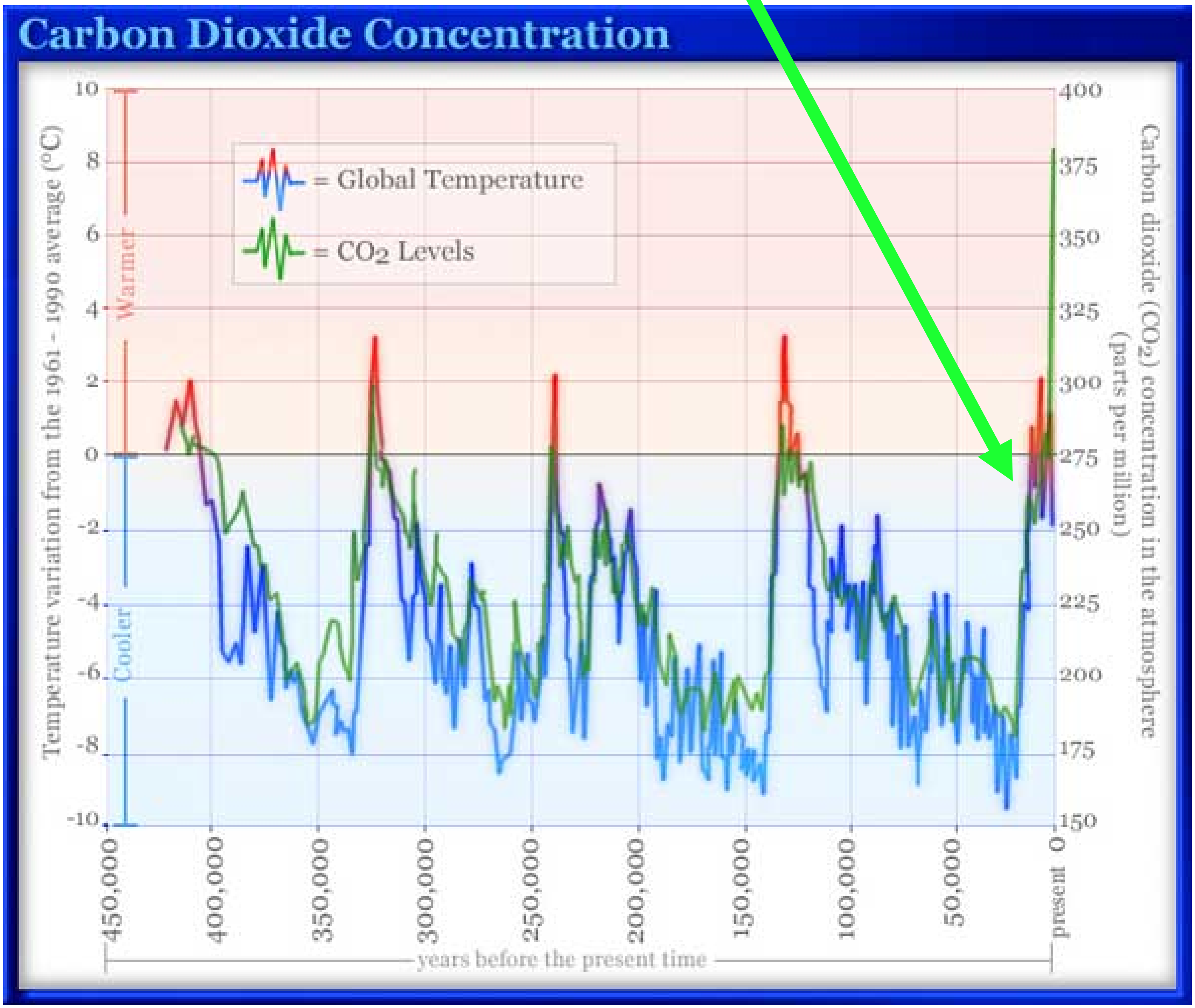
→20,000 years ago was time of Ice Ages. Sea levels were low. Mammoths walked here!

→ Native Americans followed 14,000 years ago!!!!

The start of civilization didn't occur until 10,000 years ago. Why?



The start of a warm and relatively stable climate period!!!

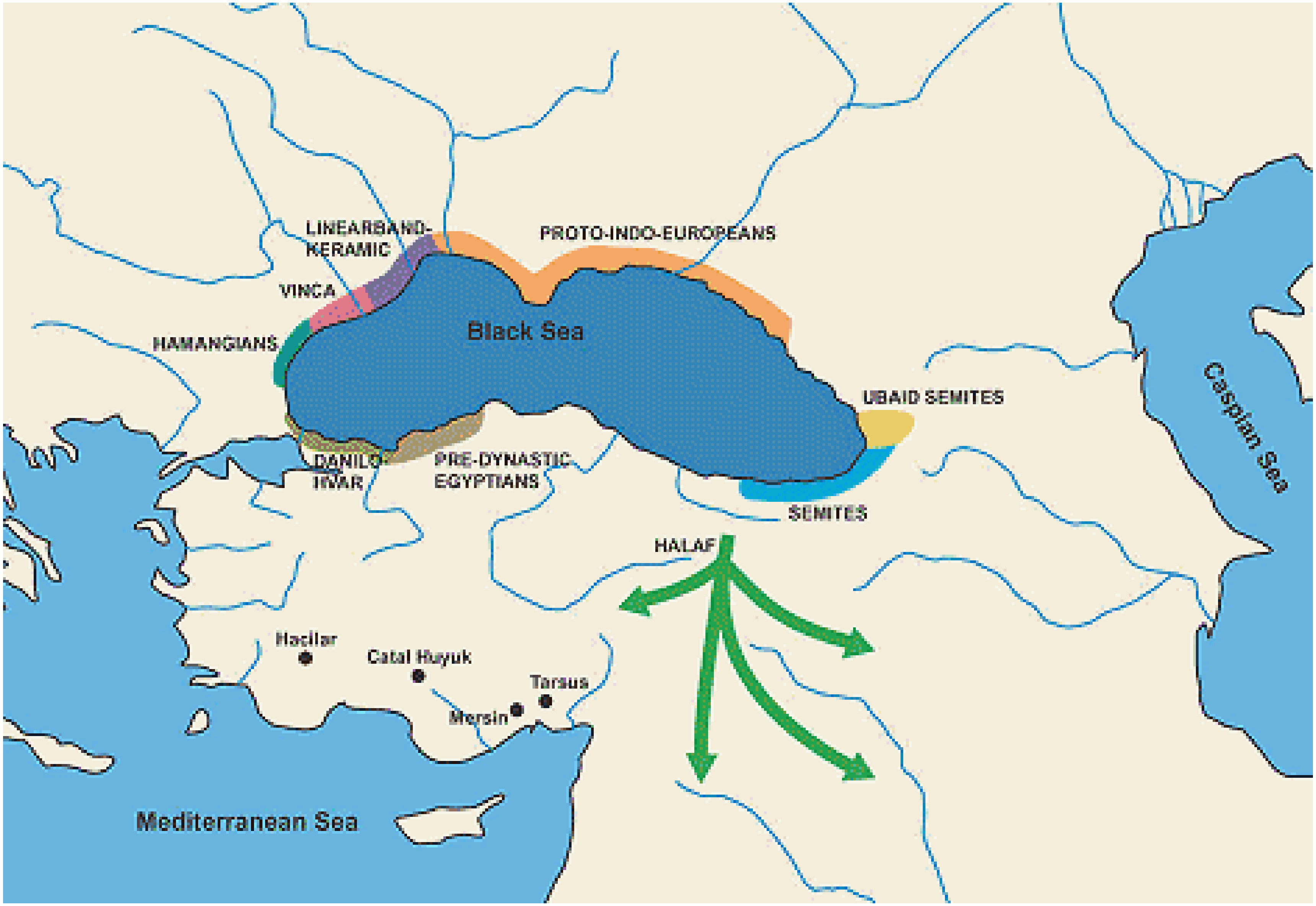


Many cultures have a myth similar to the story of the expulsion from Eden. Why?

