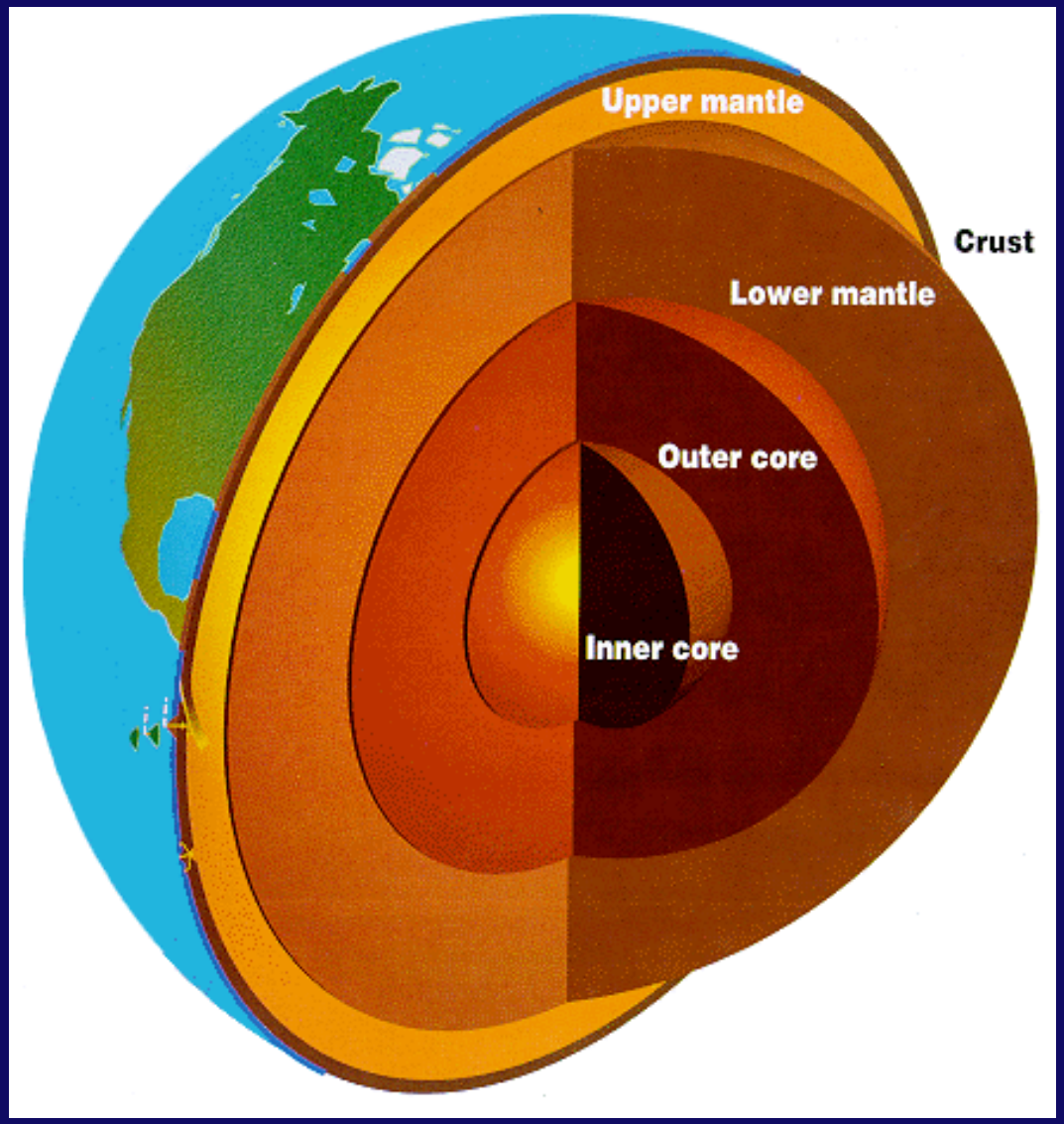
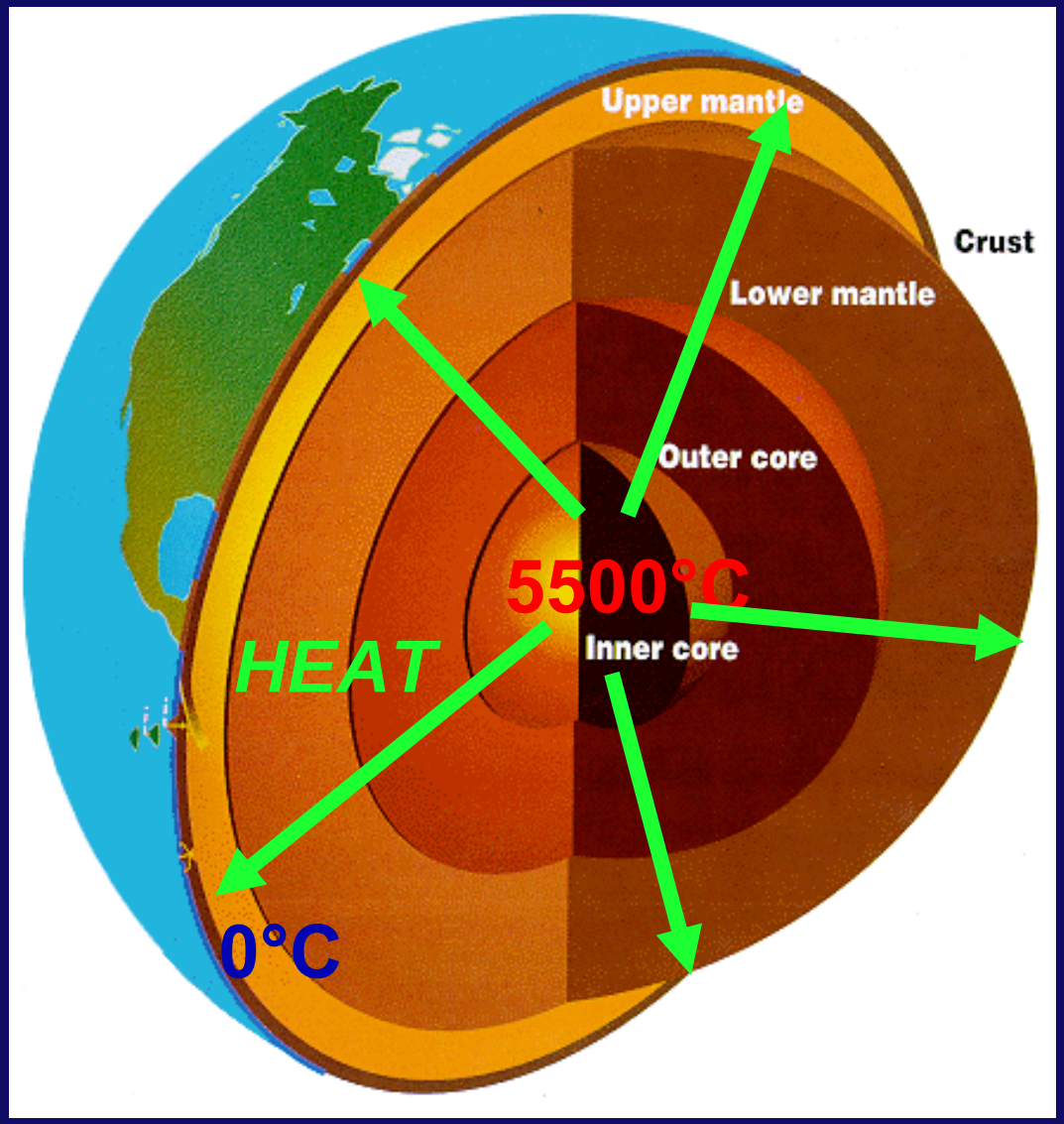
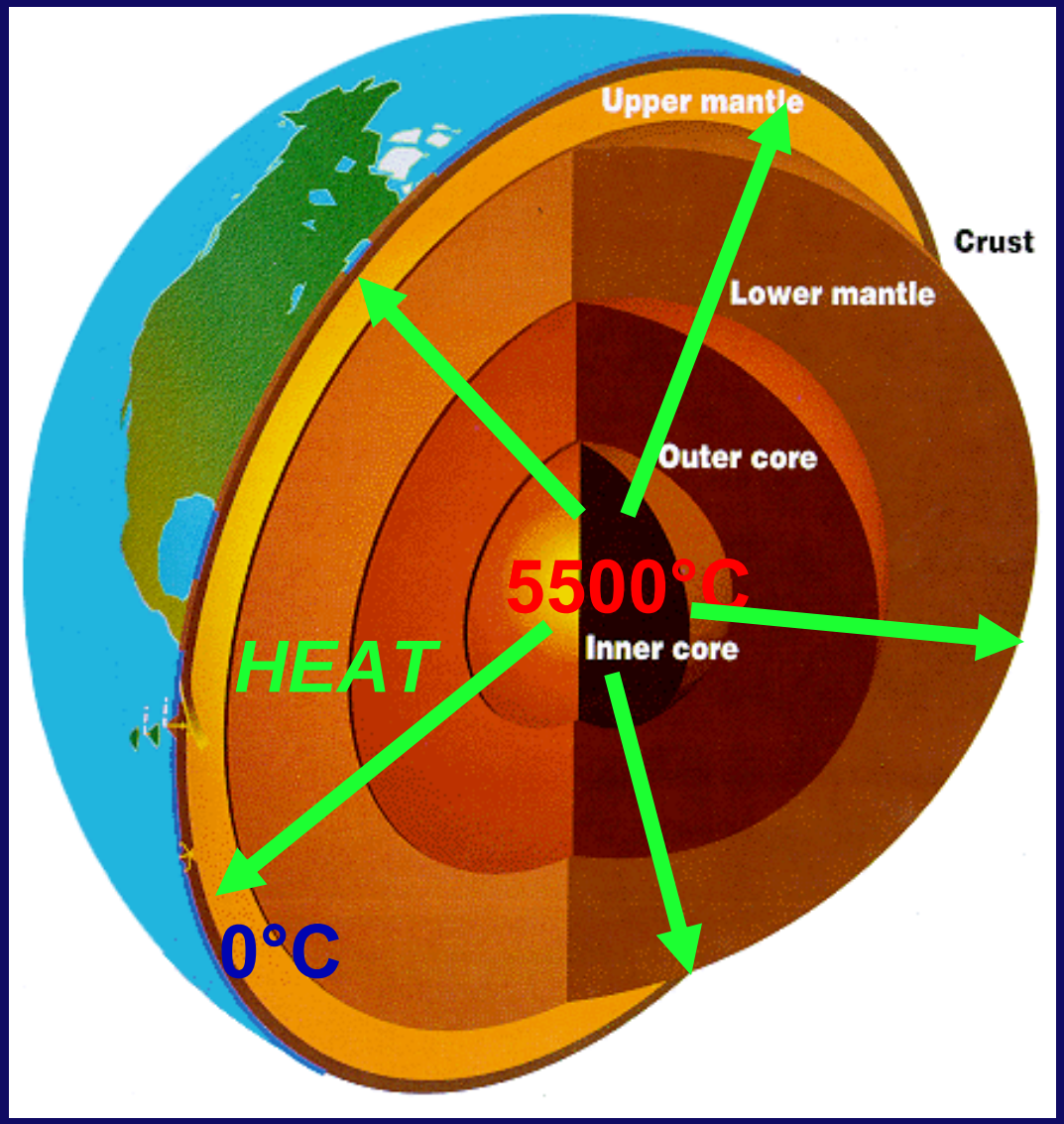

Upper mantle
Crust
Lower mantle
Outer core
Inner core


Upper mantle
Crust
Lower mantle
Outer core
5500°C
Inner core
HEAT
0°C

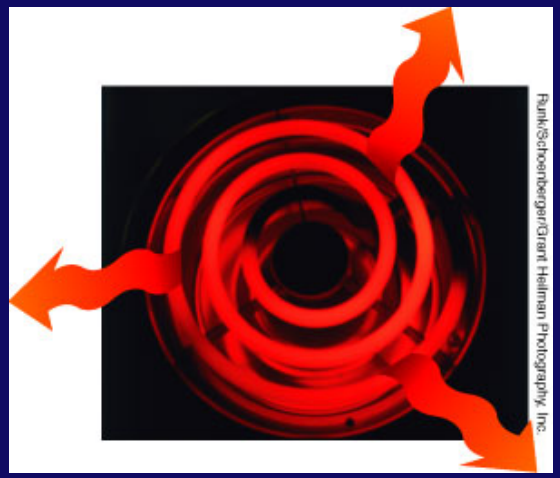
Heat flows *Dramatically* outward from Earth's Interior

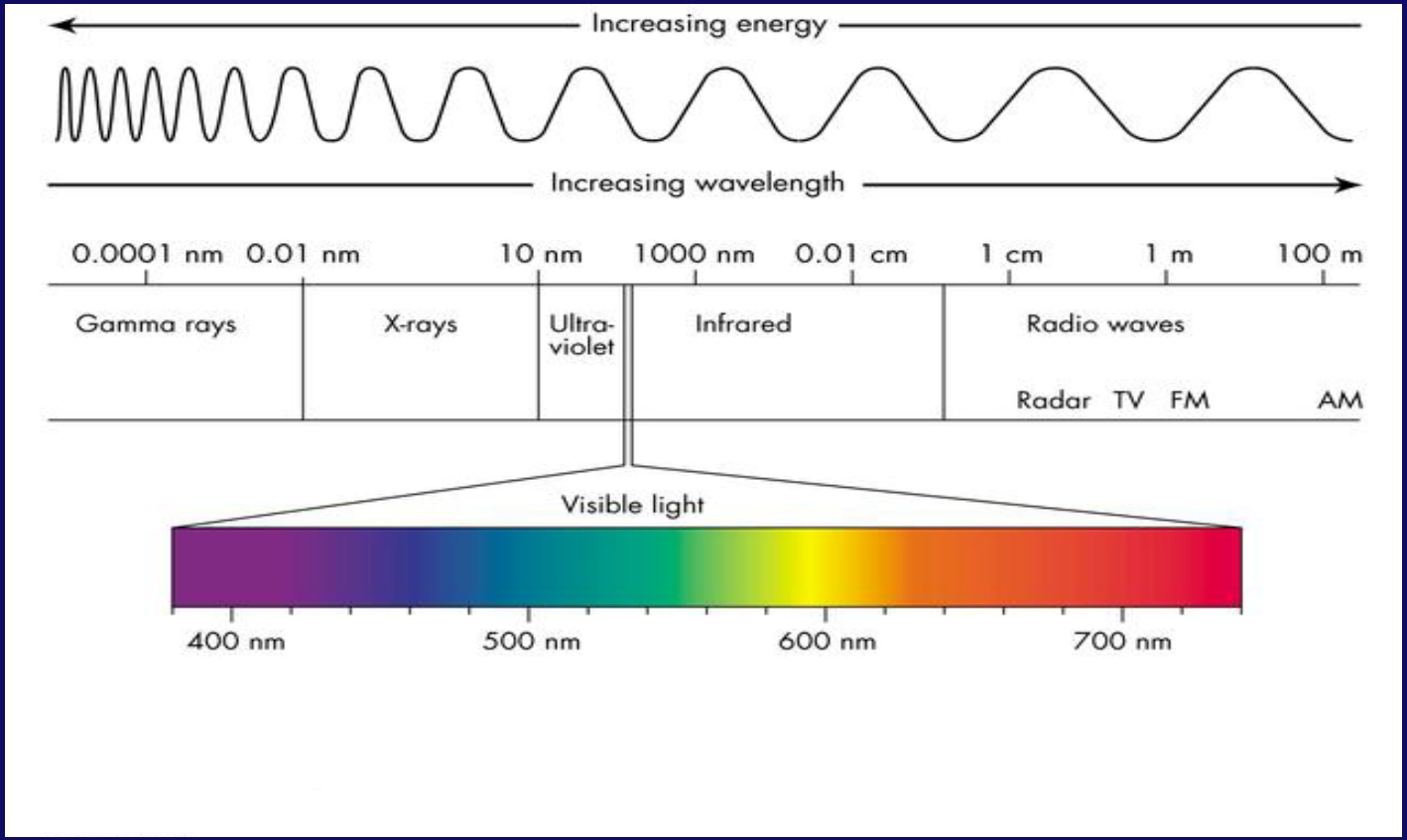


How it happens shapes the whole planet's history.

The 3 means of heat flow:

1. Radiation





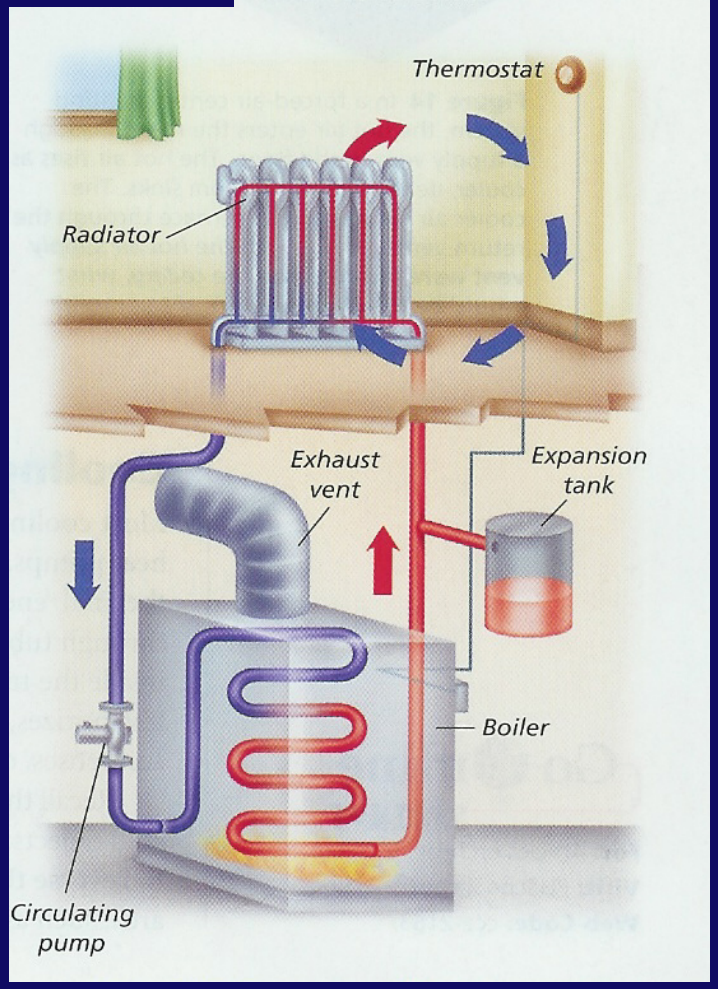
The 3 means of heat flow:

1. Radiation
2. Conduction

The 3 means of heat flow:

1. Radiation
2. Conduction
3. *CONVECTION*

Figure 13 Within the pipes of this hot-water heating system, the water circulates in a convection current. In each room, the air moves in a convection current. **Relating Cause and Effect** ***Why has the water returning to the boiler cooled down?***



Hot-water Heating

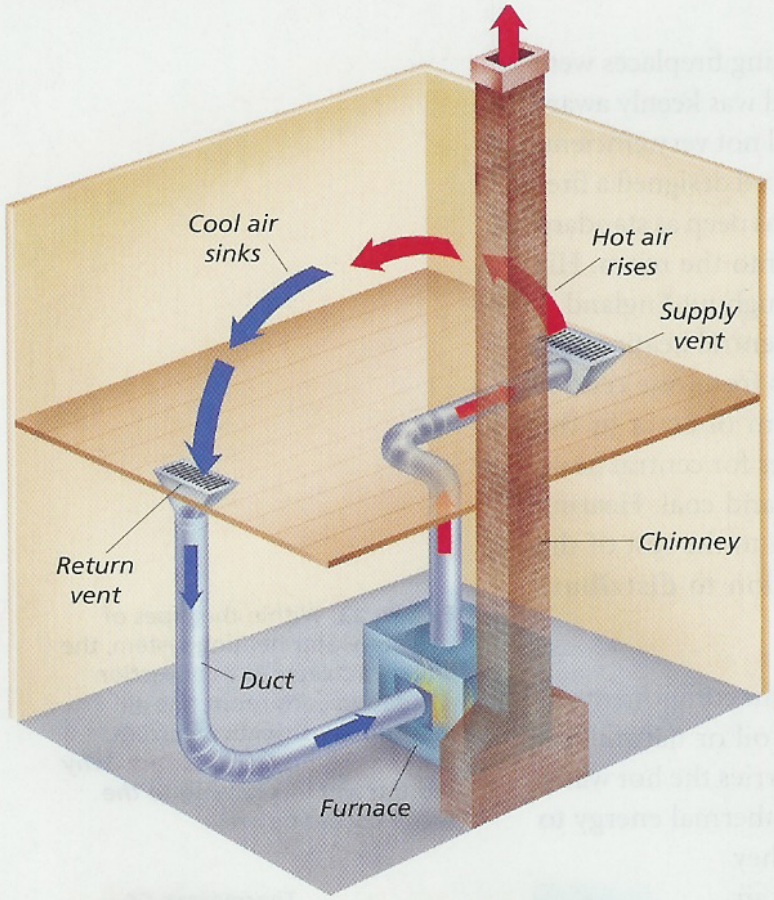


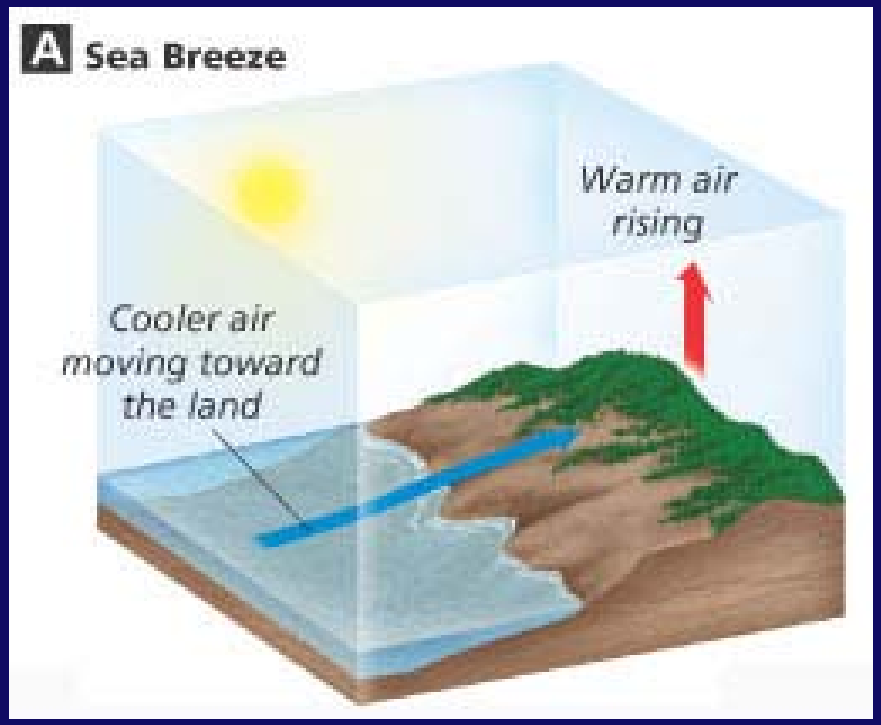
Figure 14 In a forced-air central heating system, the hot air enters the room through a supply vent in the floor. The hot air rises as cooler, denser air in the room sinks. The cooler air returns to the furnace through the return vent. **Inferring** ***If the hot air supply vent were located near the ceiling, what would be the warmest part of the room?***

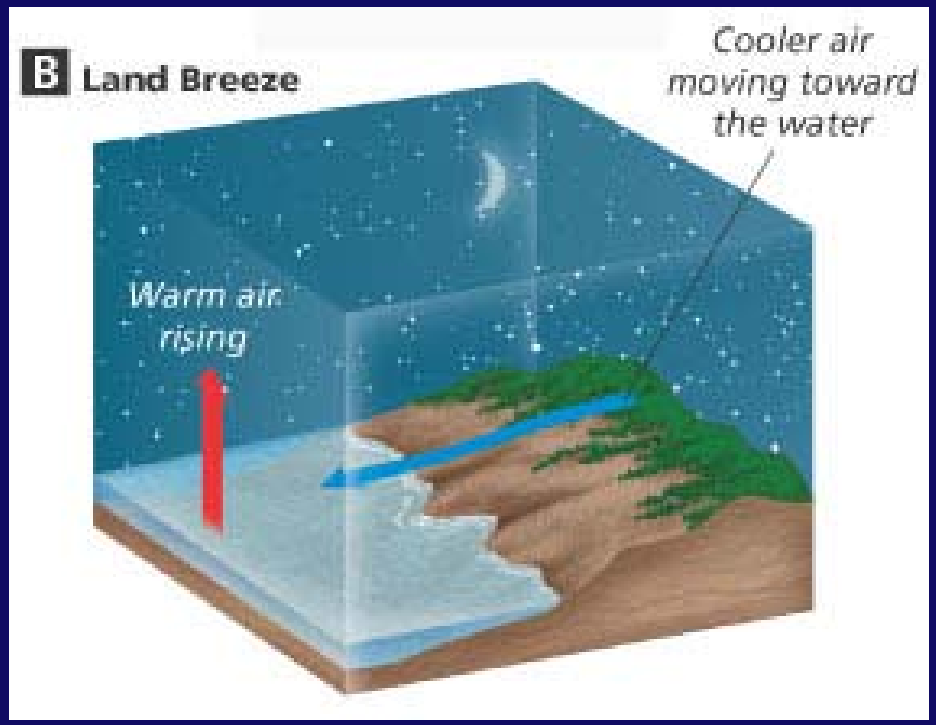
Forced-Air Heating

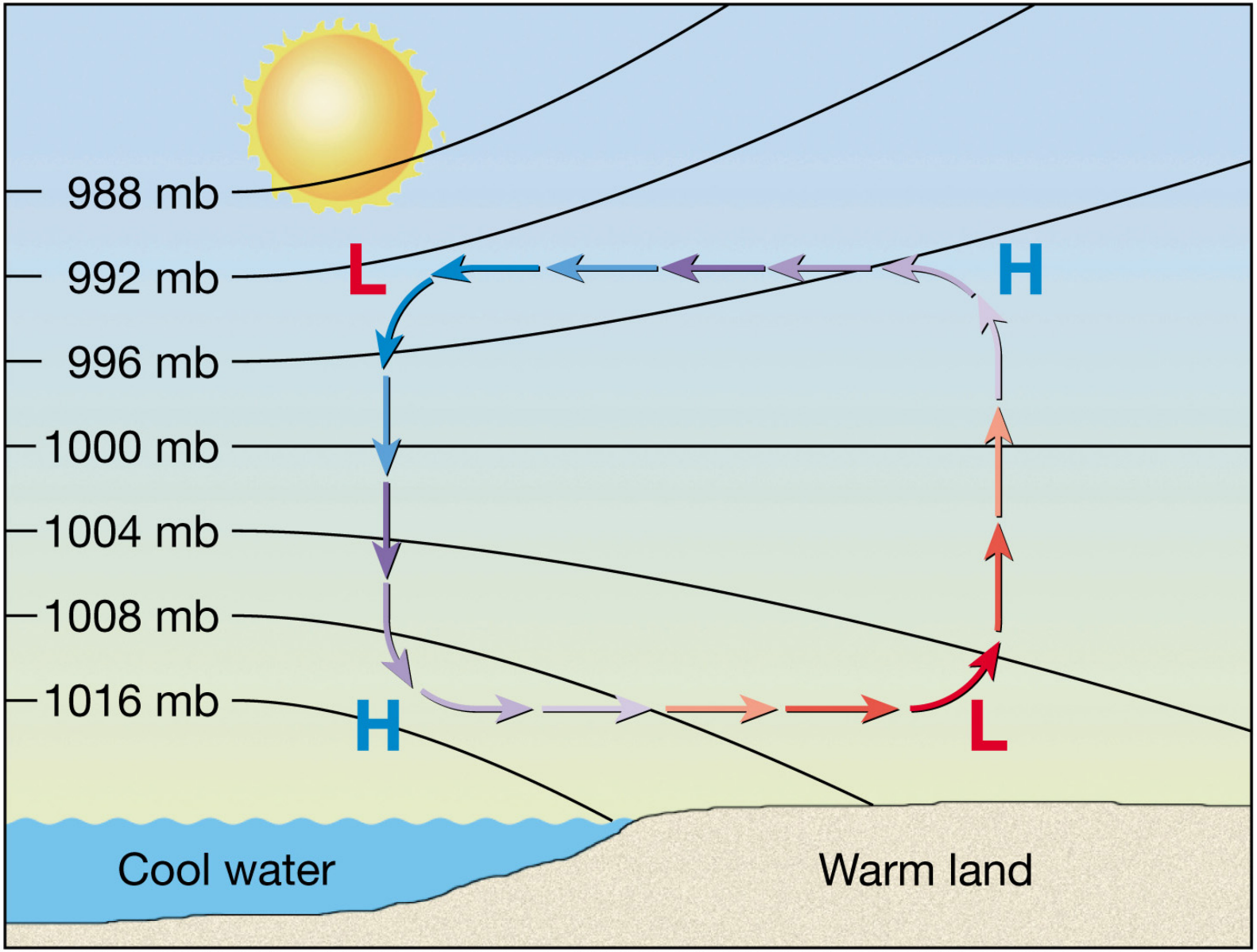
Picture yourself at the shore, with a nice breeze blowing.

Is the air salty or not?

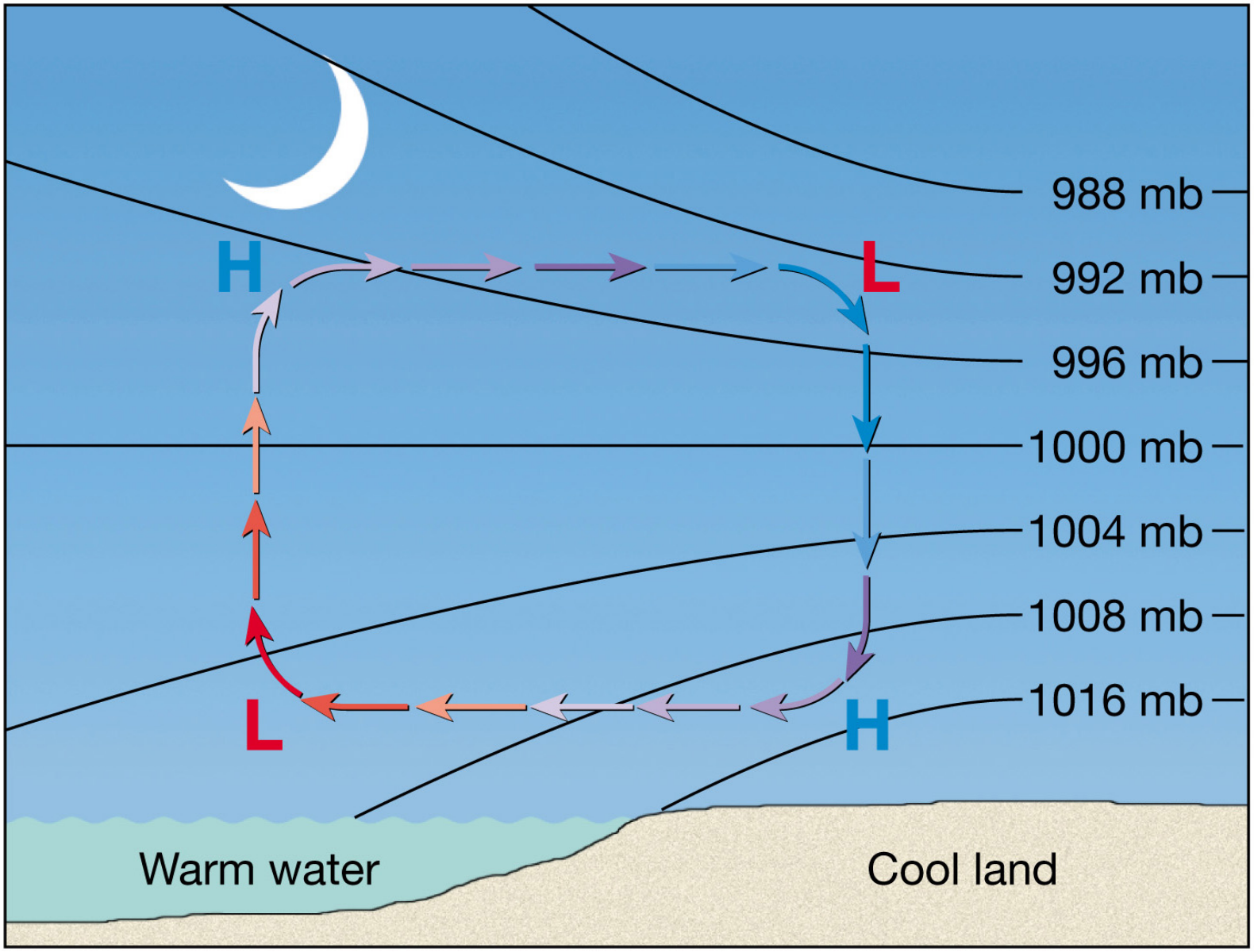
It Depends on the Time of Day!!!






988 mb
992 mb
996 mb
1000 mb
1004 mb
1008 mb
1016 mb
L
H
H
L
Cool water
Warm land

A. Sea breeze

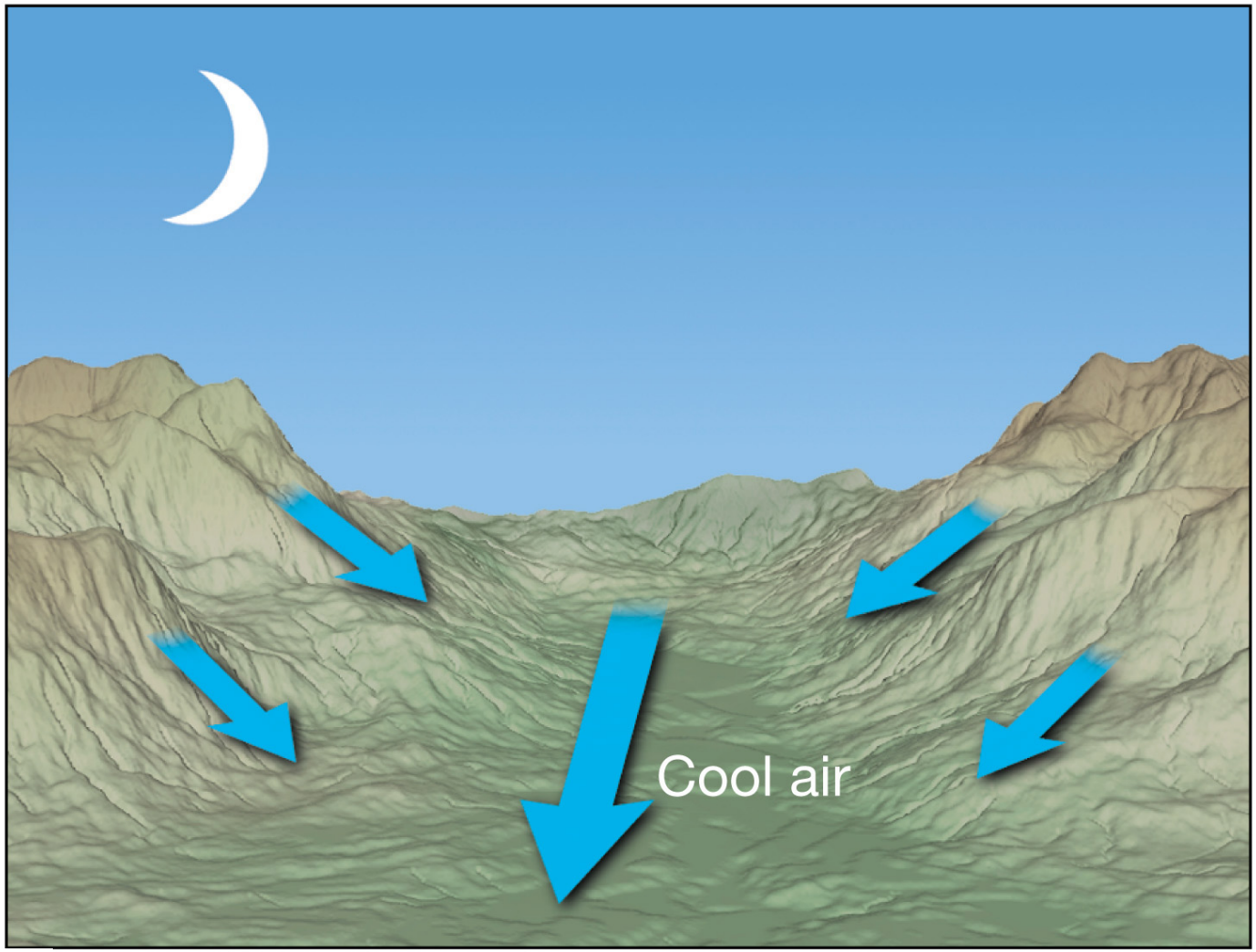


B. Land breeze

Imagine that you are in a mountainous region, especially a desert, at night.

What is the rushing noise you hear?

Cold air rushes down the sides of the mountains.

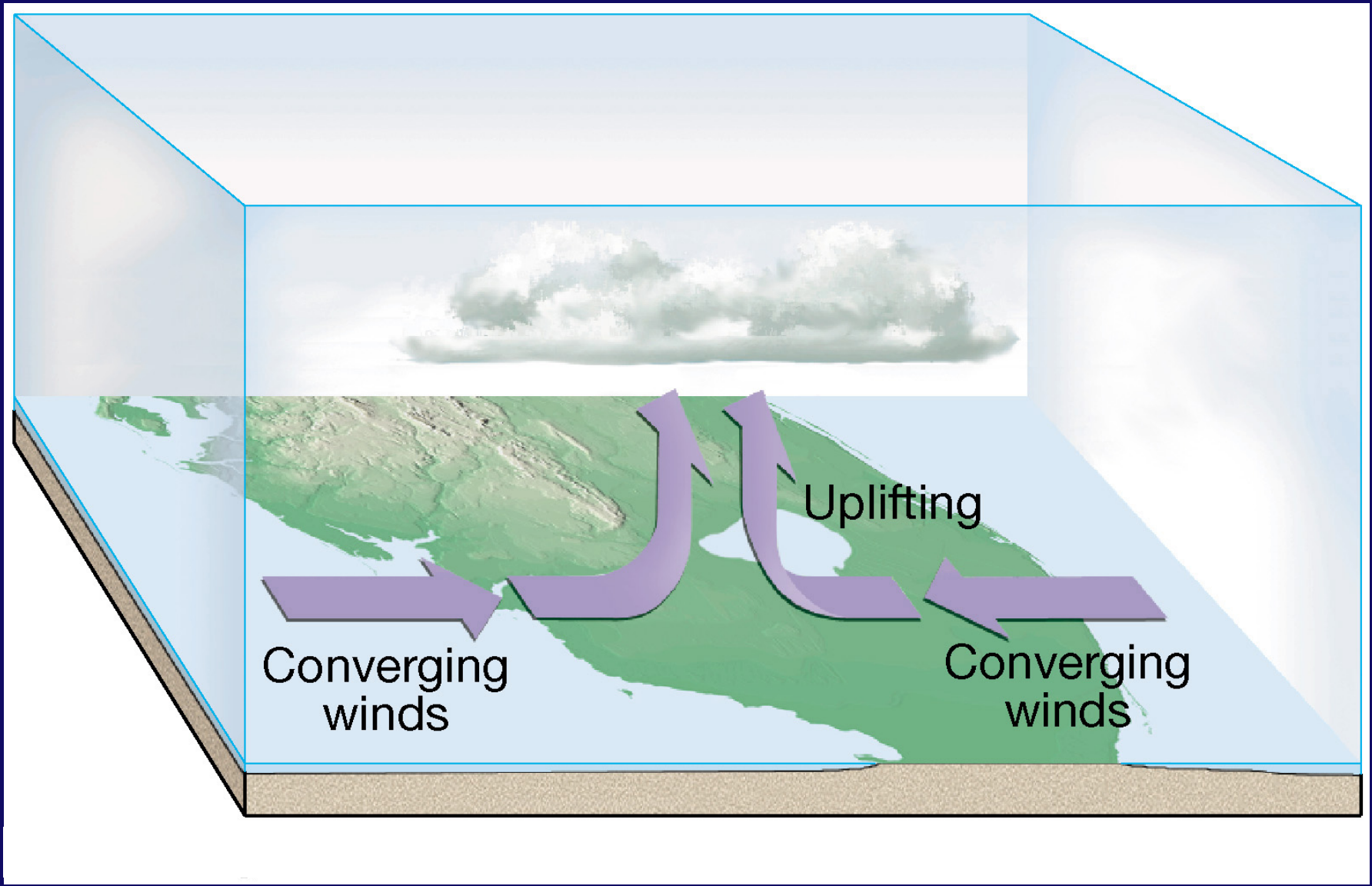


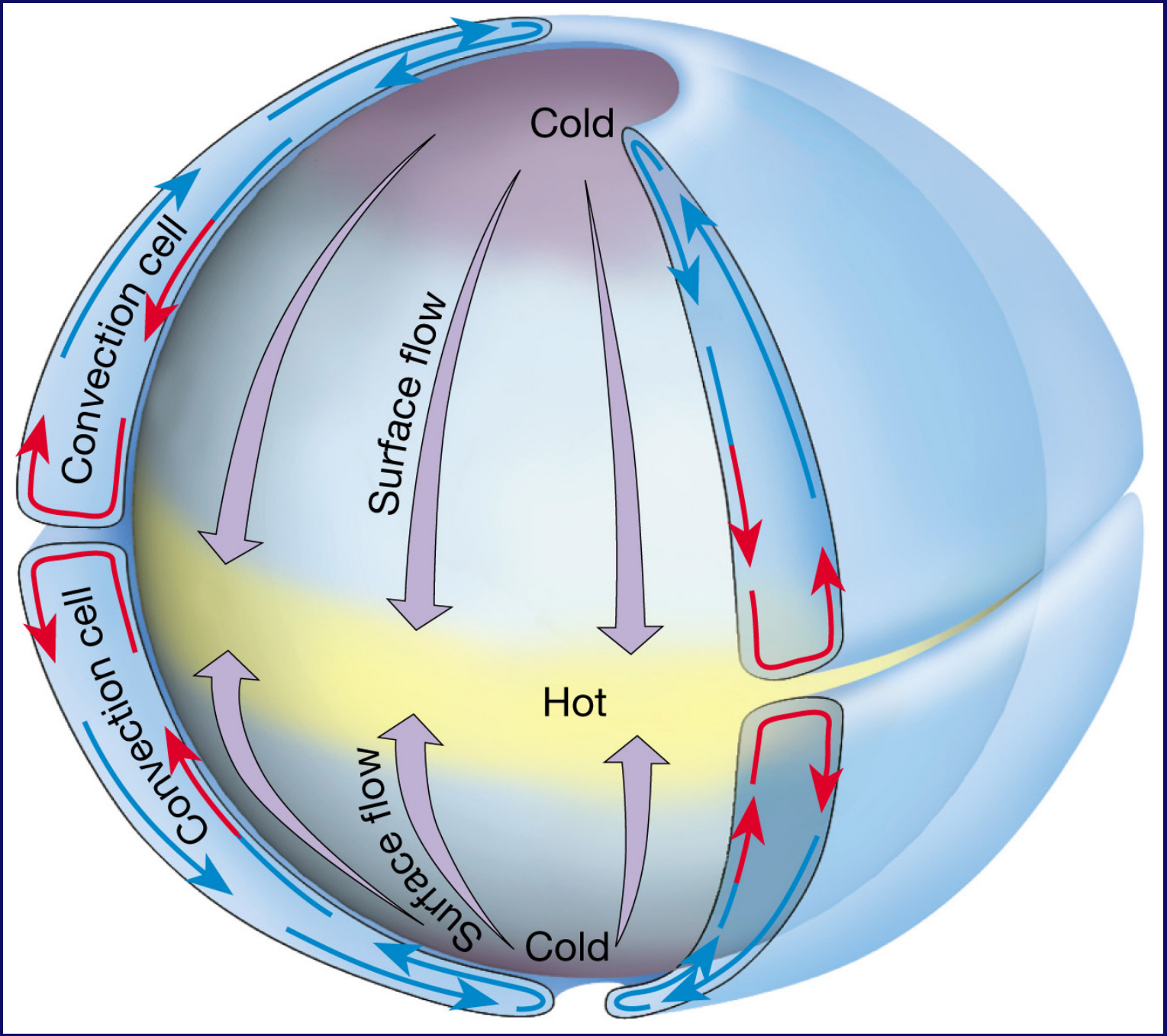
Mountain breeze

If you take a trip to Disneyworld in the summer, people will tell you that it always rains in the afternoon.

Why?

The warm land air rises, causing condensation and precipitation.




Cold
Convection cell
Surface flow
Convection cell
Hot
Surface flow
Cold

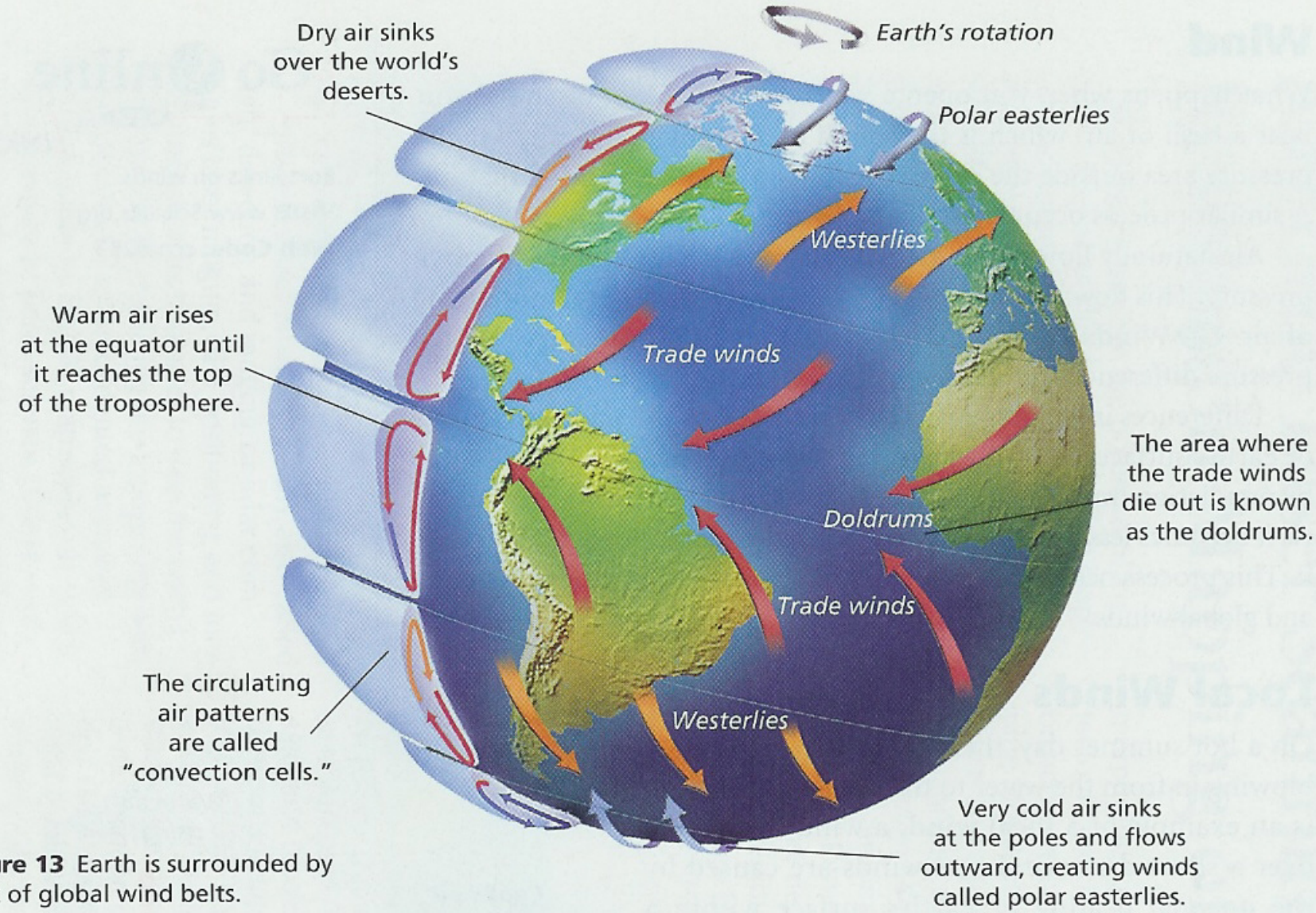
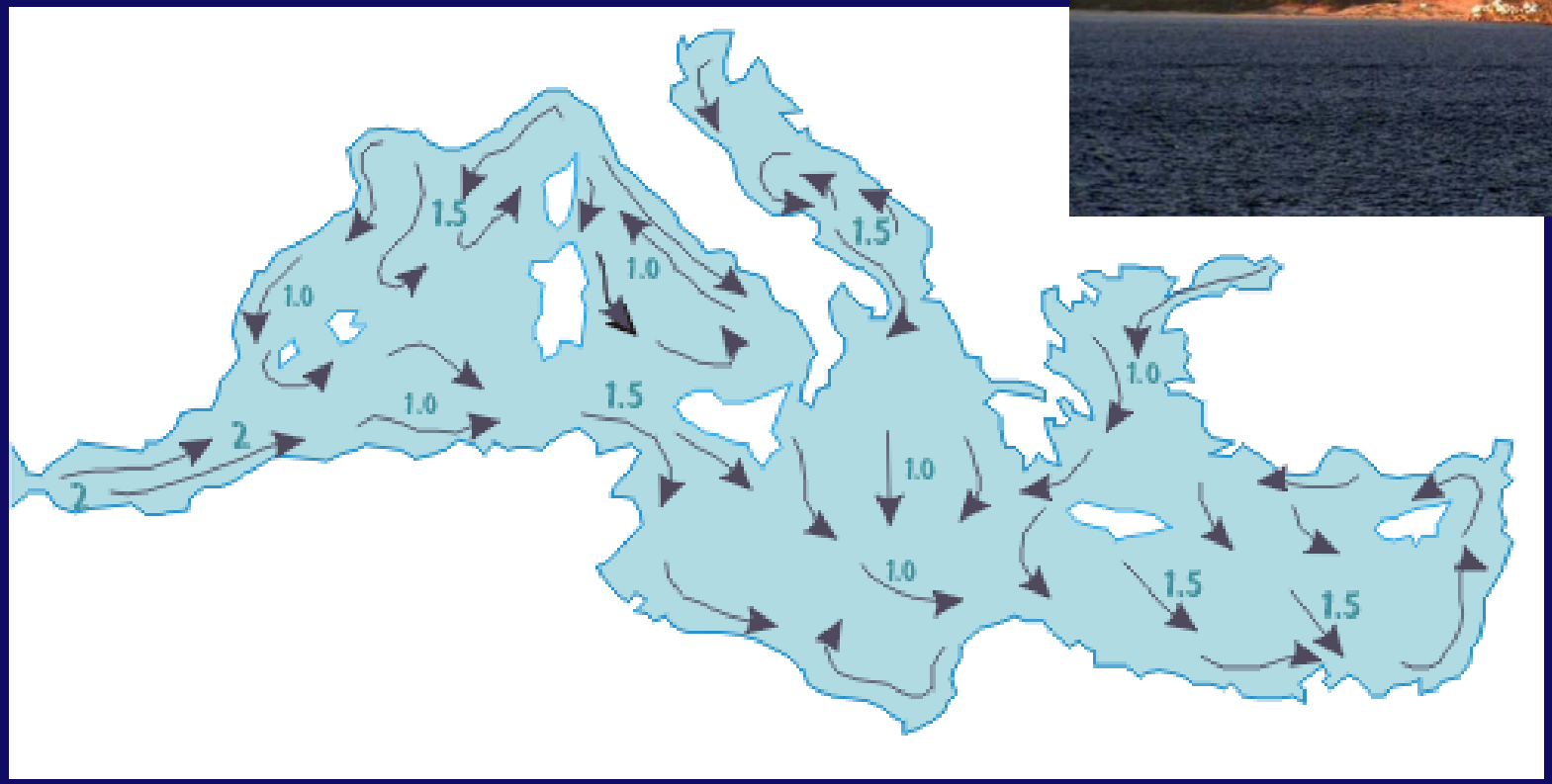


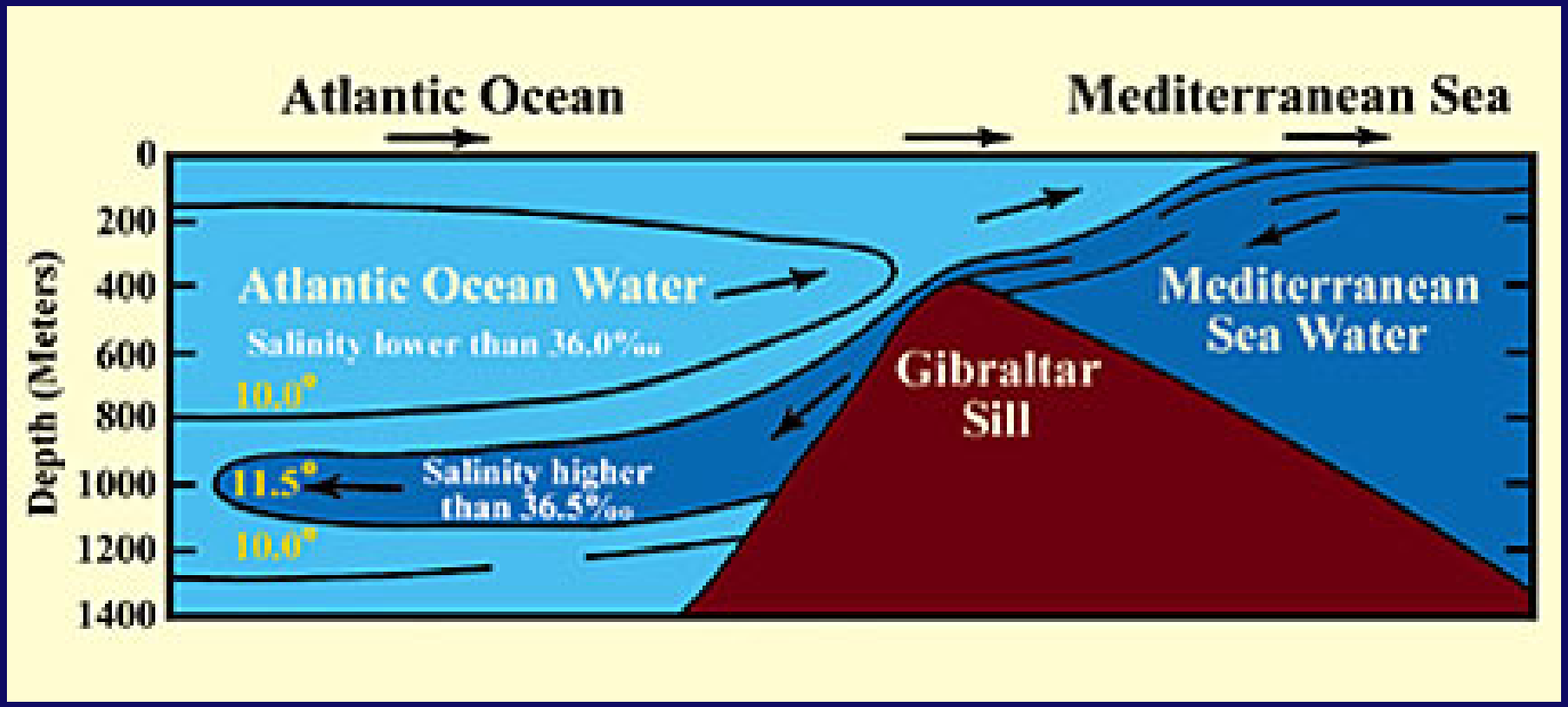
Figure 13 Earth is surrounded by a set of global wind belts.

If you visit Gibraltar, the current is always flowing eastward, into the Mediterranean.

How is this possible?



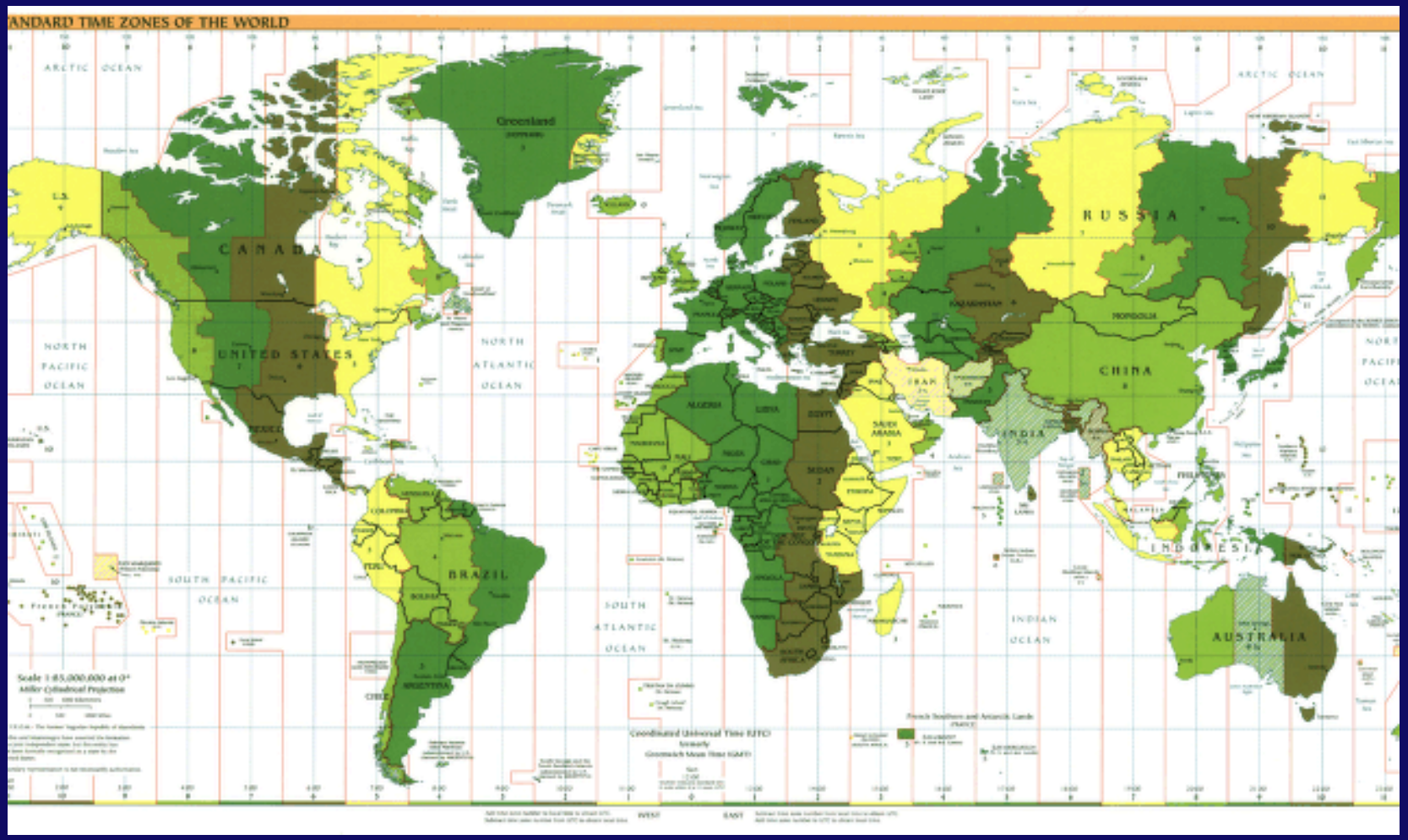
Evaporation makes the Mediterranean water salty and dense, so it sinks.



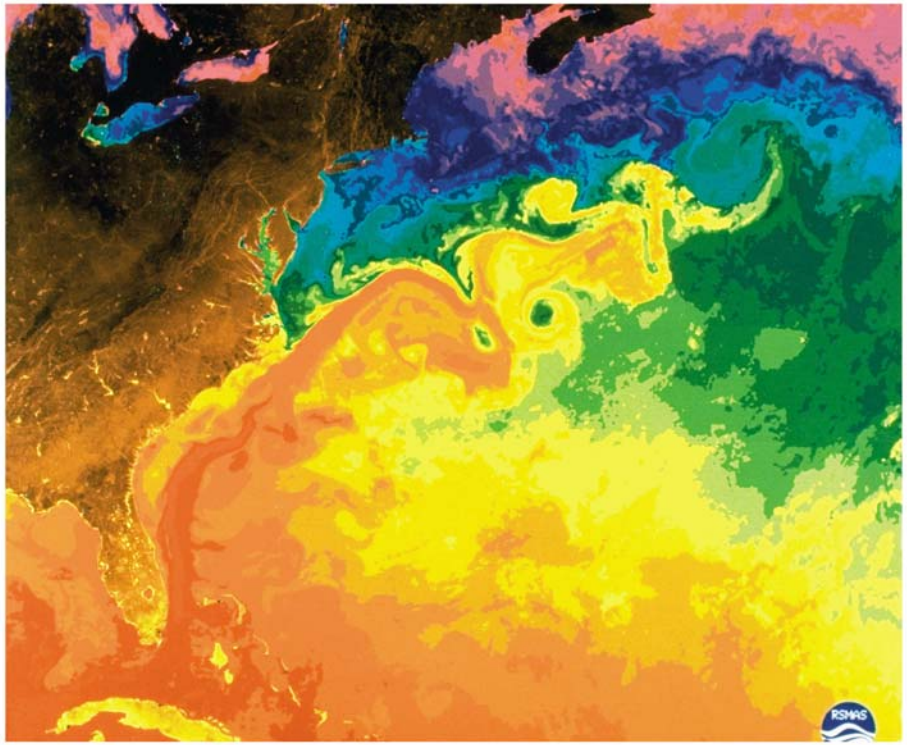
Convection can be driven by CHEMICAL density differences as well as THERMAL density differences!!!!!

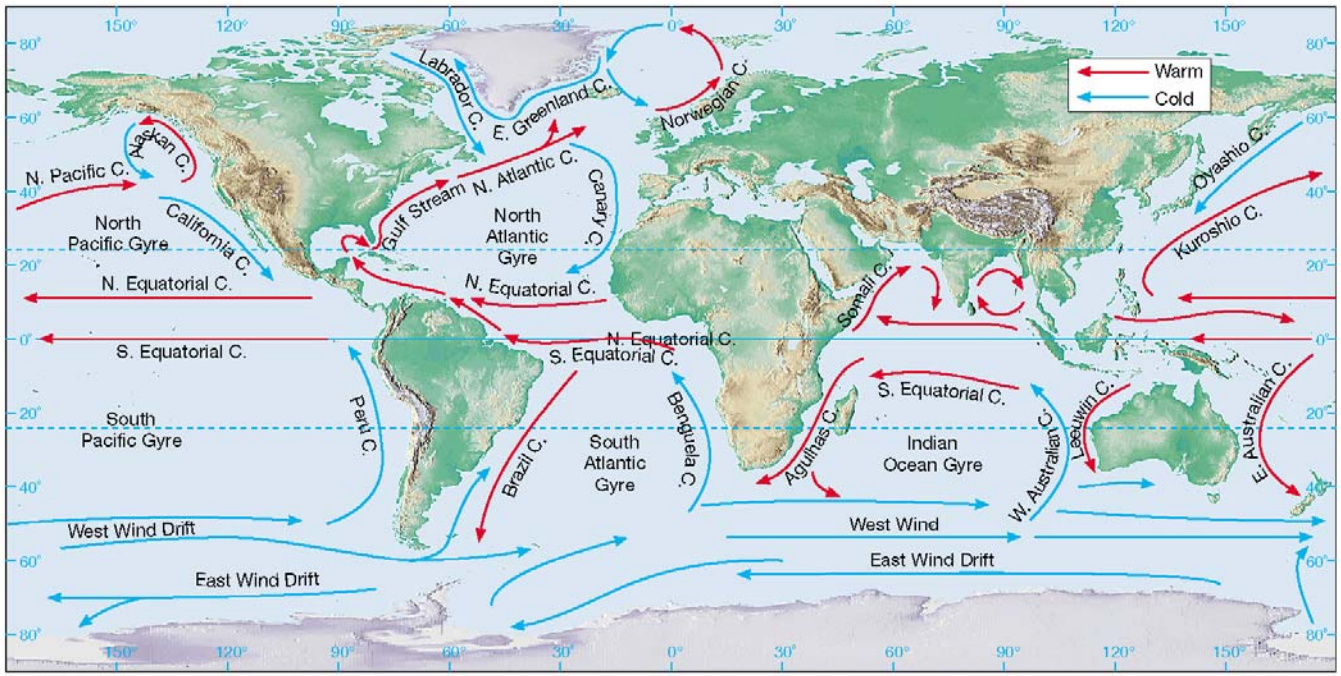
England is at the same latitude as Hudson Bay and southern Alaska.

Why isn't it as cold?



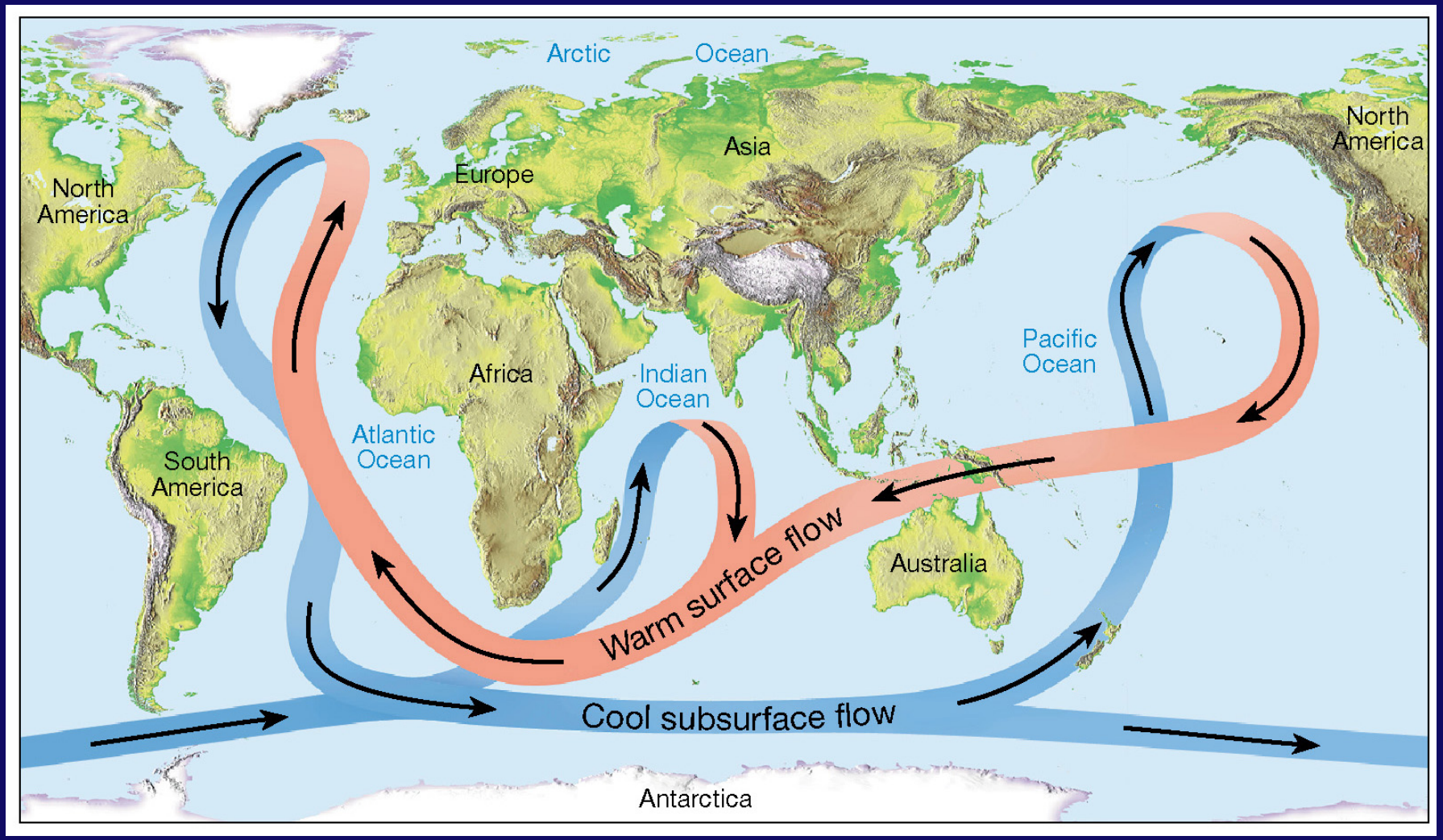
Because of the
***Gulf Stream*.**



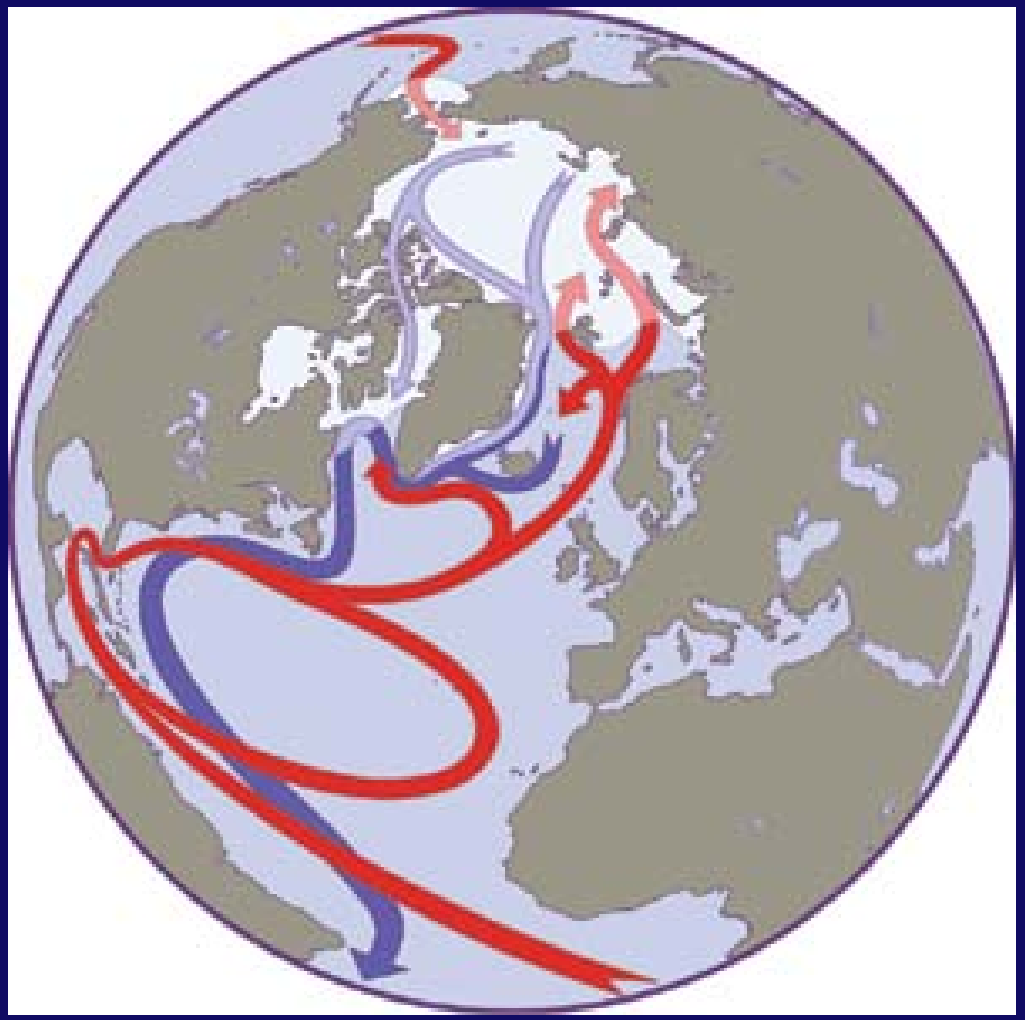


It is believed that and increased Greenhouse Effect could freeze Europe.

How could this happen?

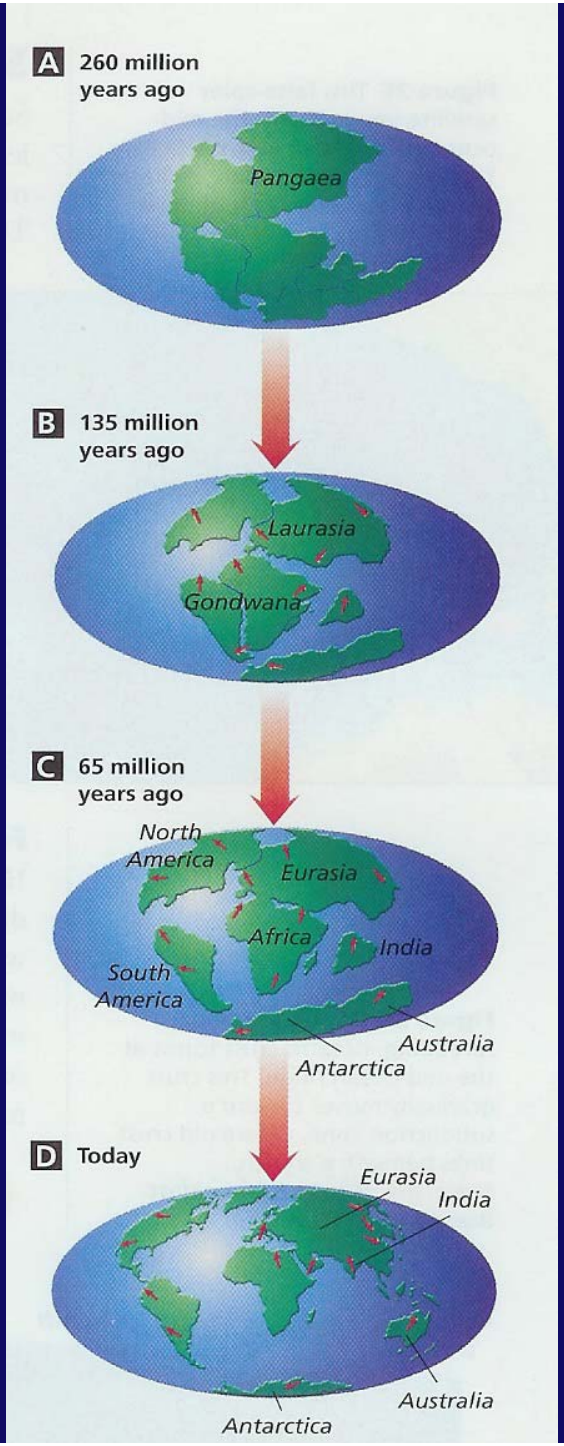


The sudden flood of fresh water (not salty → less dense → doesn't sink) melted from Greenland could shut off the Atlantic *thermohaline circulation*.

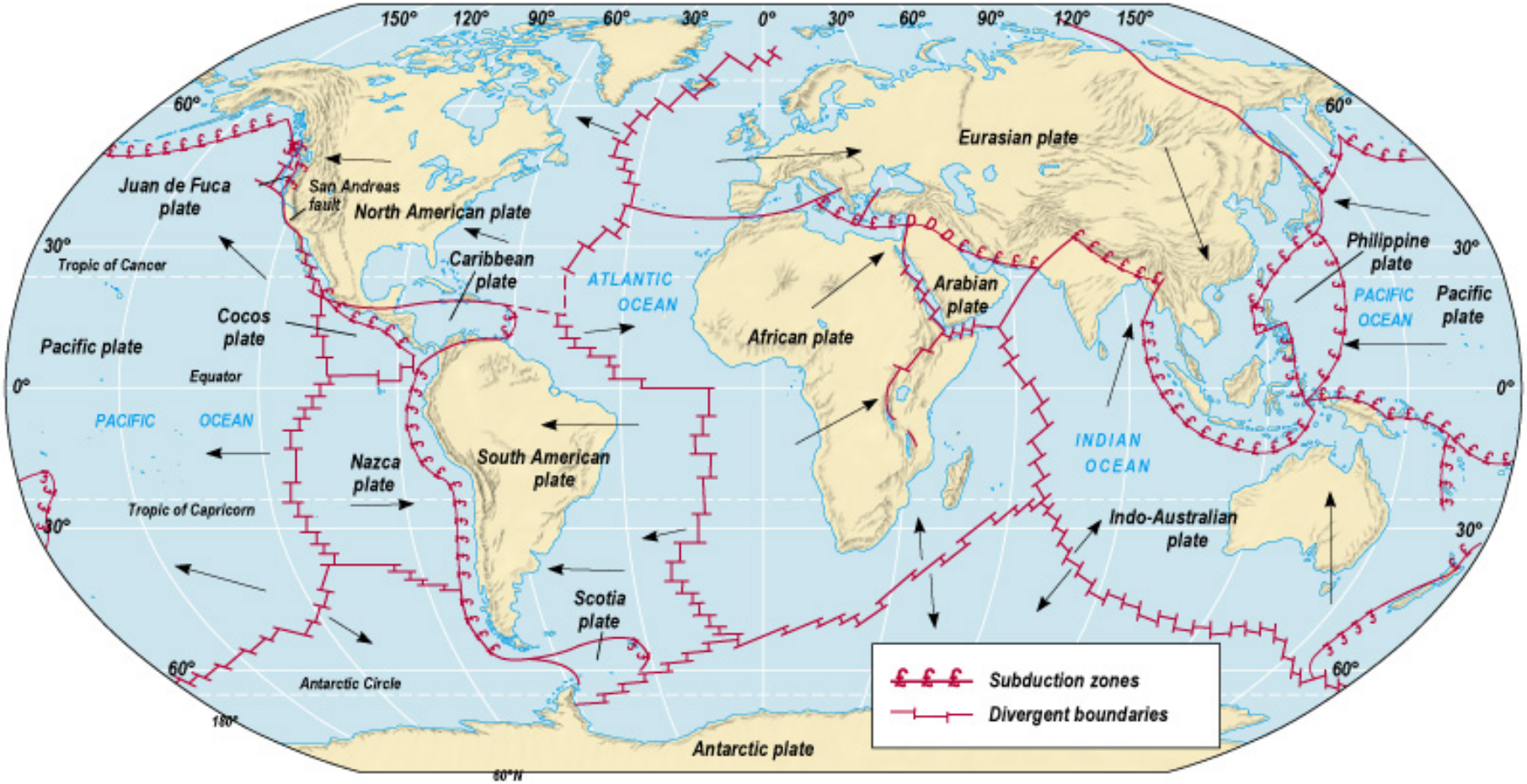


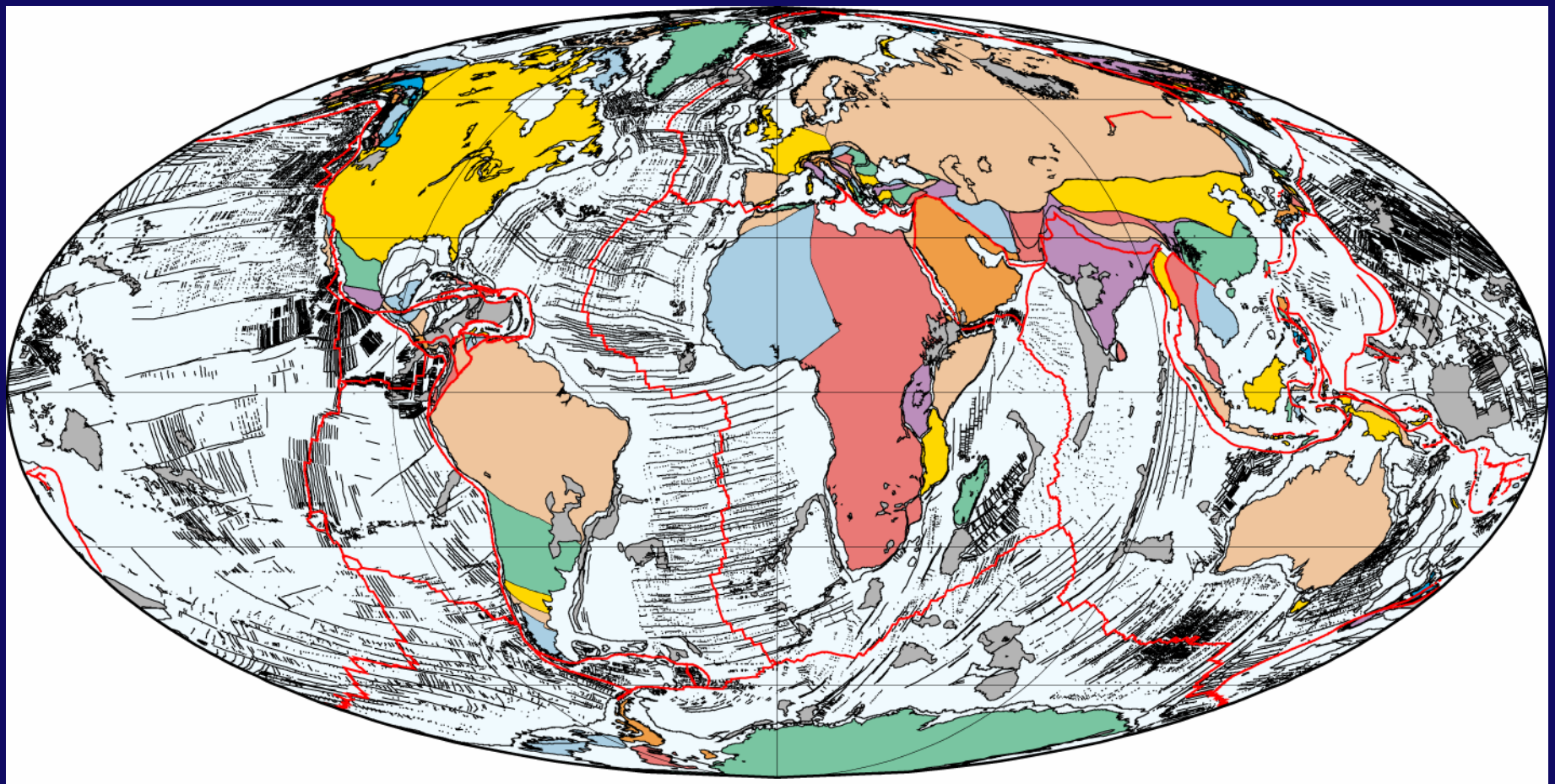
Earth's tectonic plates have been moving around Earth's surface for at least 4 billion years.

How does the rock move?



Locations of the Major Tectonic "Plates"