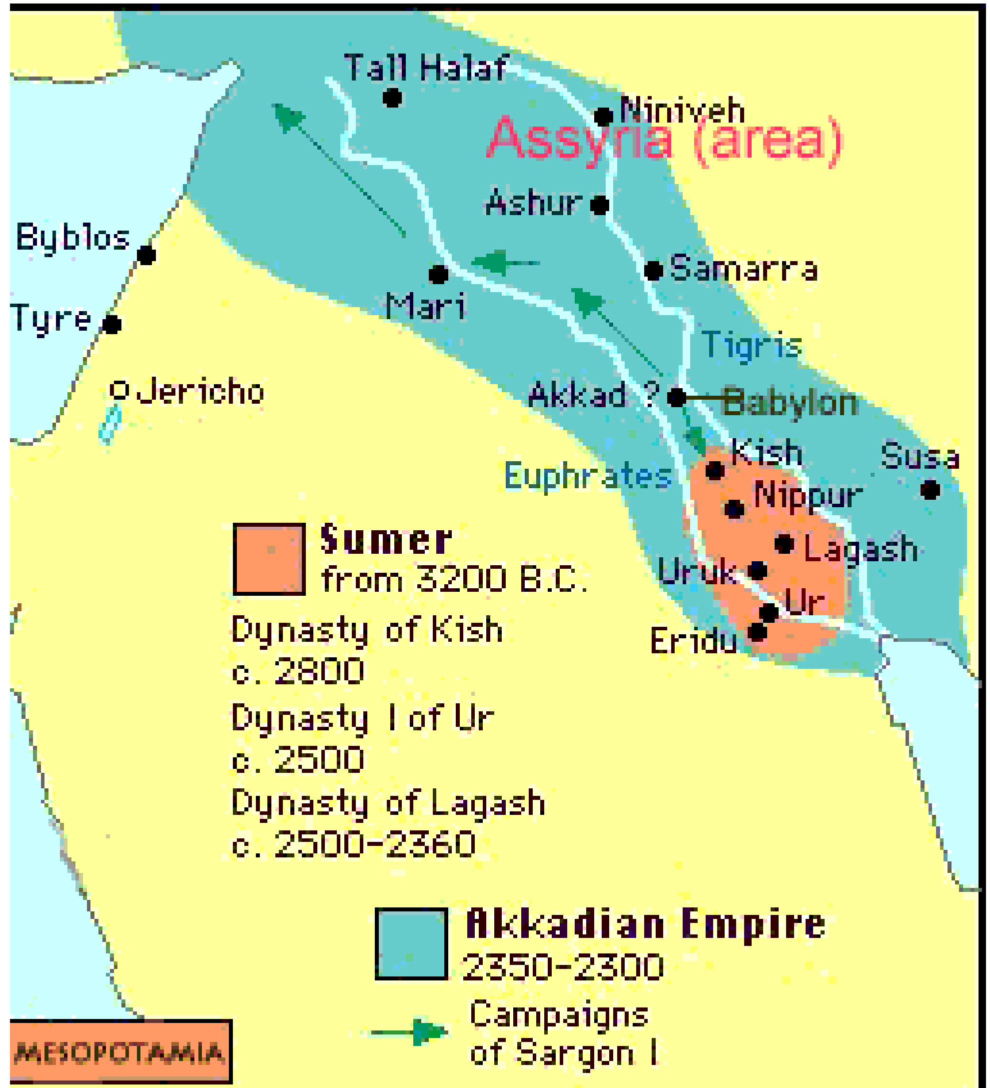
Rising Sea Levels After the End of the Ice Age forced many people from their homelands!!

The Egyptian and Semitic peoples originated in Eastern Europe. Why did they leave?

The Black Sea flooded dramatically 5,600 BCE!!



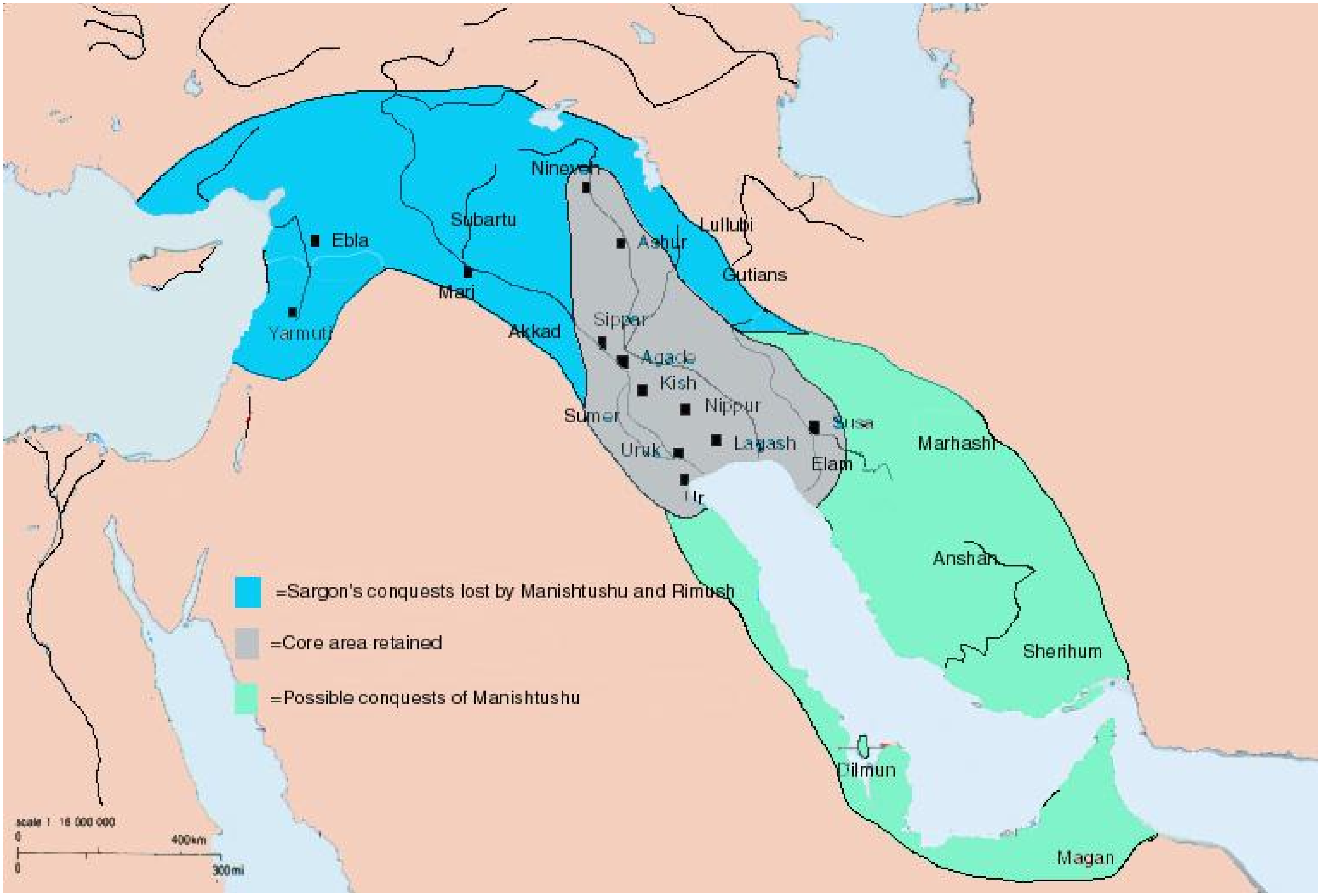
Most of these cultures have similar flood myths!!