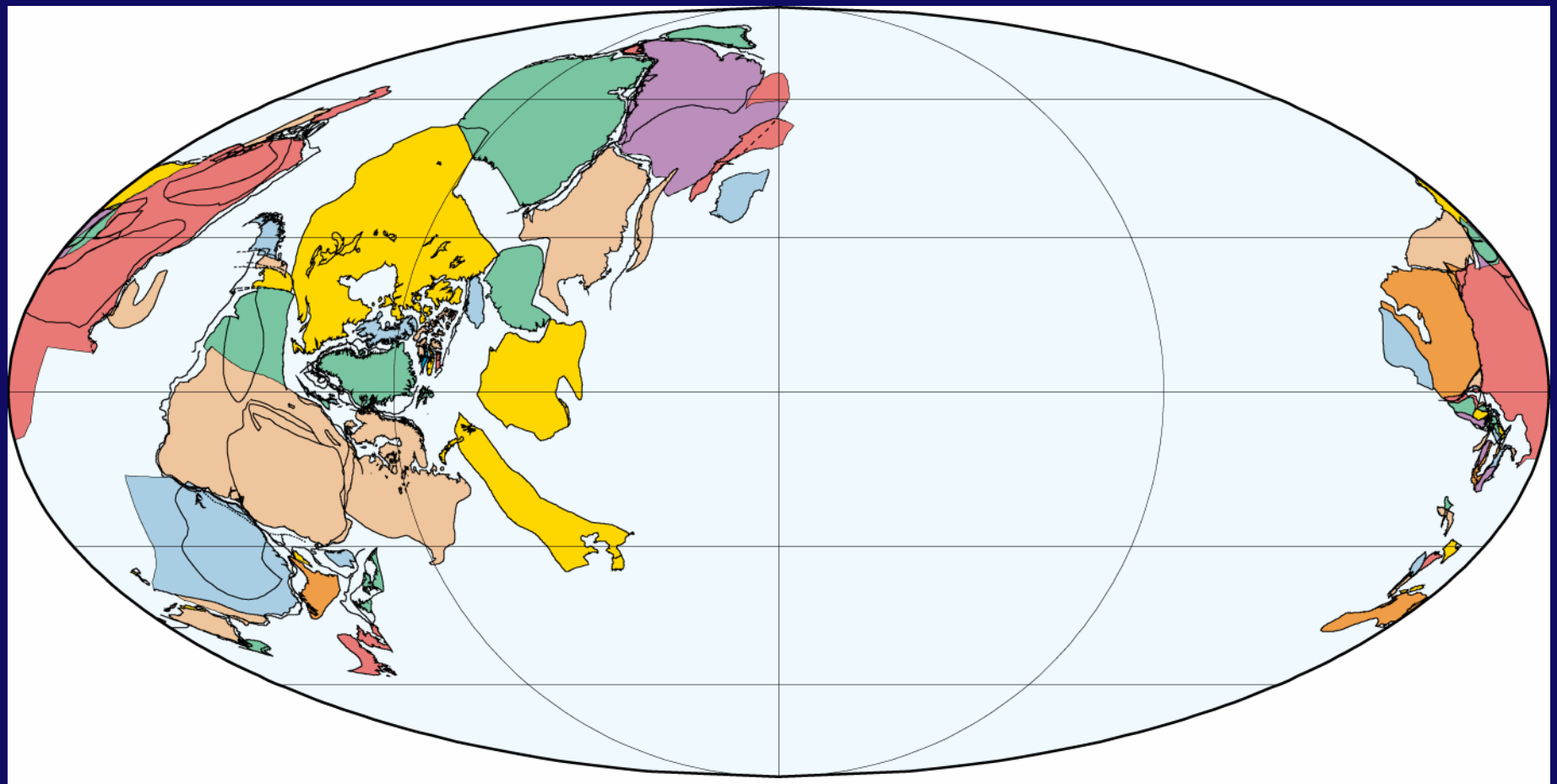


0 Ma

Present Day

PLATES/UTIG

August 2002

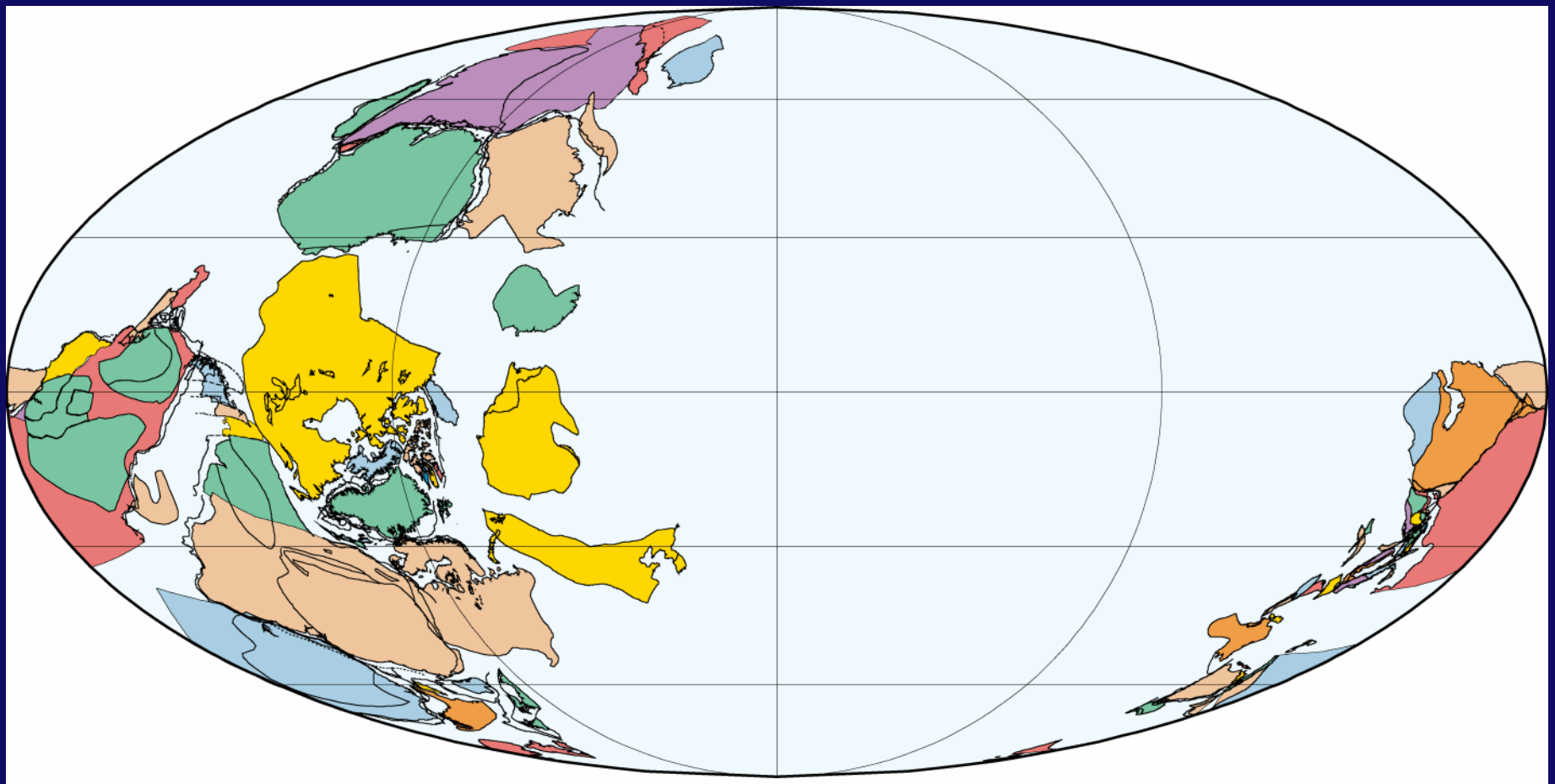


750 Ma

Late Proterozoic

PLATES/UTIG

August 2002

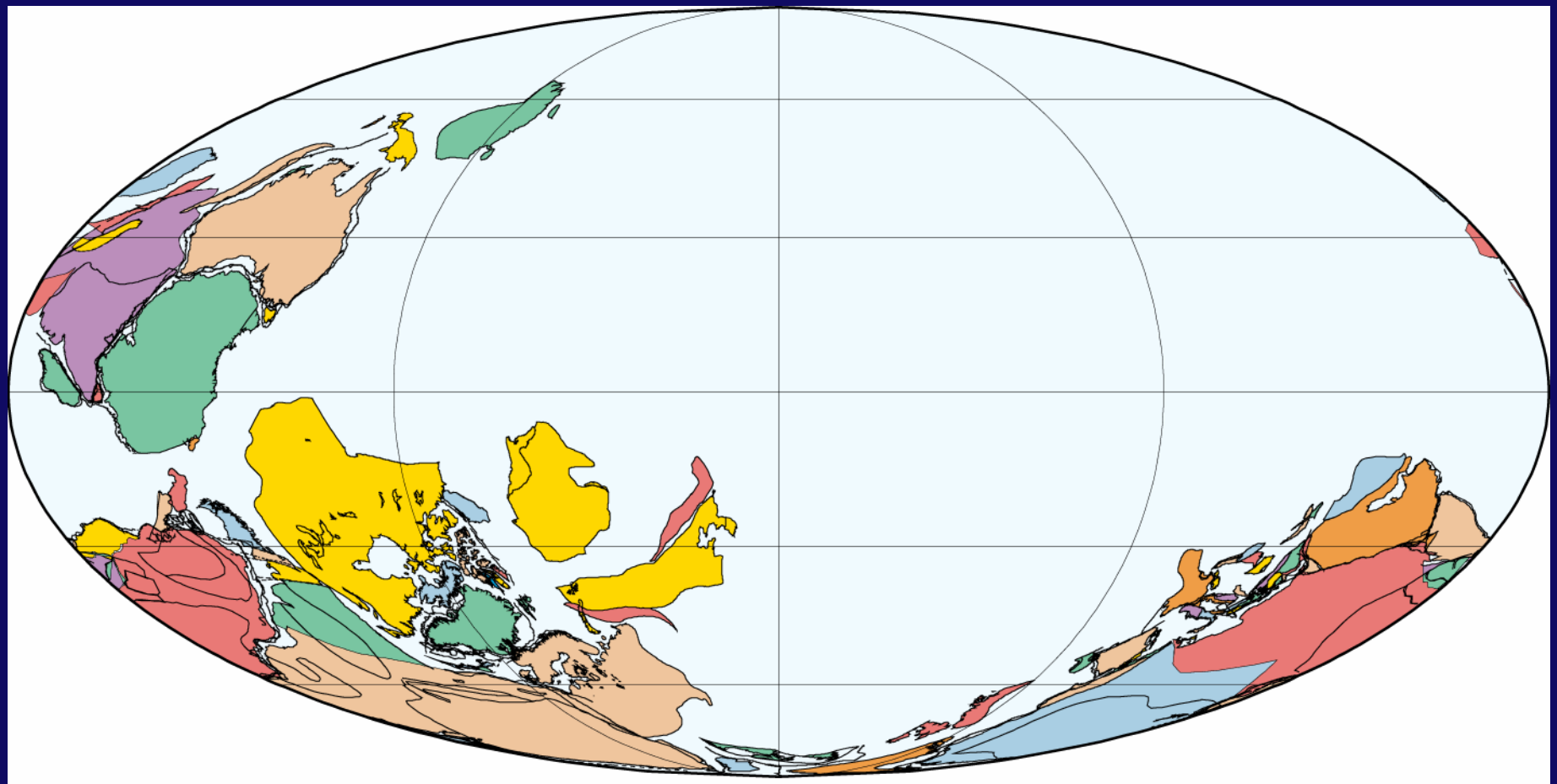


700 Ma

Late Proterozoic

PLATES/UTIG

August 2002

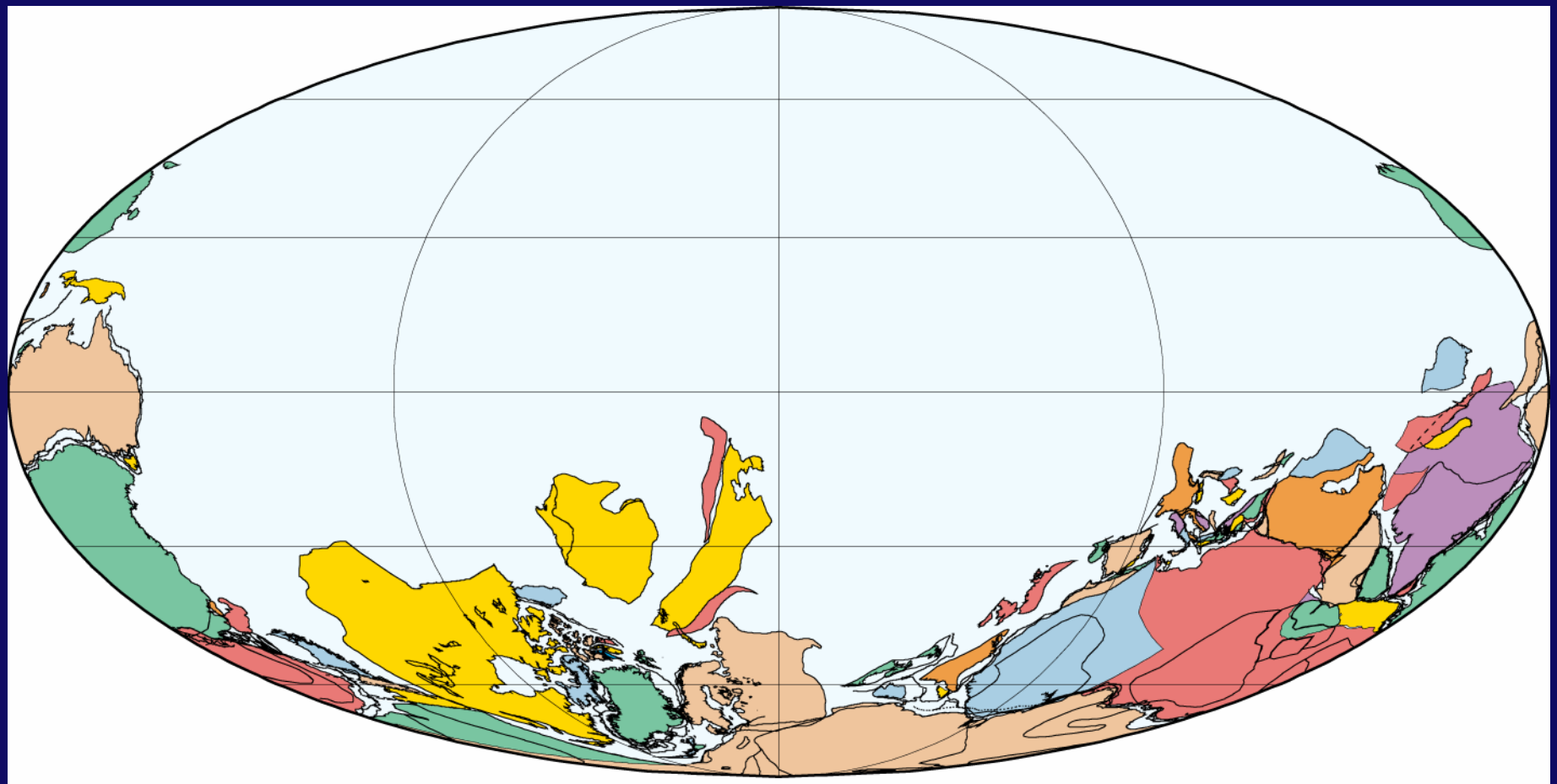


650 Ma

Late Proterozoic

PLATES/UTIG

August 2002

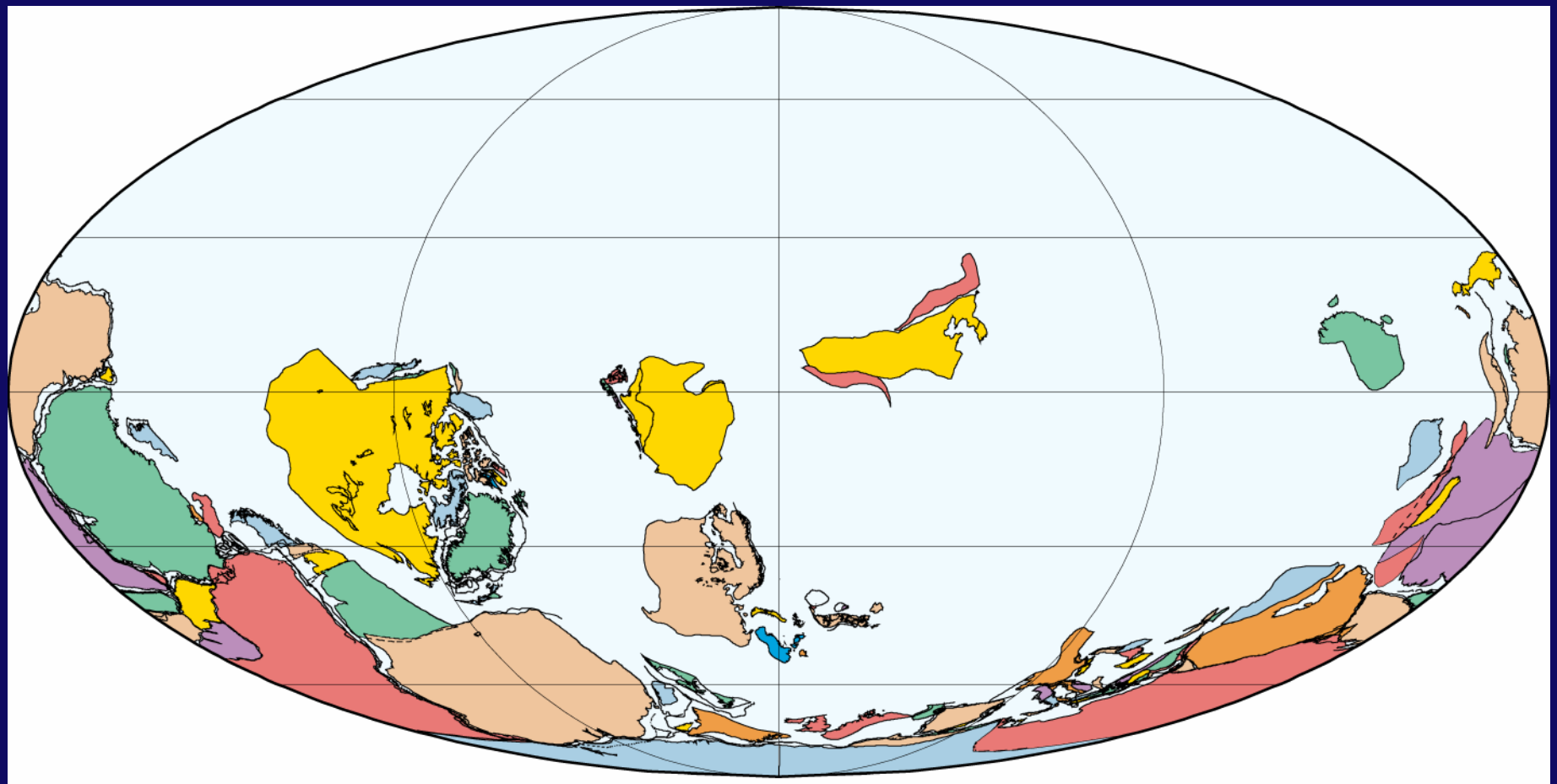


600 Ma

Late Proterozoic

PLATES/UTIG

August 2002

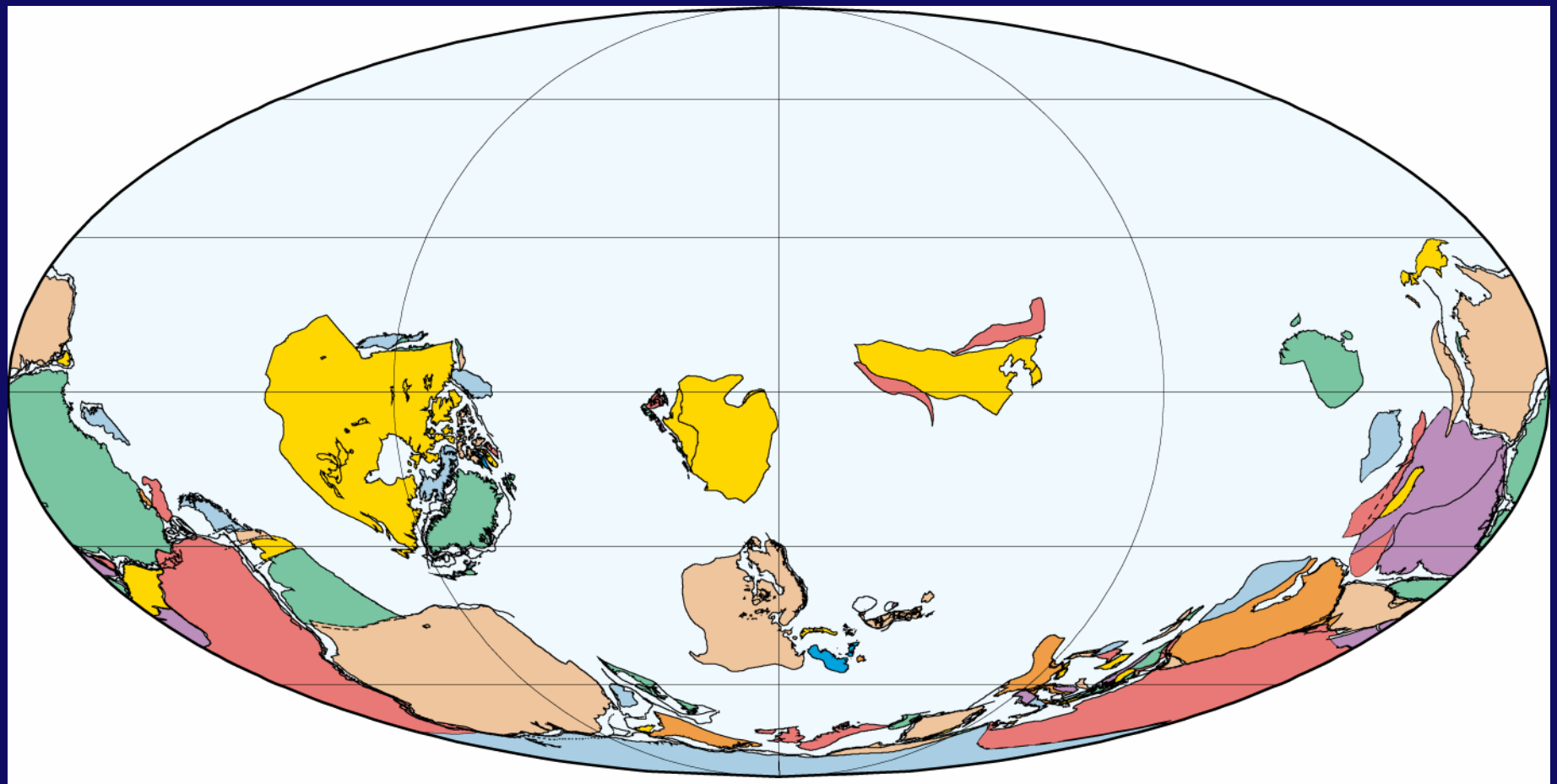


540 Ma

Nemakitian-Daldynian (Early Cambrian)

PLATES/UTIG

August 2002

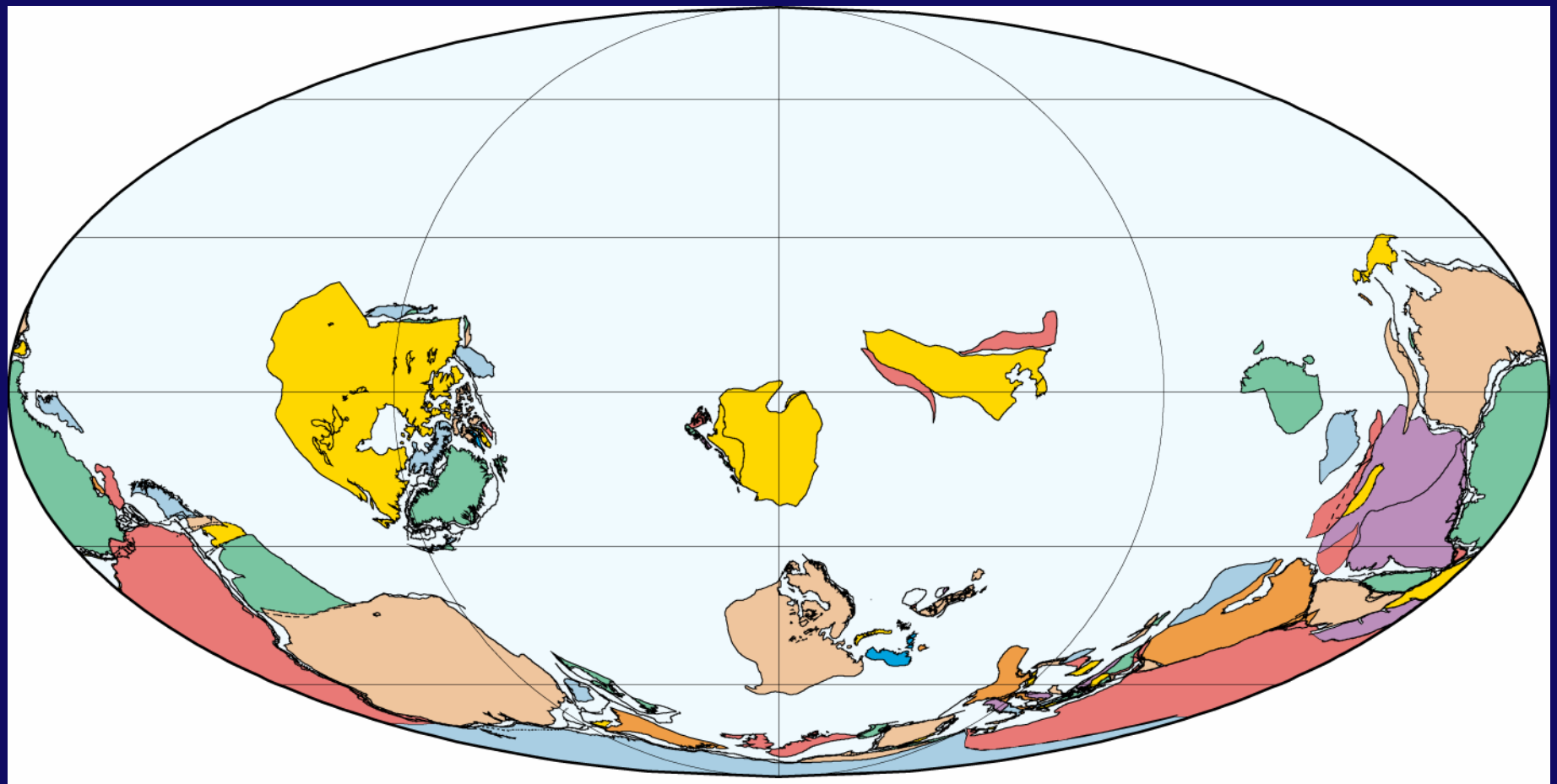


530 Ma

Late Tommotian/Early Atdabanian (Early Cambrian)

PLATES/UTIG

August 2002

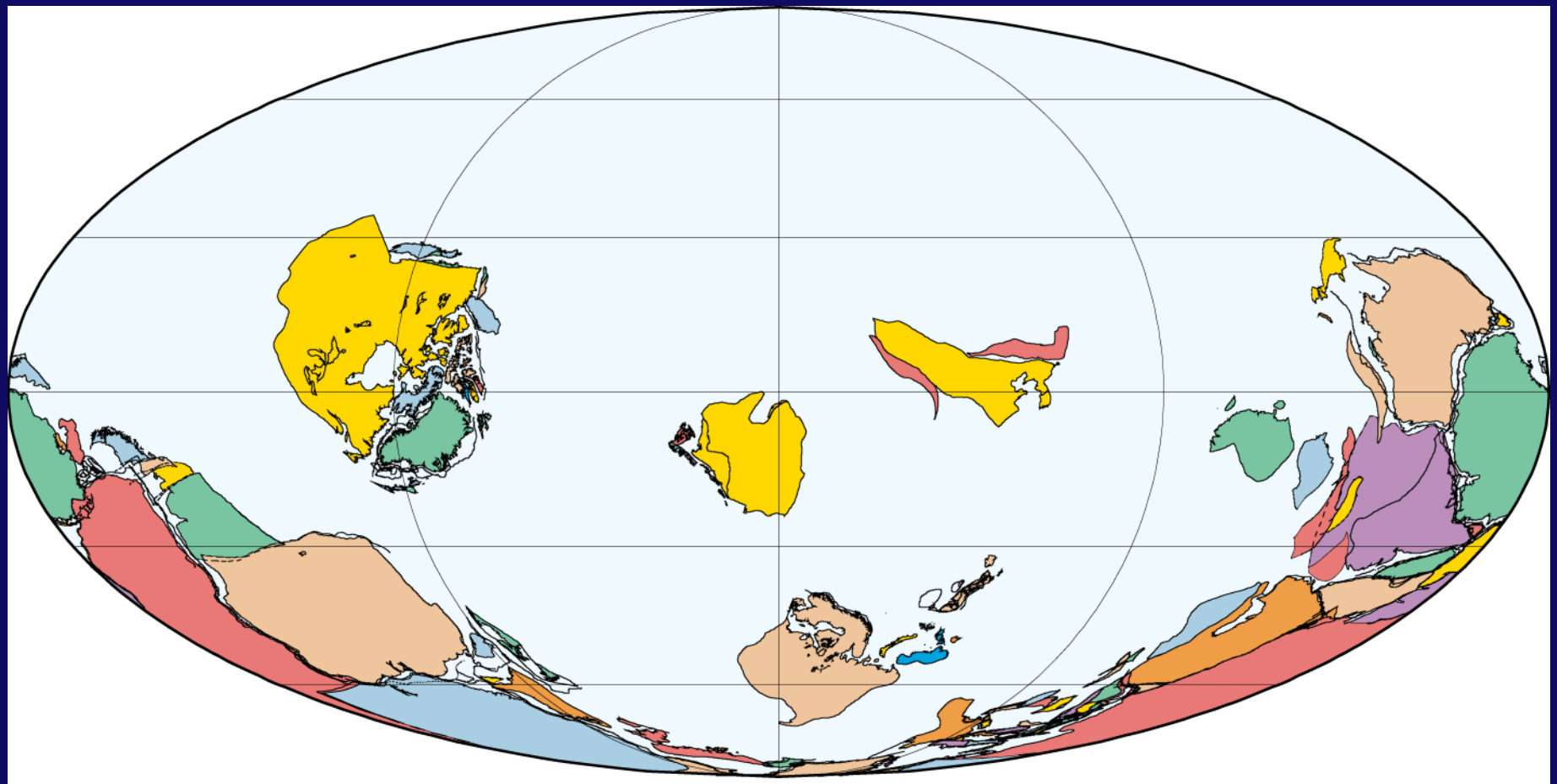


520 Ma

Lenian (Early Cambrian)

PLATES/UTIG

August 2002

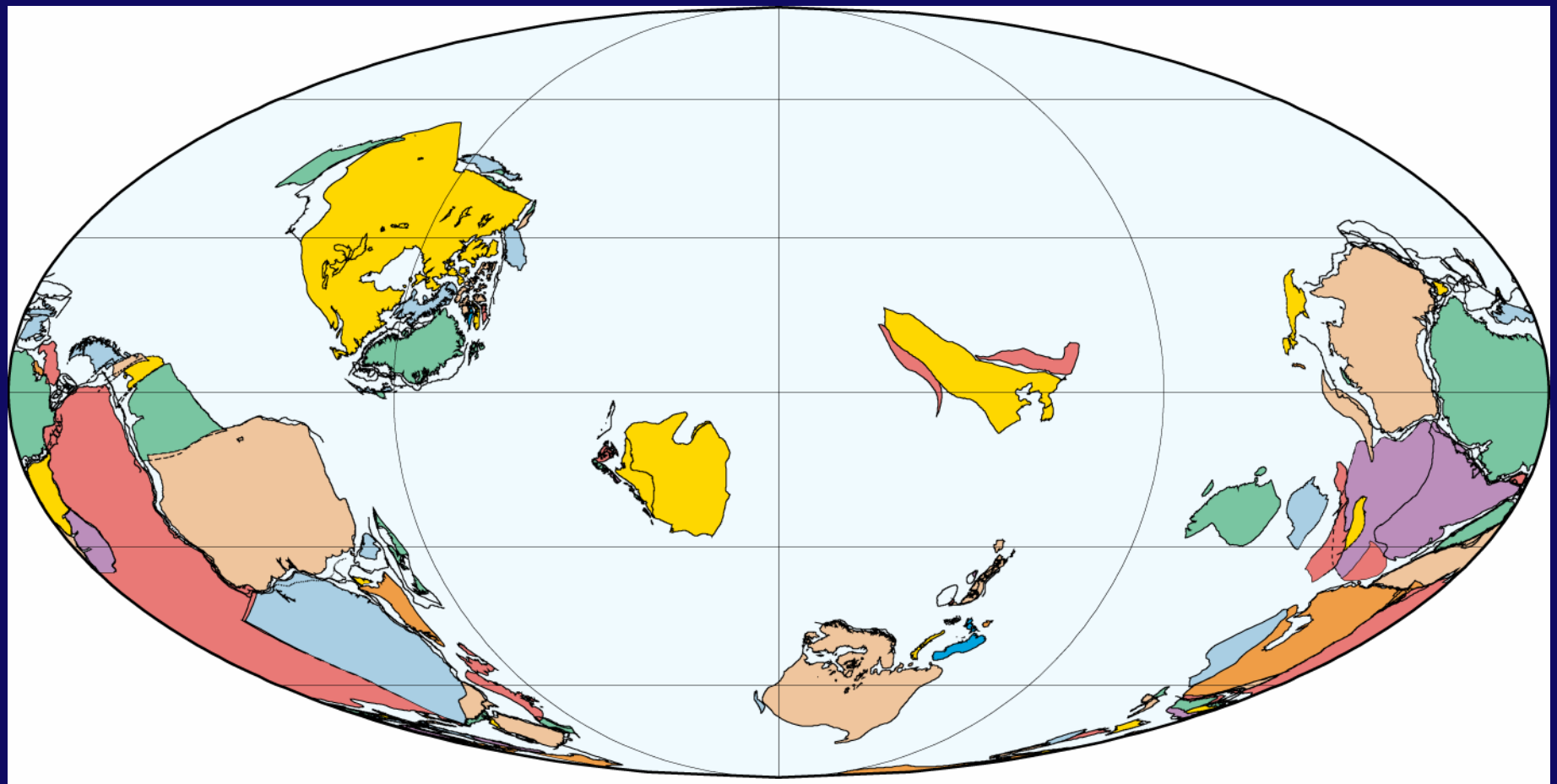


510 Ma

Middle Cambrian

PLATES/UTIG

August 2002

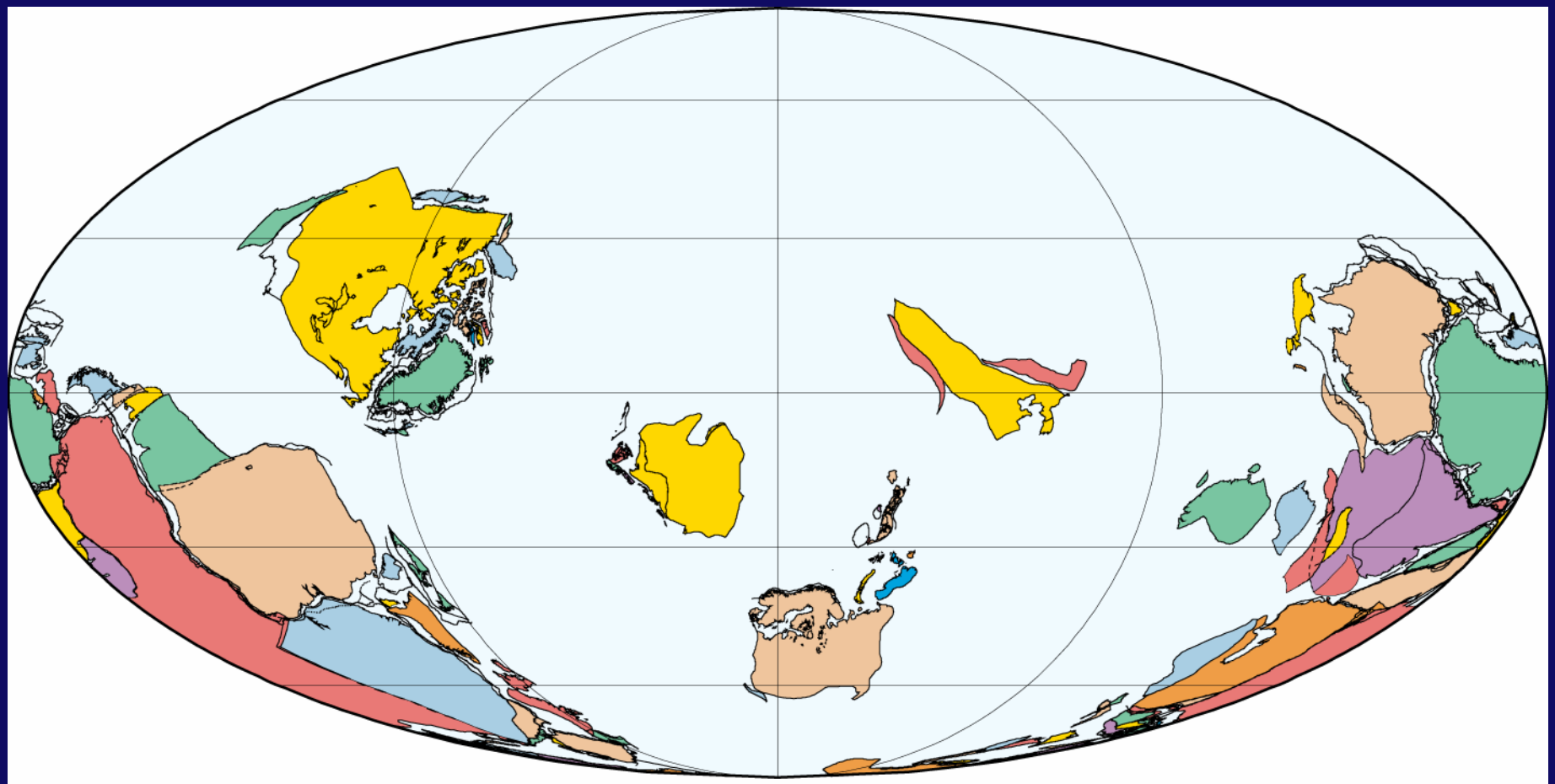


500 Ma

Late Cambrian

PLATES/UTIG

August 2002

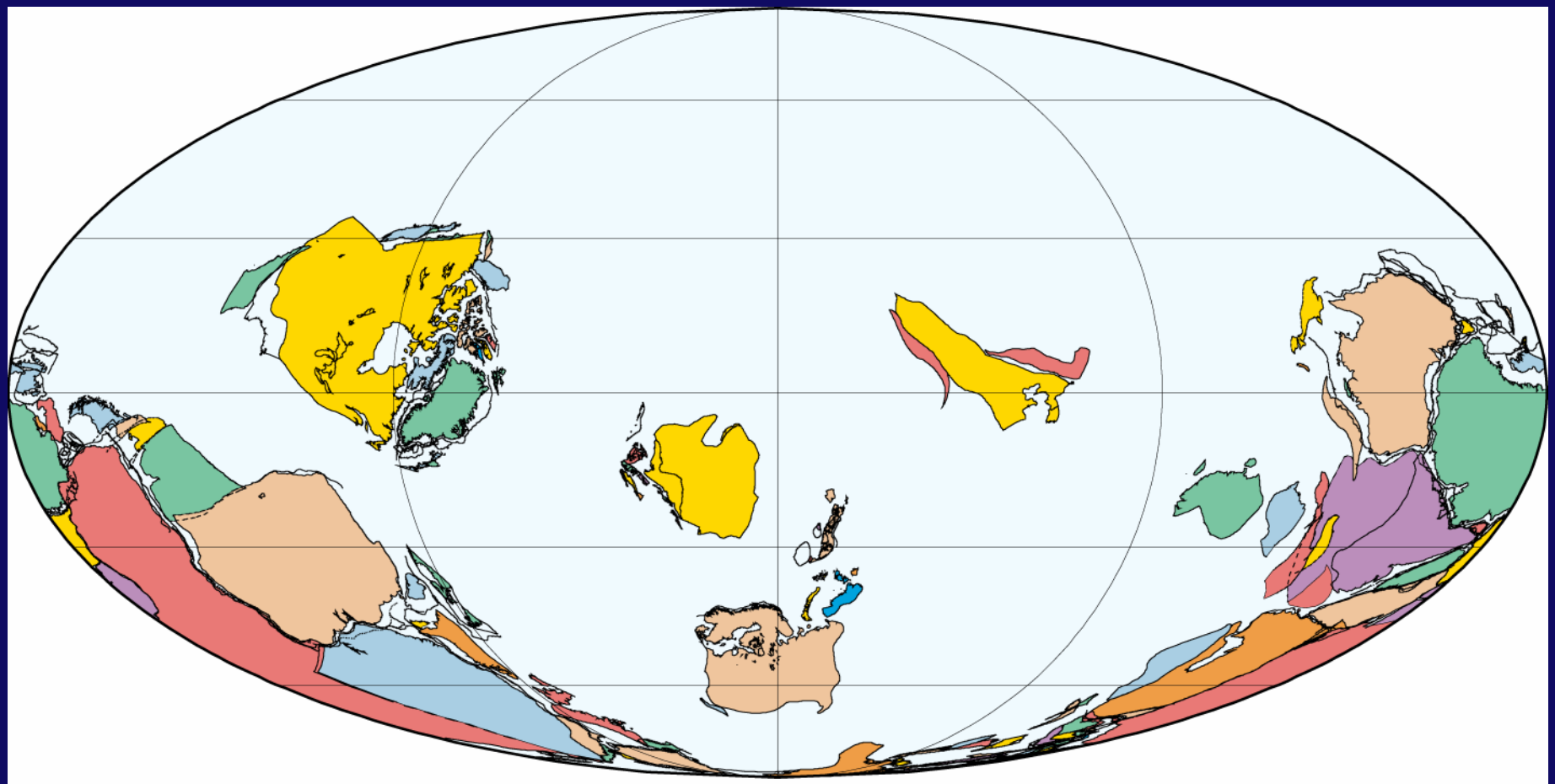


490 Ma

Tremadocian (Early Ordovician)

PLATES/UTIG

August 2002

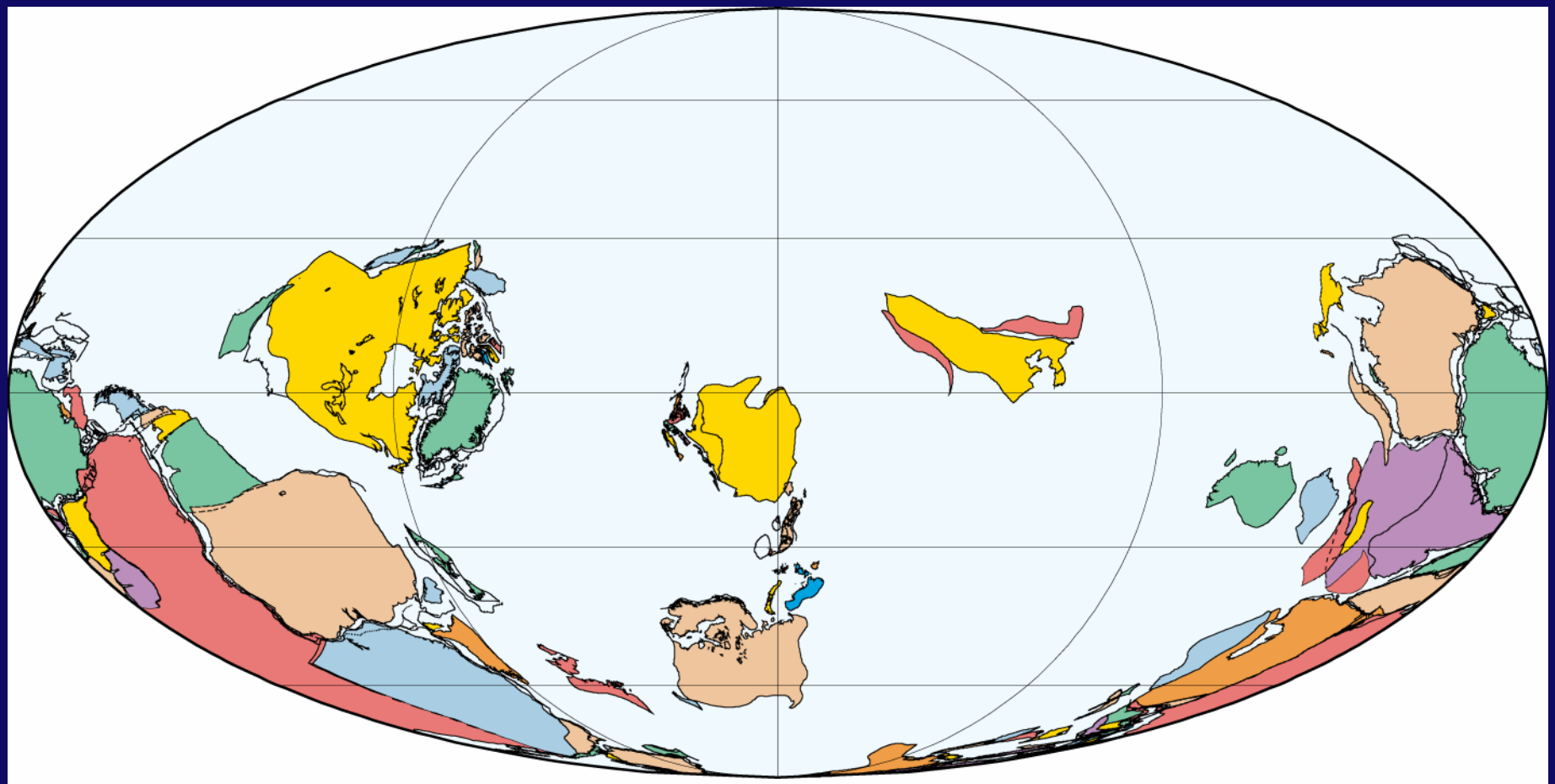


480 Ma

Arenigian (Early Ordovician)

PLATES/UTIG

August 2002

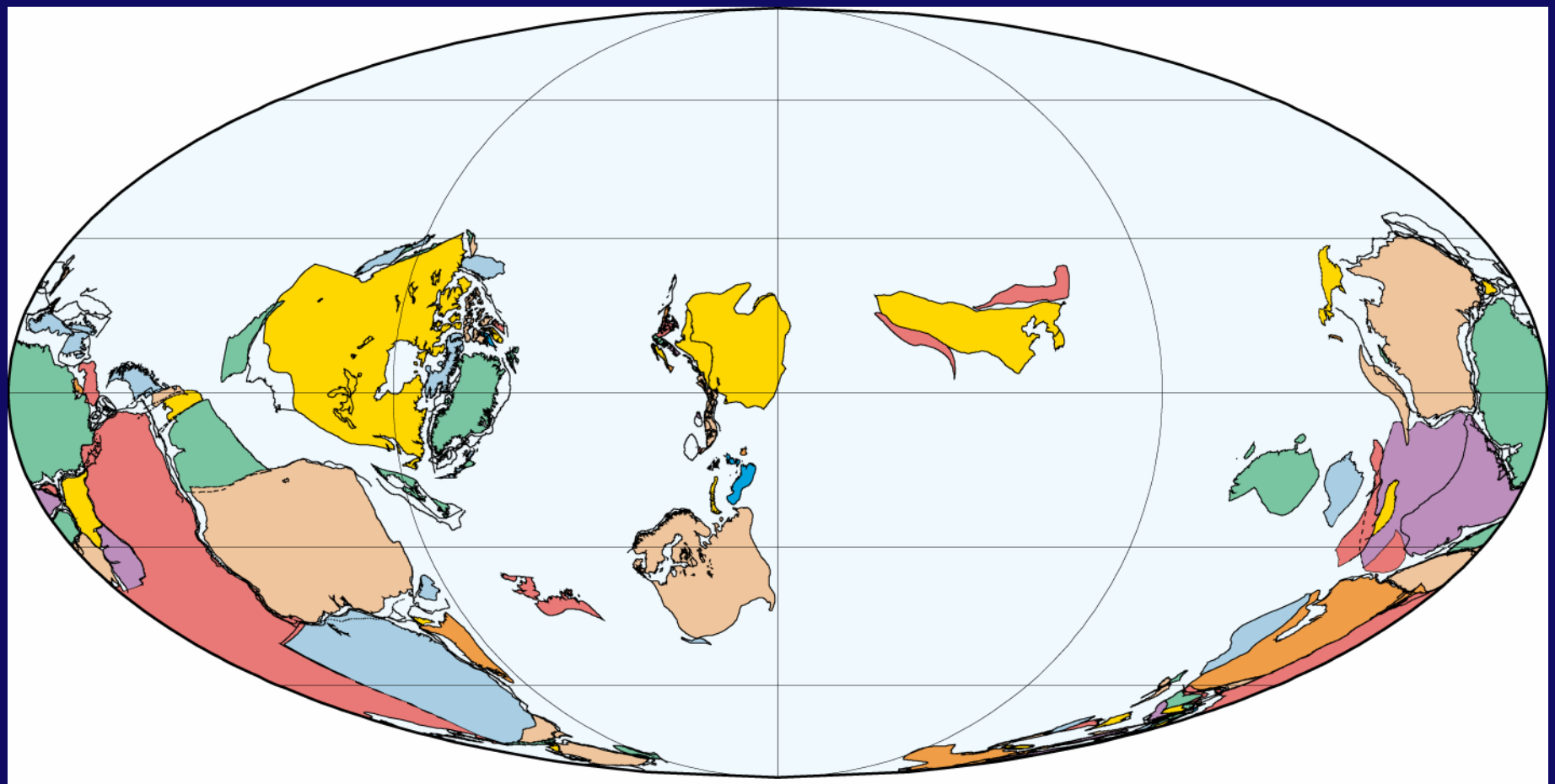


470 Ma

Late Arenigian/Early Llanvirnian (Early/Middle Ordovician)

PLATES/UTIG

August 2002

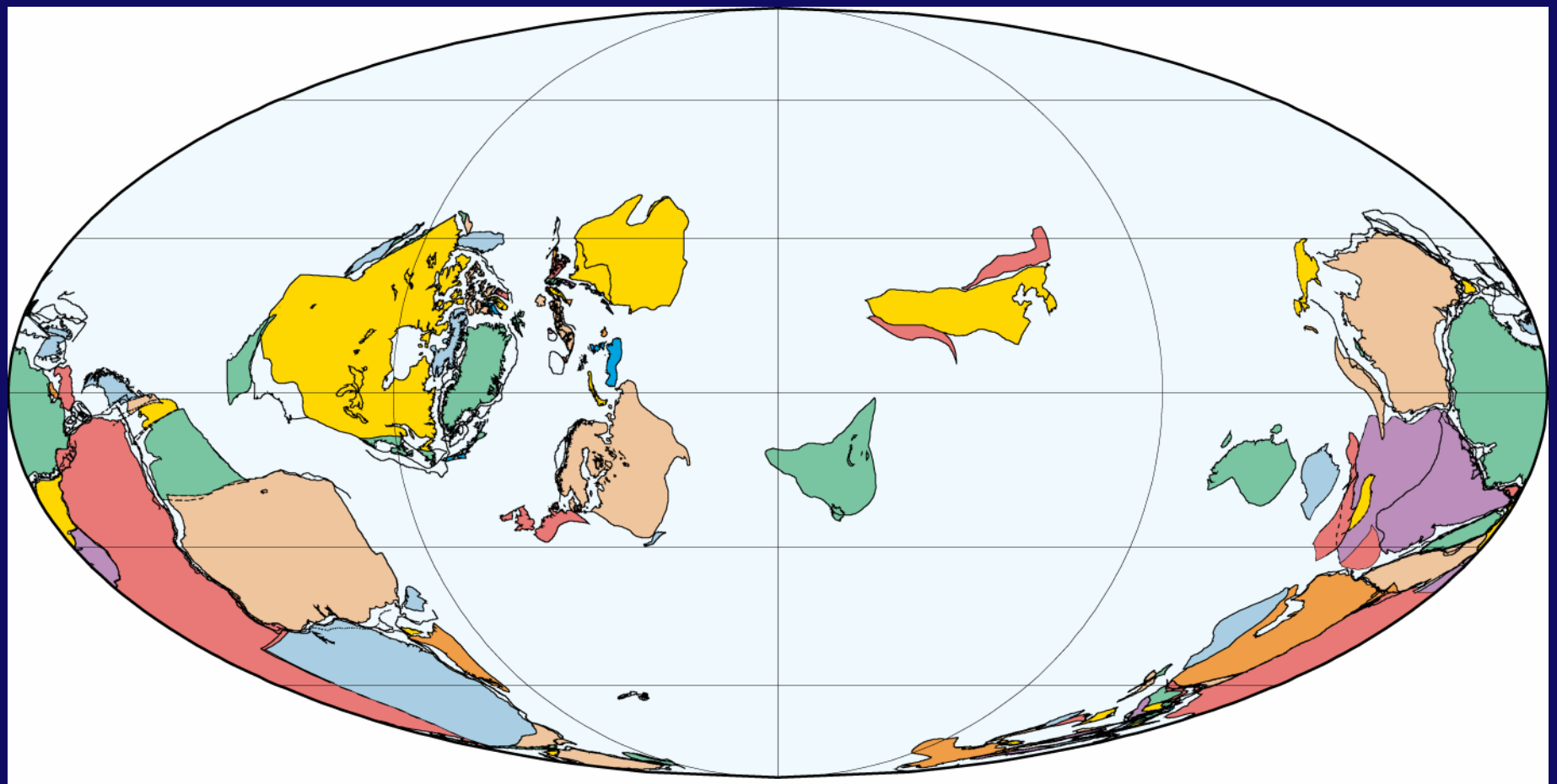


460 Ma

Llandeilan (Middle Ordovician)

PLATES/UTIG

August 2002

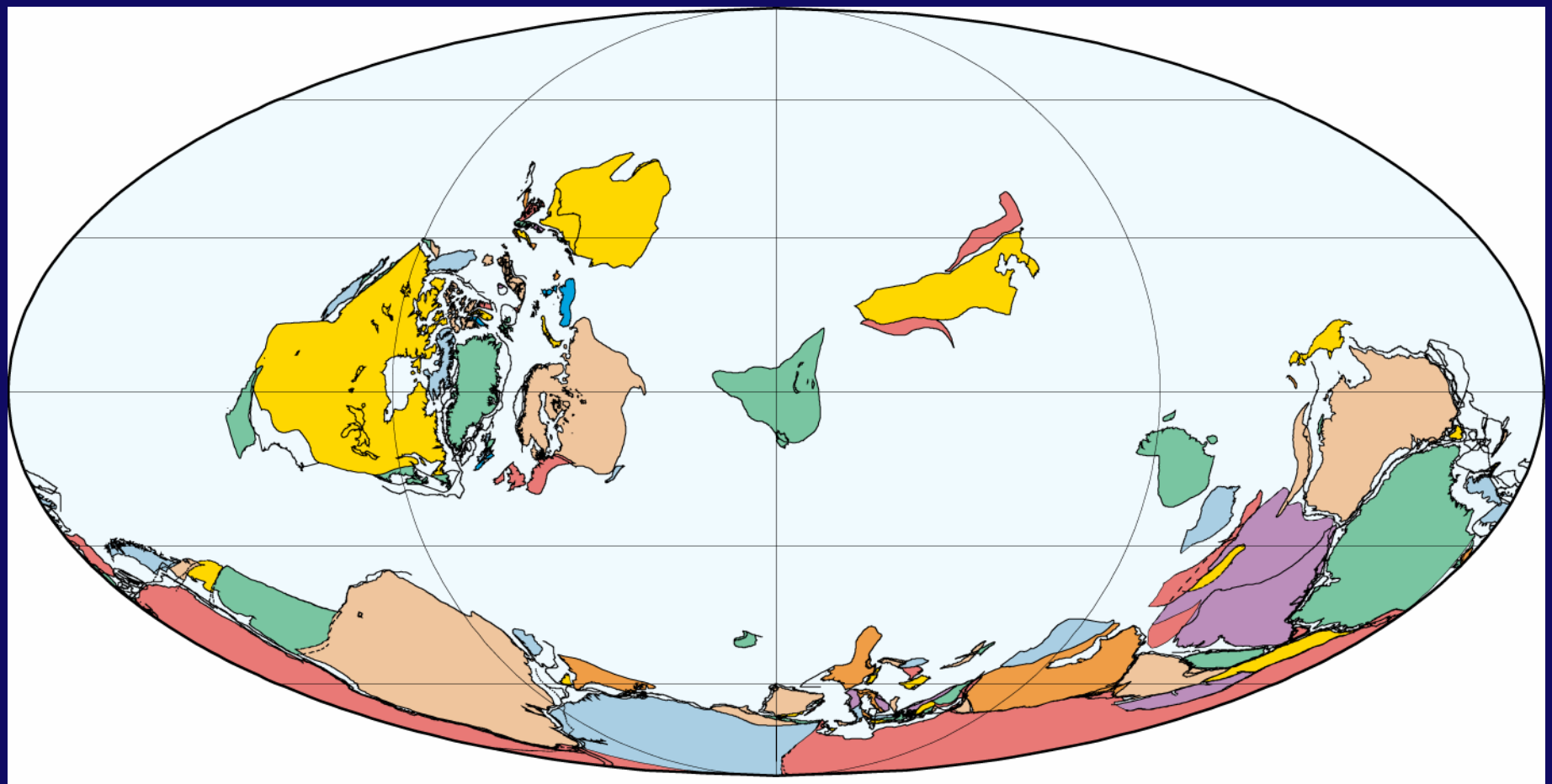


450 Ma

Caradocian (Late Ordovician)

PLATES/UTIG

August 2002

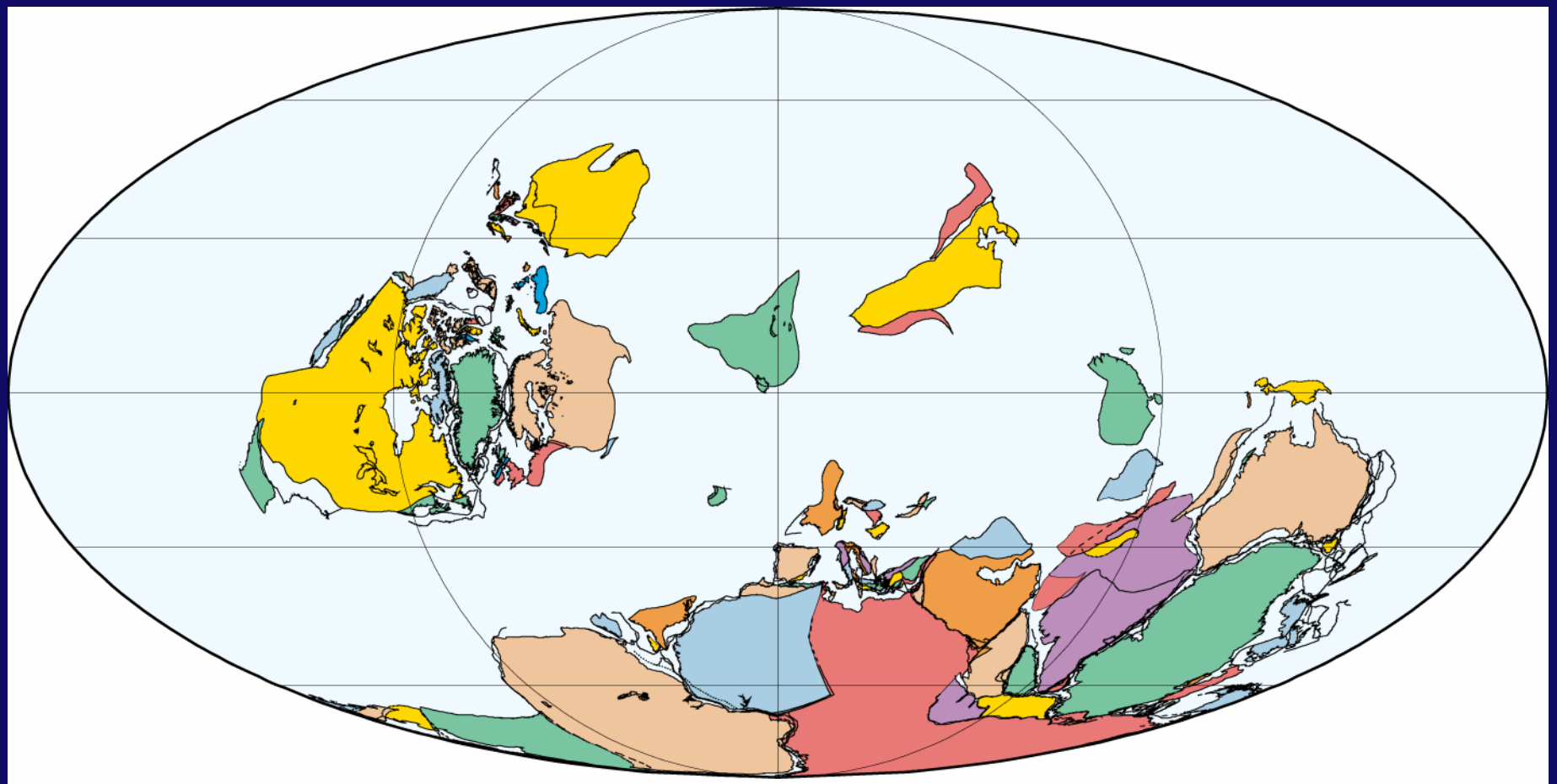


440 Ma

Early Llandoverian (Early Silurian)

PLATES/UTIG

August 2002

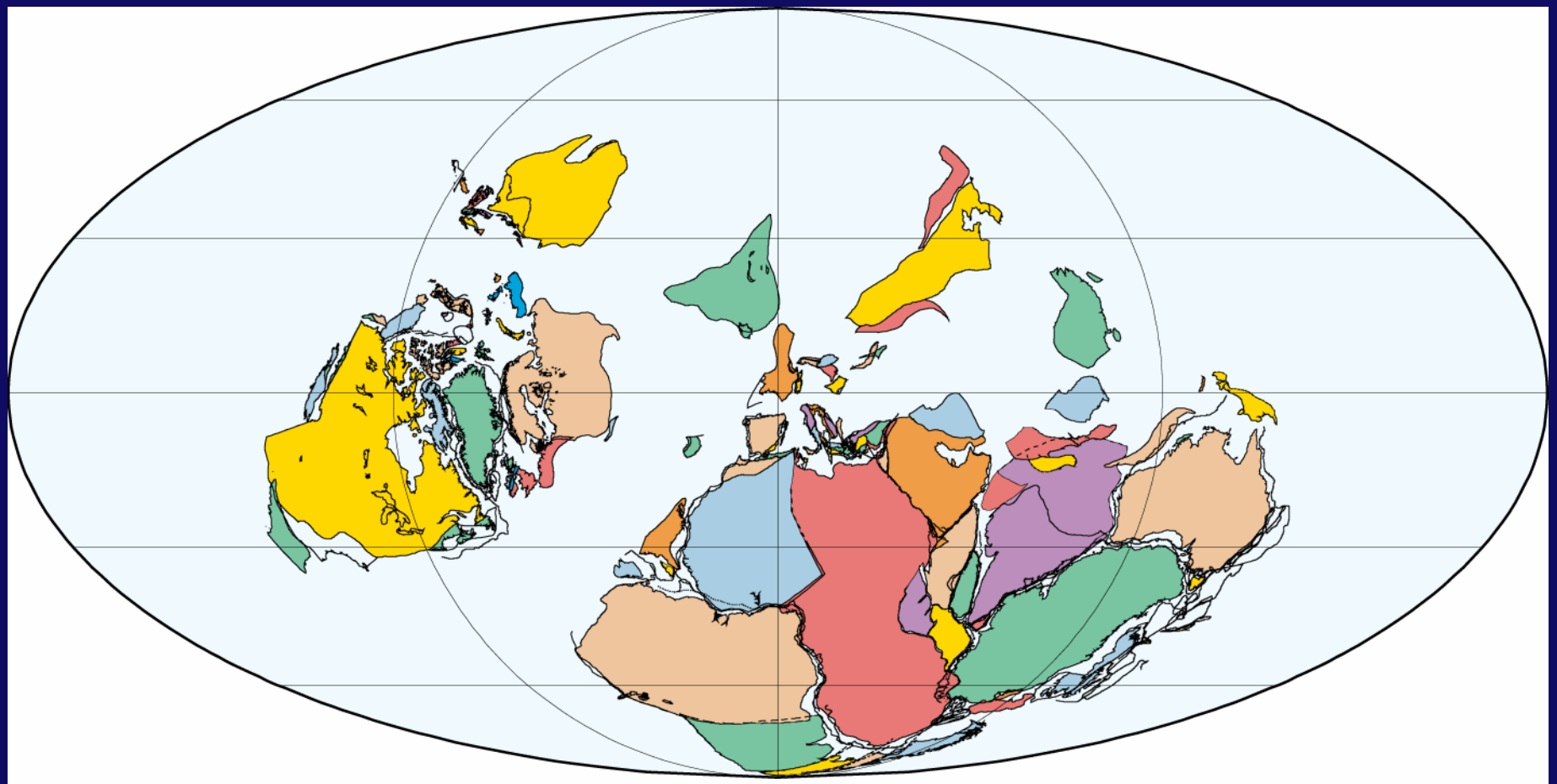


430 Ma

Late Llandoverian (Early Silurian)

PLATES/UTIG

August 2002

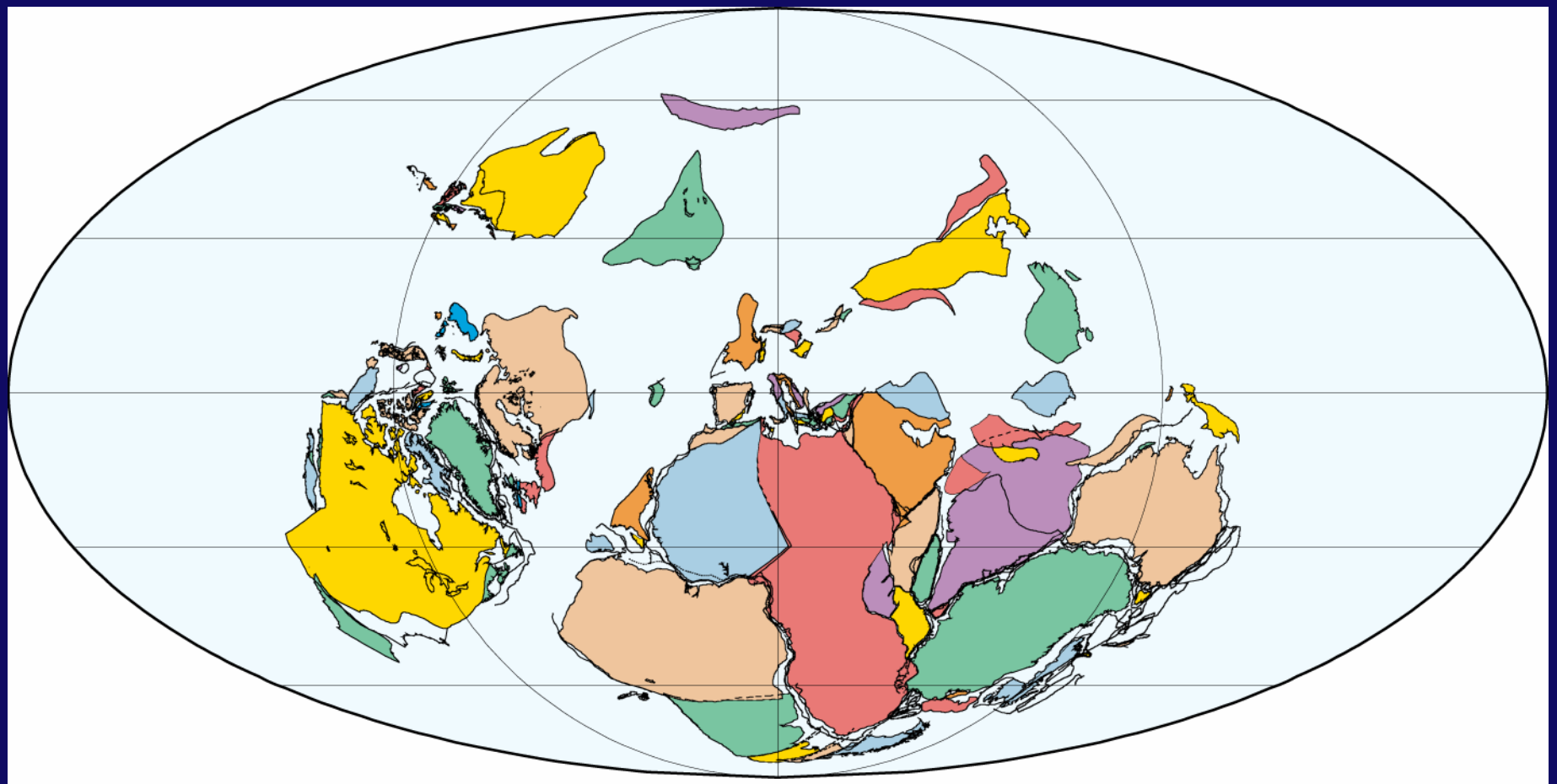


420 Ma

Ludlovian (Late Silurian)

PLATES/UTIG

August 2002

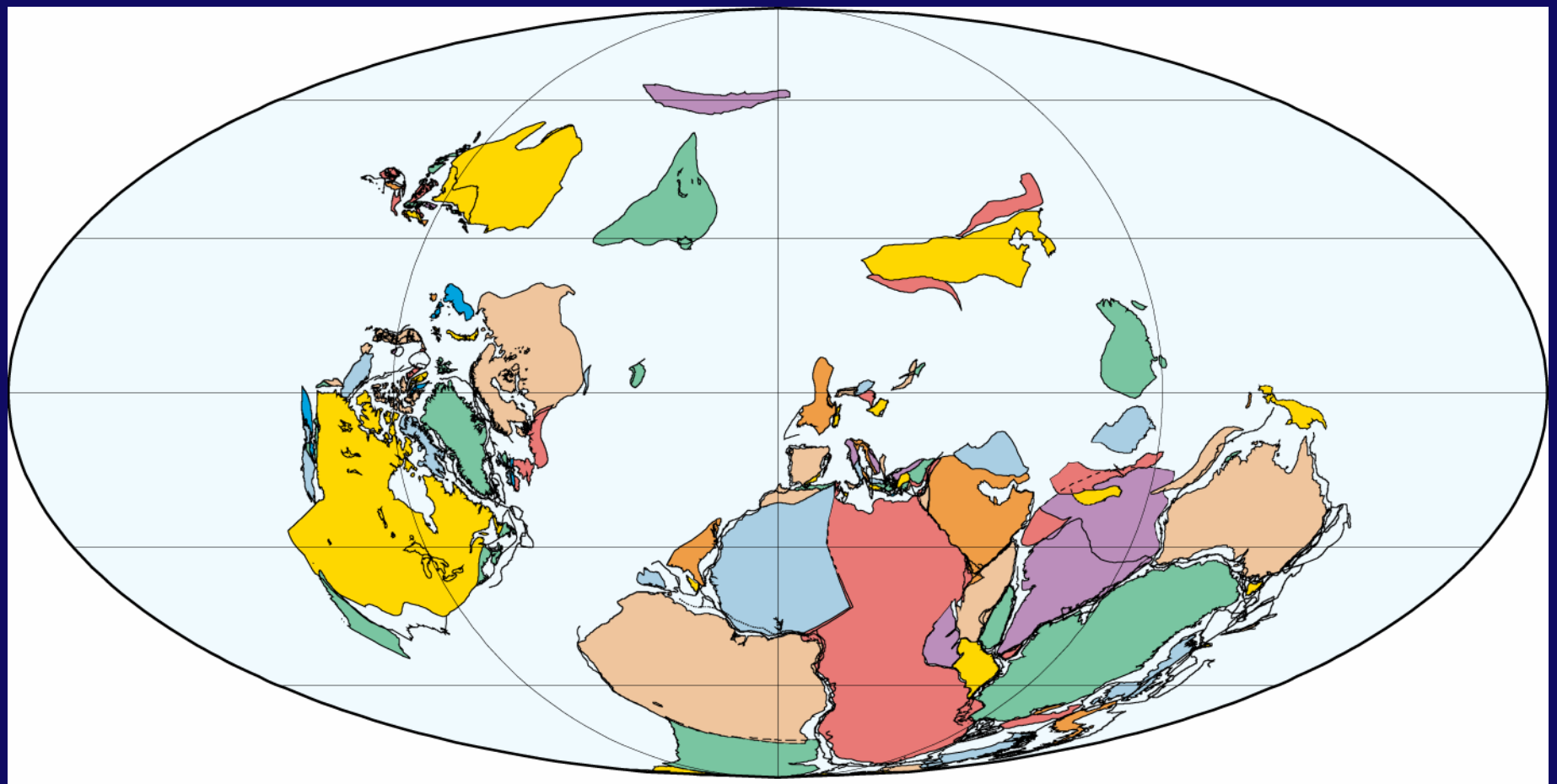


410 Ma

Early Praghian (Early Devonian)

PLATES/UTIG

August 2002

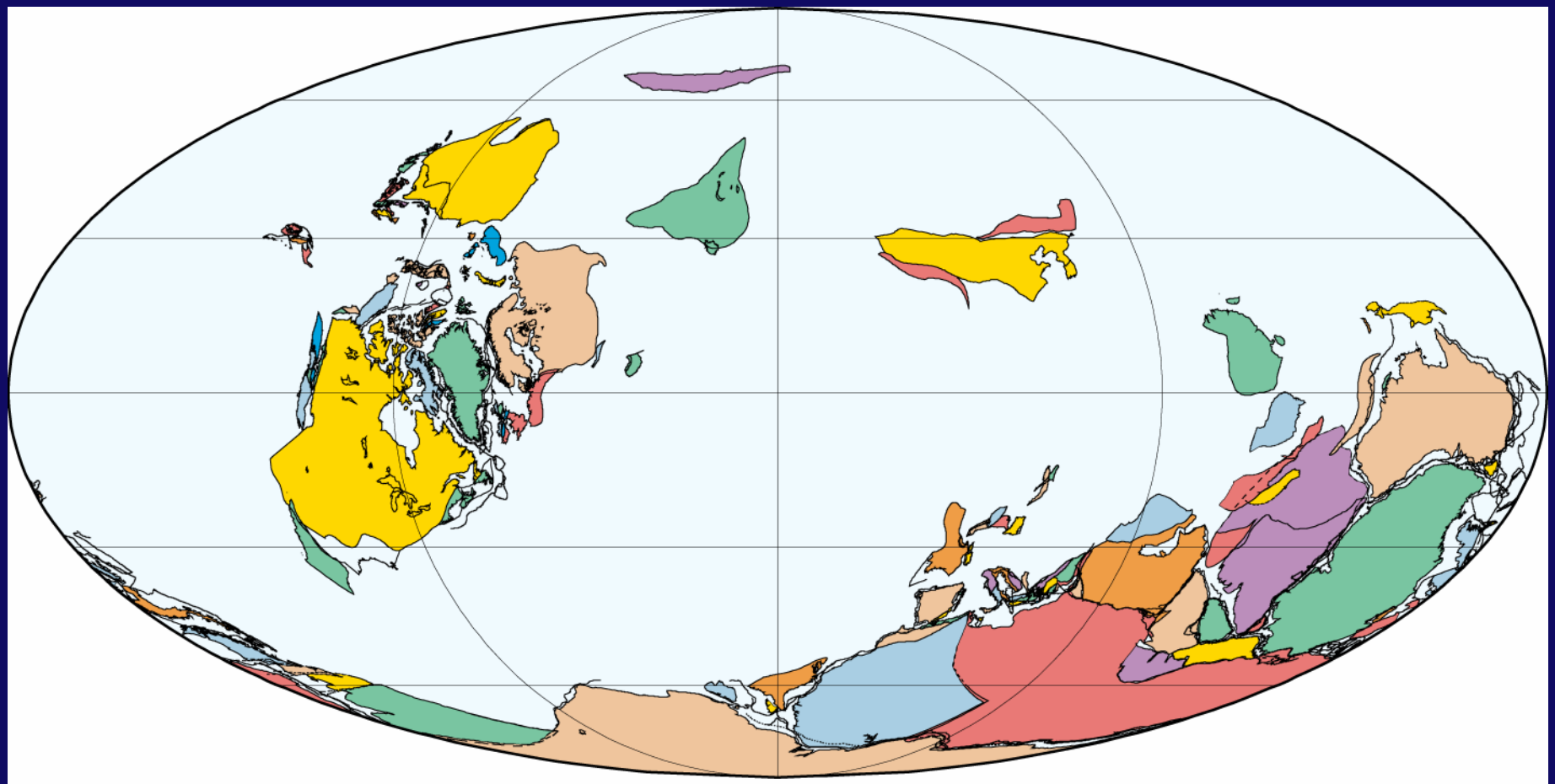


400 Ma

Late Praghian/Early Emsian (Early Devonian)

PLATES/UTIG

August 2002

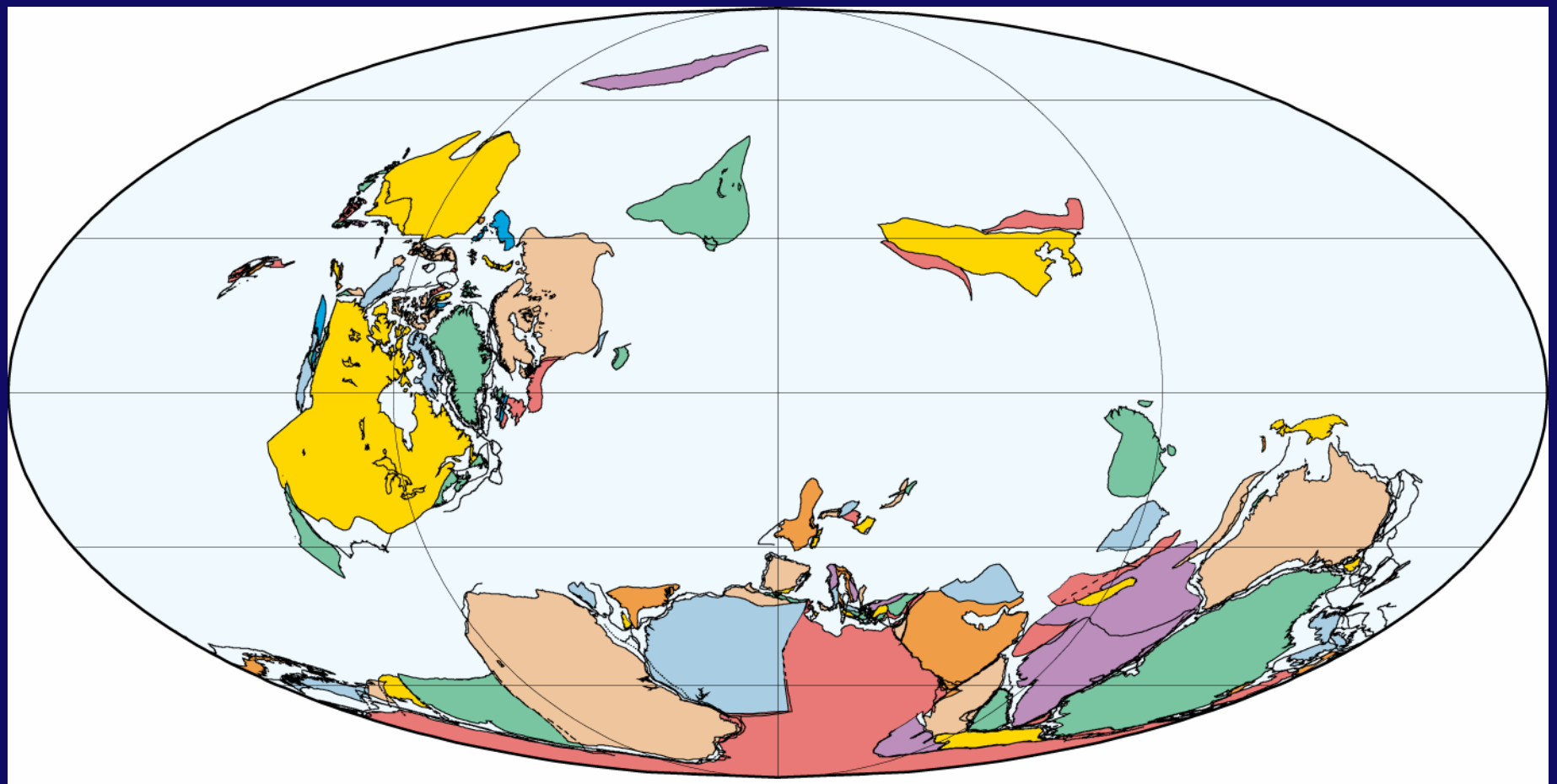


390 Ma

Early Eifelian (Early Devonian)

PLATES/UTIG

August 2002

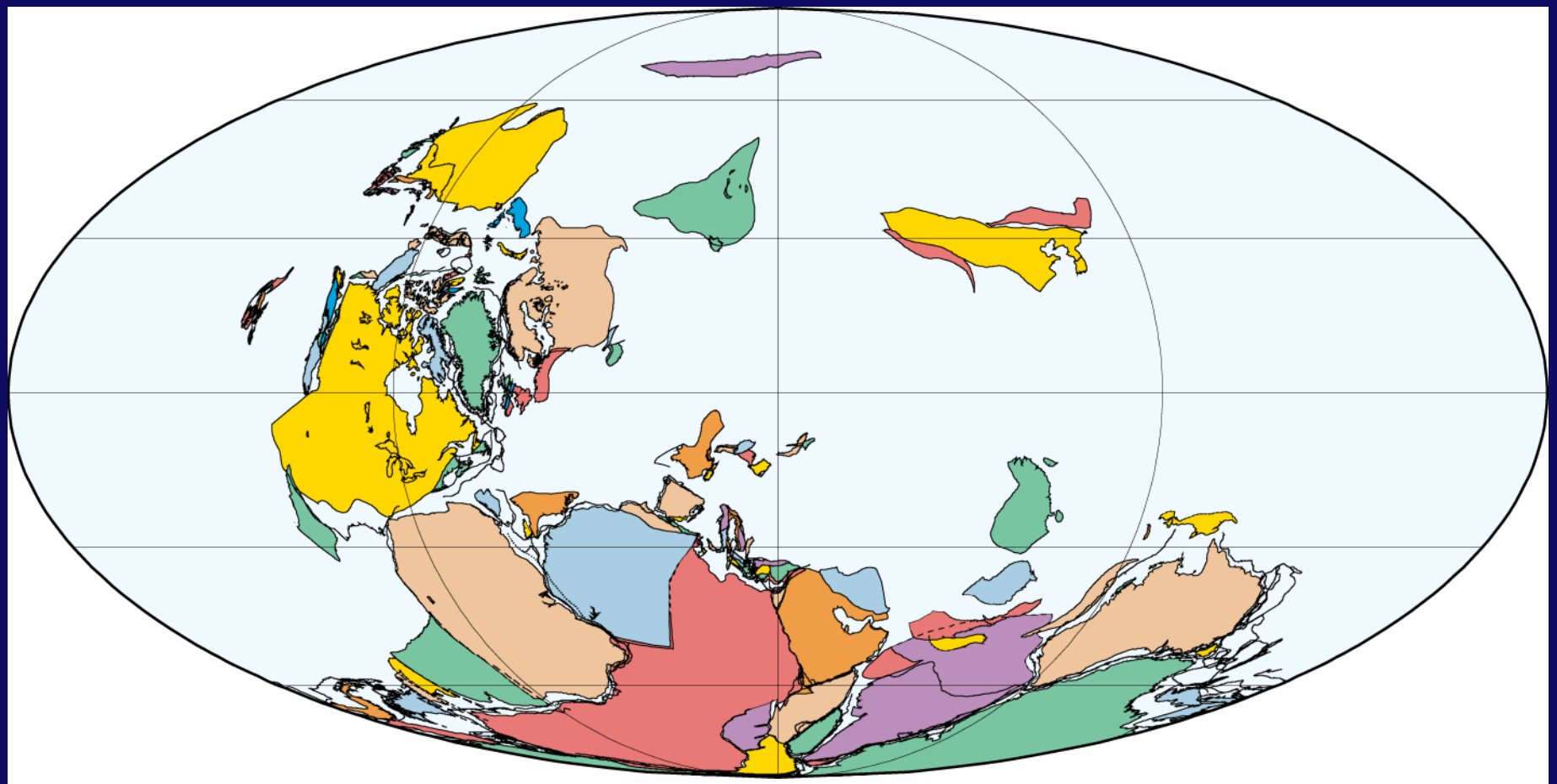


380 Ma

Late Eifelian/Early Givetian (Middle Devonian)

PLATES/UTIG

August 2002

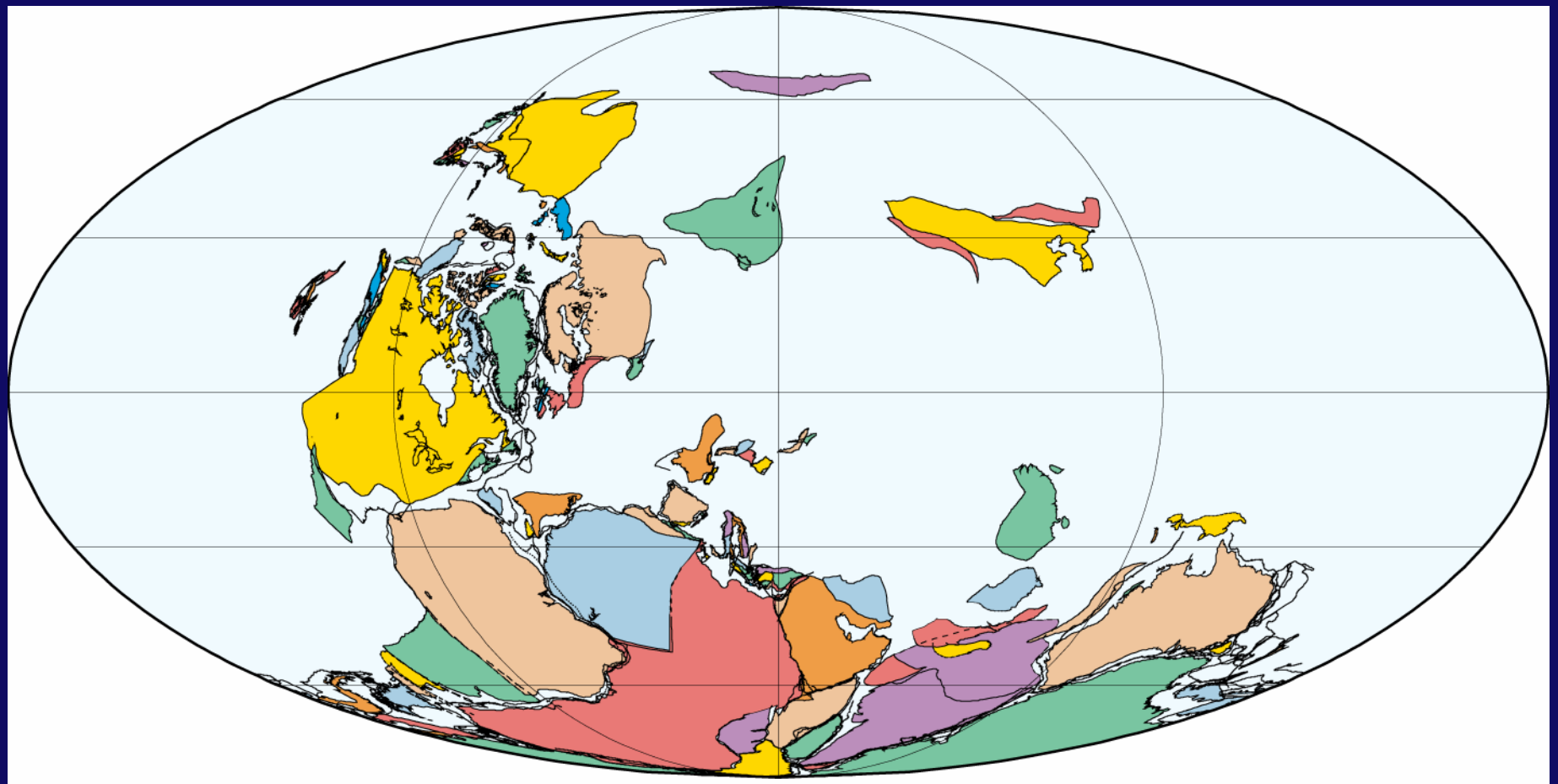


370 Ma

Late Givetian/Early Frasnian (Late Devonian)

PLATES/UTIG

August 2002

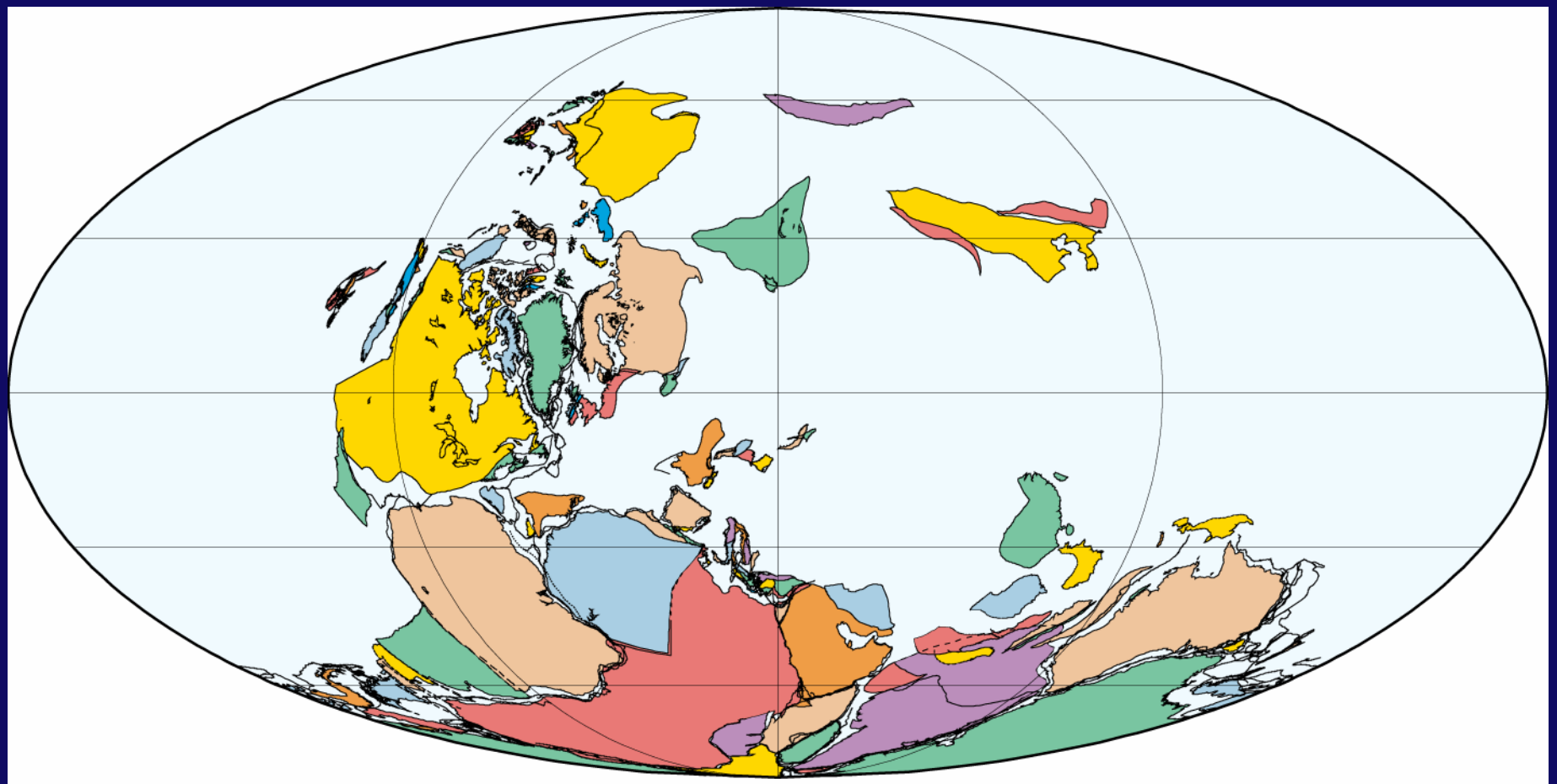


360 Ma

Famennian (Late Devonian)

PLATES/UTIG

August 2002

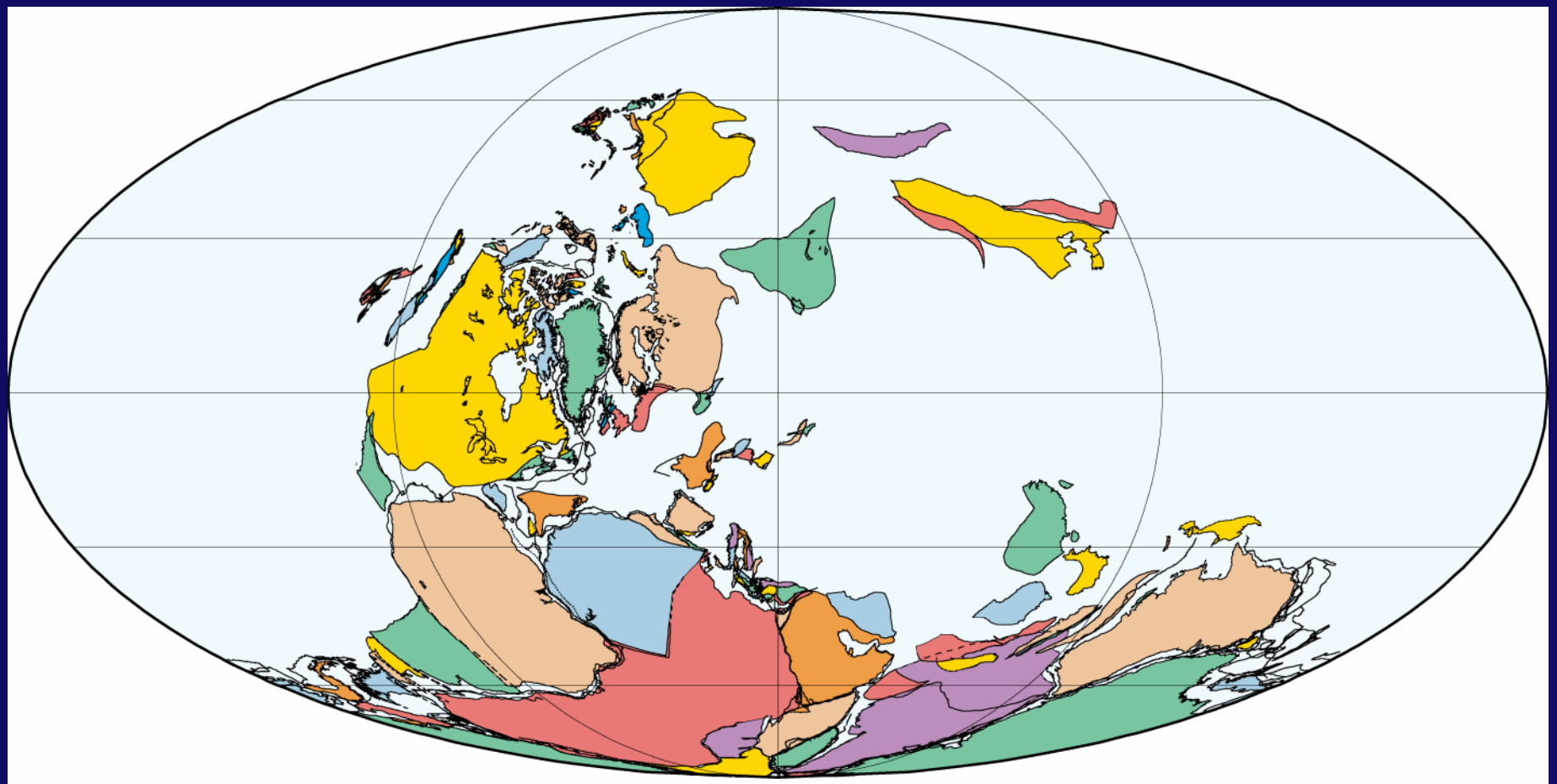


350 Ma

Tournaisian (Mississippian)