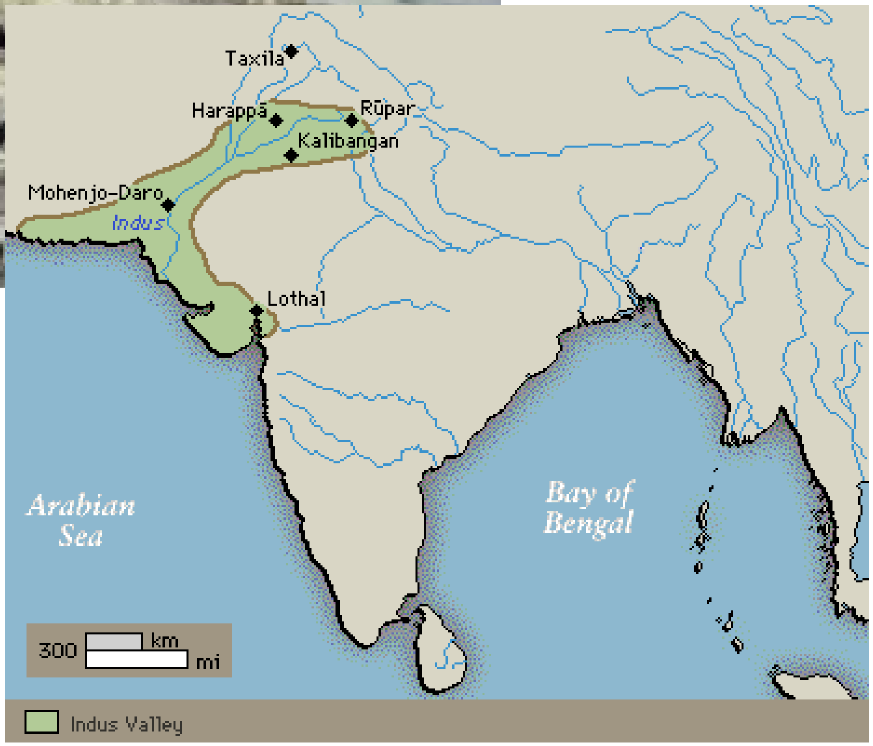
3000 BCE: Time of alternating droughts and flooding.

→ Complex societies like Akkadian Empire evolve in order to survive.

Story of Joseph warning the Egyptian Pharoah to prepare for 7 lean years.



2200 BCE: Period of extended drought causes Akkadian Empire to collapse.

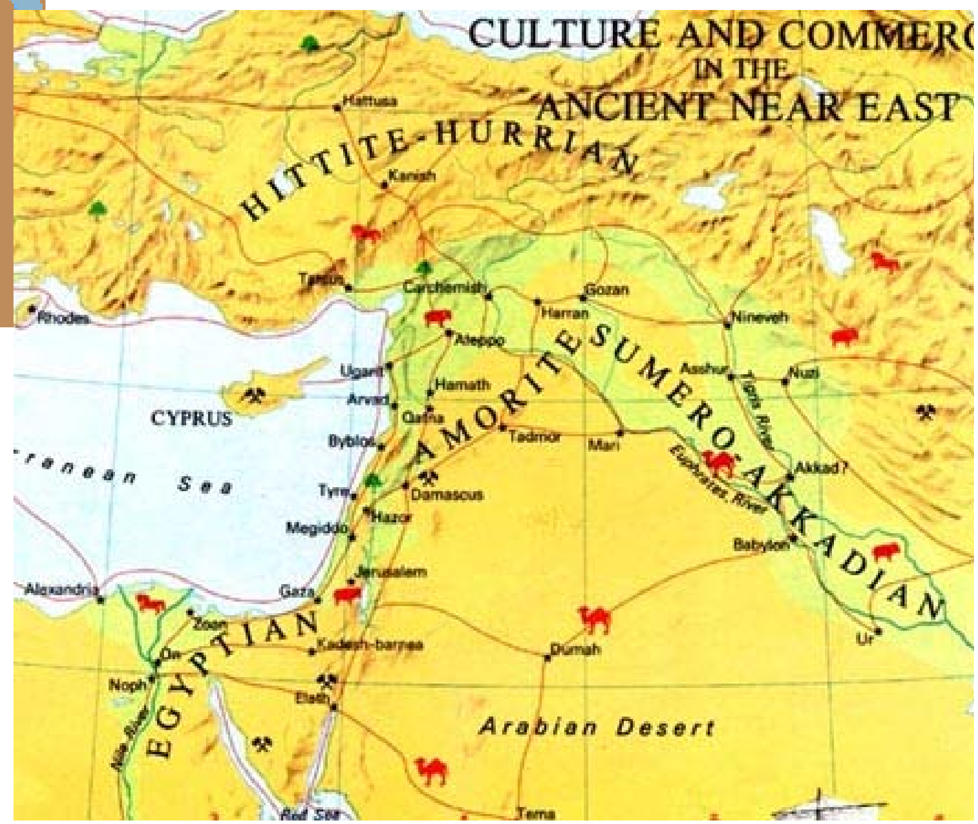


1900 BCE: Cold and dry period.

→ Desertification destroys Indus Civilizations.

1200 BCE: Variable atmospheric circulation patterns hurt agriculture.

→ Mycenean culture collapses.



1200 BCE: Variable atmospheric circulation patterns hurt agriculture.

→ Also causes mass migrations of Phrygian and Hittite peoples.

Alexander the Great

500-400 BCE: North Atlantic thermohaline circulation shuts down.

→ Colder temperatures in Europe cause more southward migrations. Macedonians overrun Greece.

300 BCE: Warming period in Asia.

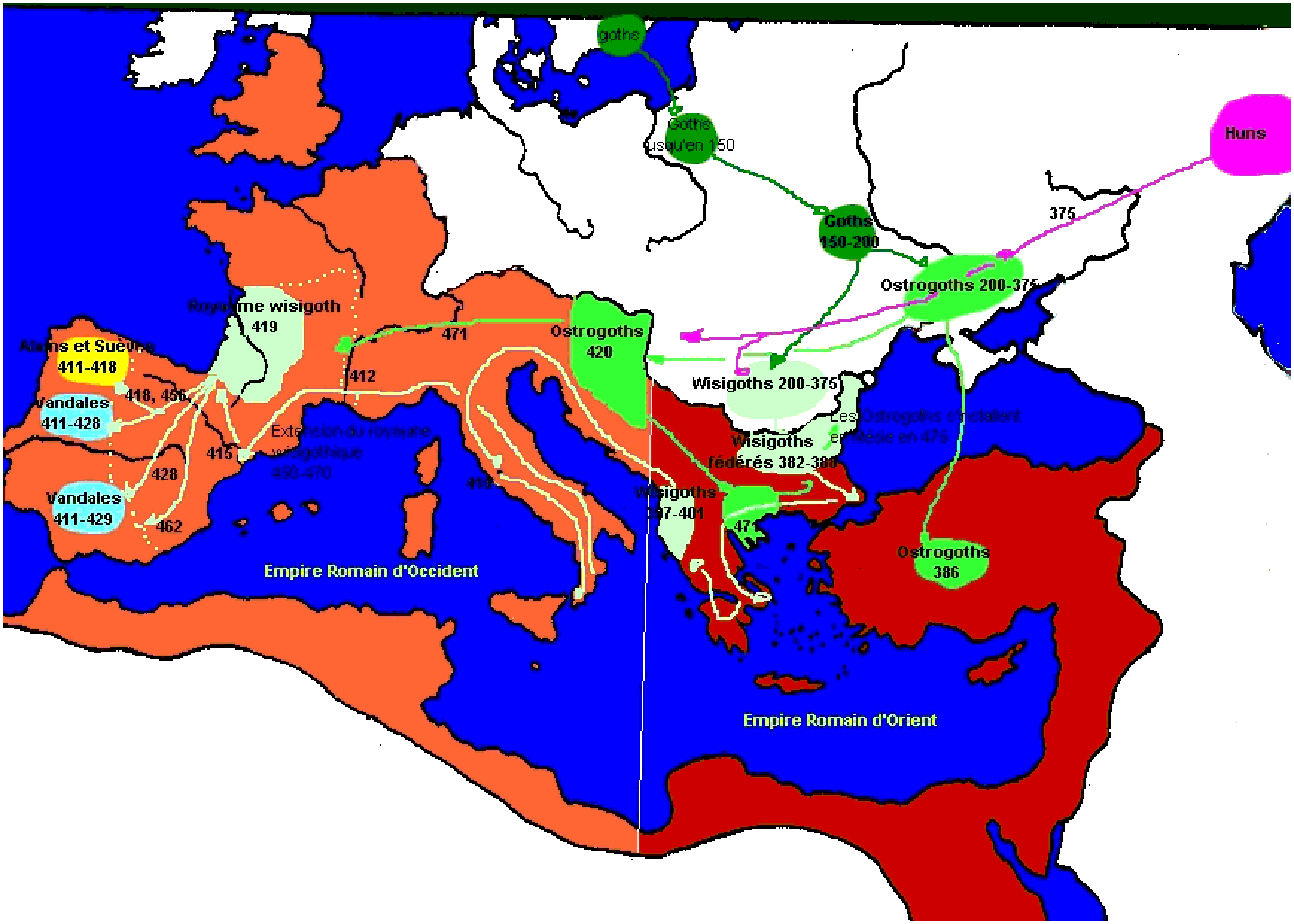
→ Opening of the “Silk Route.”