PLATES/UTIG

August 2002

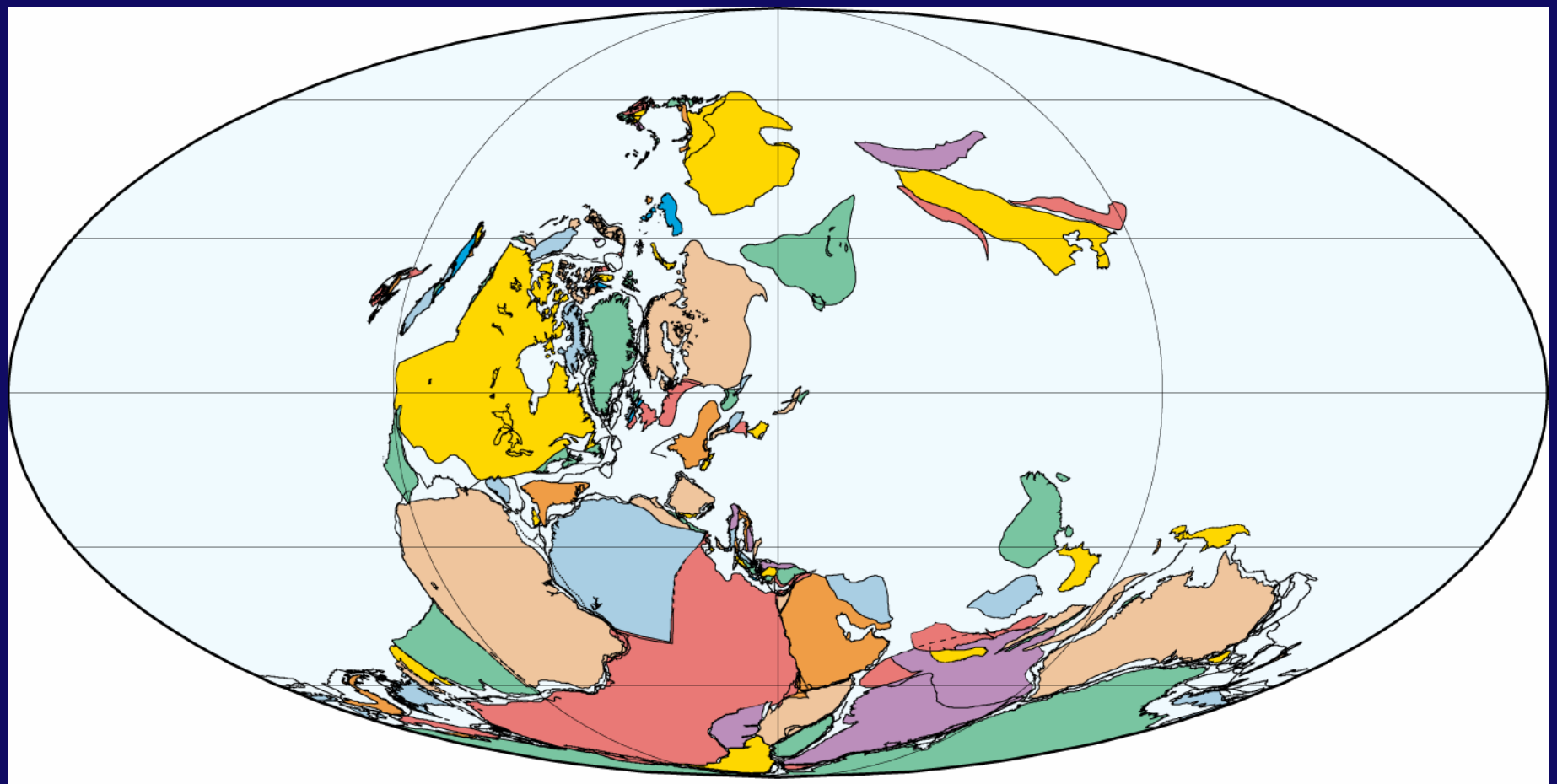


340 Ma

Early Visean (Mississippian)

PLATES/UTIG

August 2002

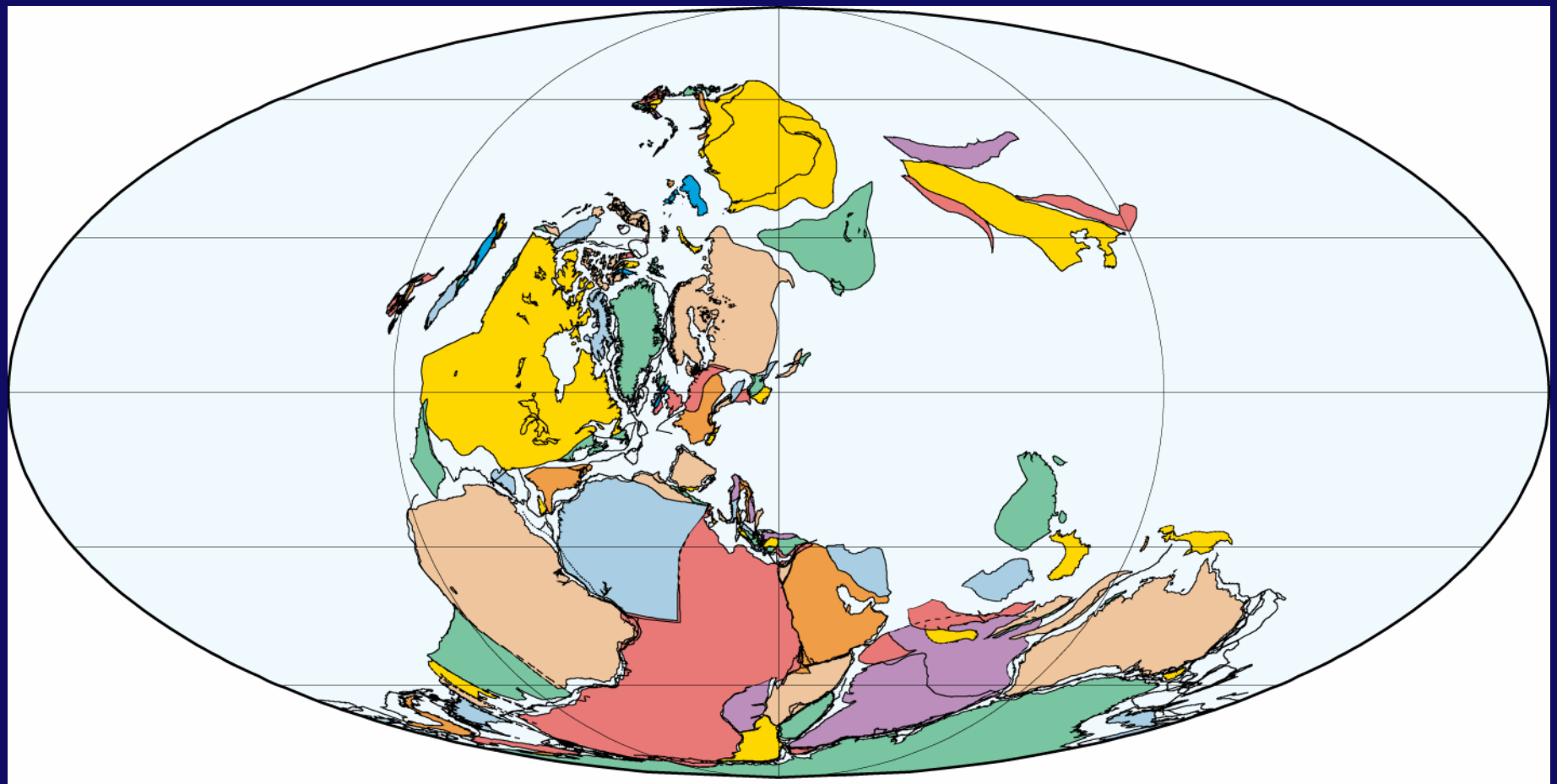


330 Ma

Late Visean (Mississippian)

PLATES/UTIG

August 2002

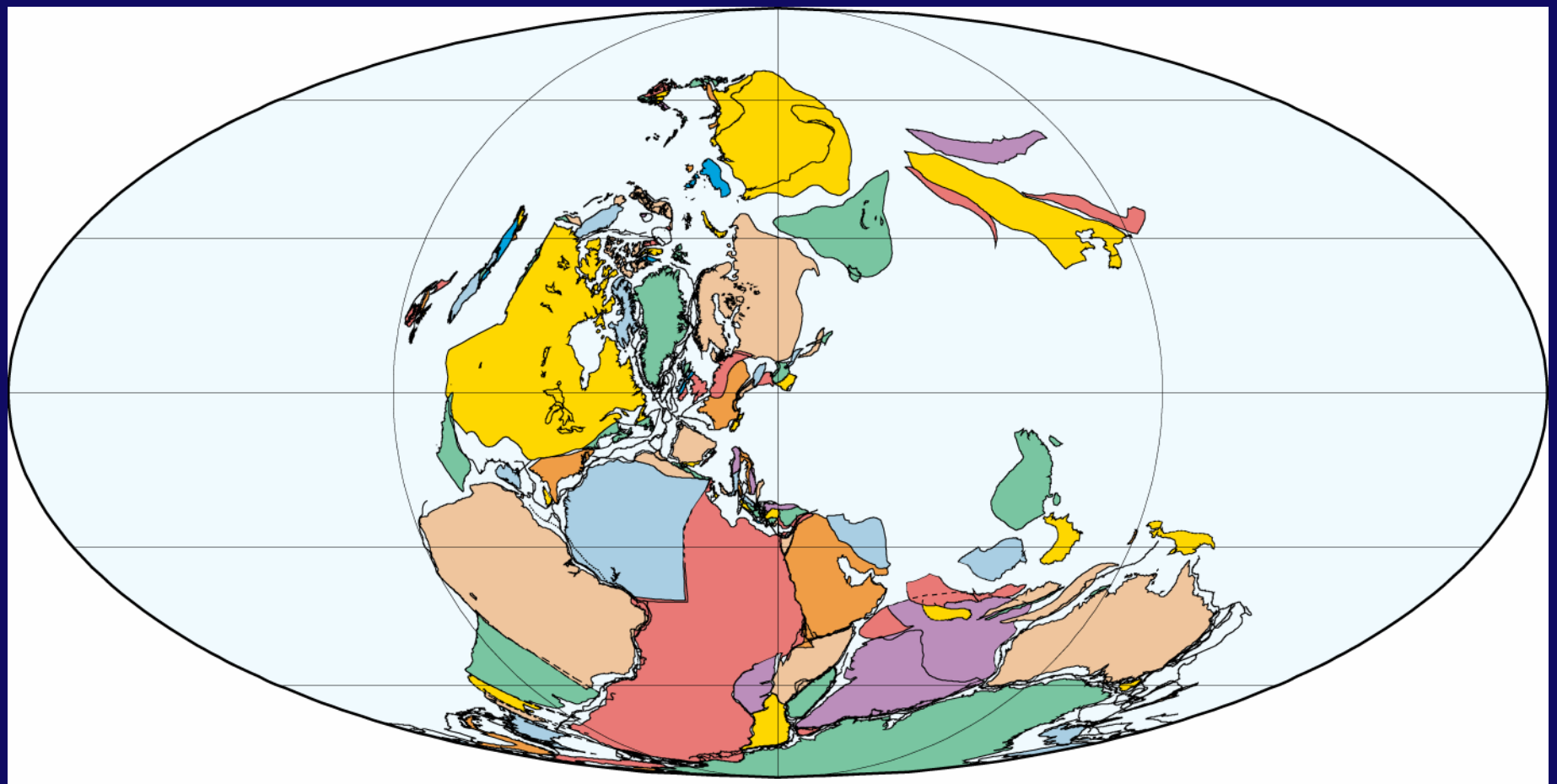


320 Ma

Bashkirian (Pennsylvanian)

PLATES/UTIG

August 2002

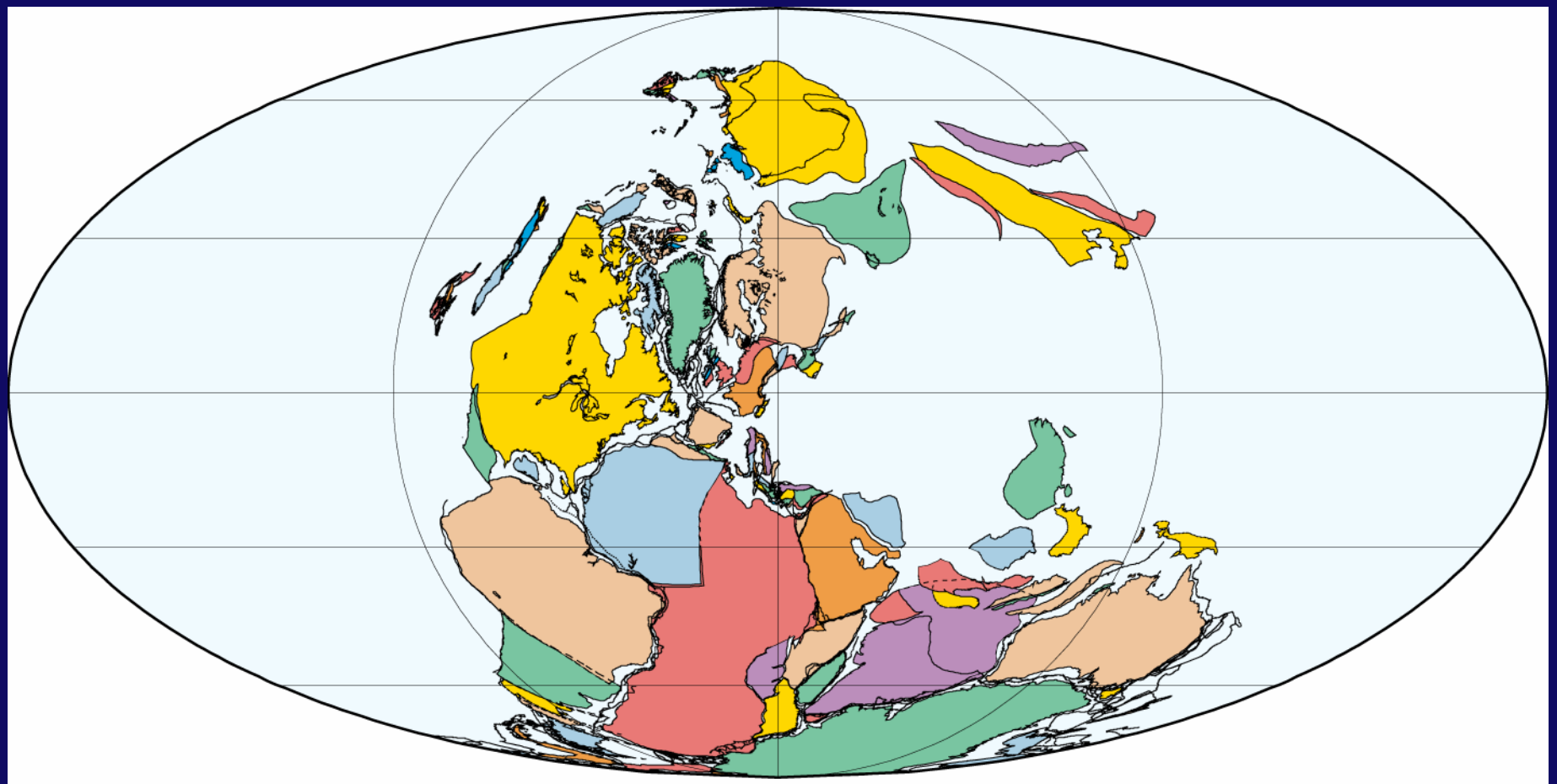


310 Ma

Moscovian (Pennsylvanian)

PLATES/UTIG

August 2002

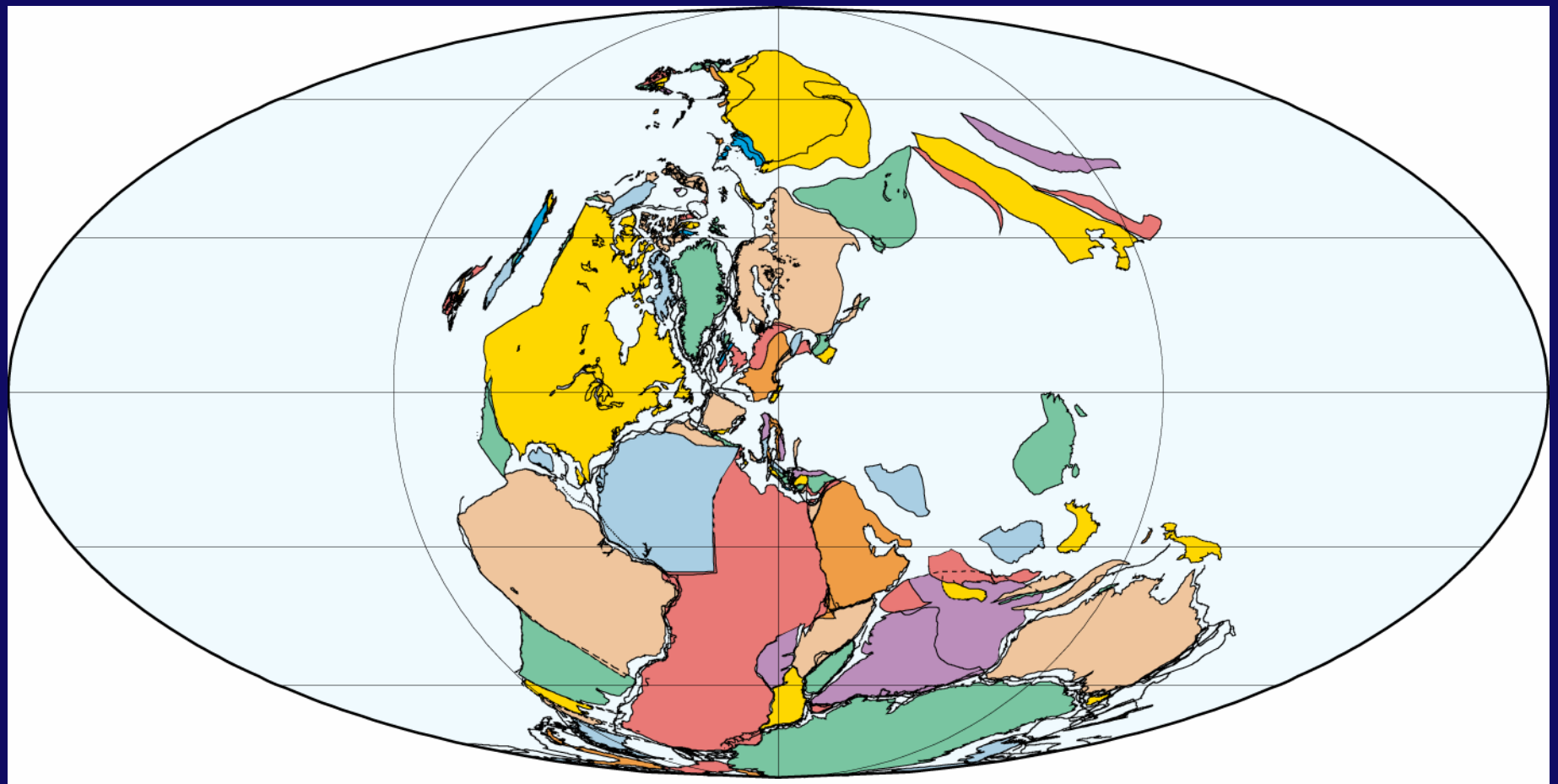


300 Ma

Kasimovian (Pennsylvanian)

PLATES/UTIG

August 2002

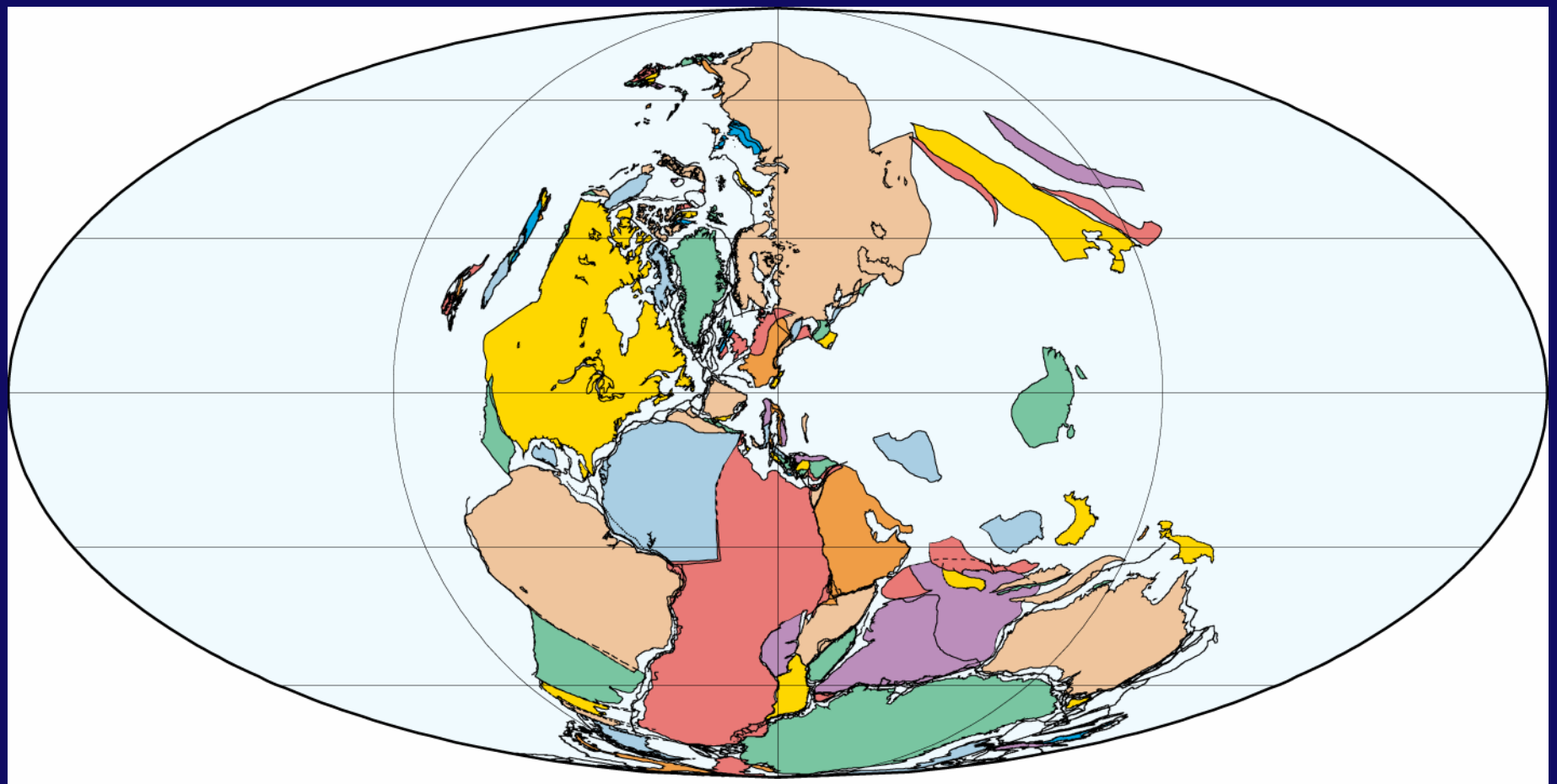


290 Ma

Late Gzelian/Early Asselian (Pennsylvanian/Permian)

PLATES/UTIG

August 2002

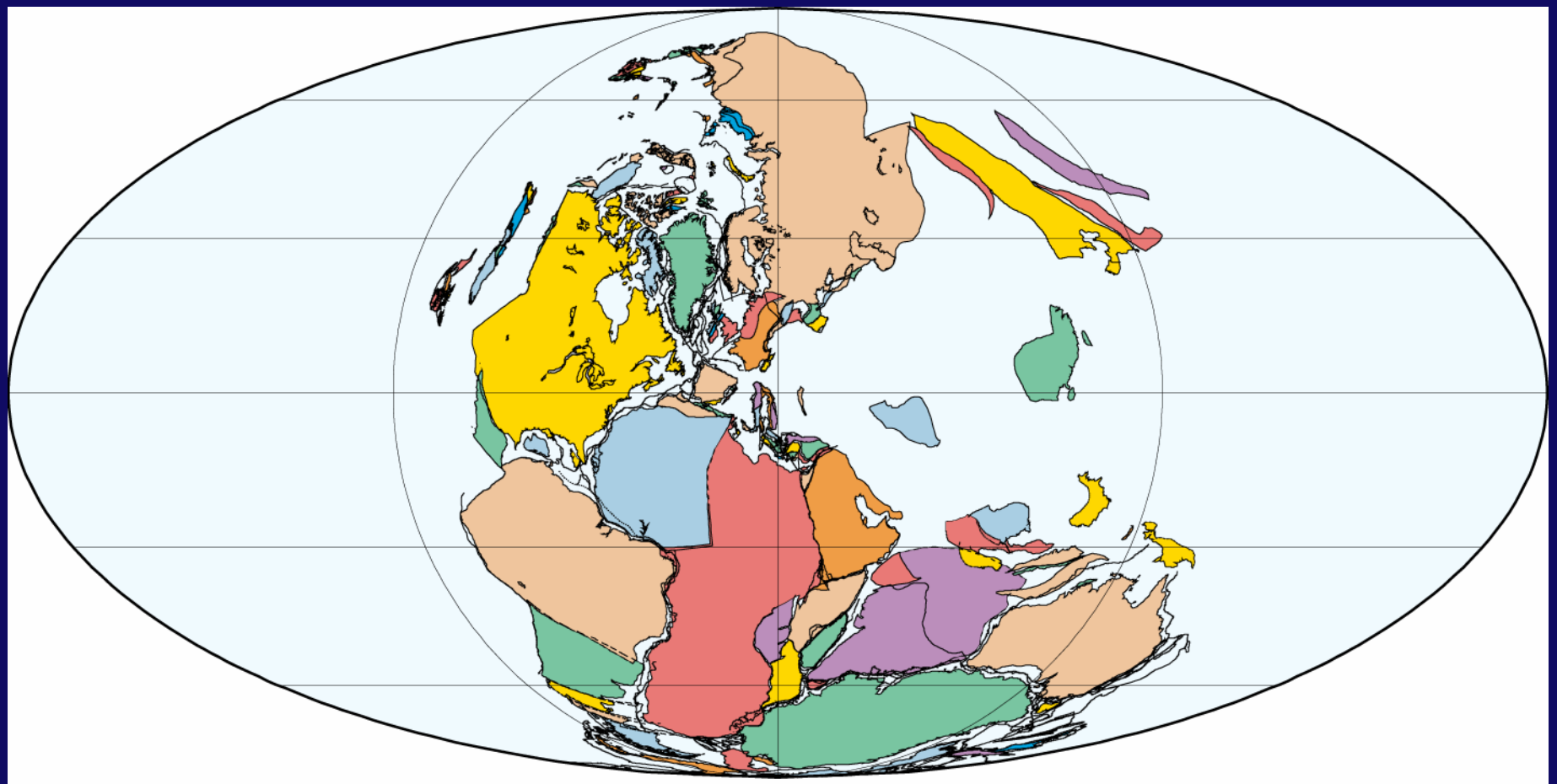


280 Ma

Early Sakmarian (Early Permian)

PLATES/UTIG

August 2002

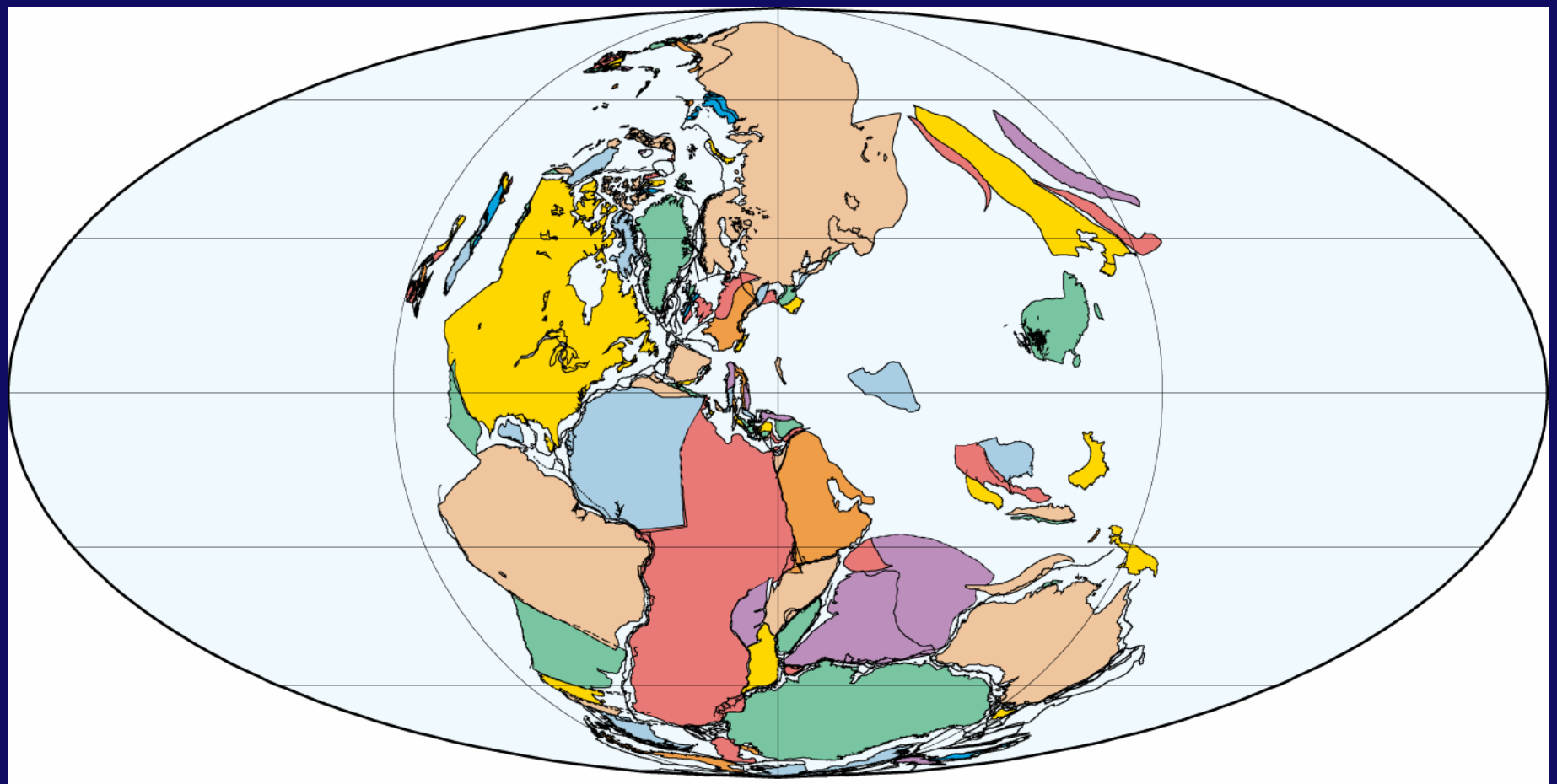


270 Ma

Late Sakmarian (Early Permian)

PLATES/UTIG

August 2002

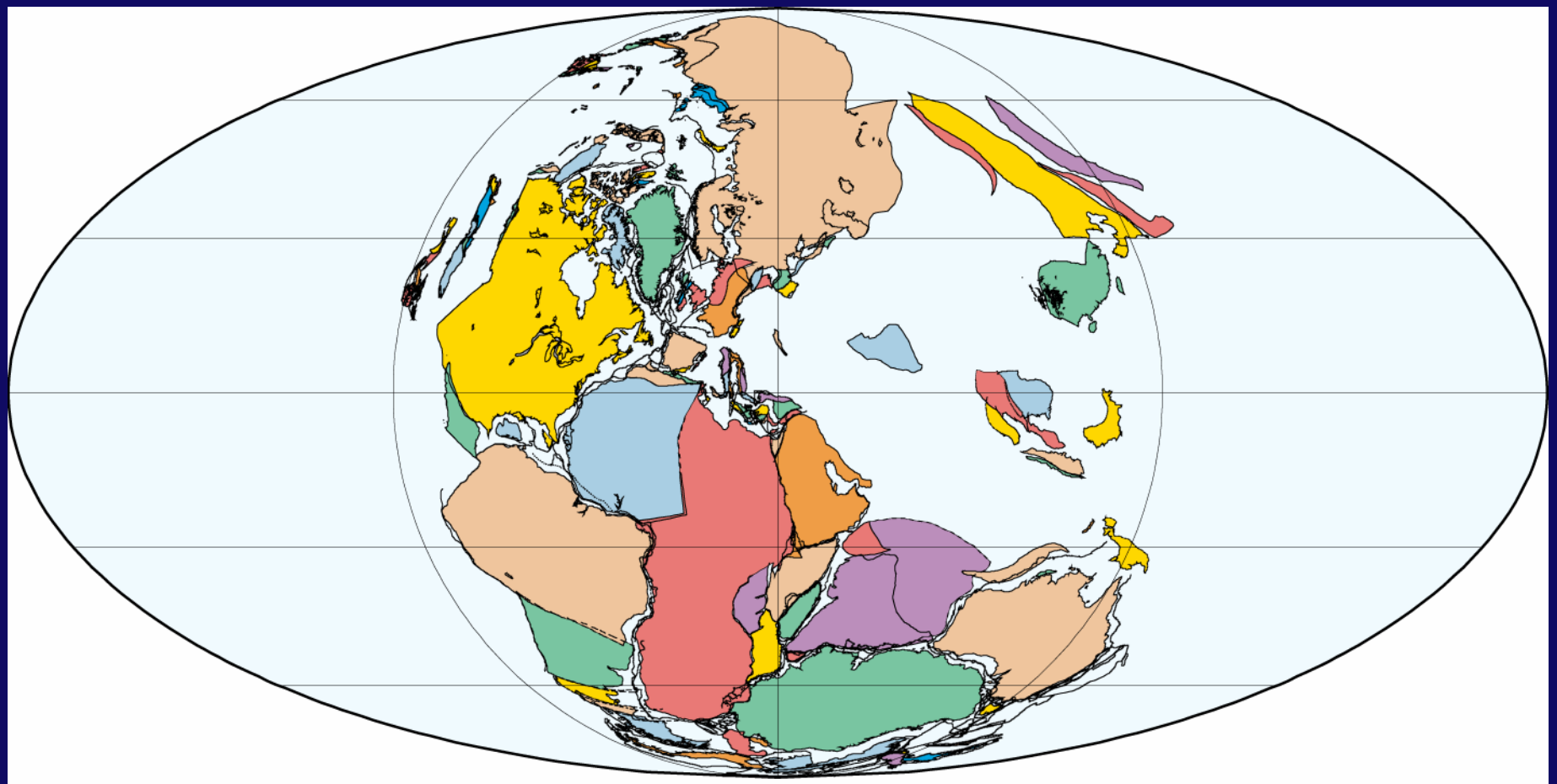


260 Ma

Late Artinskian/Early Kungurian (Early Permian)

PLATES/UTIG

August 2002

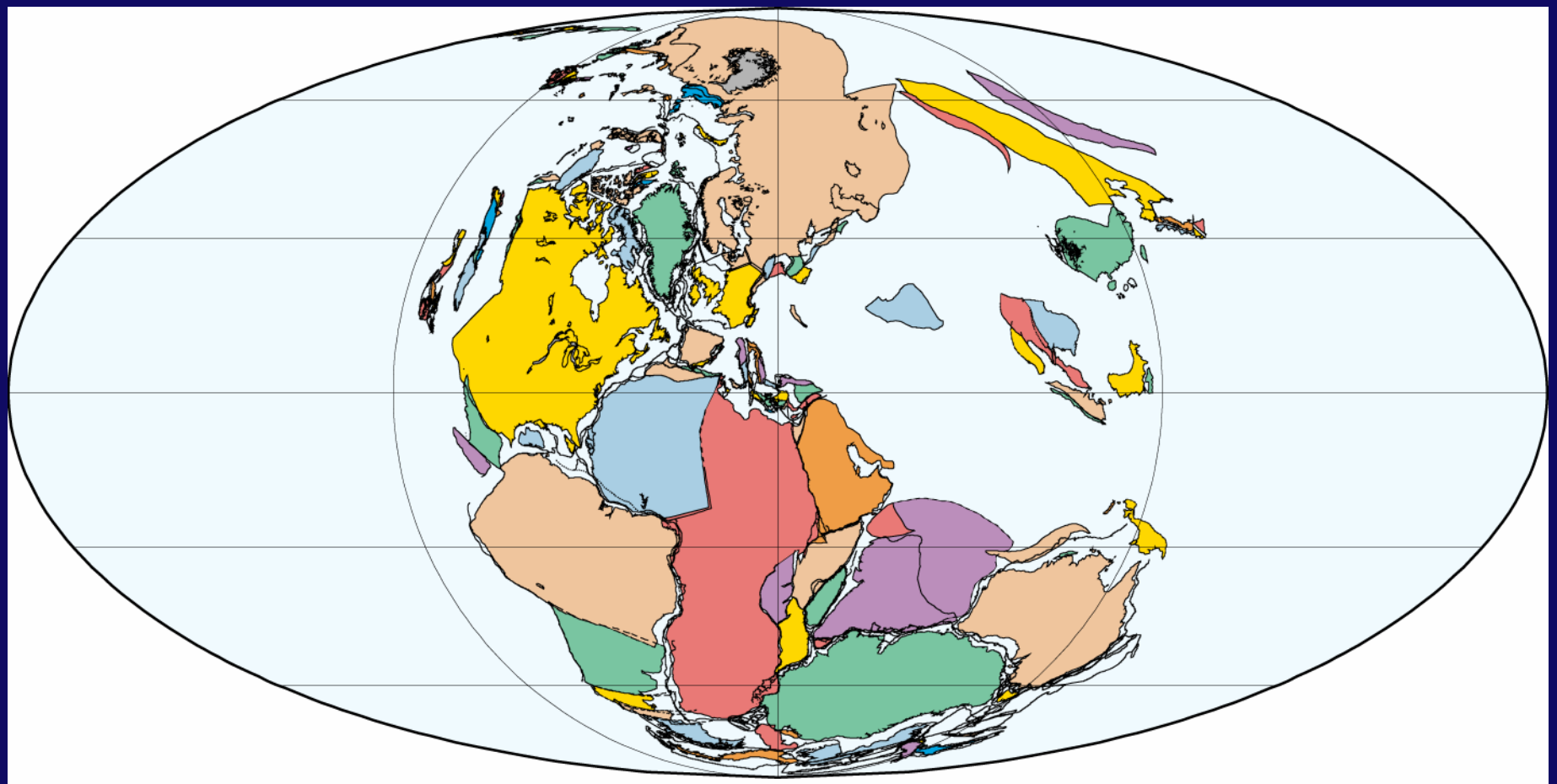


250 Ma

Tatarian (Late Permian)

PLATES/UTIG

August 2002

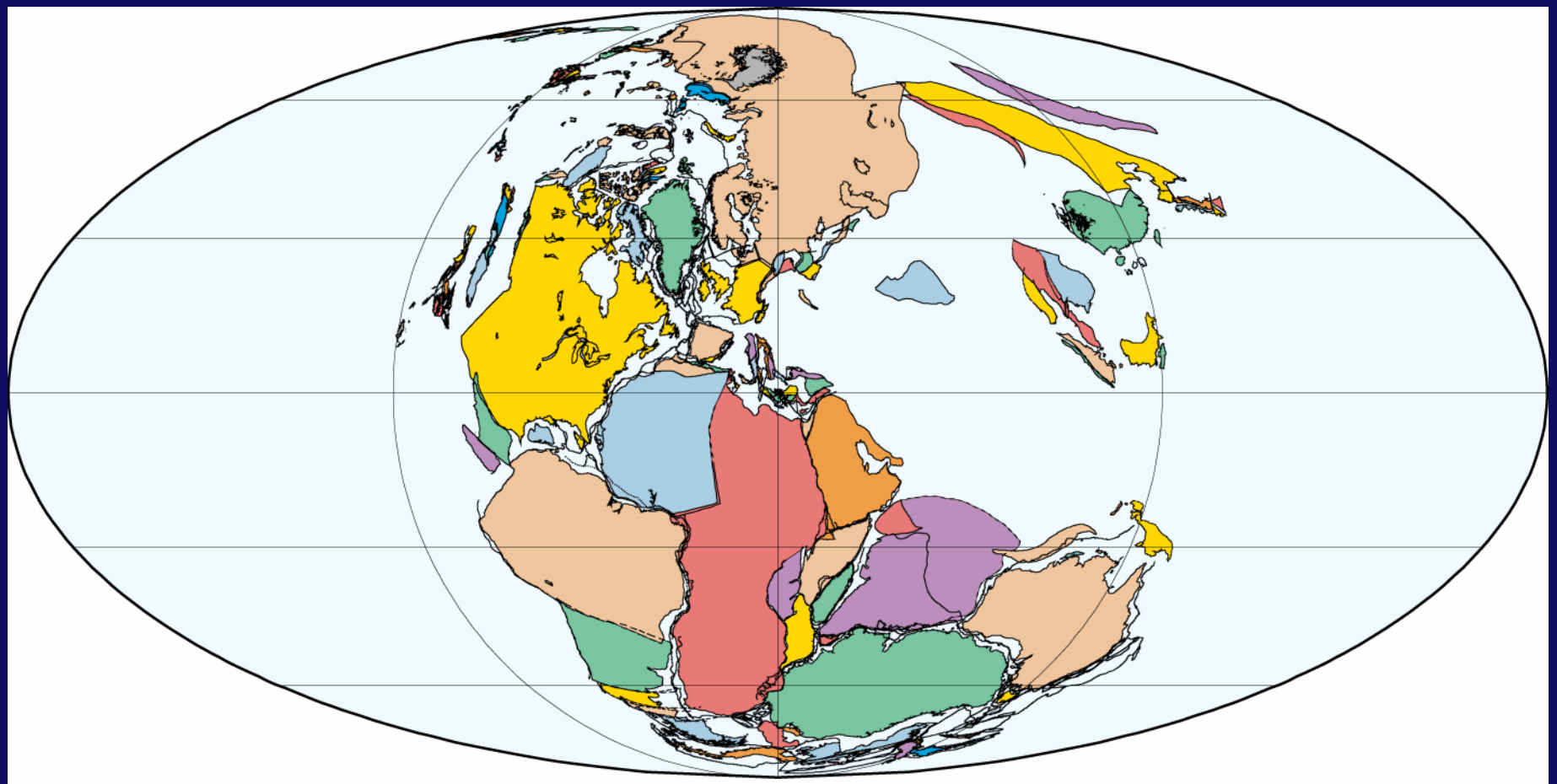


240 Ma

Anisian (Middle Triassic)

PLATES/UTIG

August 2002

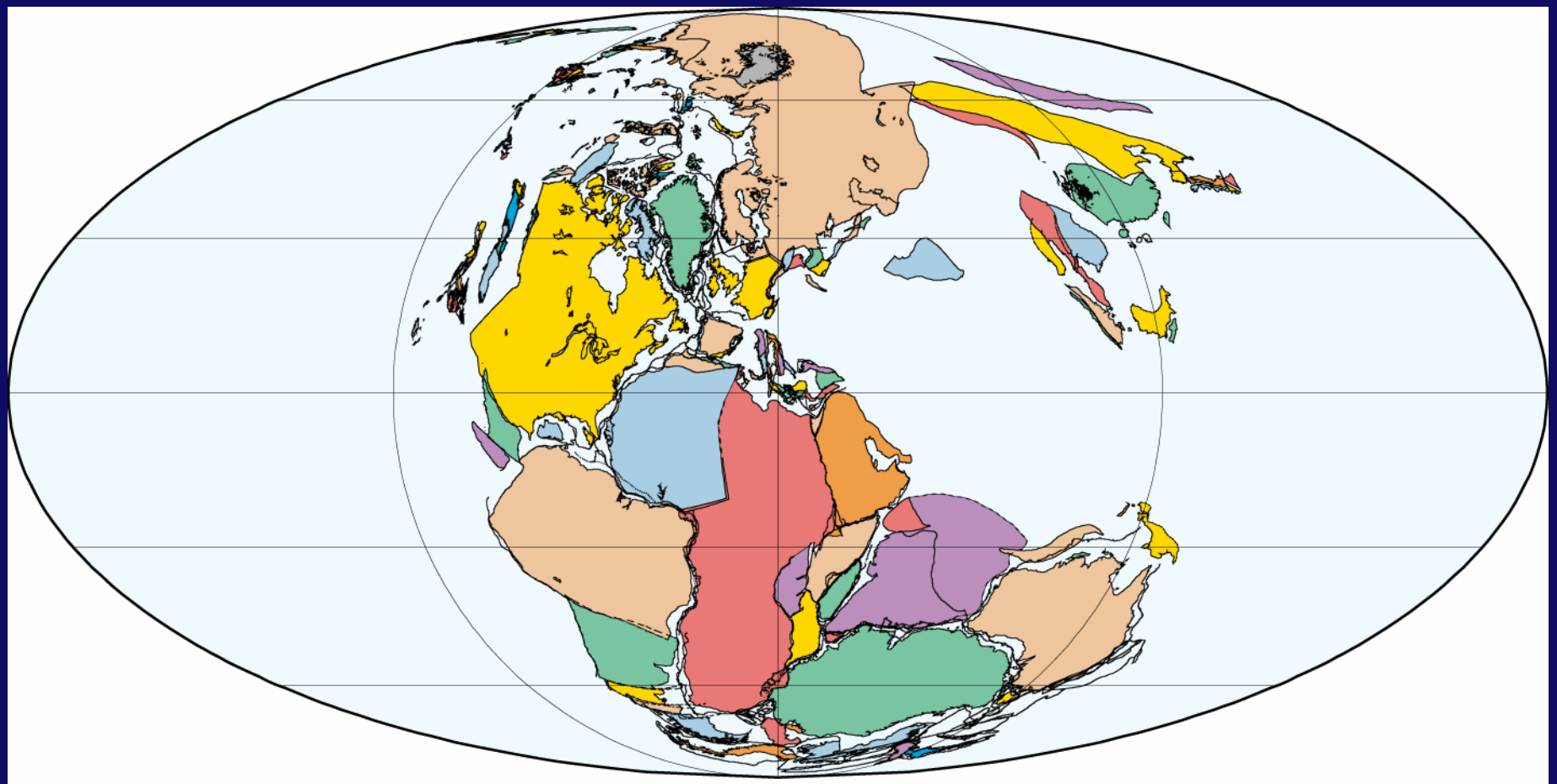


230 Ma

Ladinian (Middle Triassic)