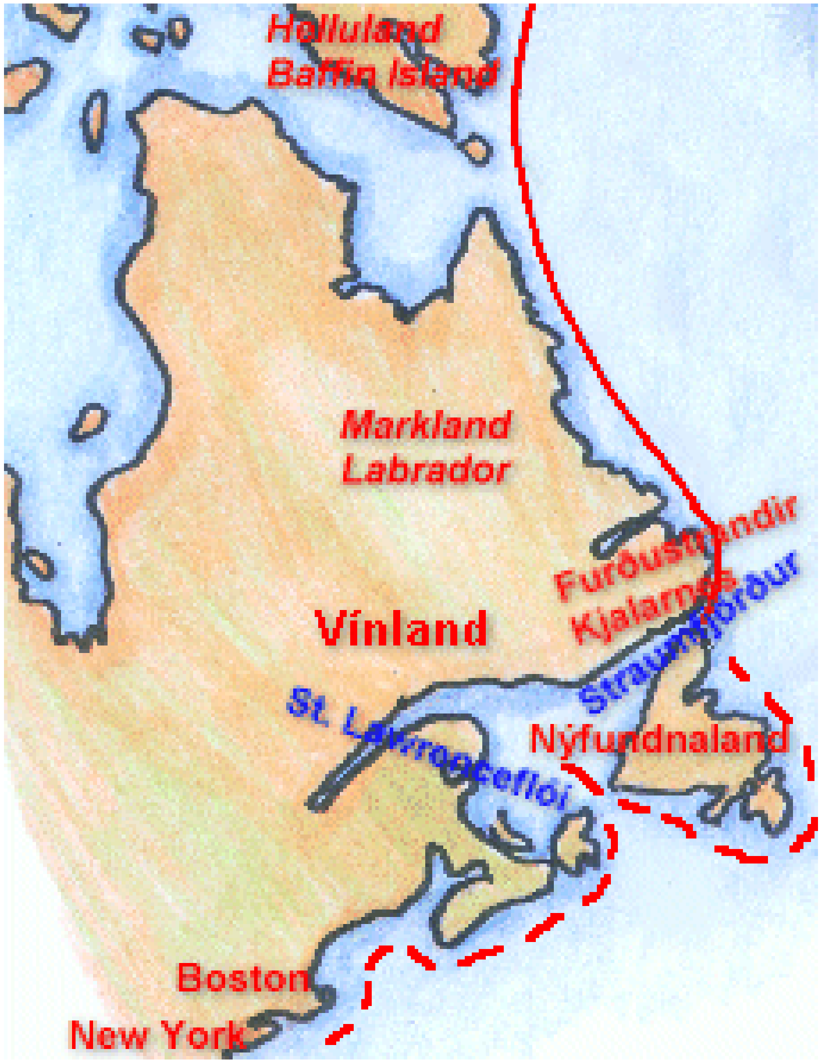
0 – 100 AD: Stable temperatures allow Roman Empire to thrive. Empire = >60 million people. Rome = >1 million.

So…why did Rome collapse?

400-500 AD: Cold spell; prolonged freezing.

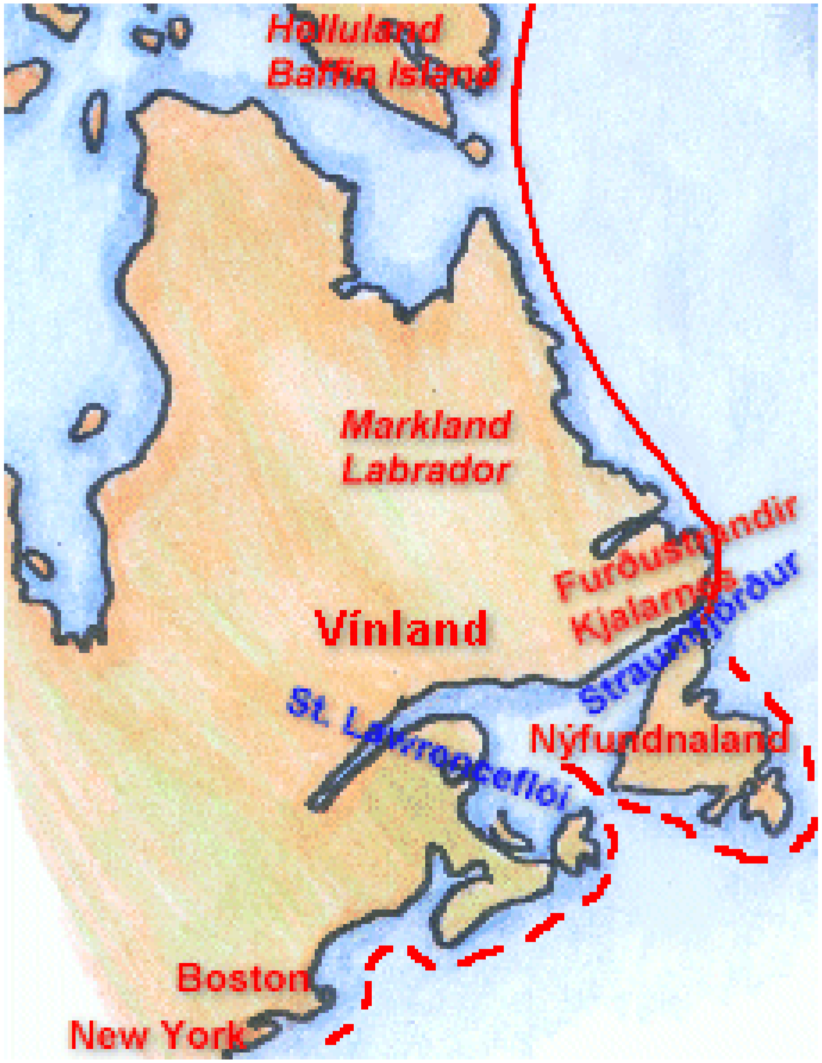
→ Southward migration of Northern Europeans






Leif Ericson's Vessel

Why is Leif Ericsson able to sail to America?



Leif Ericson's Vessel

Why is Leif Ericsson able to sail to America?

950-1300 AD: Warm and dry period

950-1300 AD: Warm and dry period
→ Mayan culture collapses

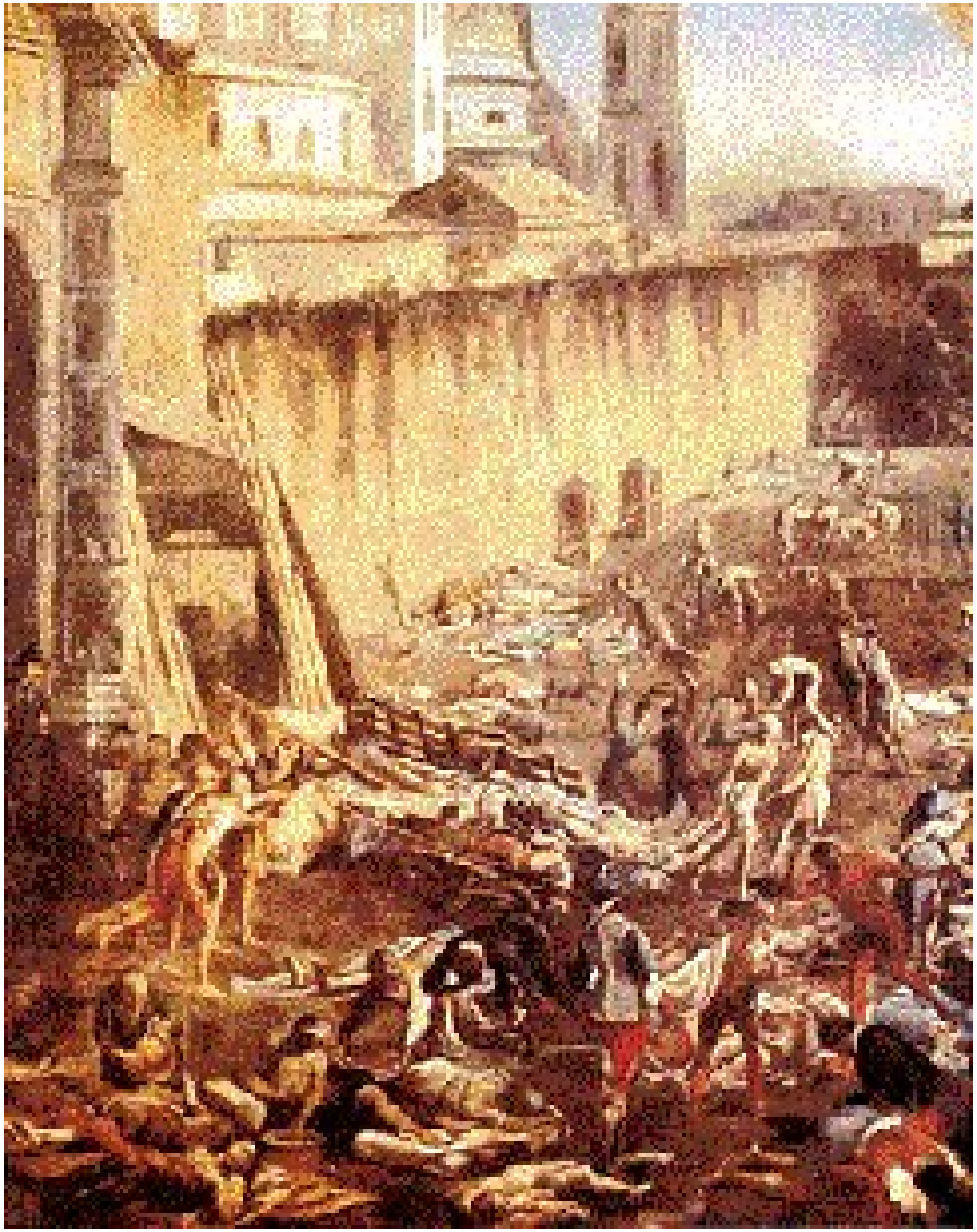
950-1300 AD: Warm and dry period
→ American Southwest cultures like the one at Chaco Canyon collapse. Anasazi peoples disappear.

Why does the plague strike in the 1300s?

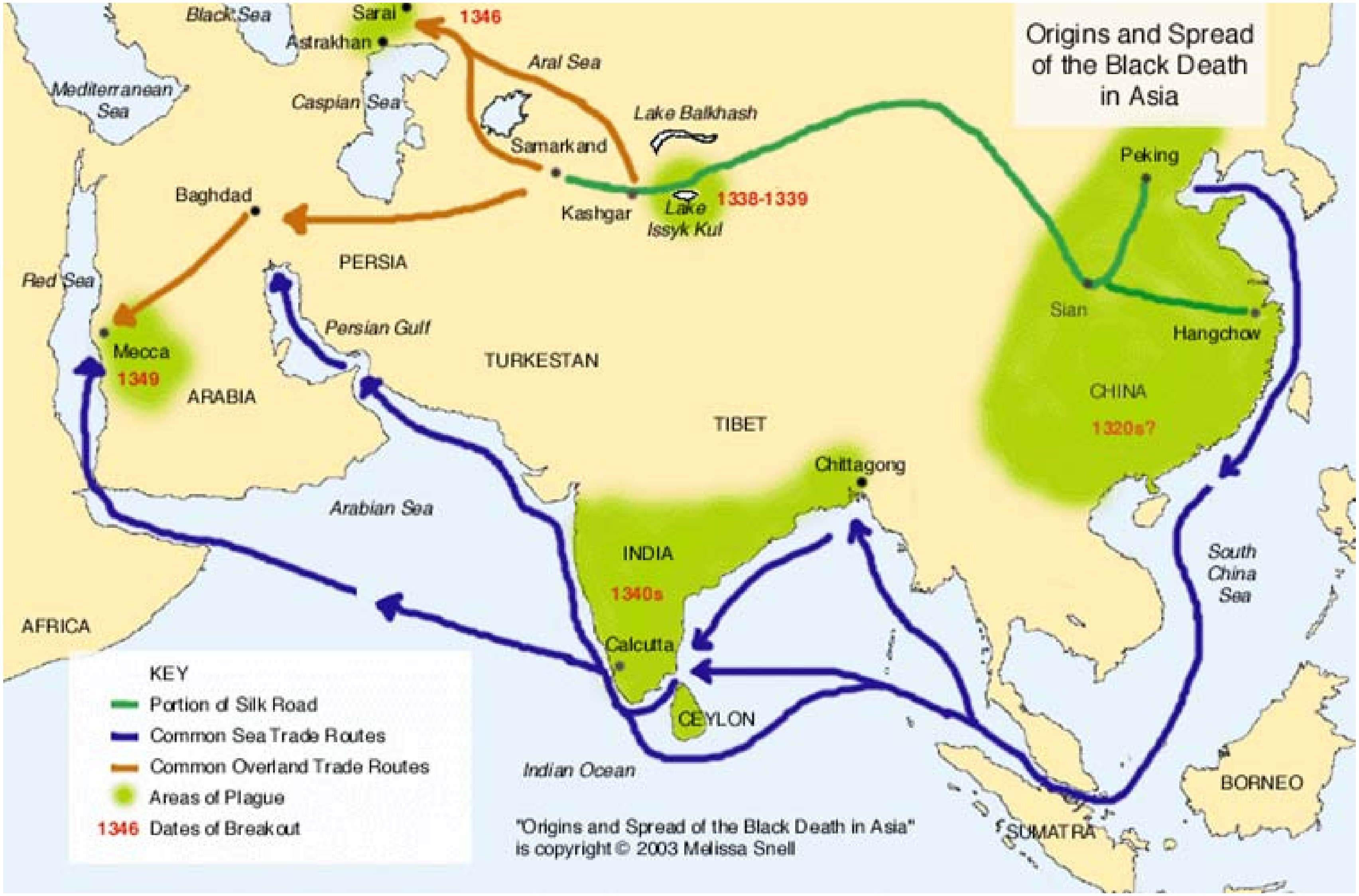
1300 AD: Cold spell due to a minimum in solar activity