PLATES/UTIG

August 2002

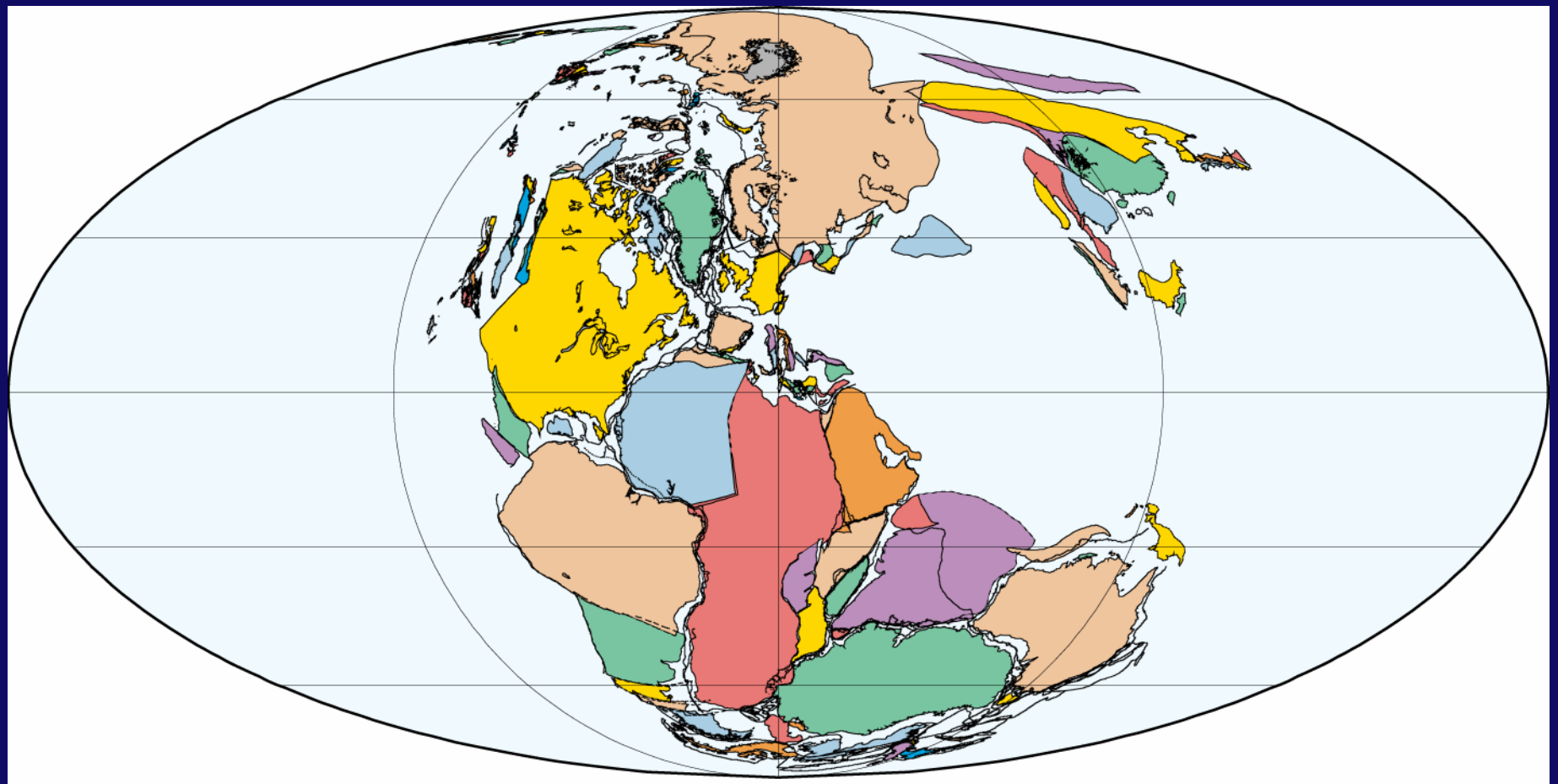


220 Ma

Early Norian (Late Triassic)

PLATES/UTIG

August 2002

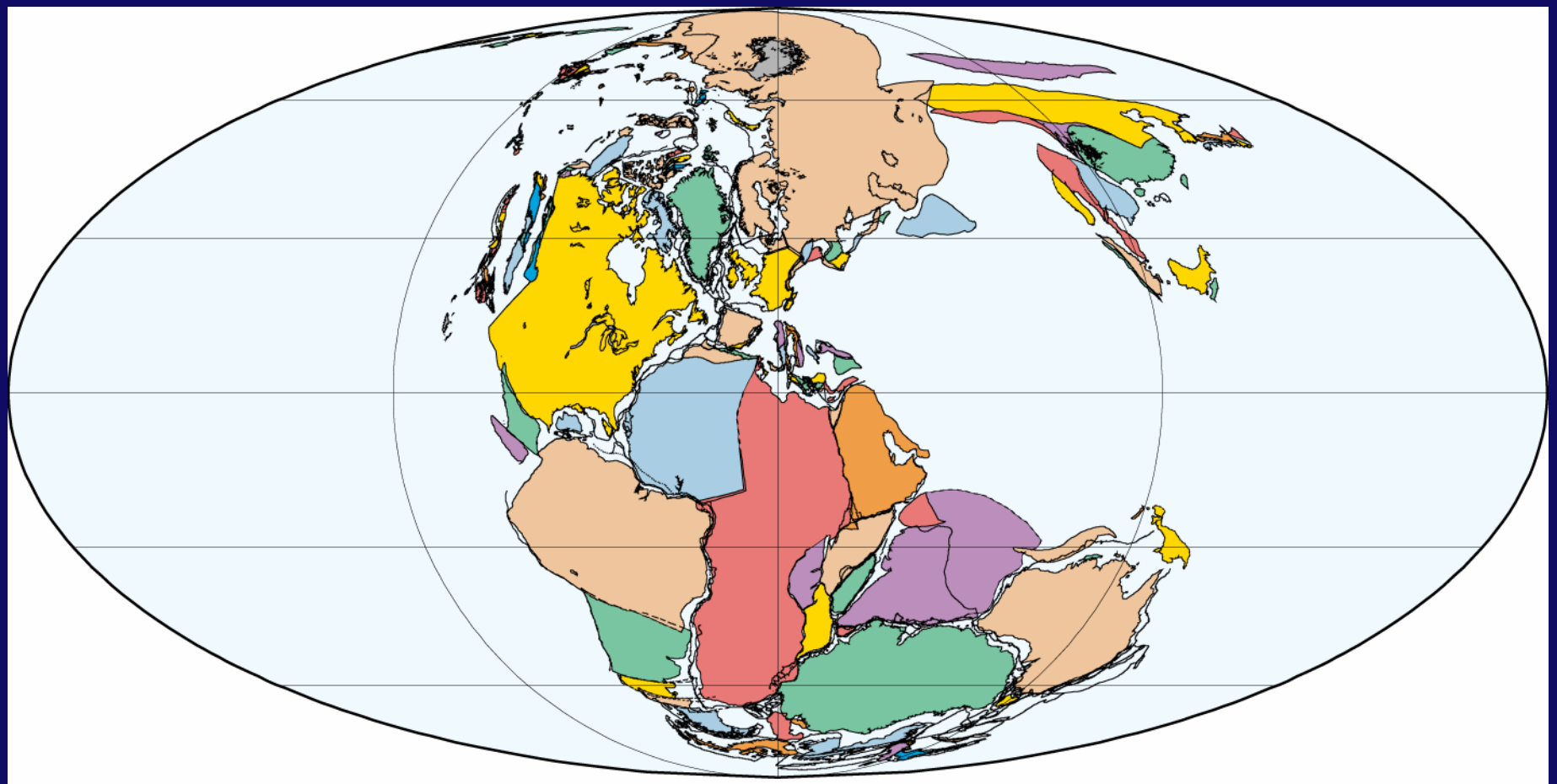


210 Ma

Late Norian (Late Triassic)

PLATES/UTIG

August 2002

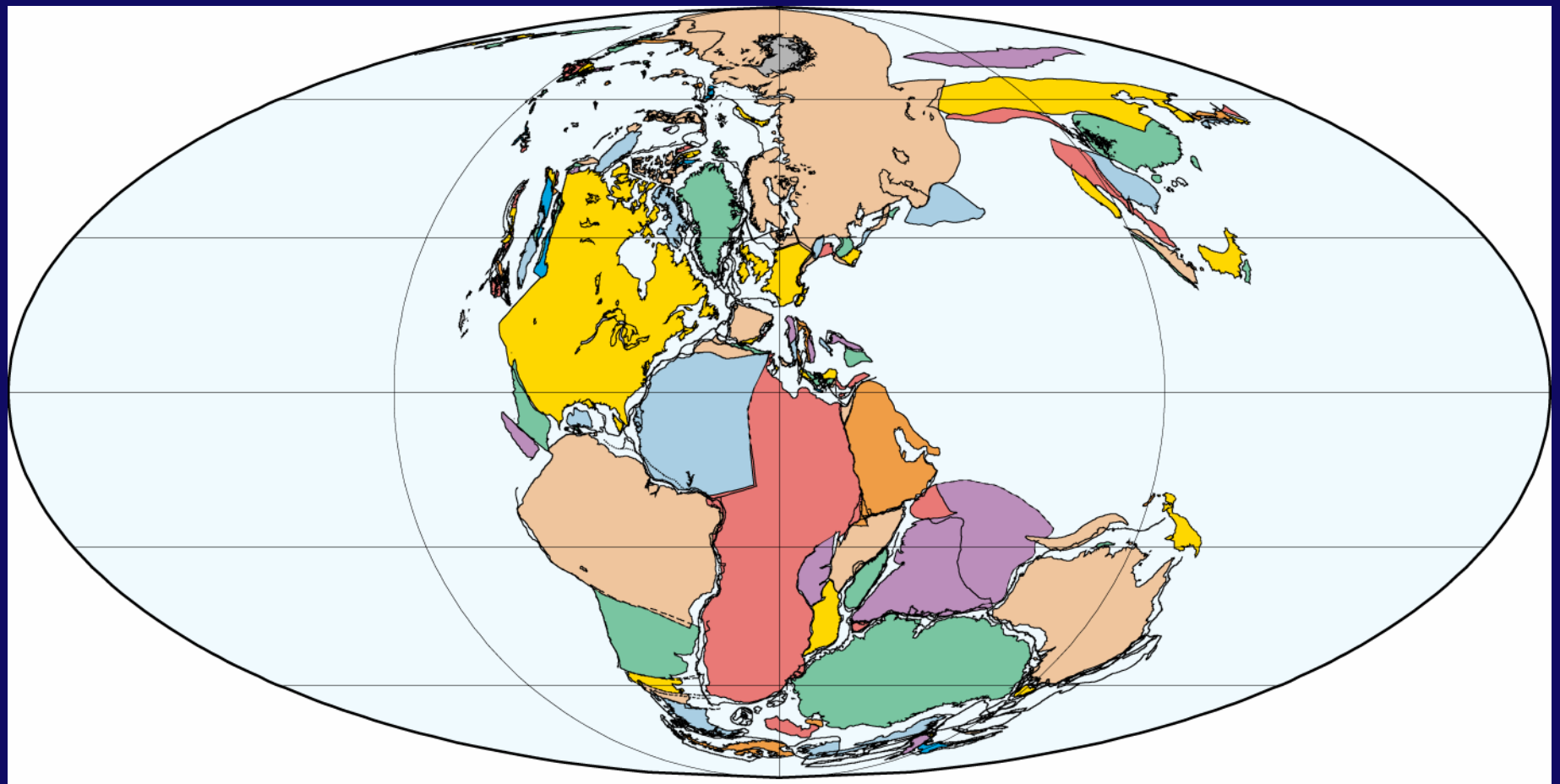


200 Ma

Sinemurian (Early Jurassic)

PLATES/UTIG

August 2002

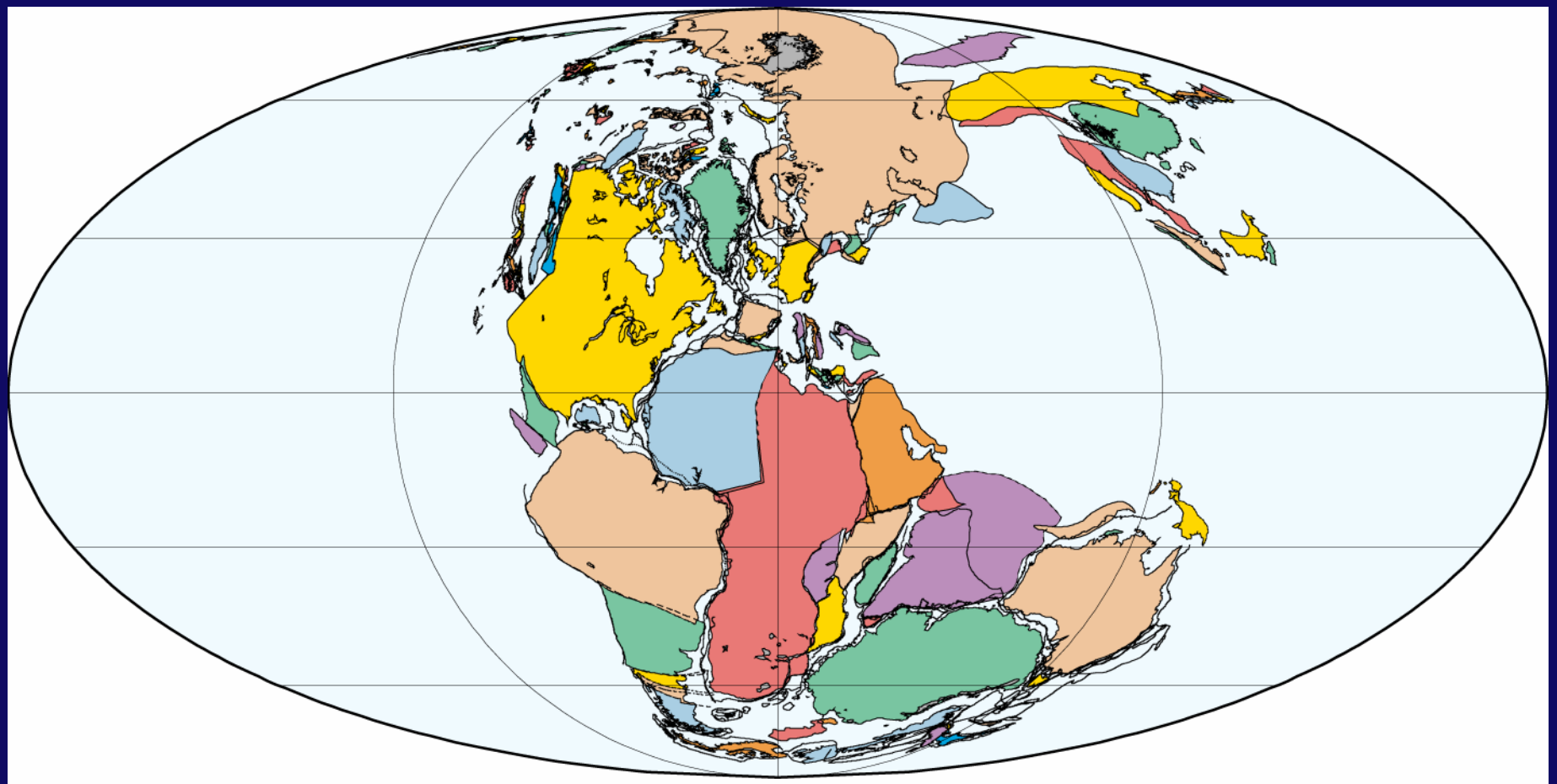


190 Ma

Pliensbachian (Early Jurassic)

PLATES/UTIG

August 2002

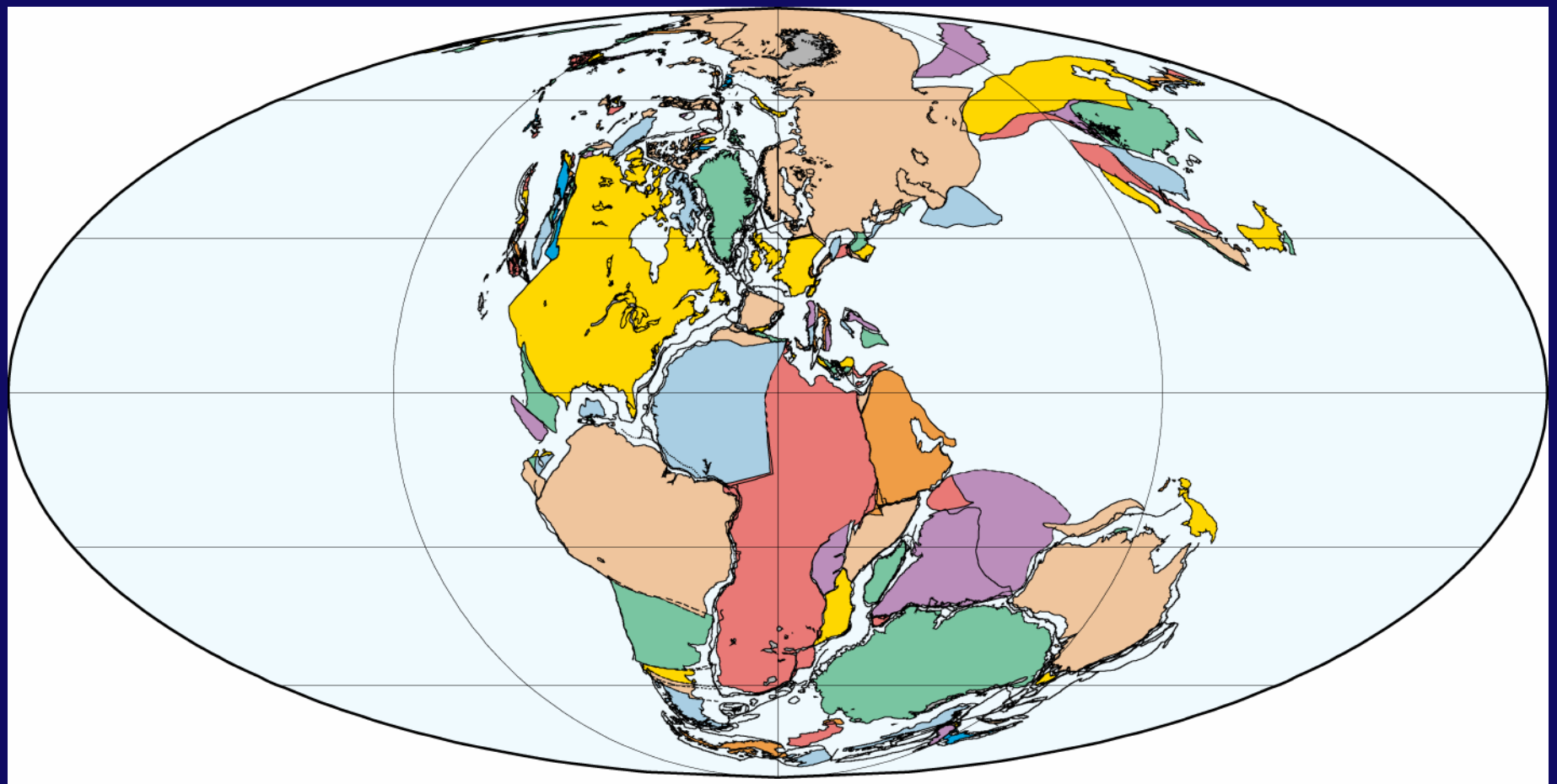


180 Ma

Aalenian (Middle Jurassic)

PLATES/UTIG

August 2002

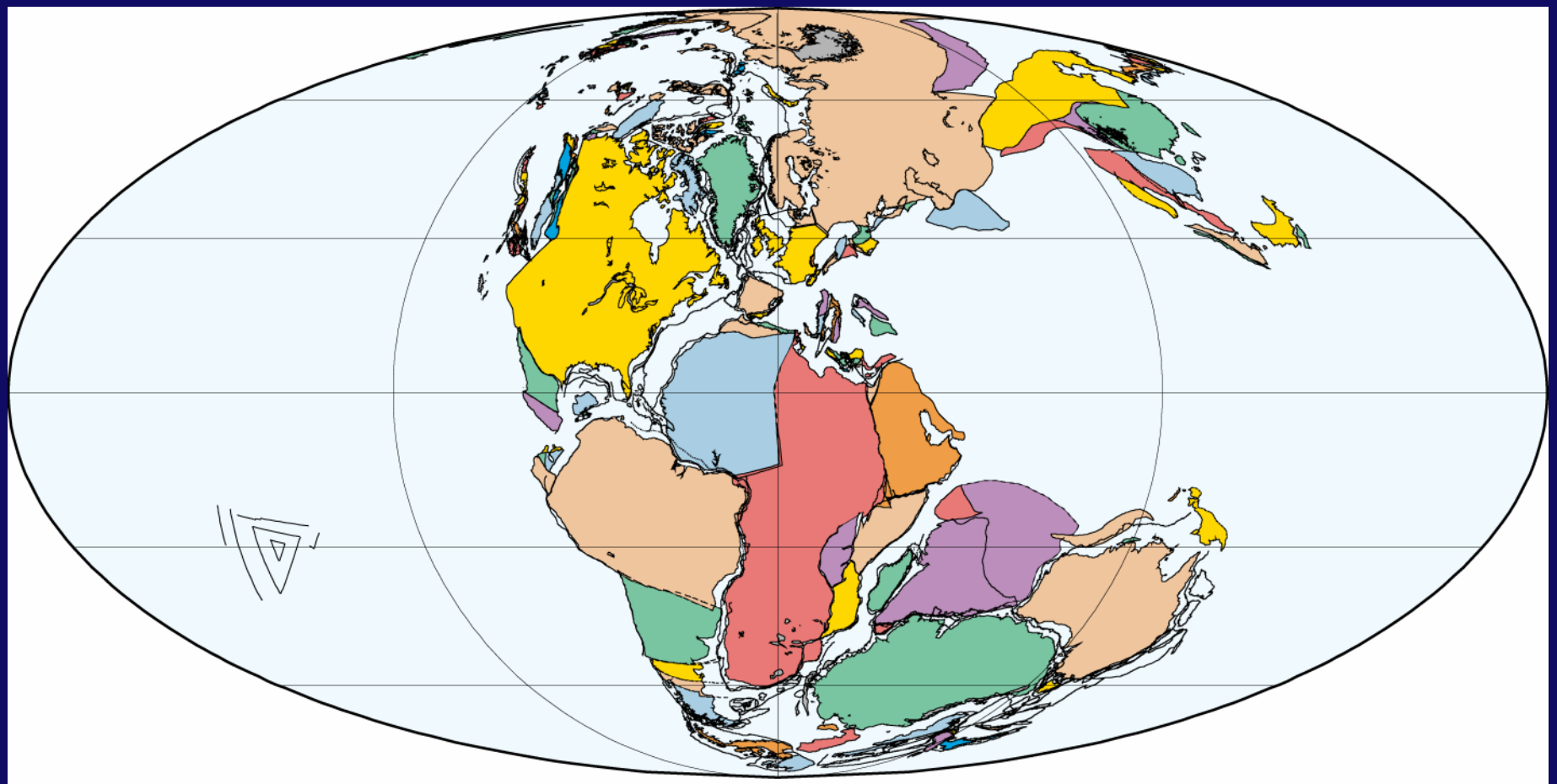


170 Ma

Bajocian (Middle Jurassic)

PLATES/UTIG

August 2002

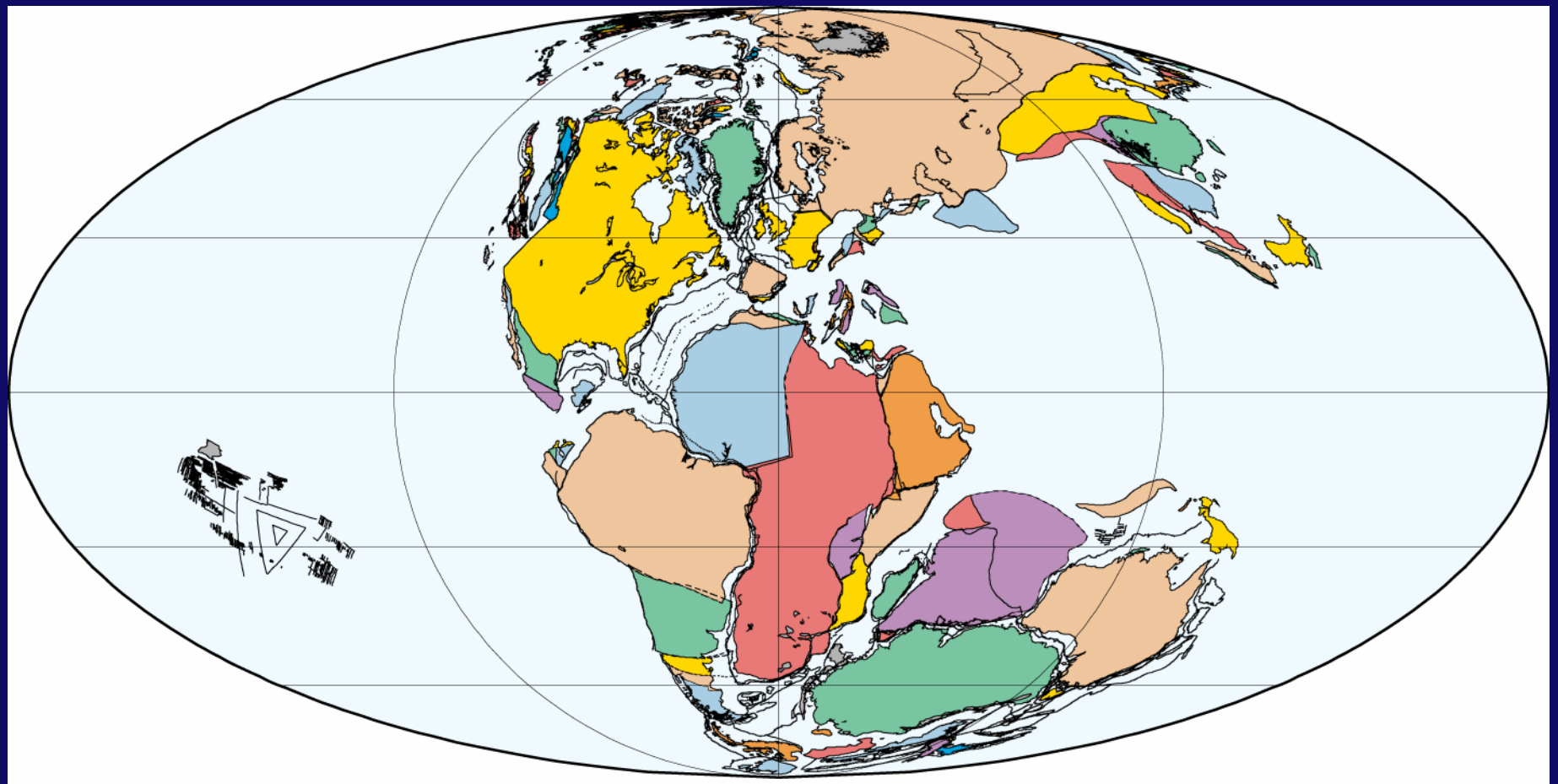


160 Ma

Callovian (Middle Jurassic)

PLATES/UTIG

August 2002

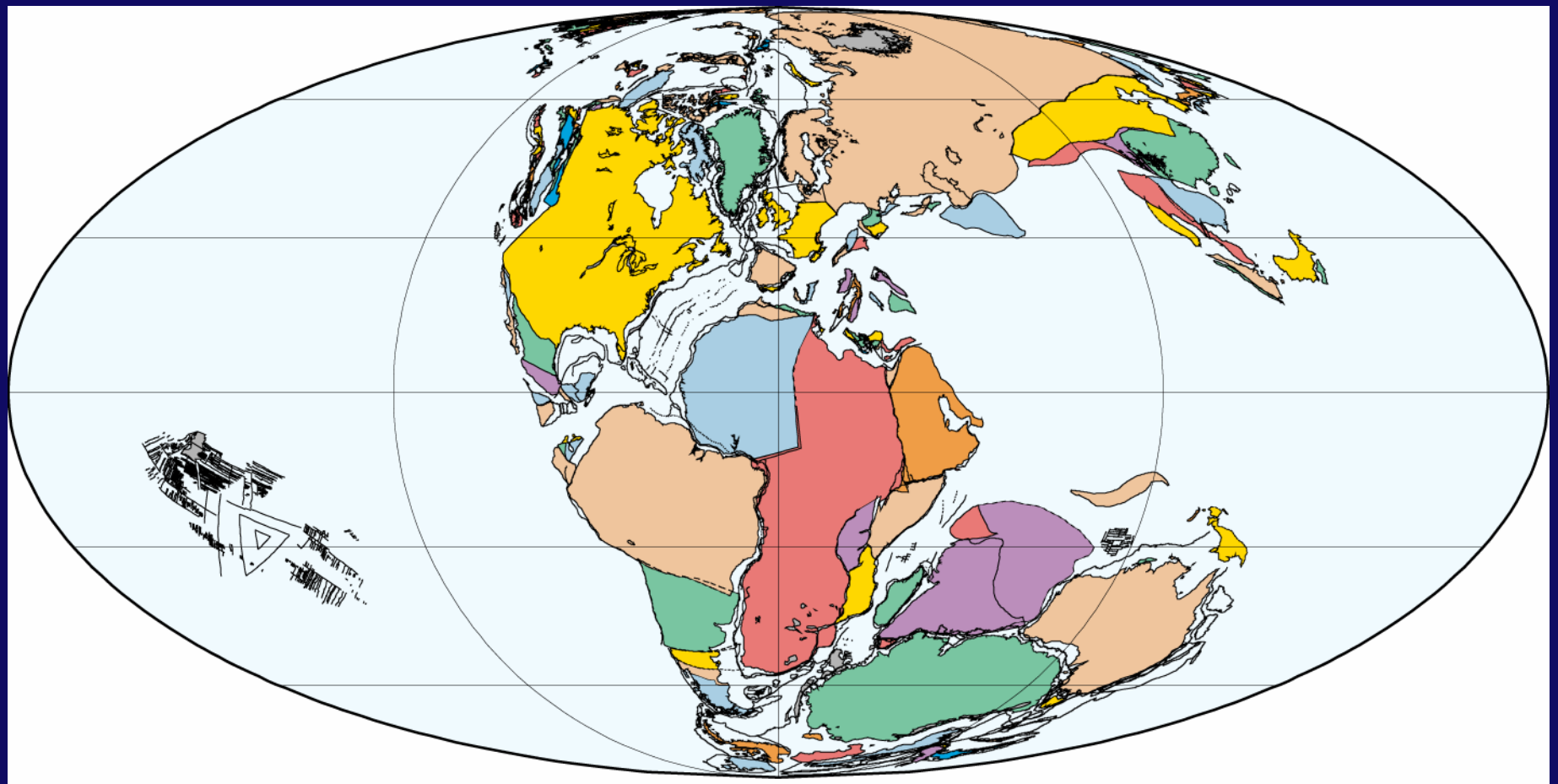


150 Ma

Volgian (Late Jurassic)

PLATES/UTIG

August 2002

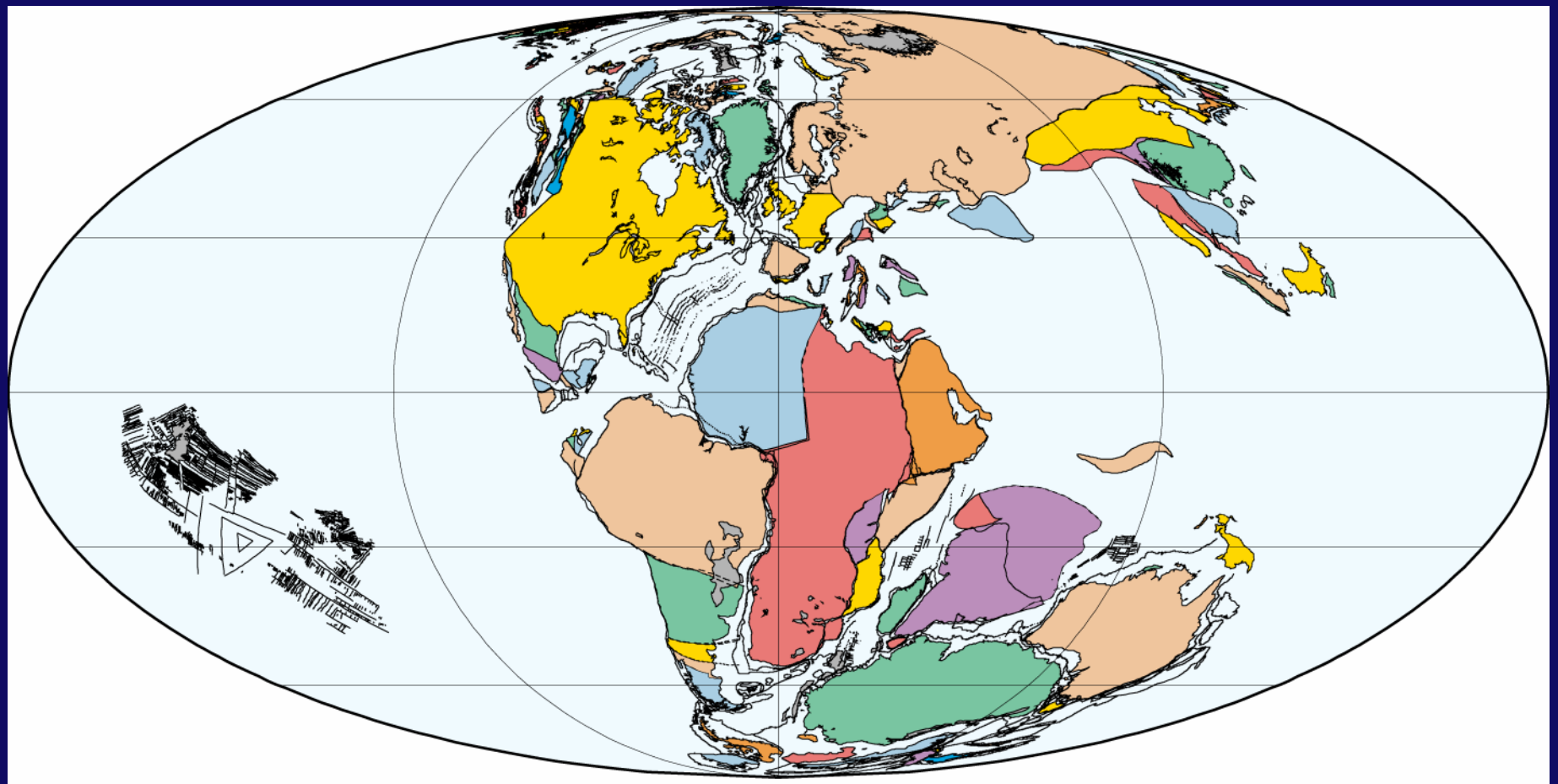


140 Ma

Ryazanian (Early Cretaceous)

PLATES/UTIG

August 2002

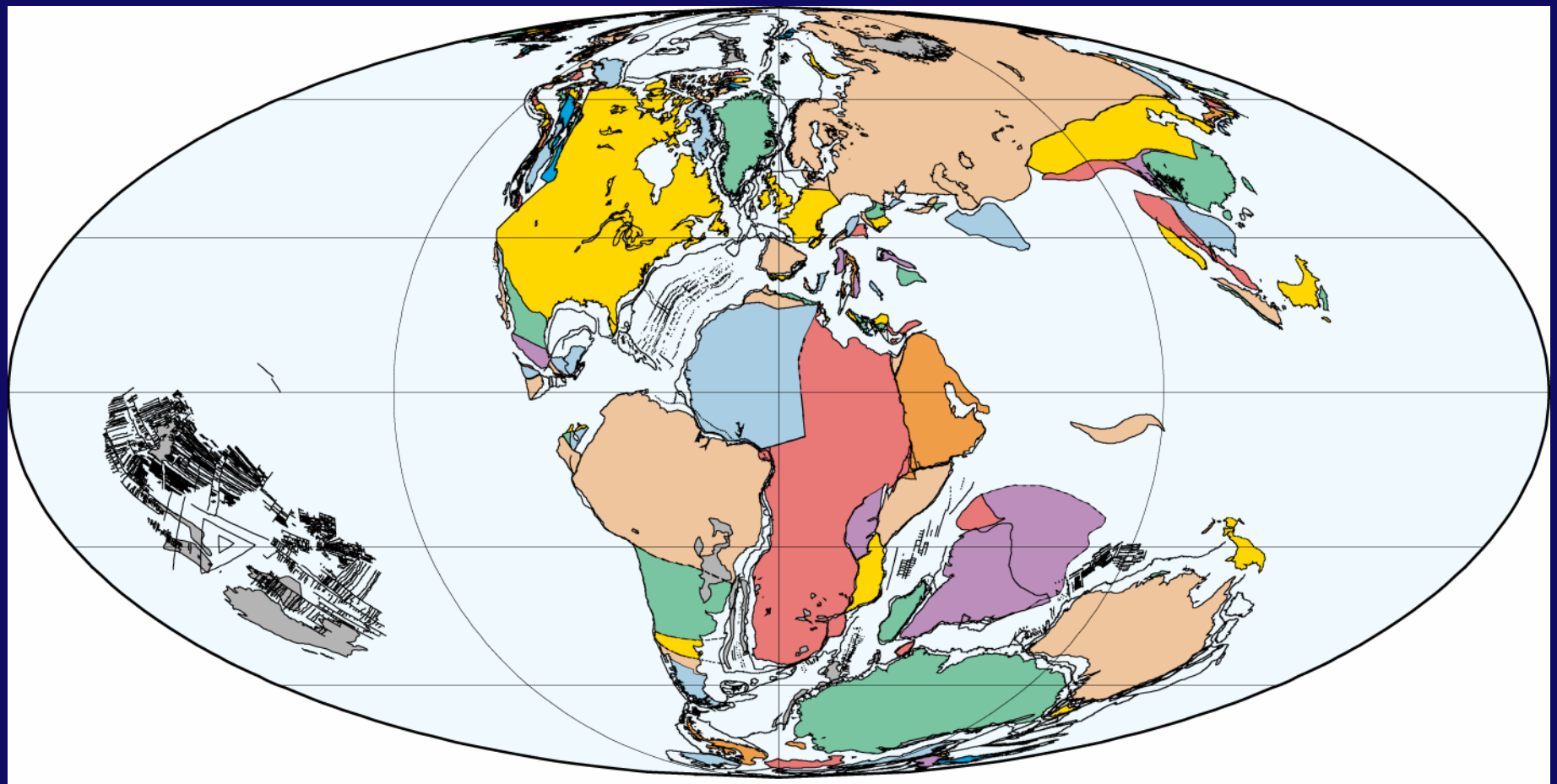


130 Ma

Hauterivian (Early Cretaceous)

PLATES/UTIG

August 2002

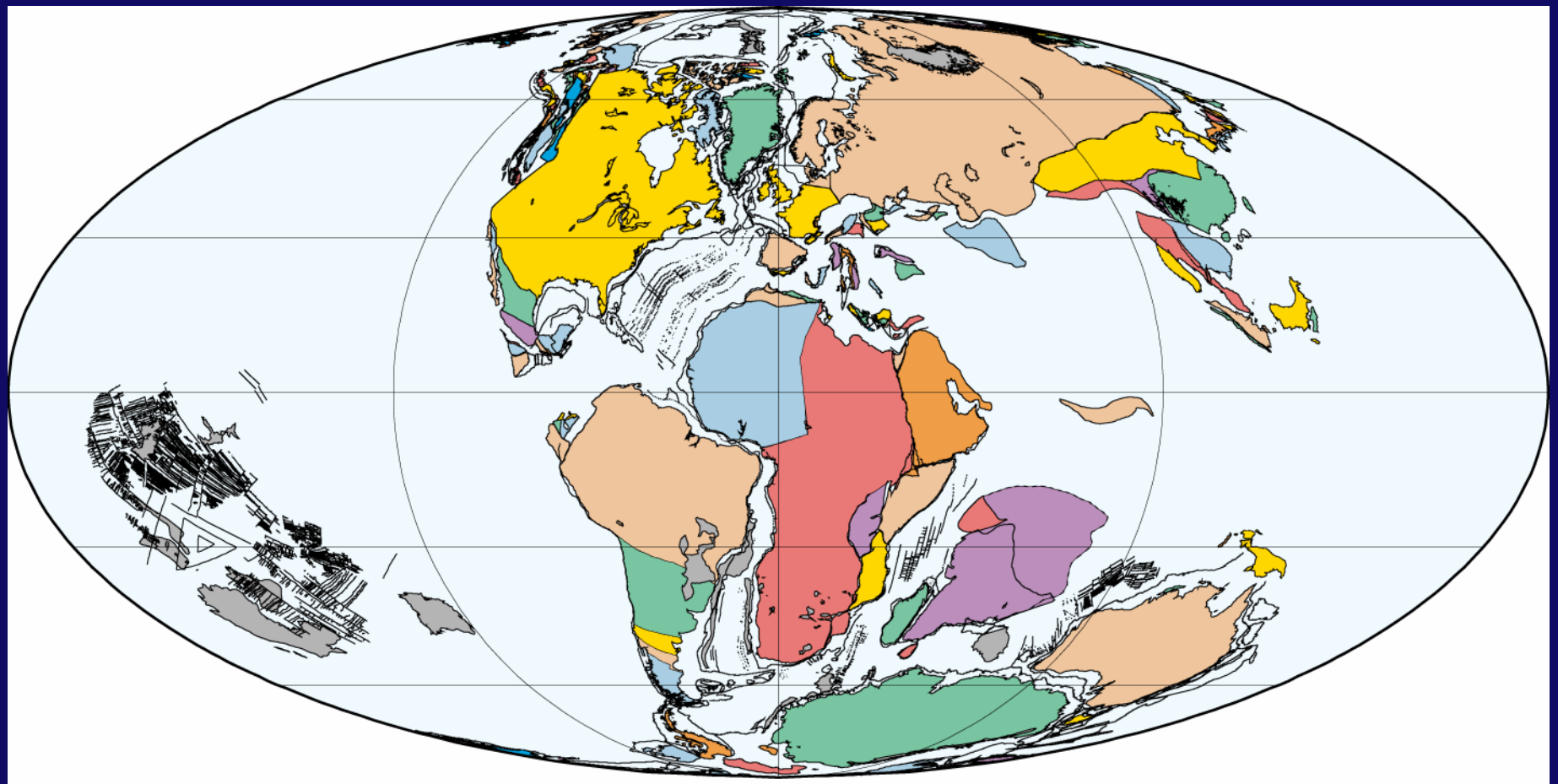


120 Ma

Aptian (Early Cretaceous)

PLATES/UTIG

August 2002

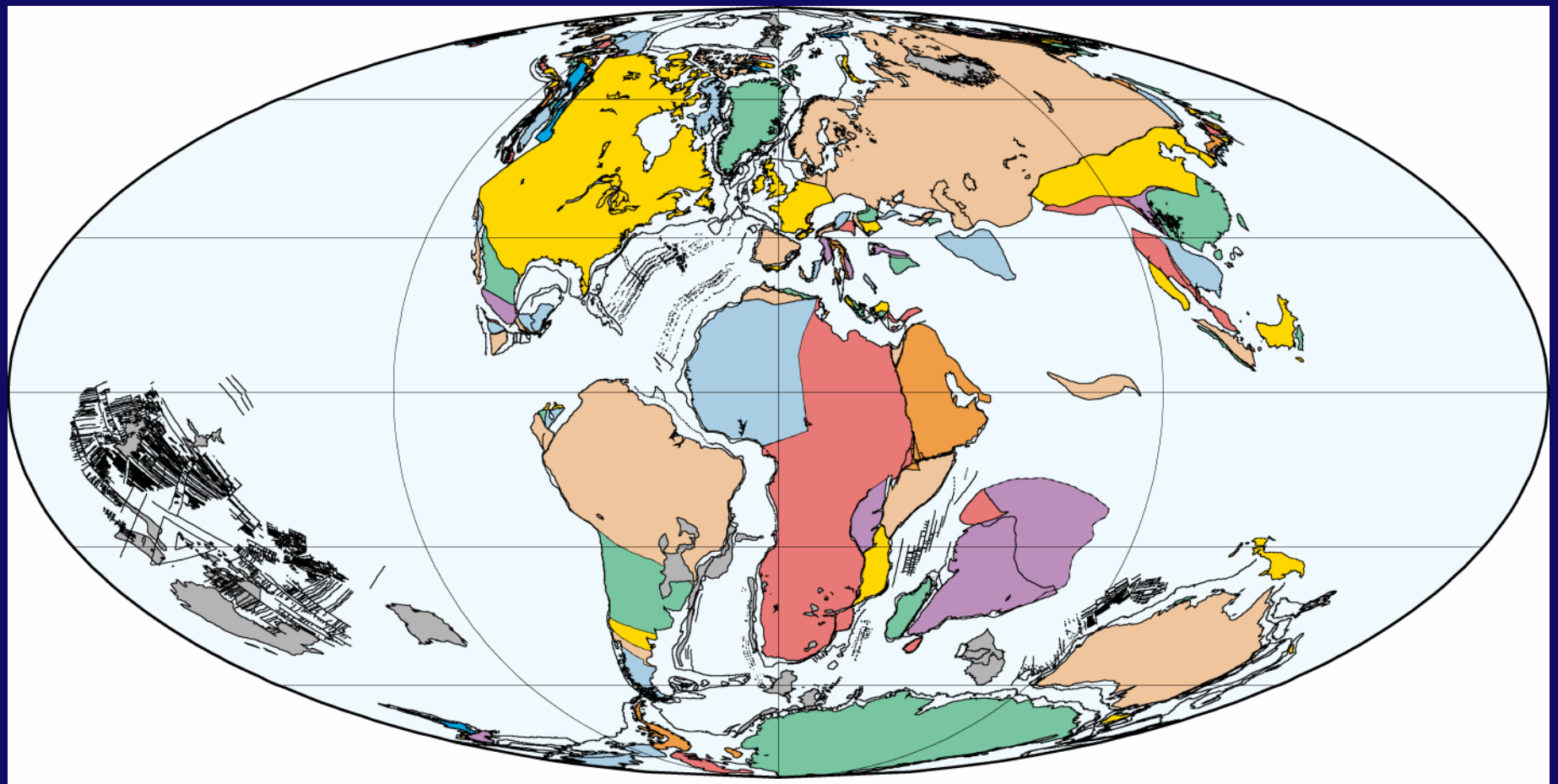


110 Ma

Early Albian (Early Cretaceous)

PLATES/UTIG

August 2002

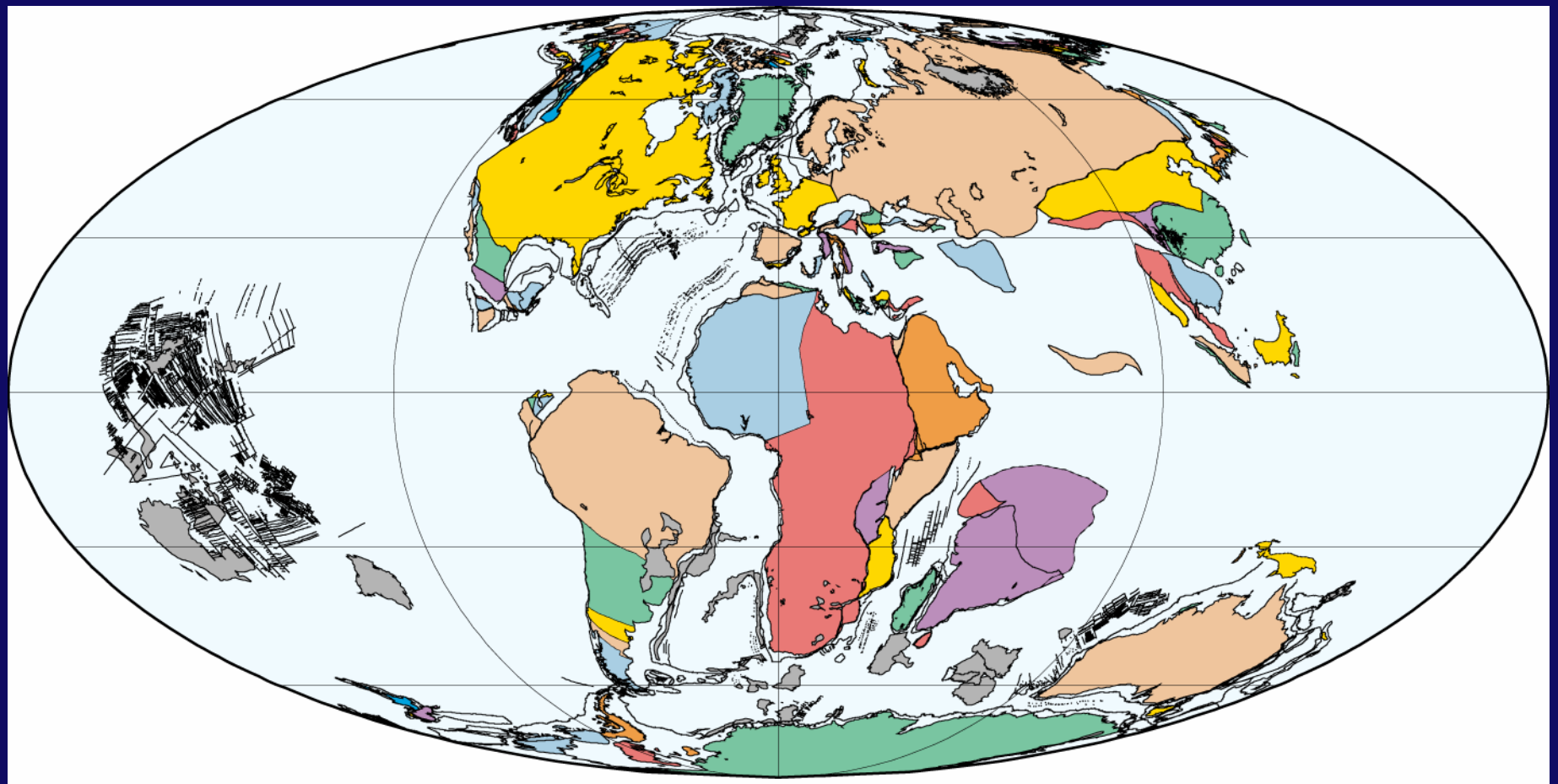


100 Ma

Late Albian (Early Cretaceous)

PLATES/UTIG

August 2002

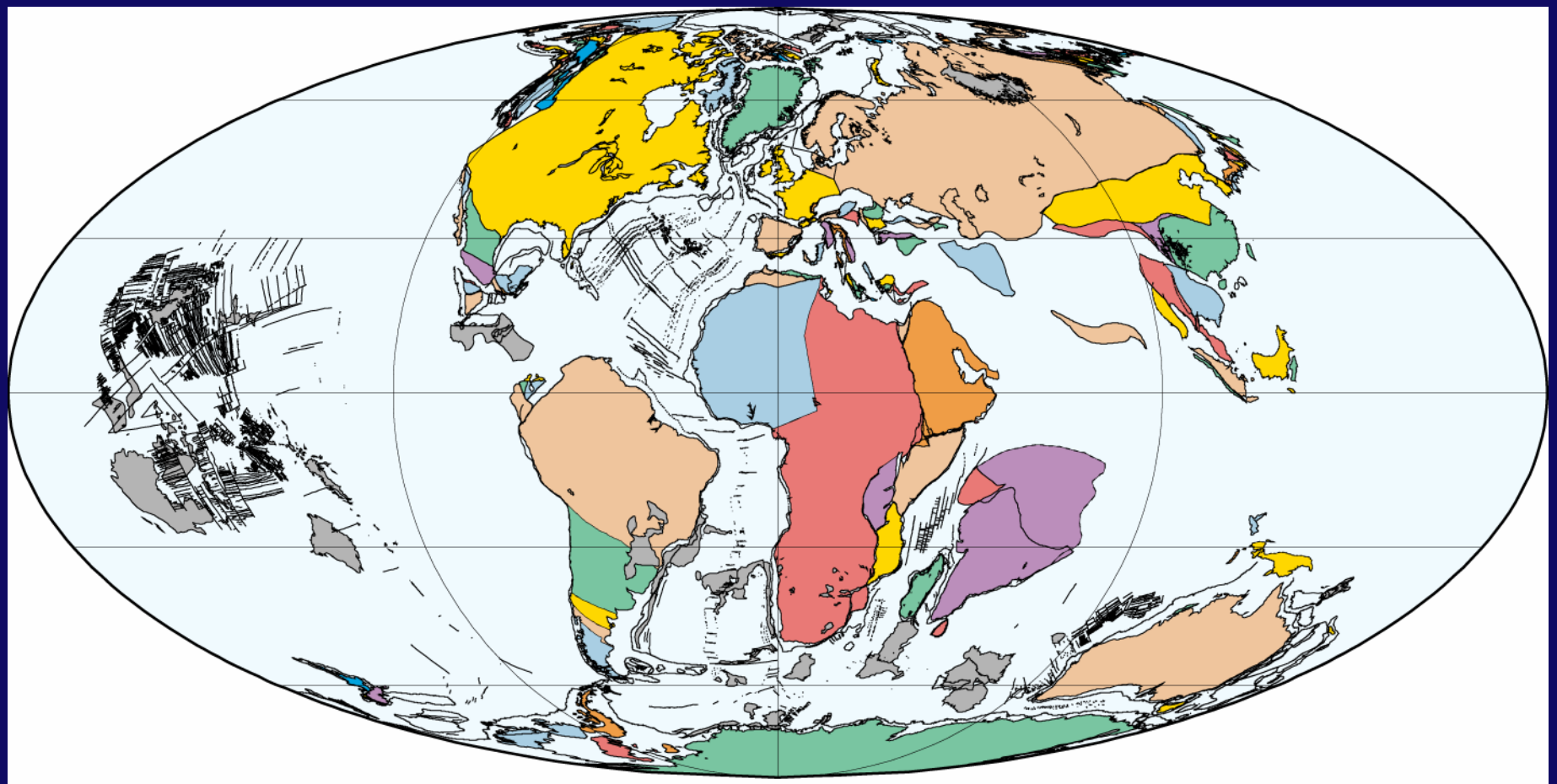


90 Ma

Turonian (Late Cretaceous)

PLATES/UTIG

August 2002

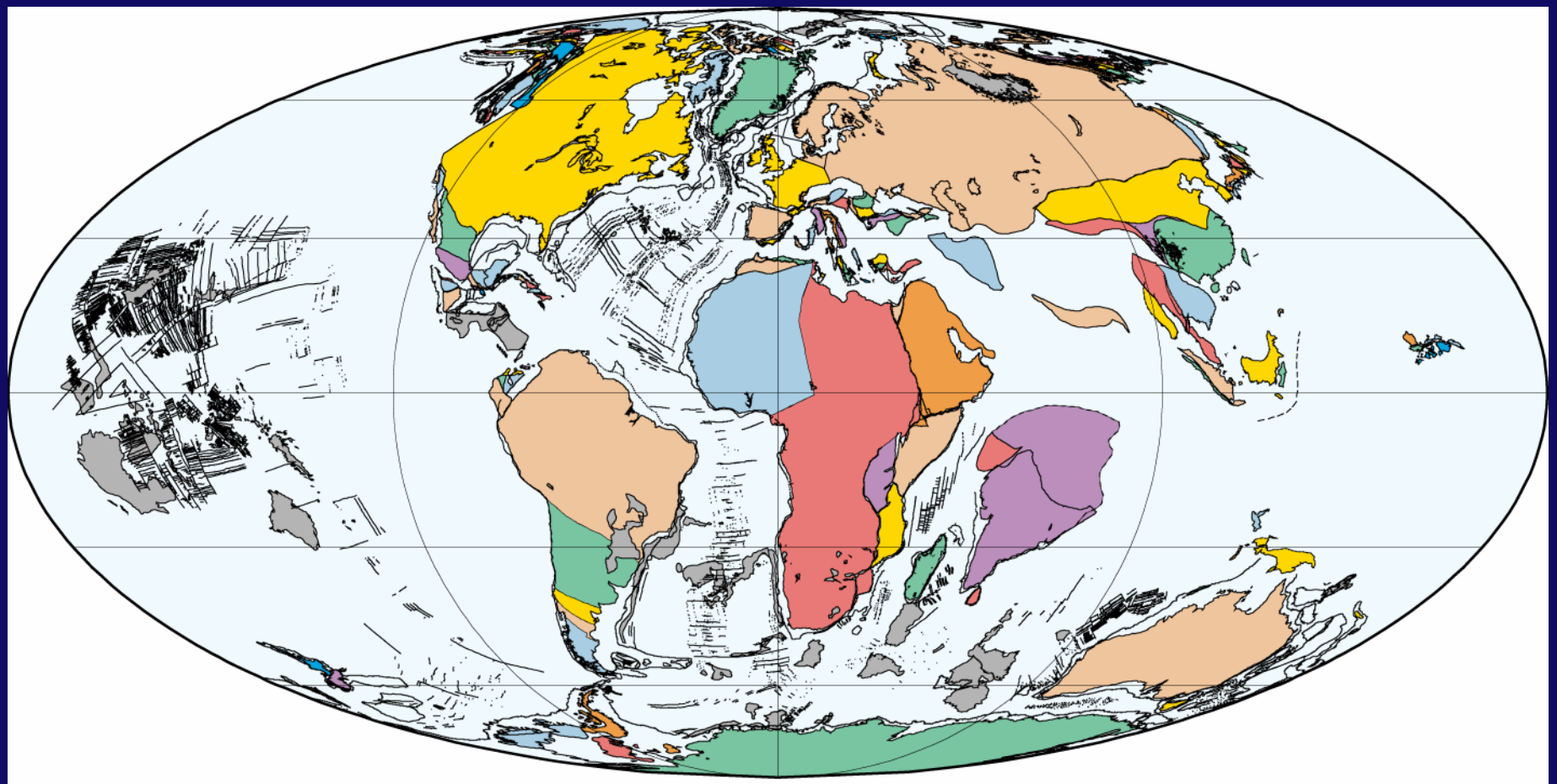


80 Ma

Campanian (Late Cretaceous)

PLATES/UTIG

August 2002

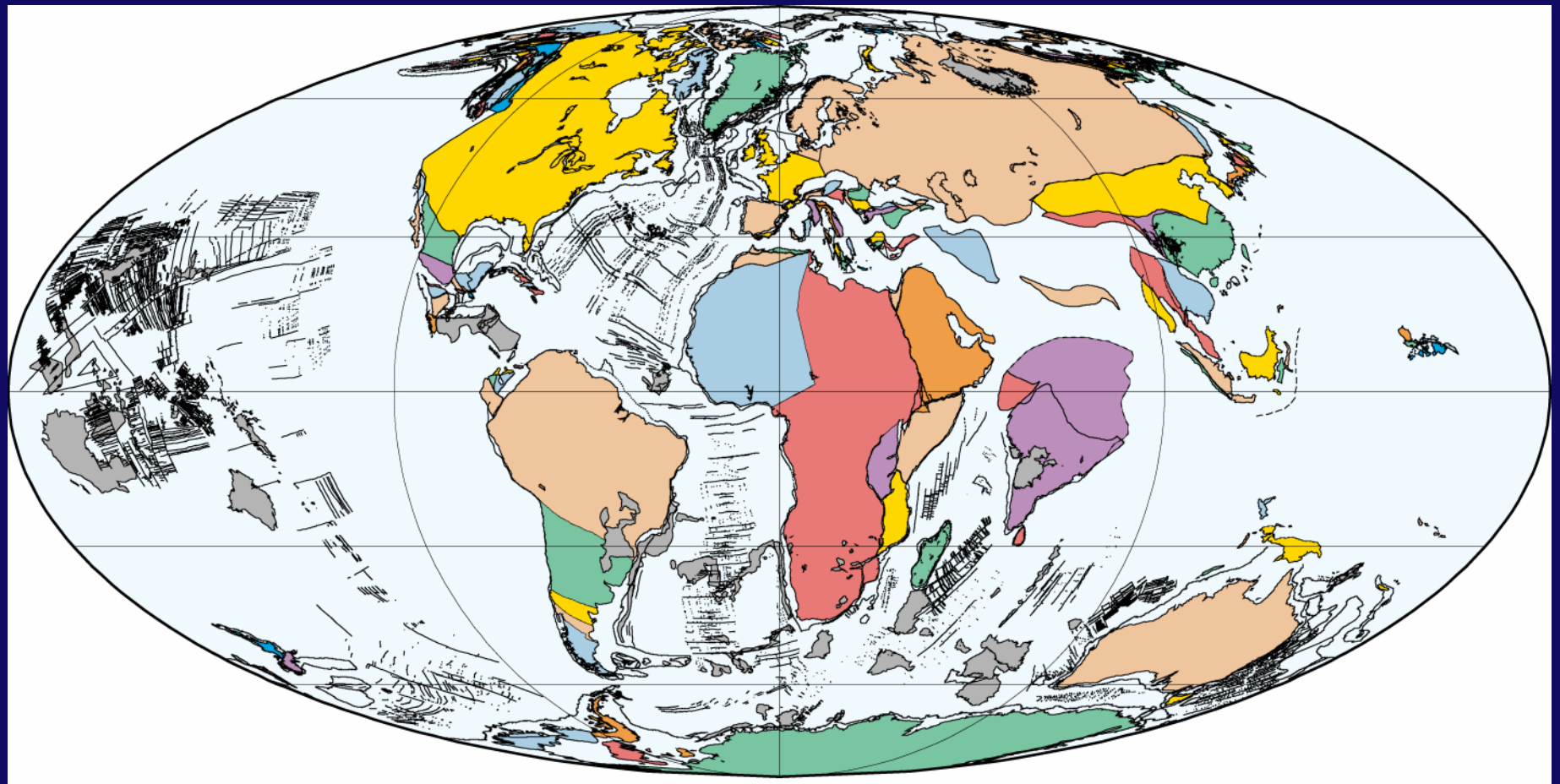


70 Ma

Maastrichtian (Late Cretaceous)

PLATES/UTIG

August 2002

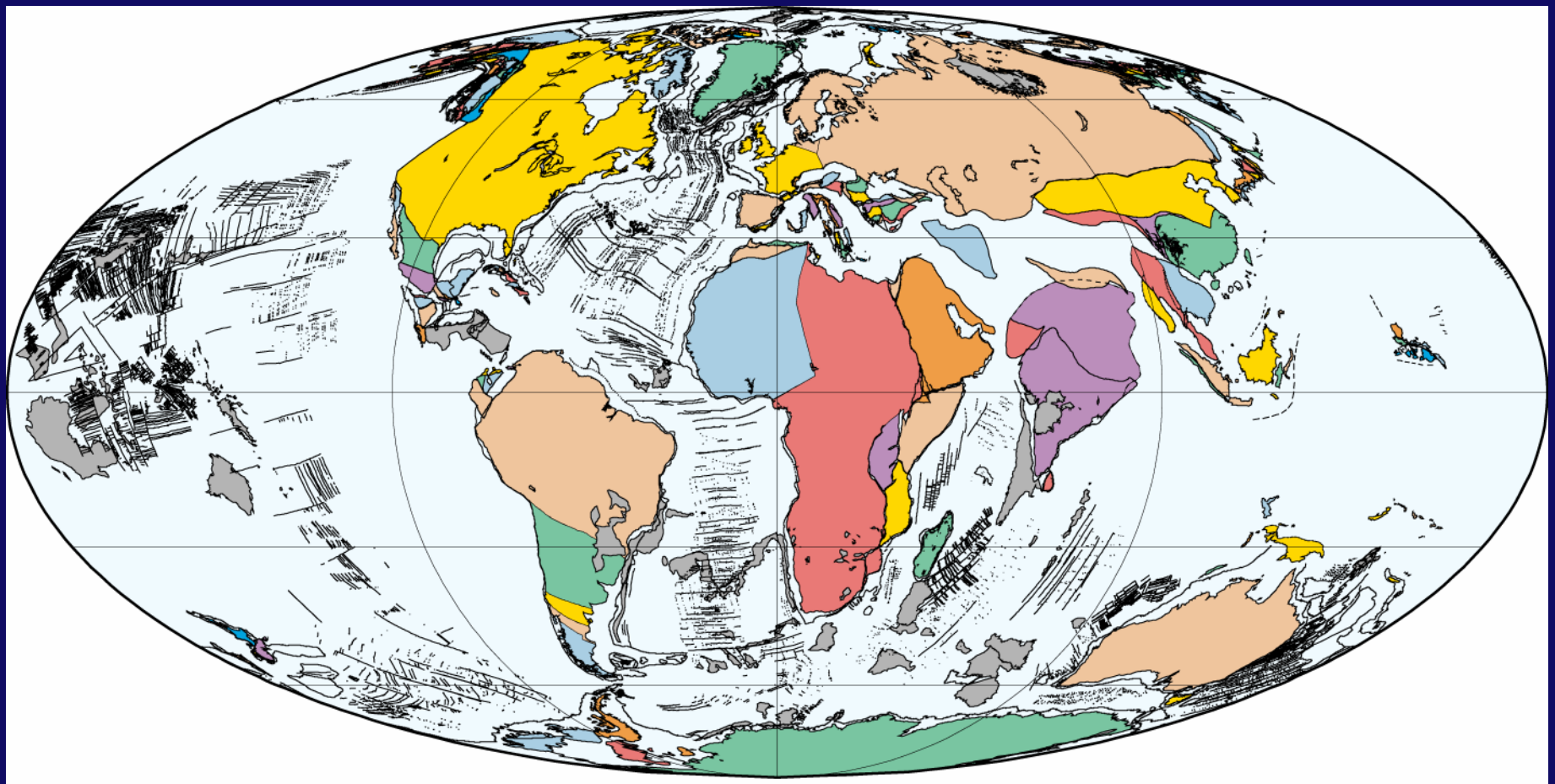


60 Ma

Late Paleocene

PLATES/UTIG

August 2002

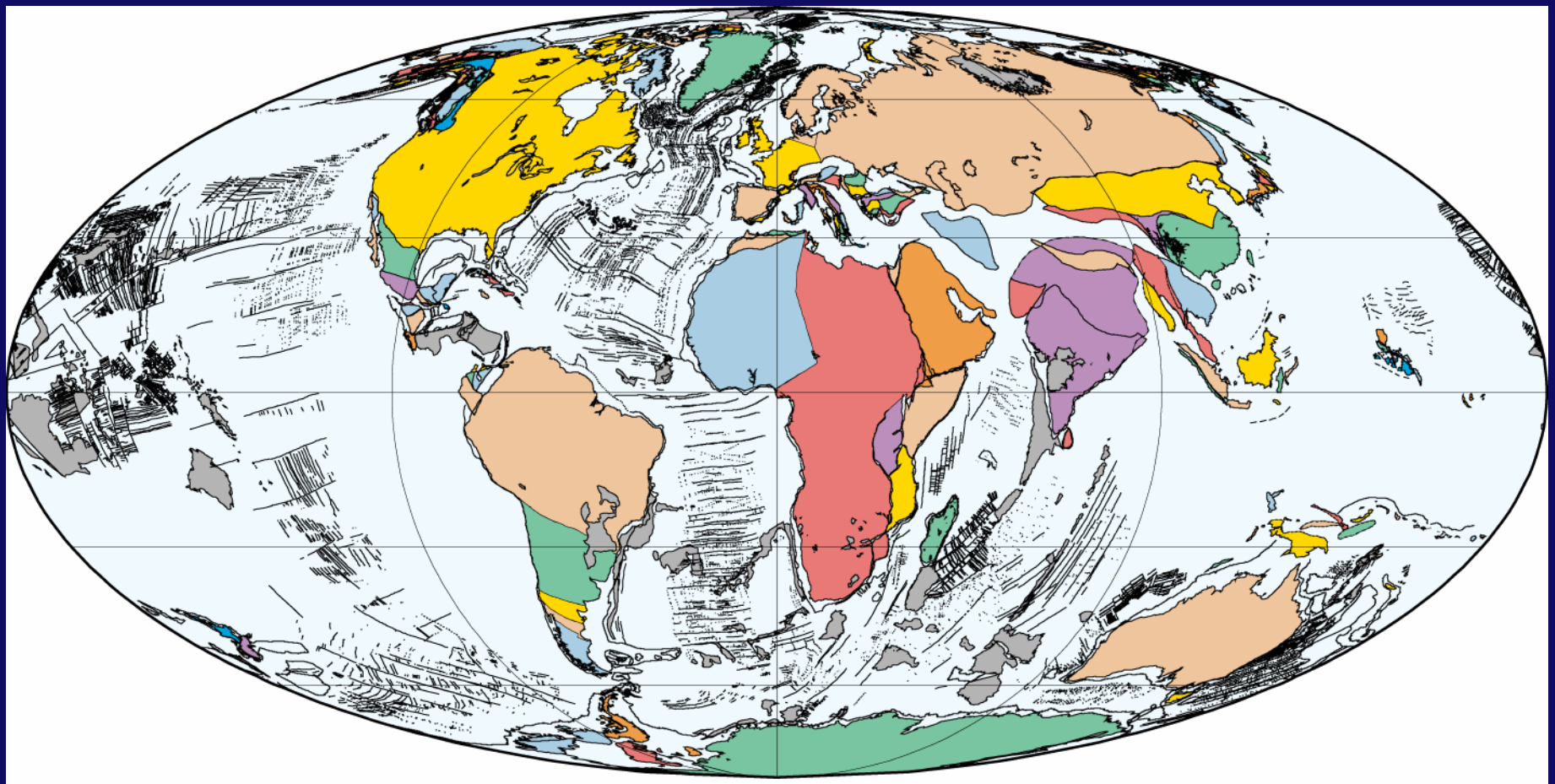


50 Ma

Early Eocene

PLATES/UTIG

August 2002

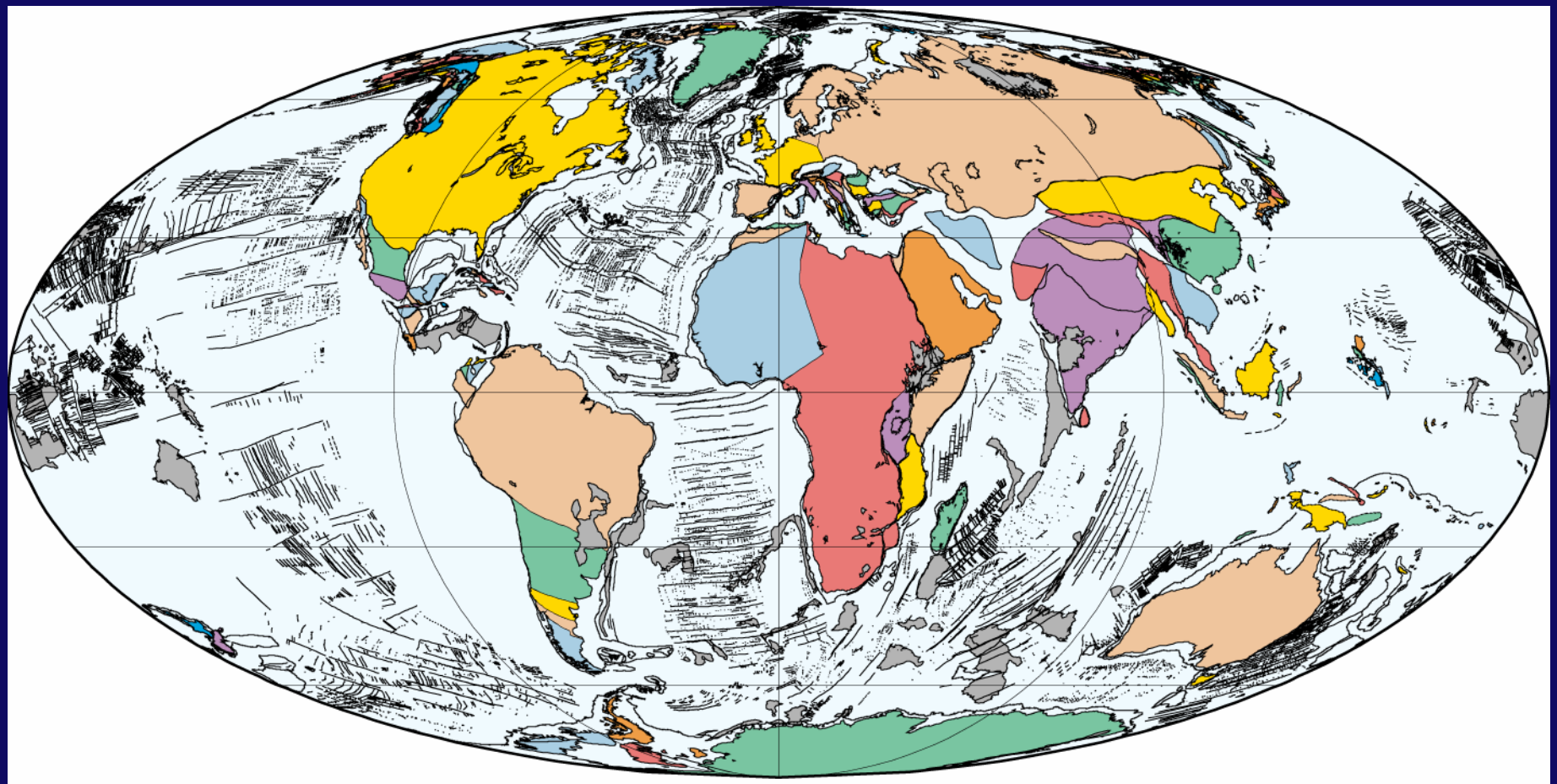


40 Ma

Middle Eocene

PLATES/UTIG

August 2002

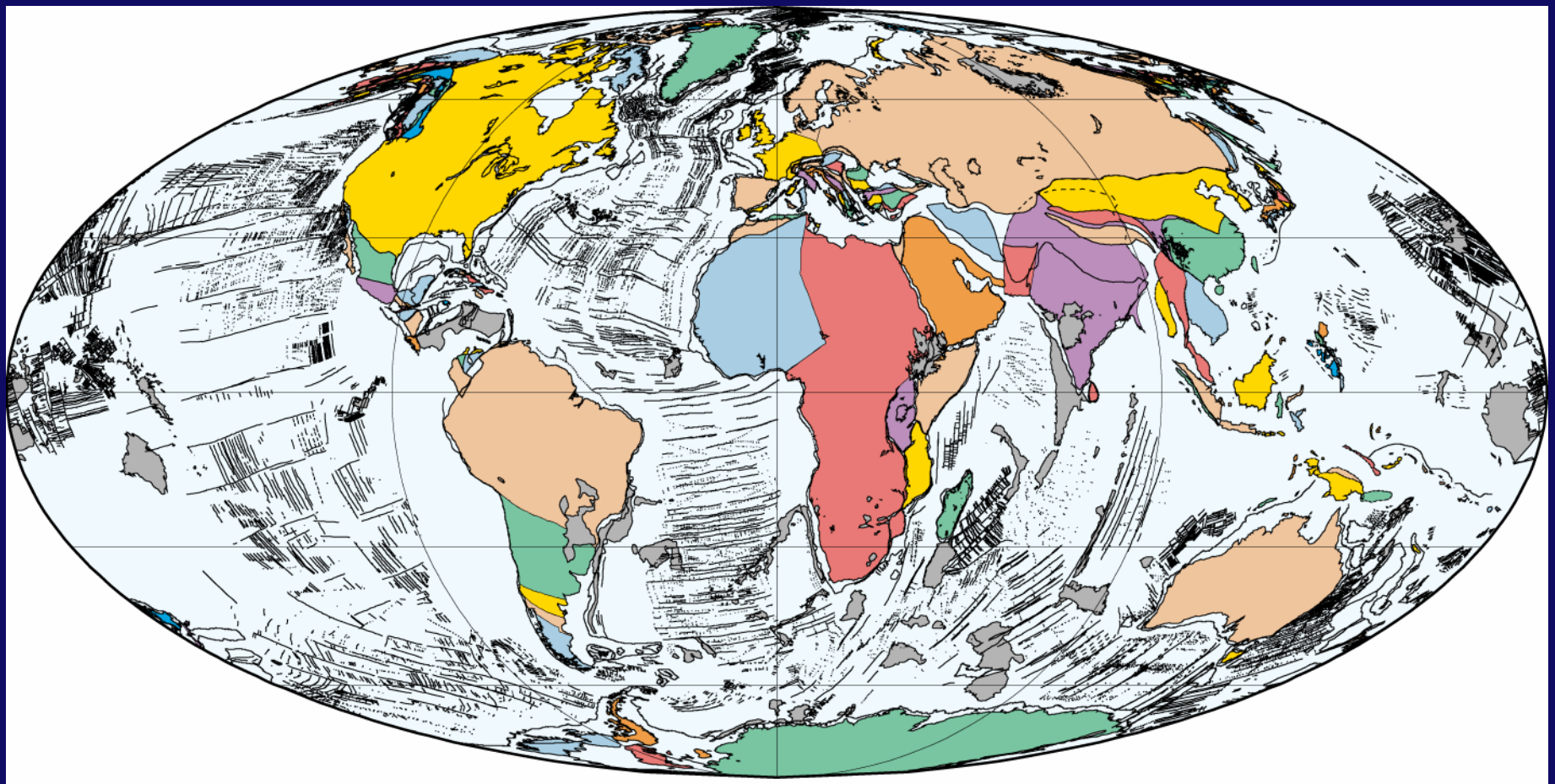


30 Ma

Early Oligocene

PLATES/UTIG

August 2002

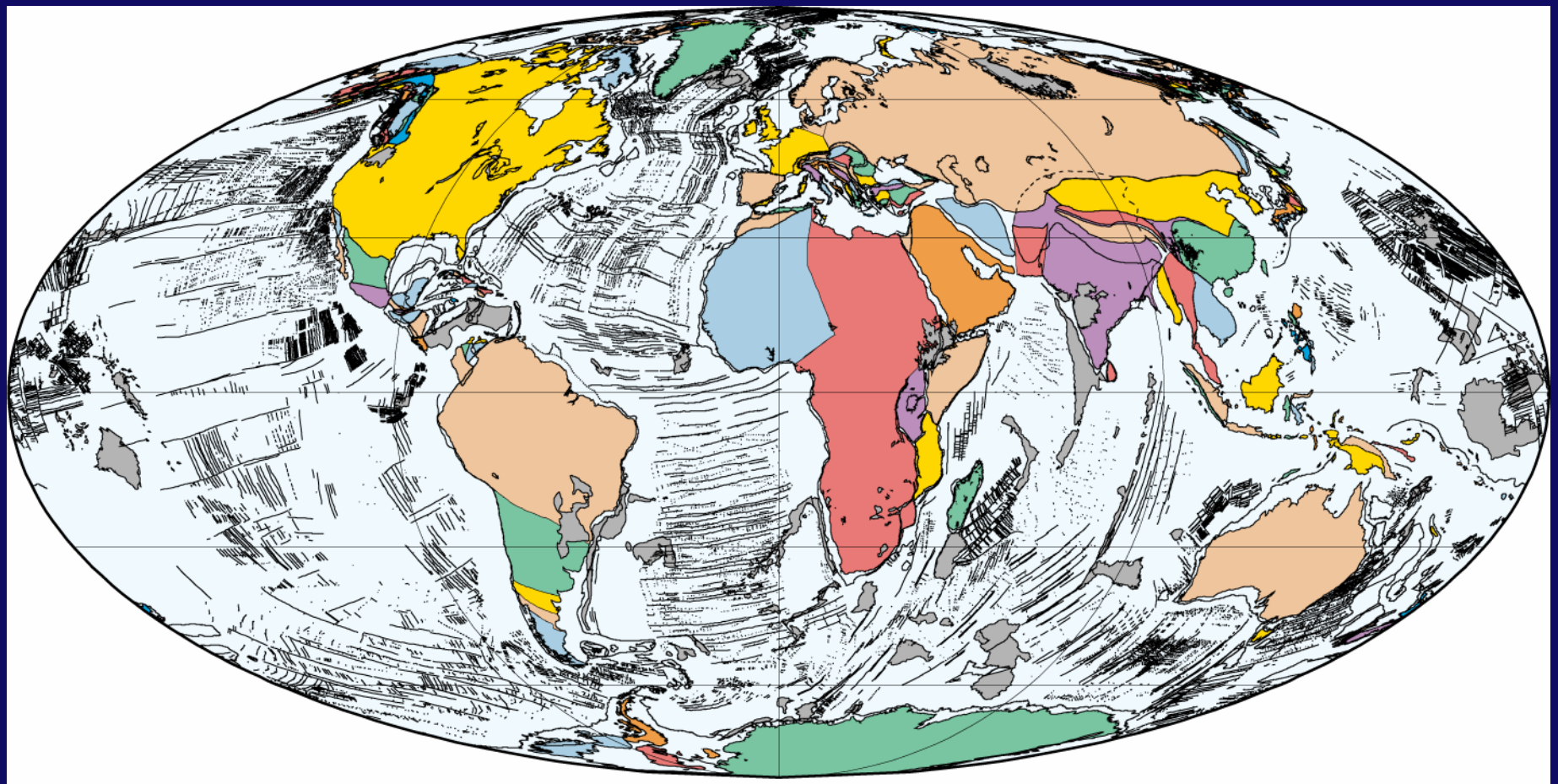


20 Ma

Early Miocene

PLATES/UTIG

August 2002

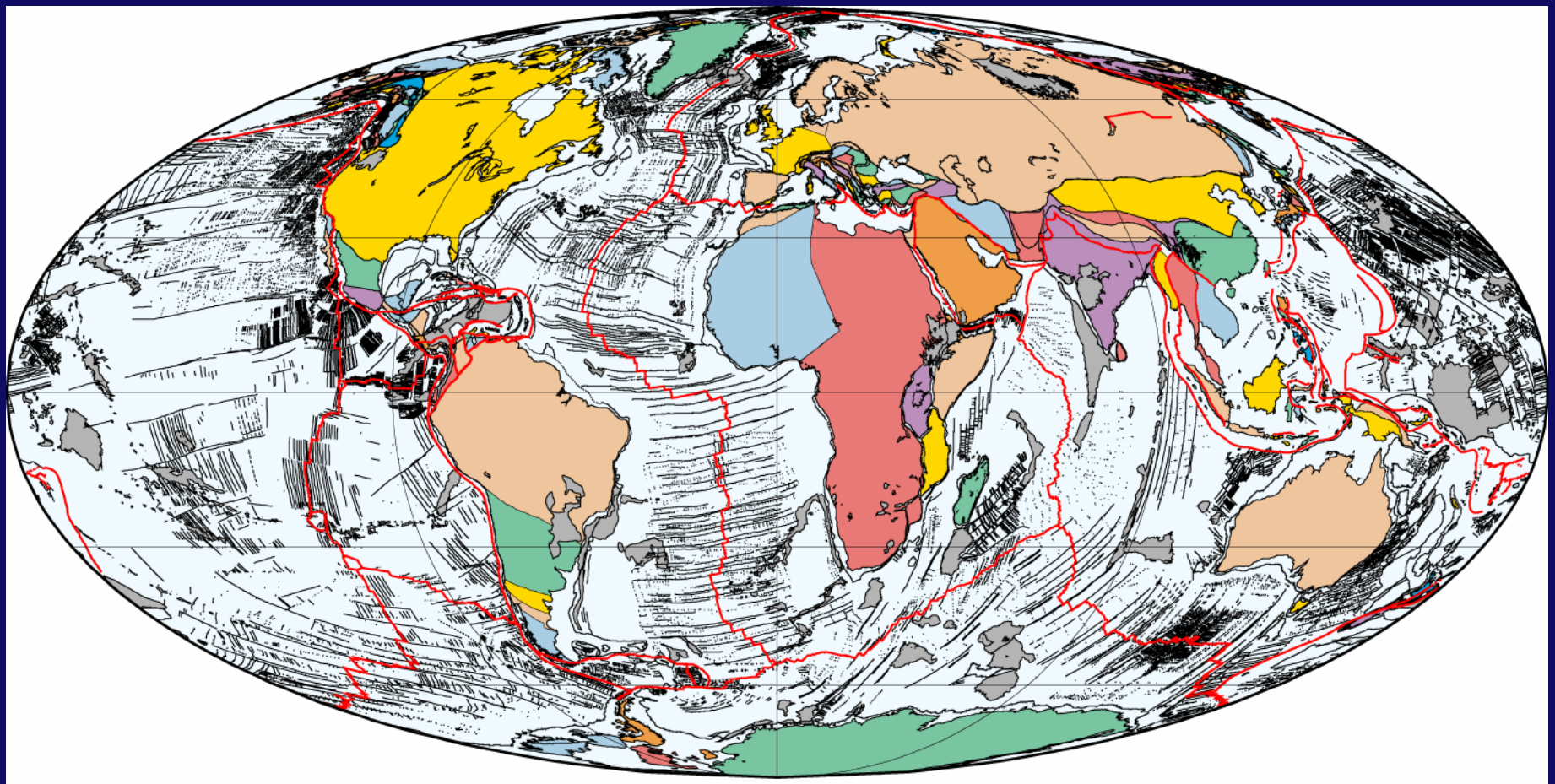


10 Ma

Late Miocene

PLATES/UTIG

August 2002



0 Ma

Present Day

PLATES/UTIG

August 2002

Earth's Mantle Convection is driven by internal radioactive decay.

→ Like a bowl of Miso Soup in a microwave oven (and the continents are the pieces of tofu!)!

If the “Rayleigh number” is greater than about 500, then a volume of material will convect.

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$$Ra = \frac{(\text{Density})(\text{Gravity})(\text{Thermal Expansion})(\Delta T)(\text{LxWxH of "box"})}{(\text{Viscosity})(\text{Heat Diffusivity})}$$

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$$Ra = \frac{(\text{Density})(\text{Gravity})(\text{Thermal Expansion})(\Delta T)(\text{LxWxH of "box"})}{(\text{Viscosity})(\text{Heat Diffusivity})}$$

$$= \frac{(4000\ \text{kg/m}^3)(10\ \text{m/s}^2)(0.00003\ 1/^{o}\text{C})(3500^{o}\text{C})(3000000\ \text{m})^3}{(10^{21}\ \text{Pa-s})(0.000001\ \text{m}^2/\text{s})}$$

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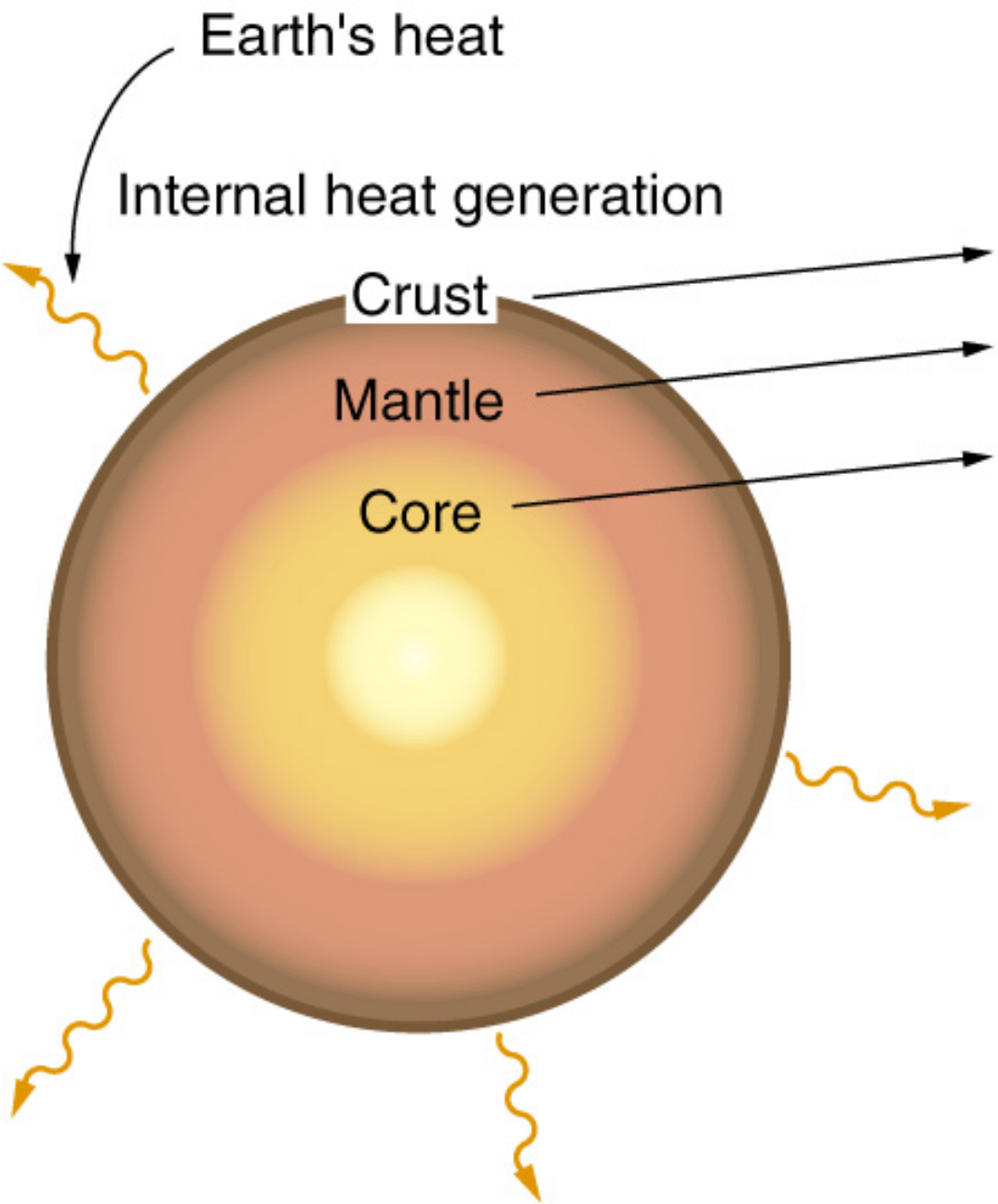
= about 100,000,000 YES, EARTH CONVECTS!