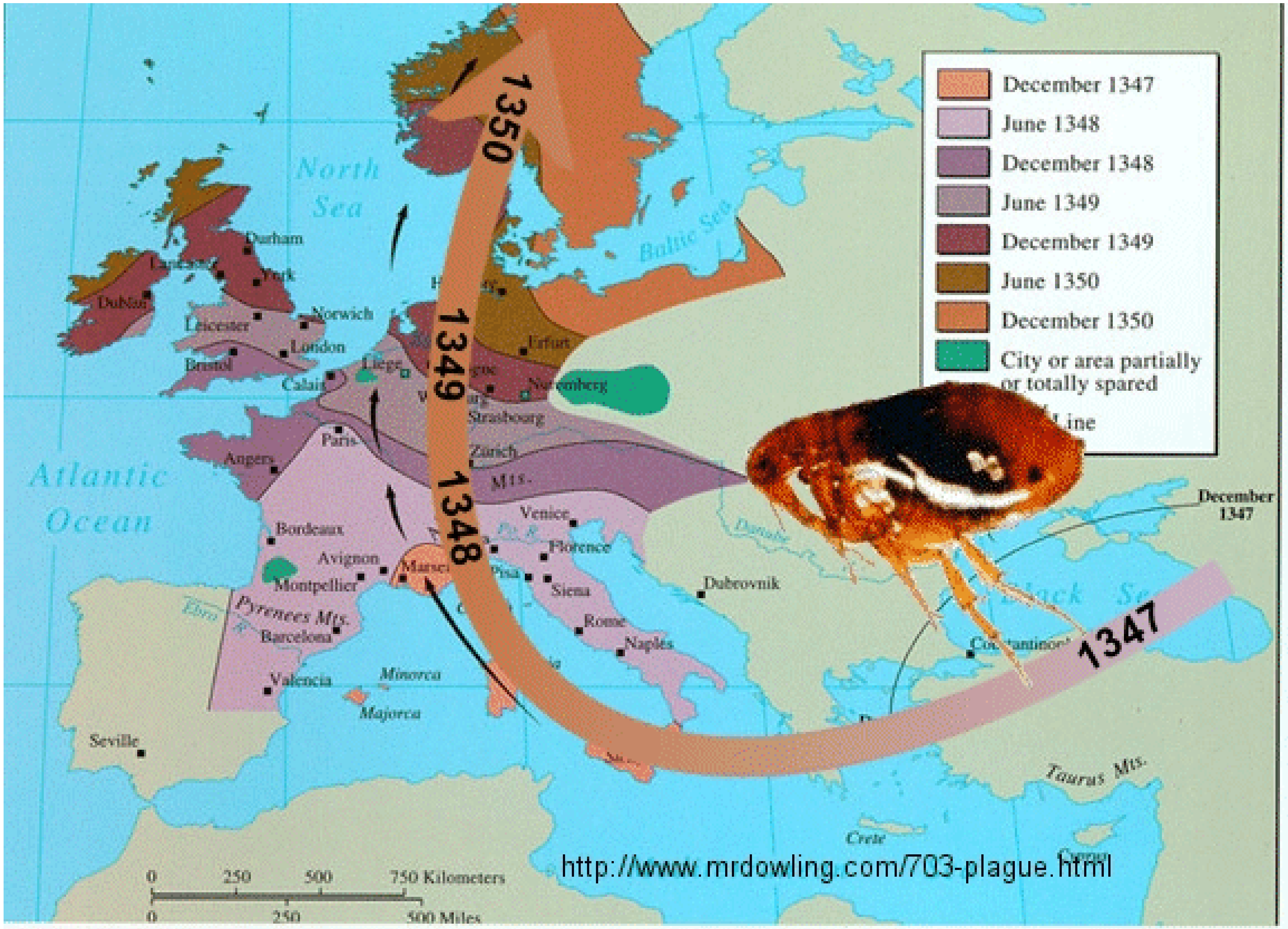
→Great famine of 1315-1317

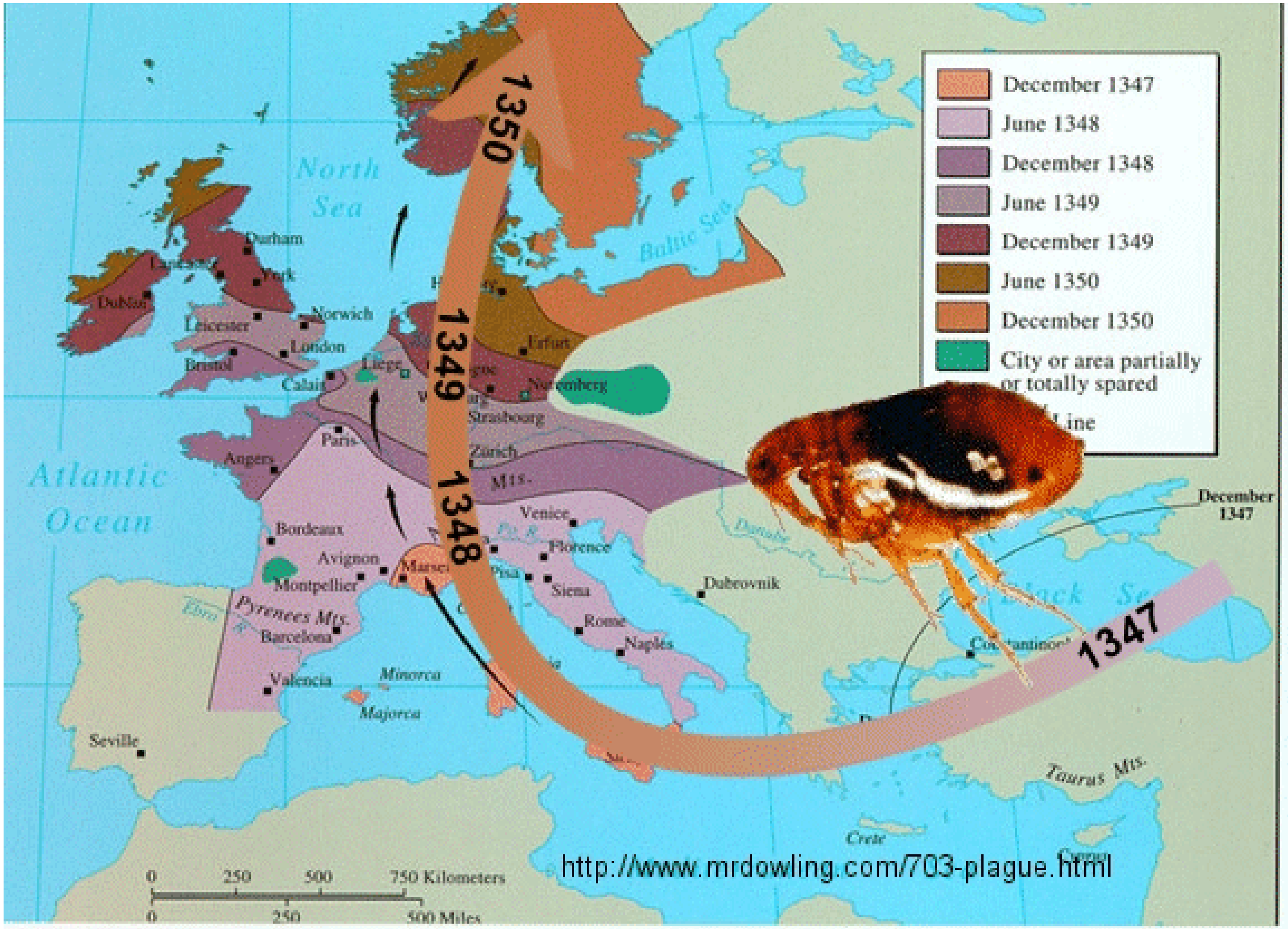
→Black Death, 1345



Begins with flooding in China. More than 7 million drown in Yangtze River.

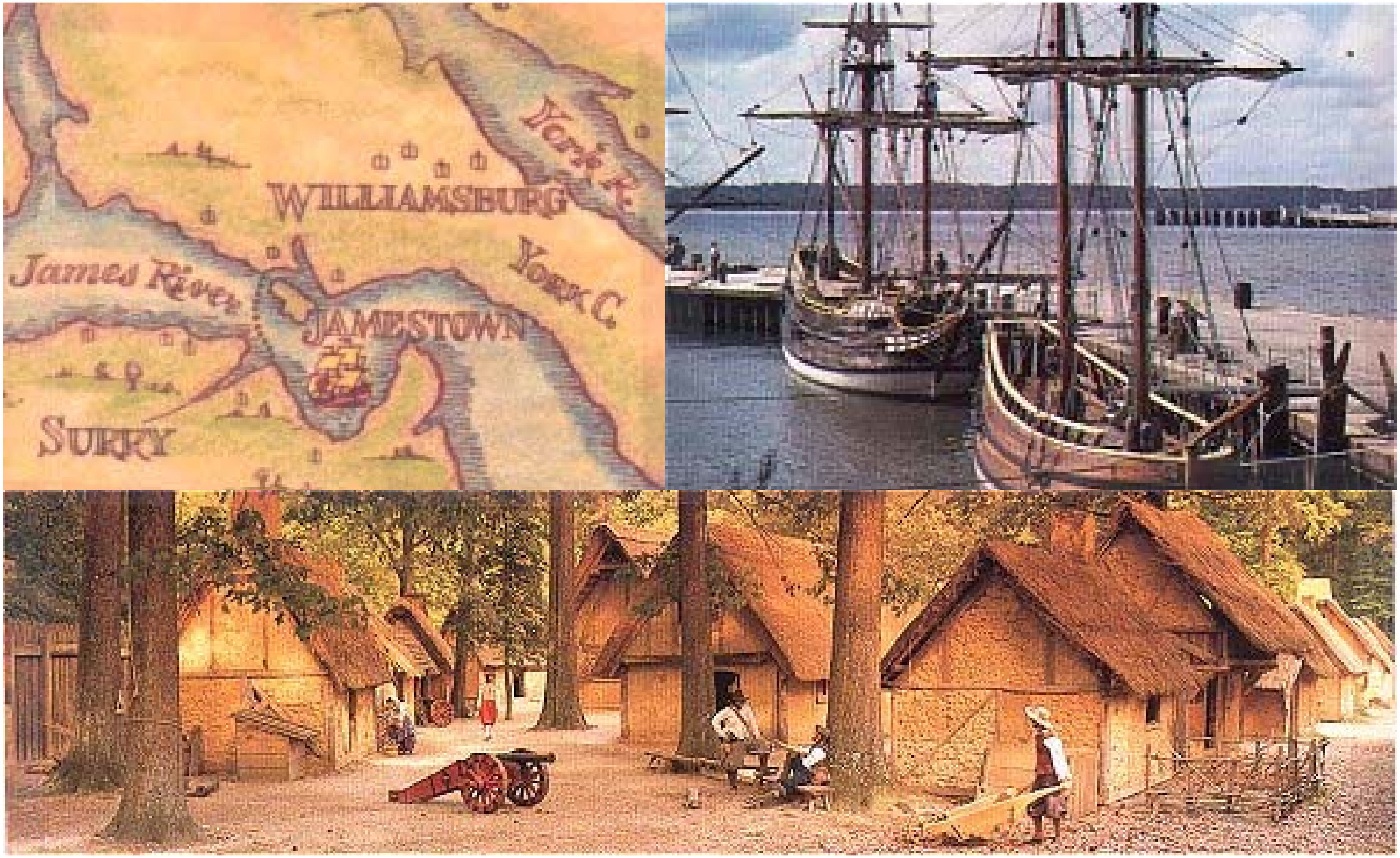



December 1347
June 1348
December 1348
June 1349
December 1349
June 1350
December 1350
City or area partially or totally spared
1350
1349
1348
1347
North Sea
Baltic Sea
Atlantic Ocean
Durham
York
Dublin
Norwich
Leicester
London
Bristol
Calais
Erfurt
Strasbourg
Zurich
Paris
Angers
Venice
Bordeaux
Avignon
Florence
Montpellier
Pisa
Siena
Dubrovnik
Pyrenees Mts.
Rome
Barcelona
Naples
Valencia
Minorca
Majorca
Seville
December 1347
Taurus Mts.
Crete
0 250 500 750 Kilometers
500 Miles
http://www.mrdowling.com/703-plague.html



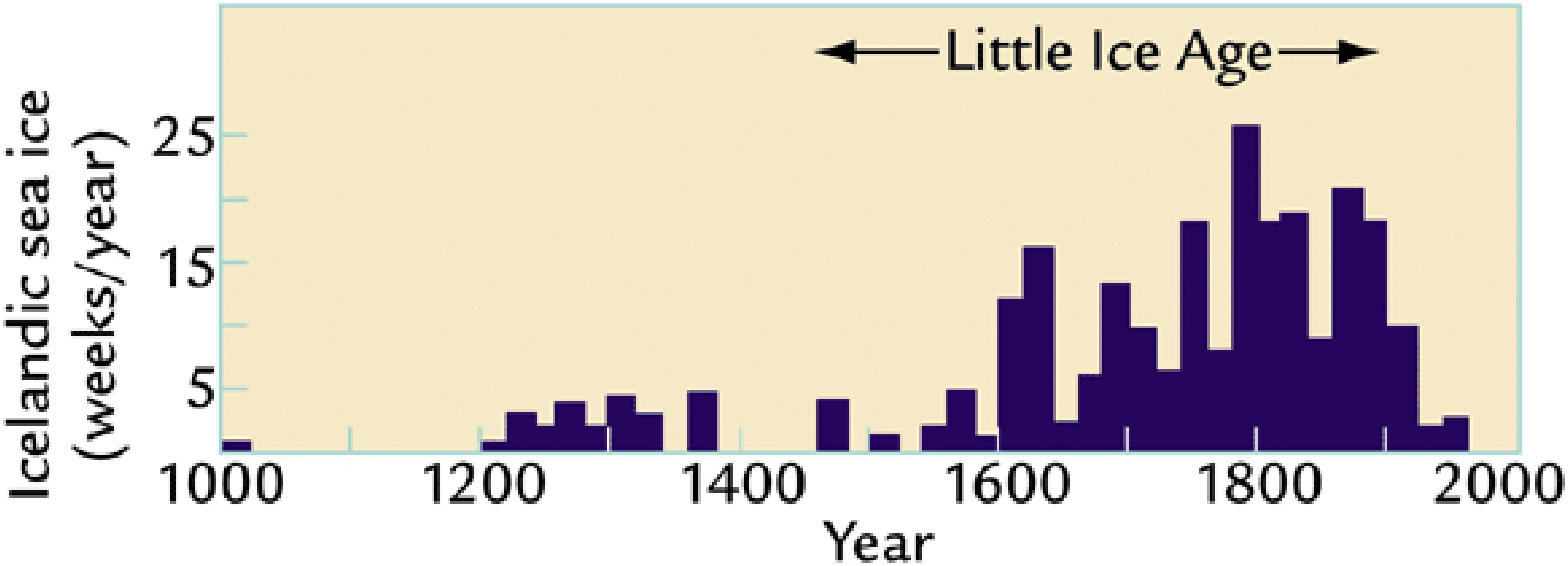
Plague returned in 1563, 1578, 1593, 1603, 1625, 1636, and 1665.

The 1563 outbreak in places like England was worst than for the Great Plague.



Late 1500's: Mega-droughts in North America

→ May have led to demise of Jamestown Colony, 1587-89.

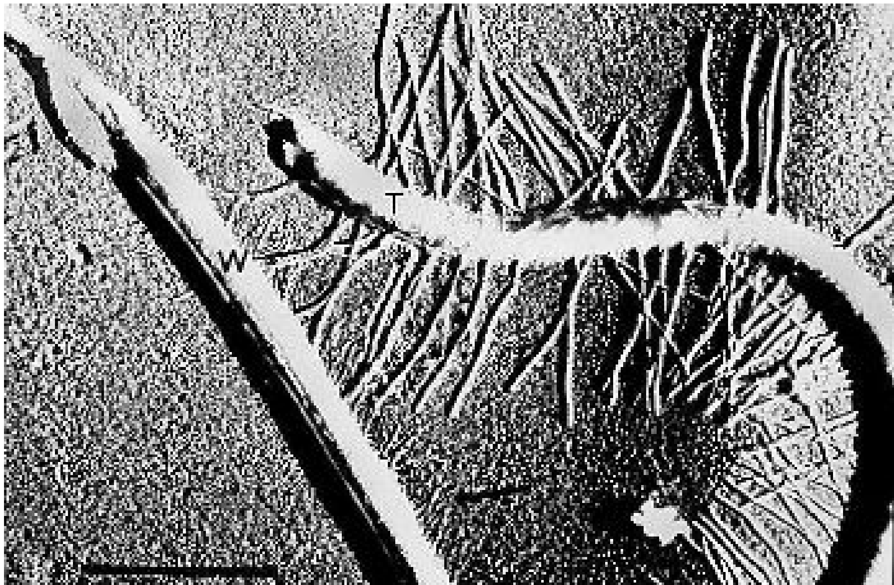


1550-1850: Little Ice Age

→ Maunder minimum (1645-1715) – period of depressed solar activity

→ Eskimos land in Scotland (1690).

→ Scots emigrate to Ireland.



DESTITUTION IN IRELAND. —

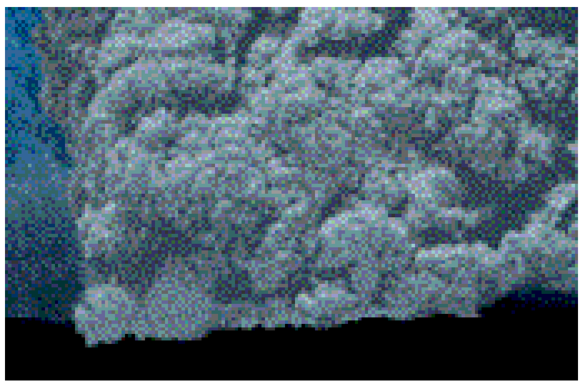
1840s: Increased warming and rains in Europe

→ Led to potato blight in Ireland. Huge migration to America.

After 1815 there is a huge push of U.S. Westward Expansion. Why?

1816 is known as the “Year without a summer.”

It snows in New England in the summer.

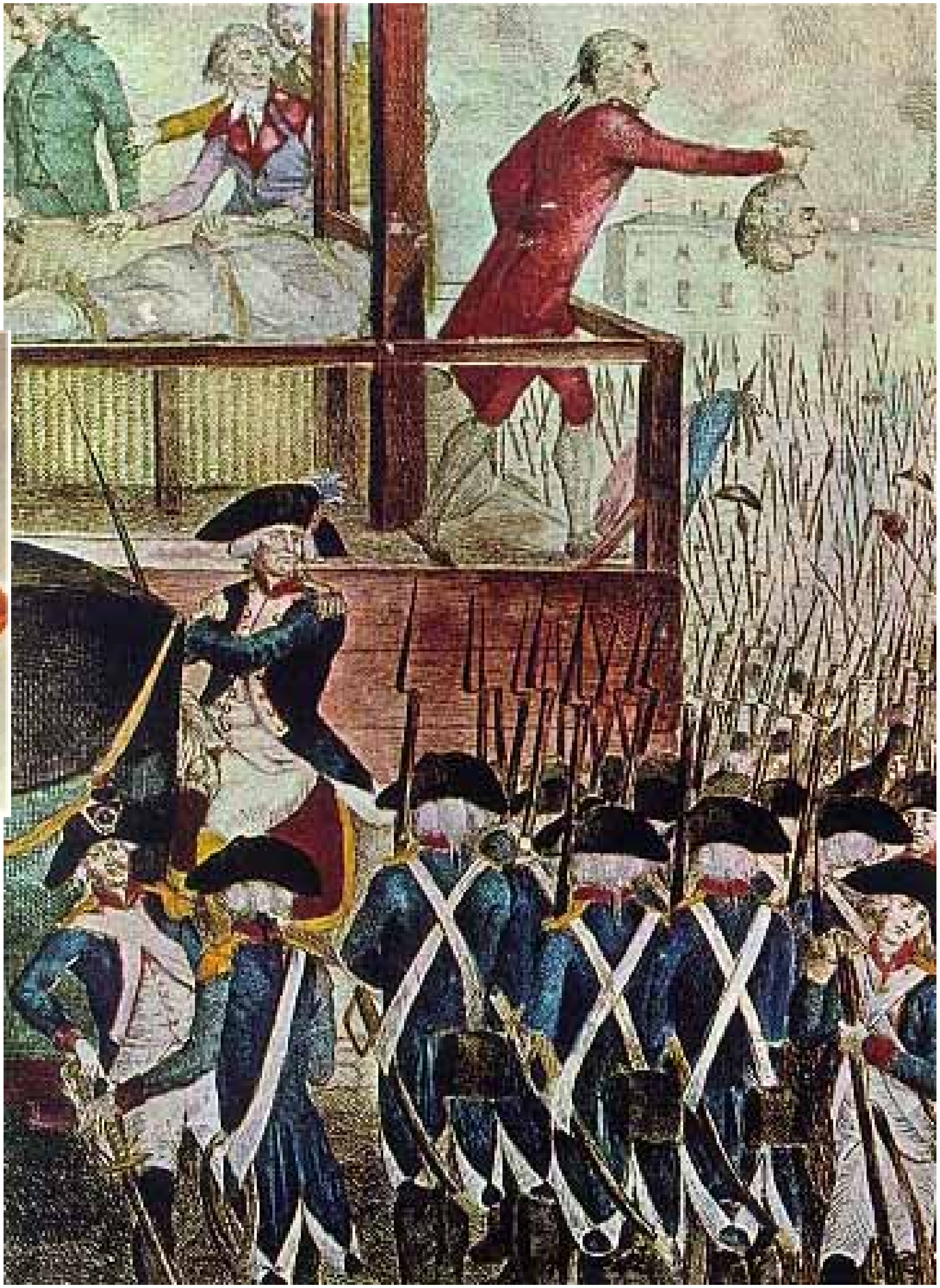


Volcanoes!

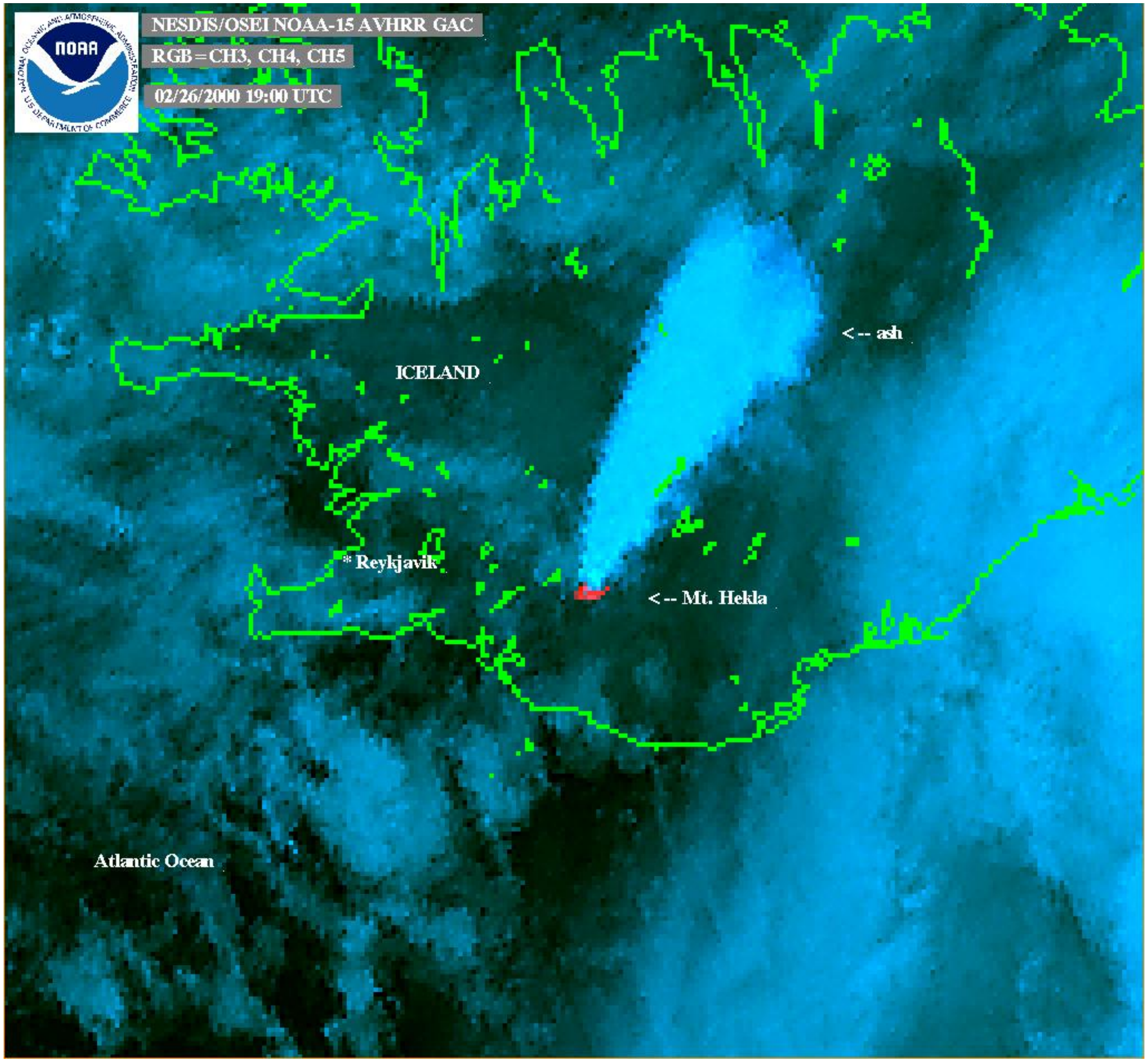
1812: Soufriere volcano, St. Vincent Island

1814: Mayon volcano, Philippines

1815: Tambora volcano, Indonesia



Why does the French Revolution occur in 1789?



1783: Hekla volcano, Iceland; Asama volcano, Japan

Last 10,000 years: VERY warm AND stable!!

. Variations in Earth's average surface temperature, over the past 20,000 years