Heat from radioactivity:

9×10^{12} watts (Crust)

21×10^{12} watts (Mantle)

2×10^{12} watts (Core)

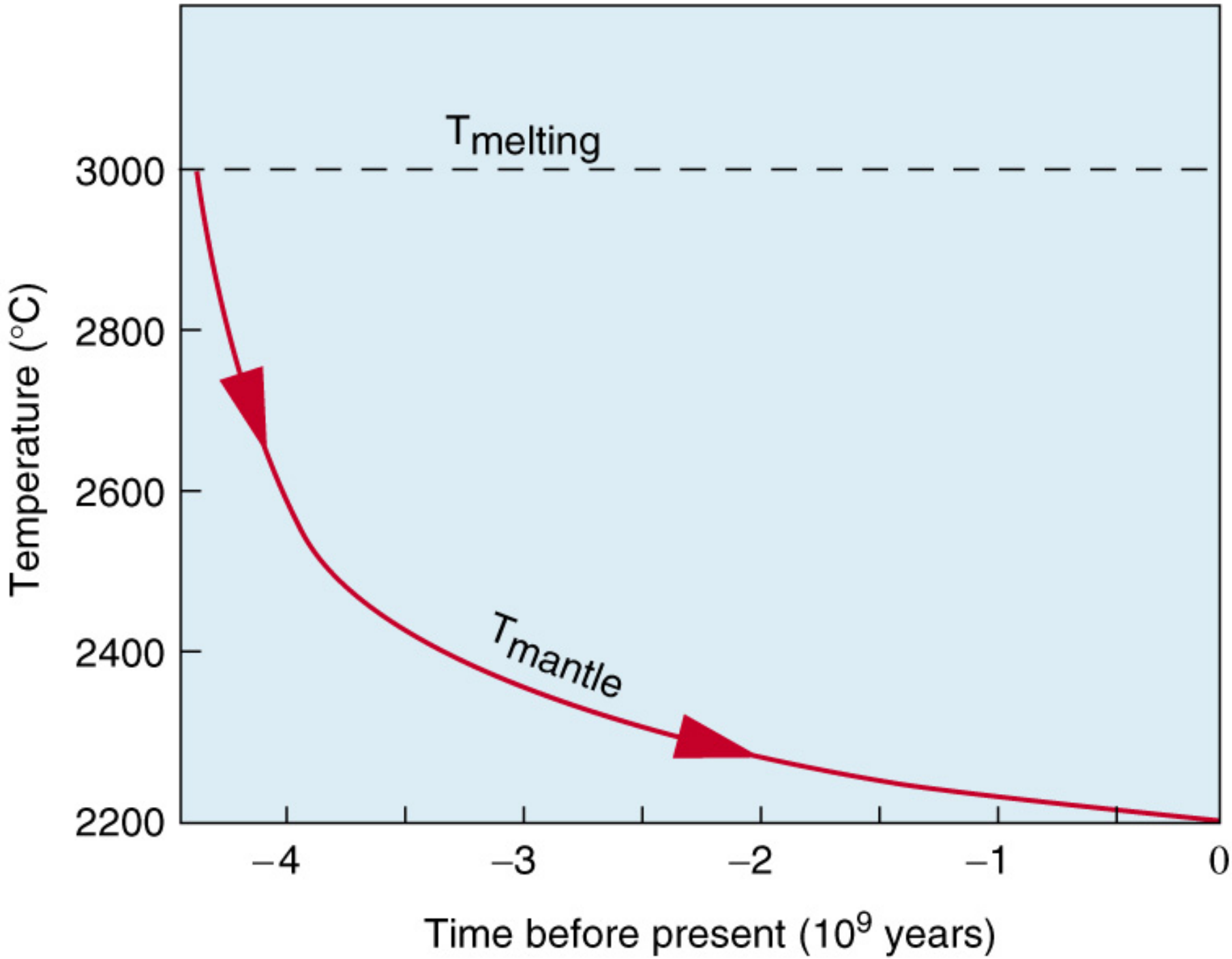
32×10^{12} watts

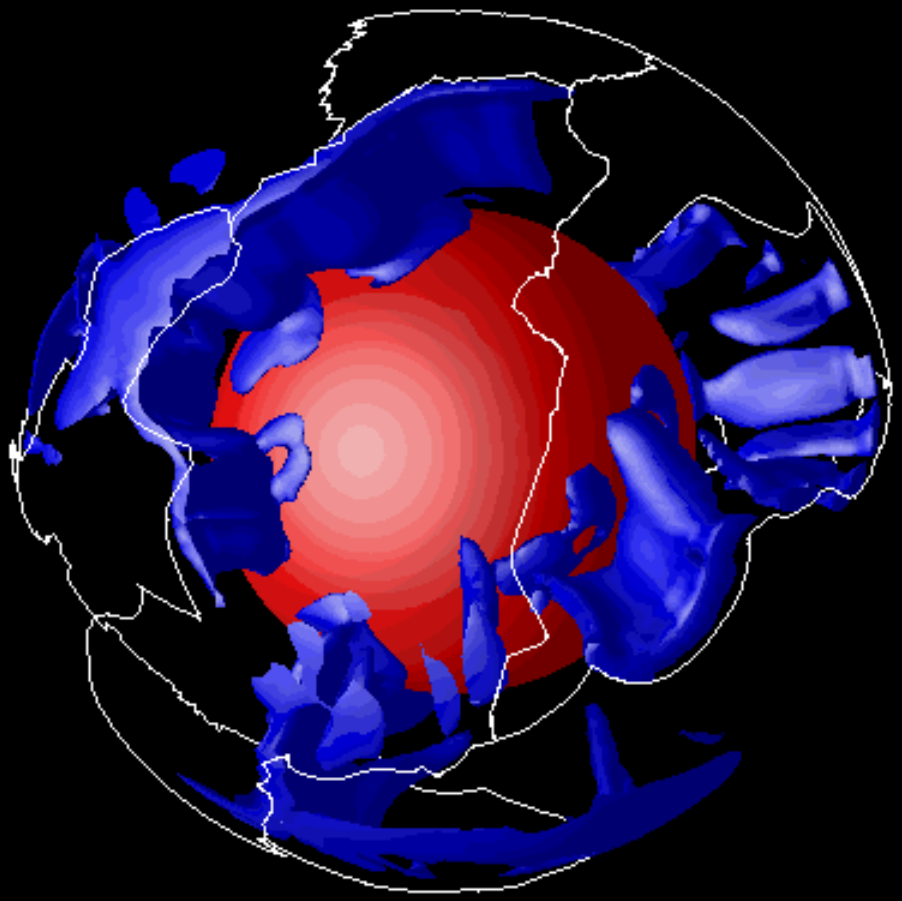
Heat from cooling:

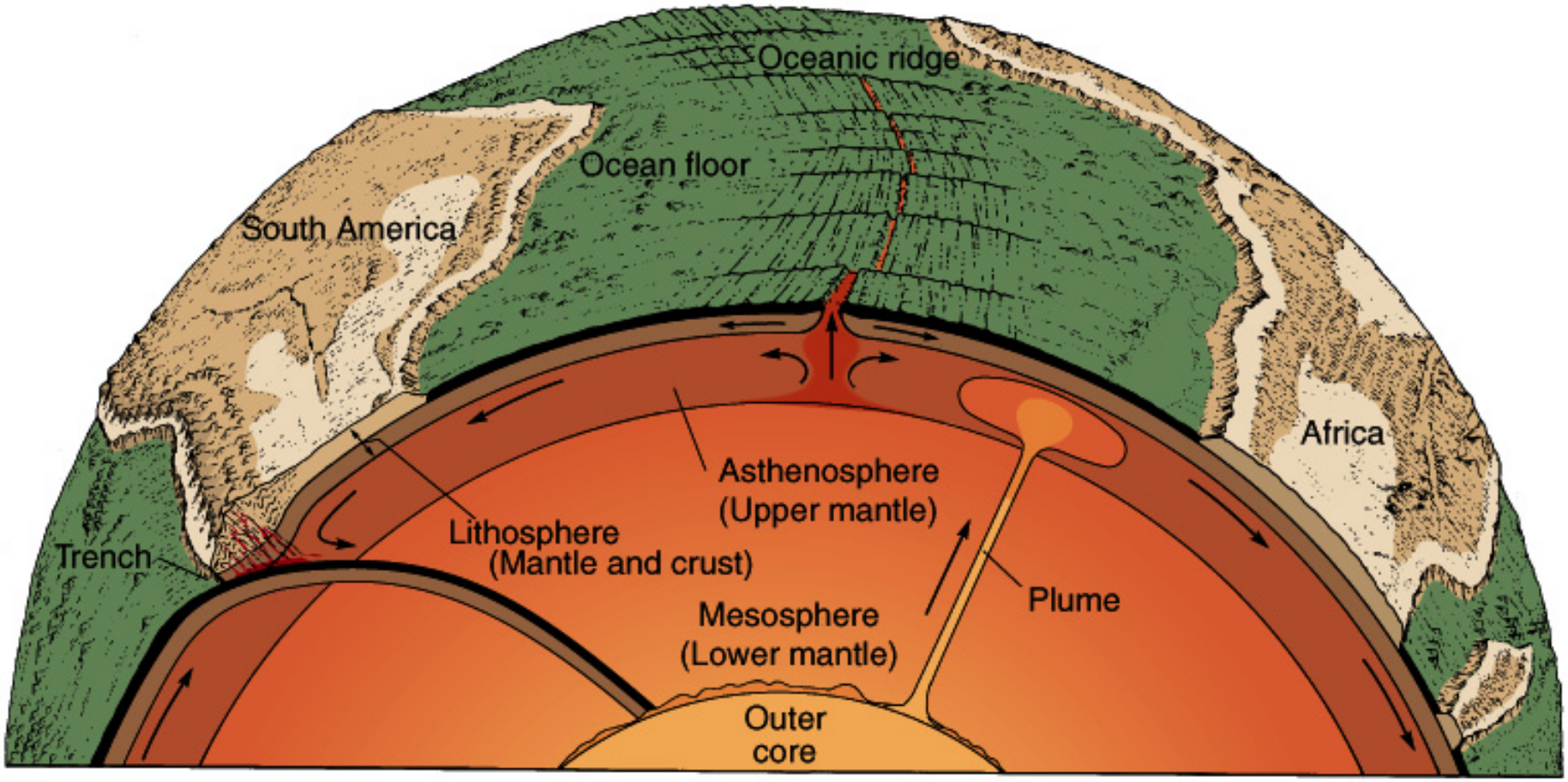
10×10^{12} watts

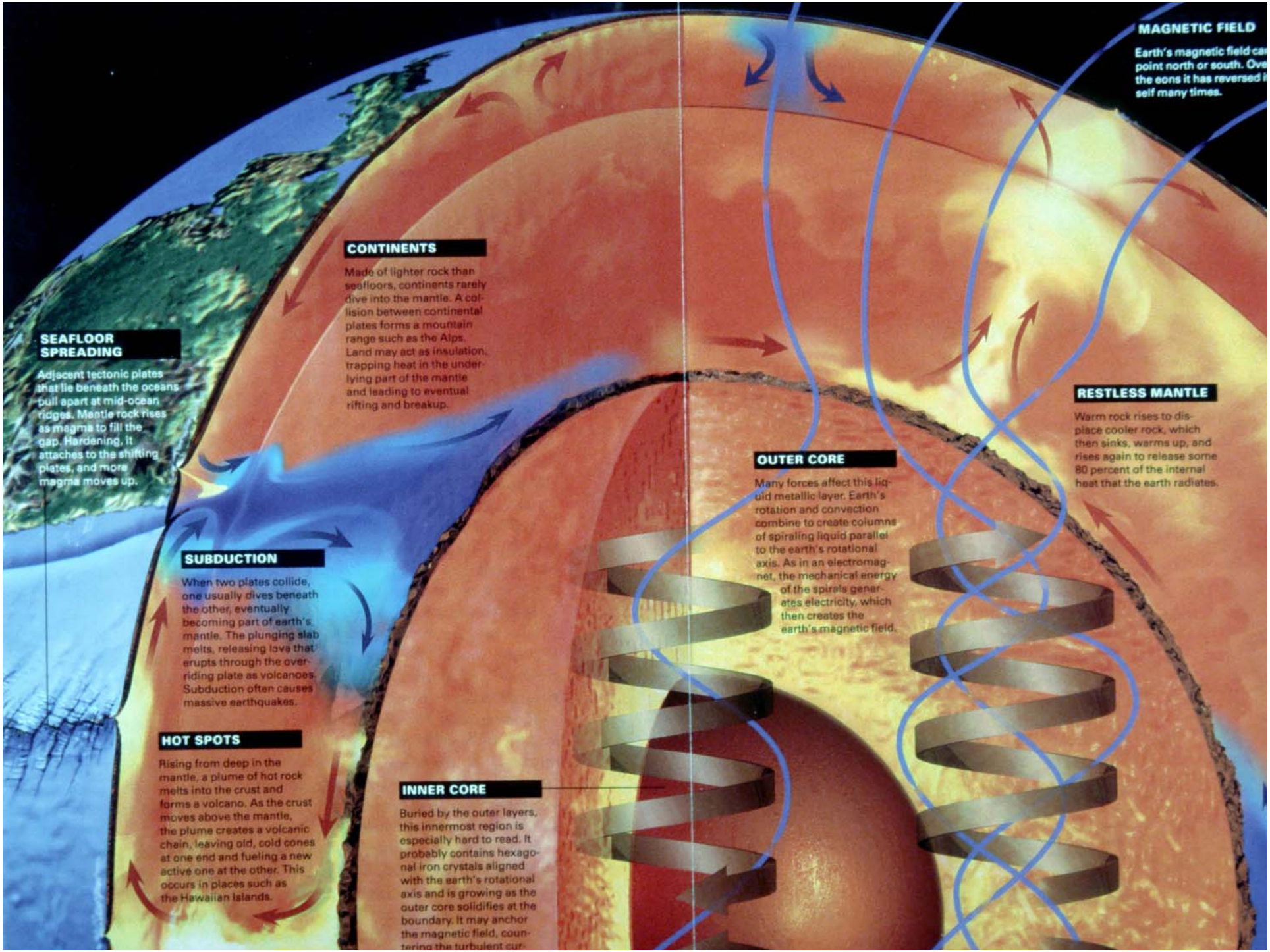
Total heat from Earth:

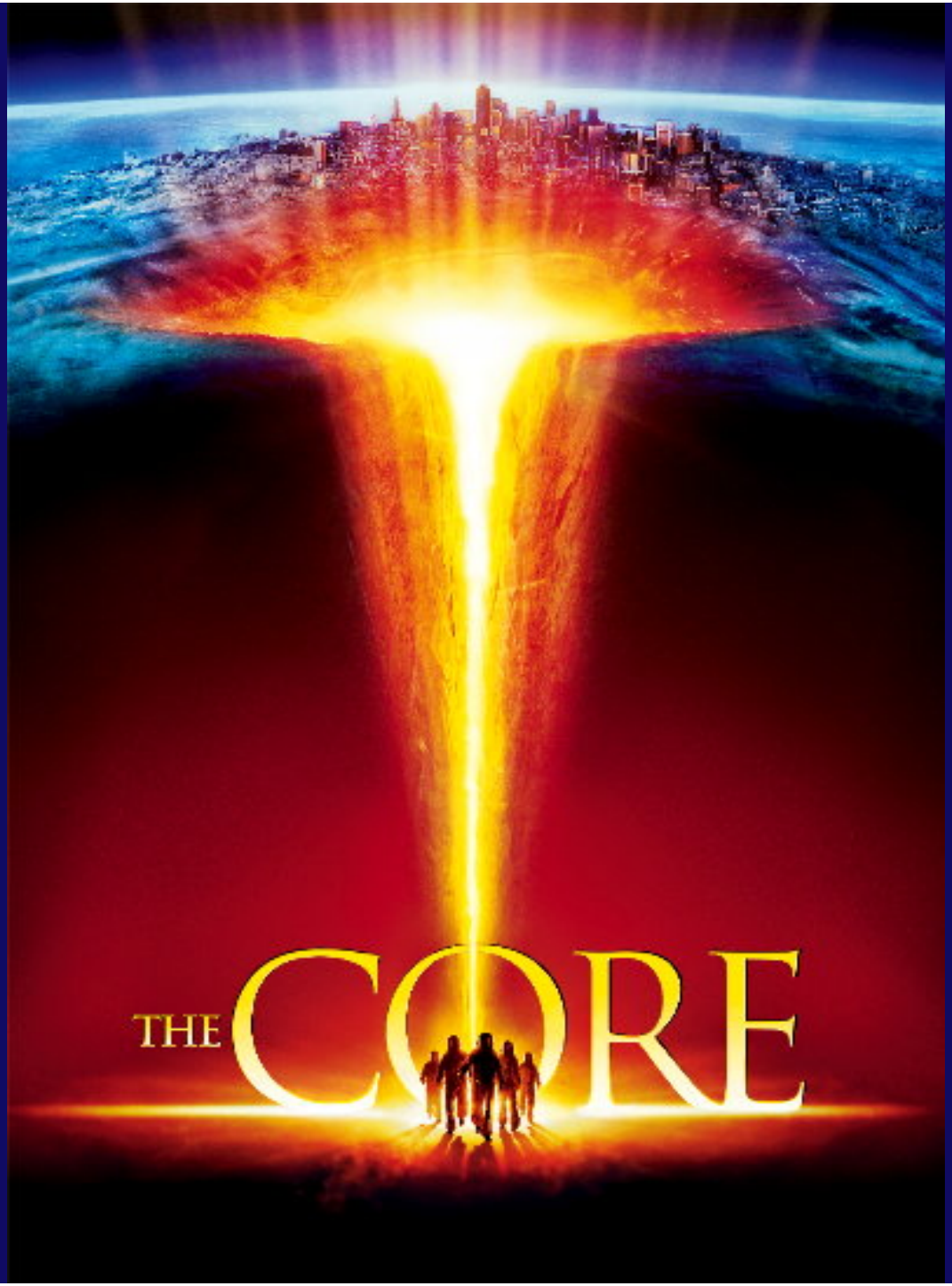
$(32 + 10) \times 10^{12}$ watts

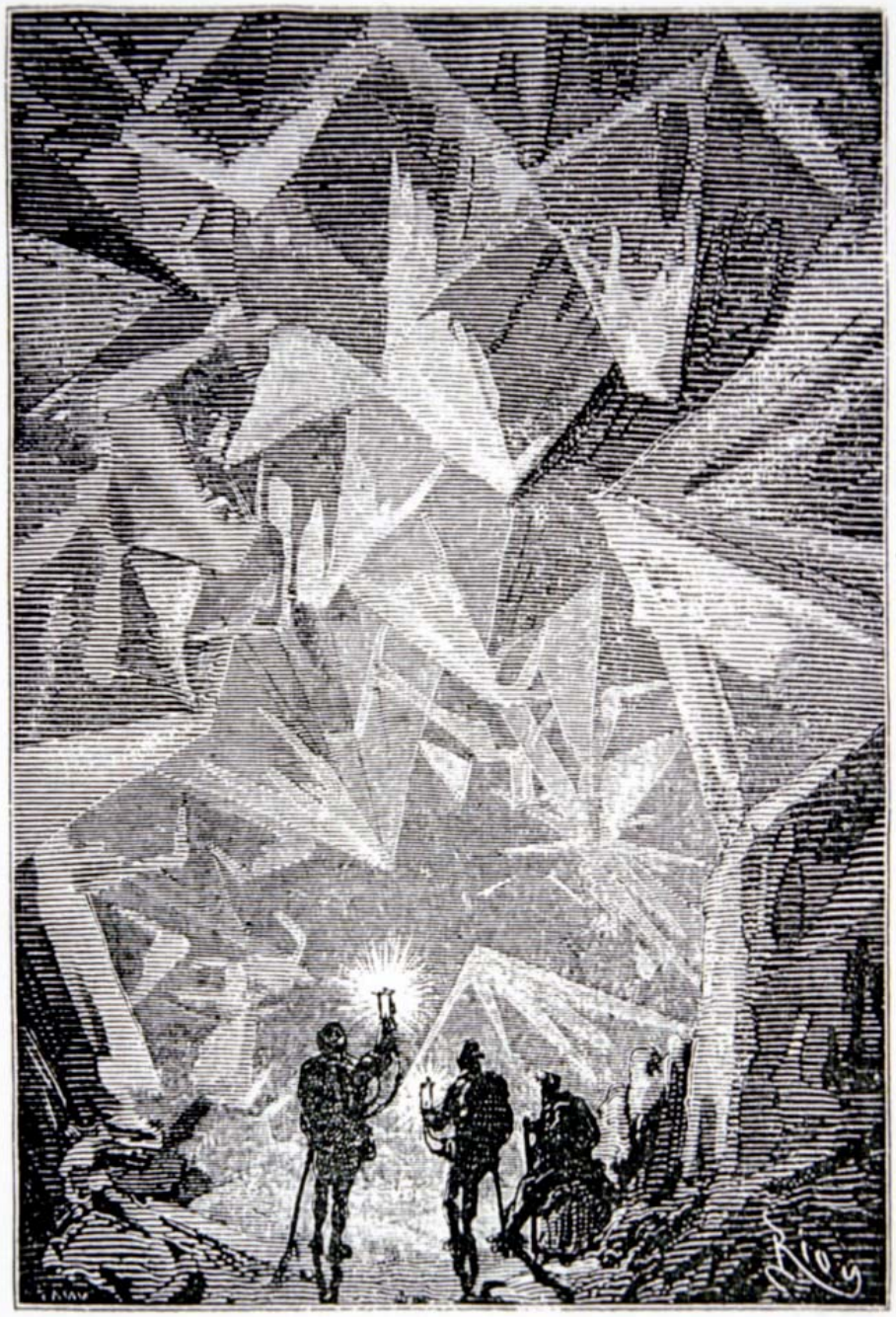

$T_{melting}$
T_{mantle}
3000
2800
2600
2400
2200
Temperature (°C)
–4
–3
–2
–1
0
Time before present (10^9 years)



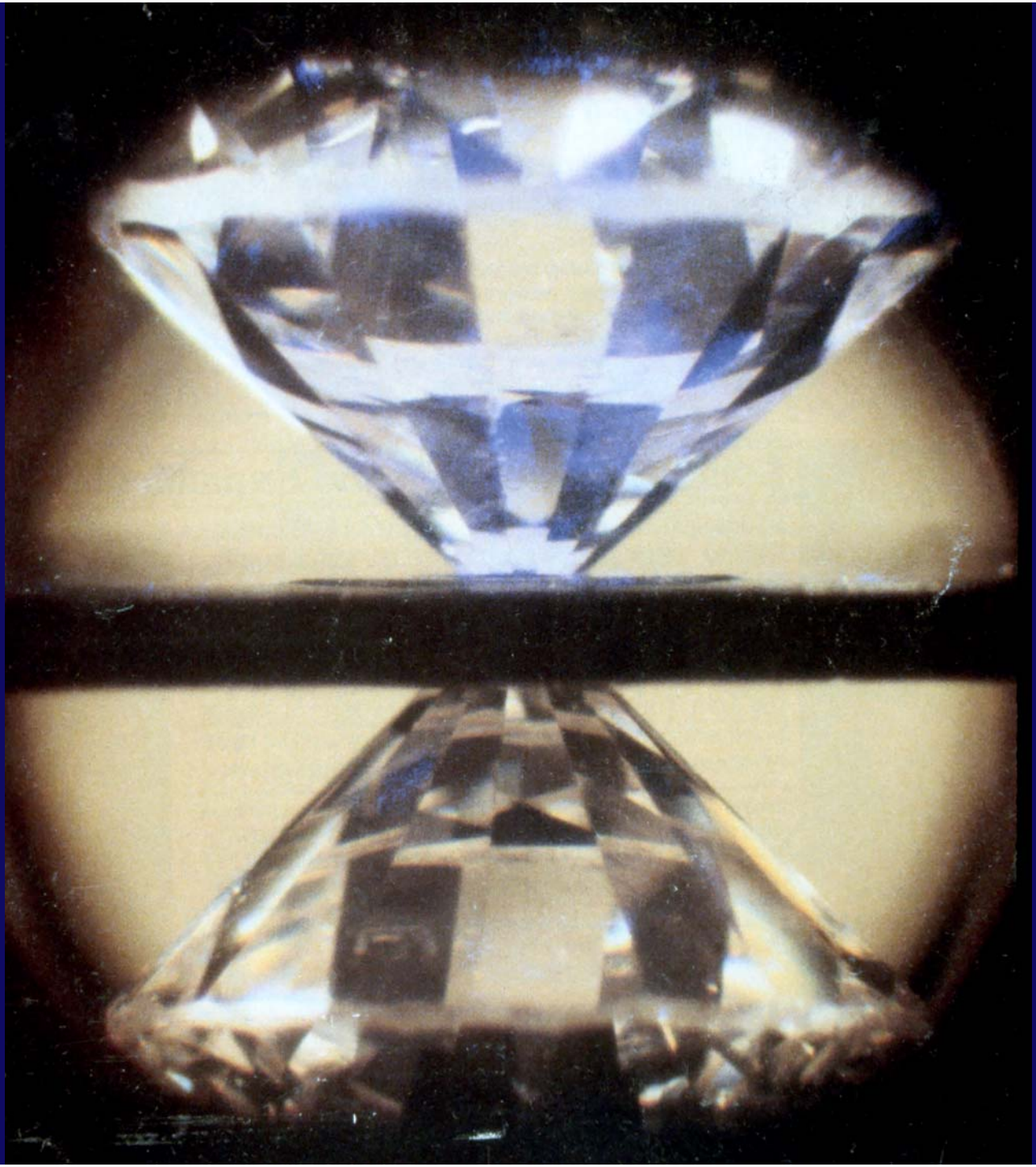

Oceanic ridge
Ocean floor
South America
Africa
Asthenosphere
(Upper mantle)
Lithosphere
(Mantle and crust)
Trench
Plume
Mesosphere
(Lower mantle)
Outer
core


MAGNETIC FIELD
Earth's magnetic field ca
point north or south. Ove
the eons it has reversed i
self many times.
CONTINENTS
Made of lighter rock than seafloors, continents rarely dive into the mantle. A collision between continental plates forms a mountain range such as the Alps. Land may act as insulation, trapping heat in the underlying part of the mantle and leading to eventual rifting and breakup.
SEAFLOOR SPREADING
Adjacent tectonic plates that lie beneath the oceans pull apart at mid-ocean ridges. Mantle rock rises as magma to fill the gap. Hardening, it attaches to the shifting plates, and more magma moves up.
RESTLESS MANTLE
Warm rock rises to displace cooler rock, which then sinks, warms up, and rises again to release some 80 percent of the internal heat that the earth radiates.
OUTER CORE
Many forces affect this liquid metallic layer. Earth's rotation and convection combine to create columns of spiraling liquid parallel to the earth's rotational axis. As in an electromagnet, the mechanical energy of the spirals generates electricity, which then creates the earth's magnetic field.
SUBDUCTION
When two plates collide, one usually dives beneath the other, eventually becoming part of earth's mantle. The plunging slab melts, releasing lava that erupts through the overriding plate as volcanoes. Subduction often causes massive earthquakes.
HOT SPOTS
Rising from deep in the mantle, a plume of hot rock melts into the crust and forms a volcano. As the crust moves above the mantle, the plume creates a volcanic chain, leaving old, cold cones at one end and fueling a new active one at the other. This occurs in places such as the Hawaiian Islands.
INNER CORE
Buried by the outer layers, this innermost region is especially hard to read. It probably contains hexagonal iron crystals aligned with the earth's rotational axis and is growing as the outer core solidifies at the boundary. It may anchor the magnetic field, countering the turbulent cur-

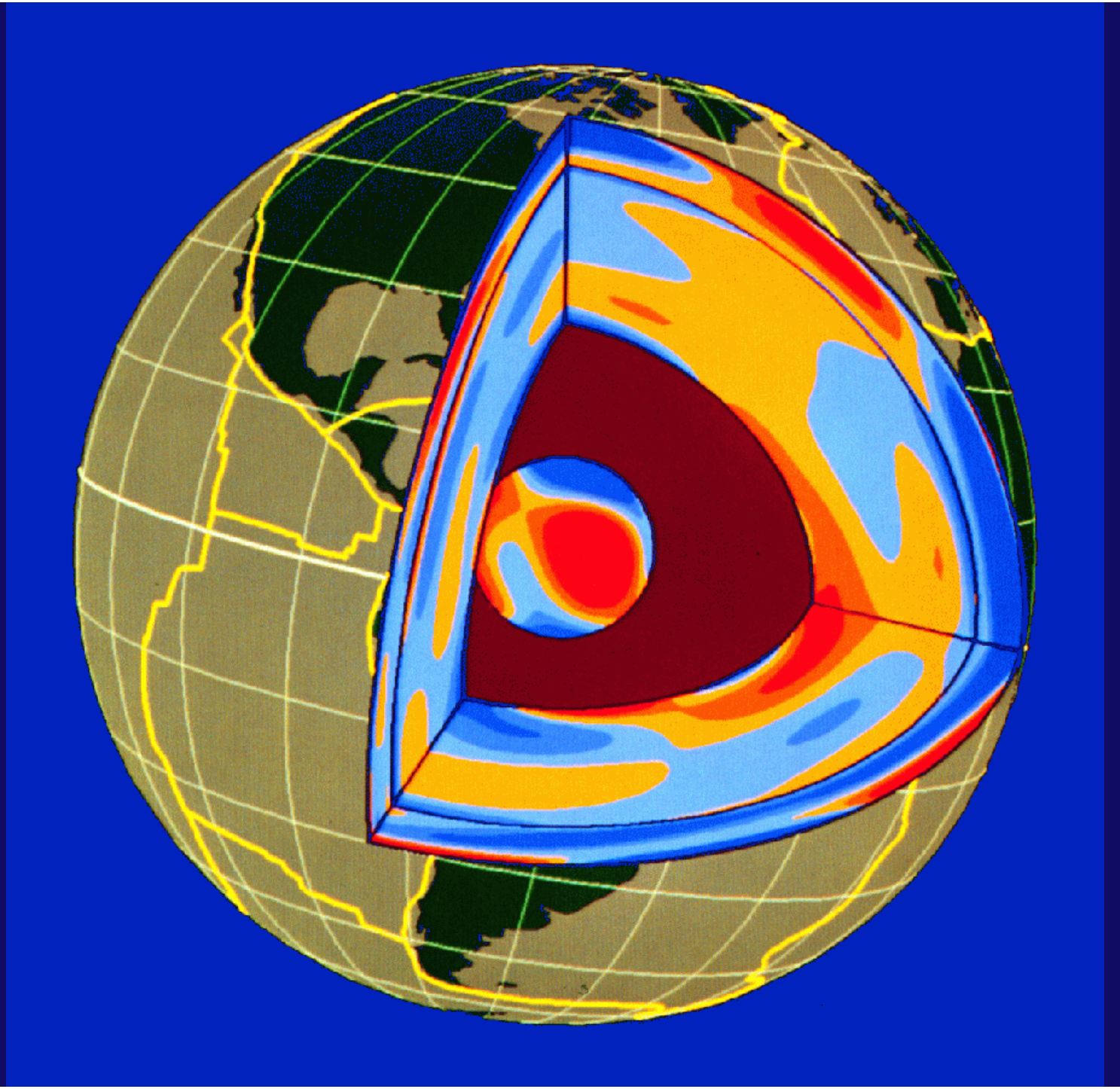

THE CORE



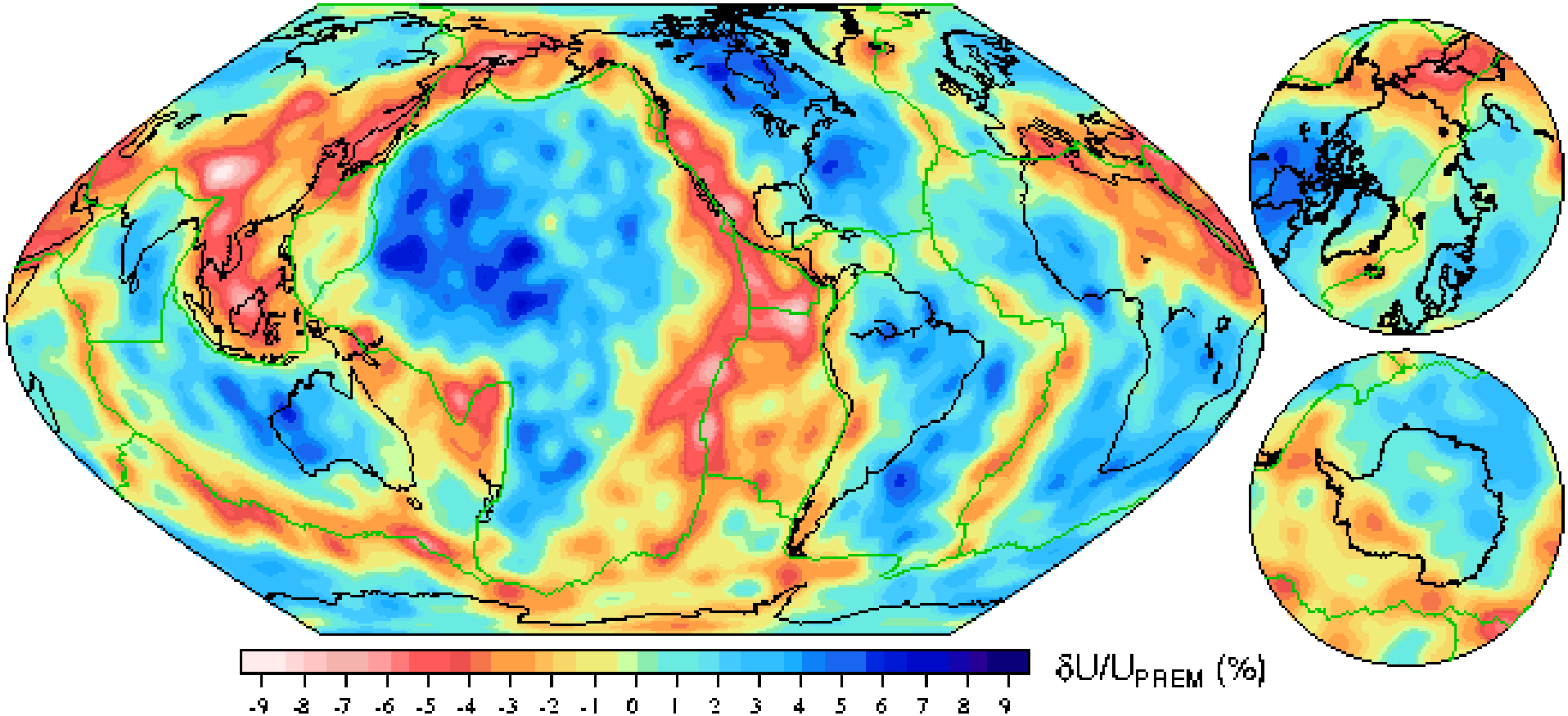
Je m'imaginais voyager à travers un diamant (p. 185).

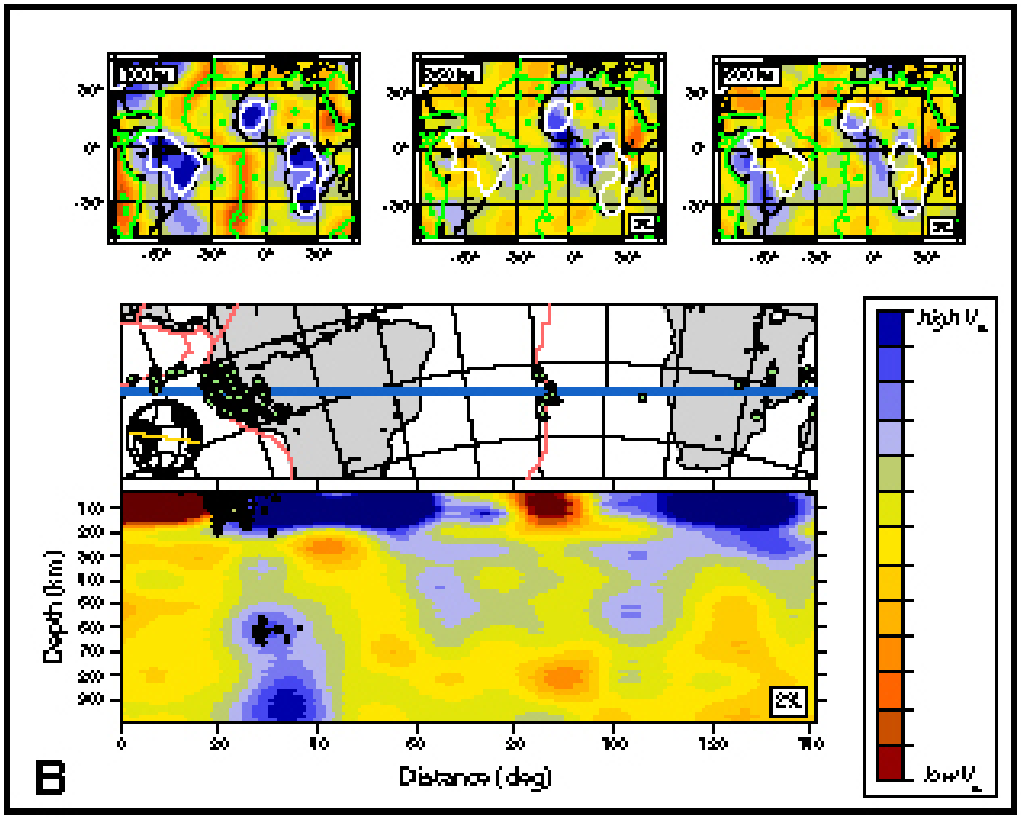


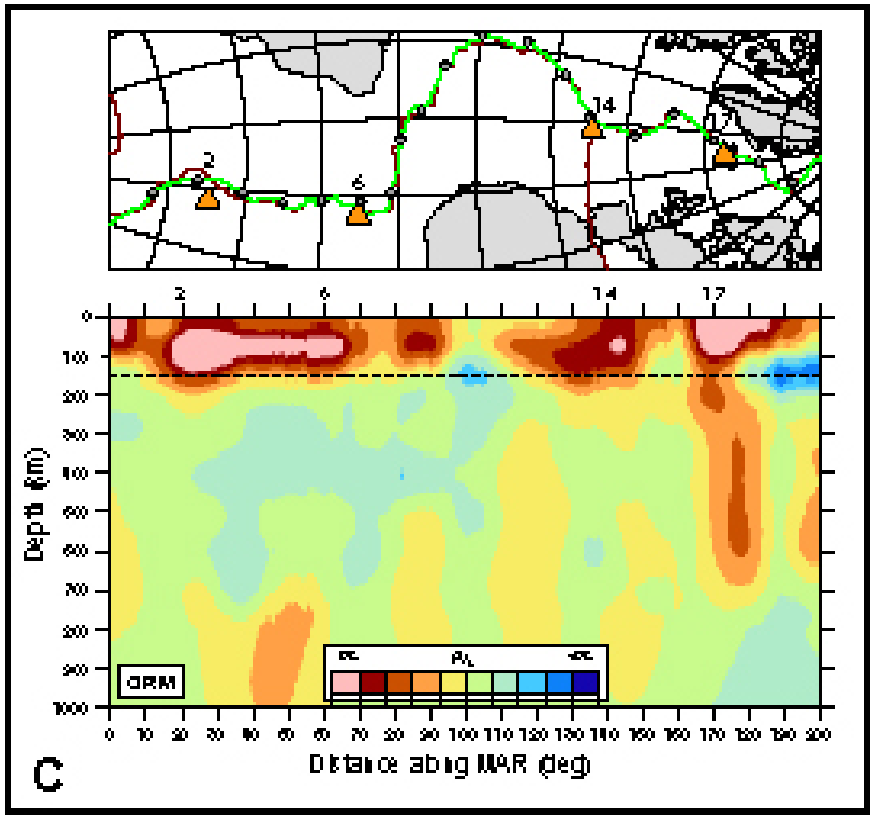
A Medical CT-Scan

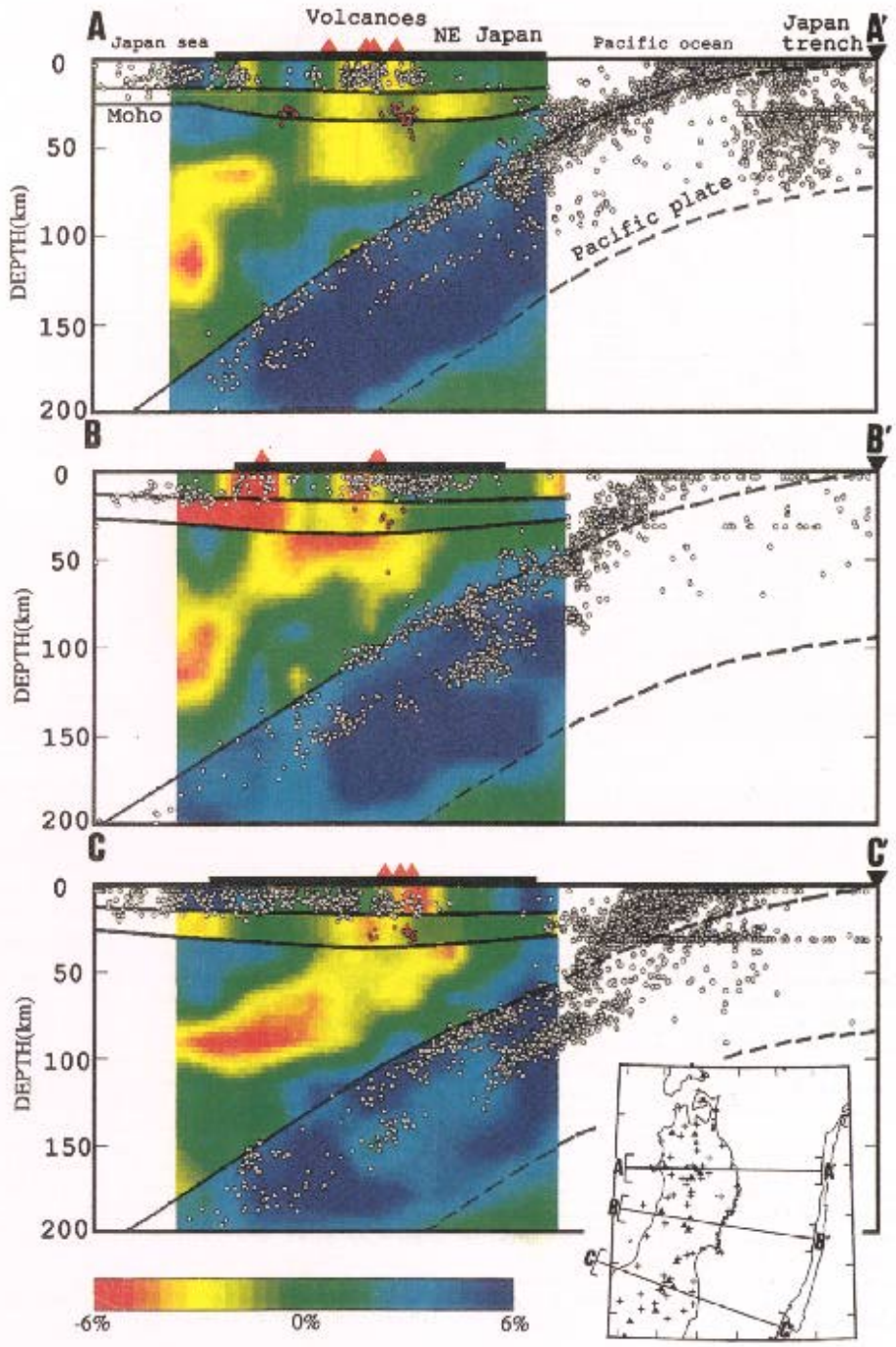


Rayleigh wave (70 s) tomography

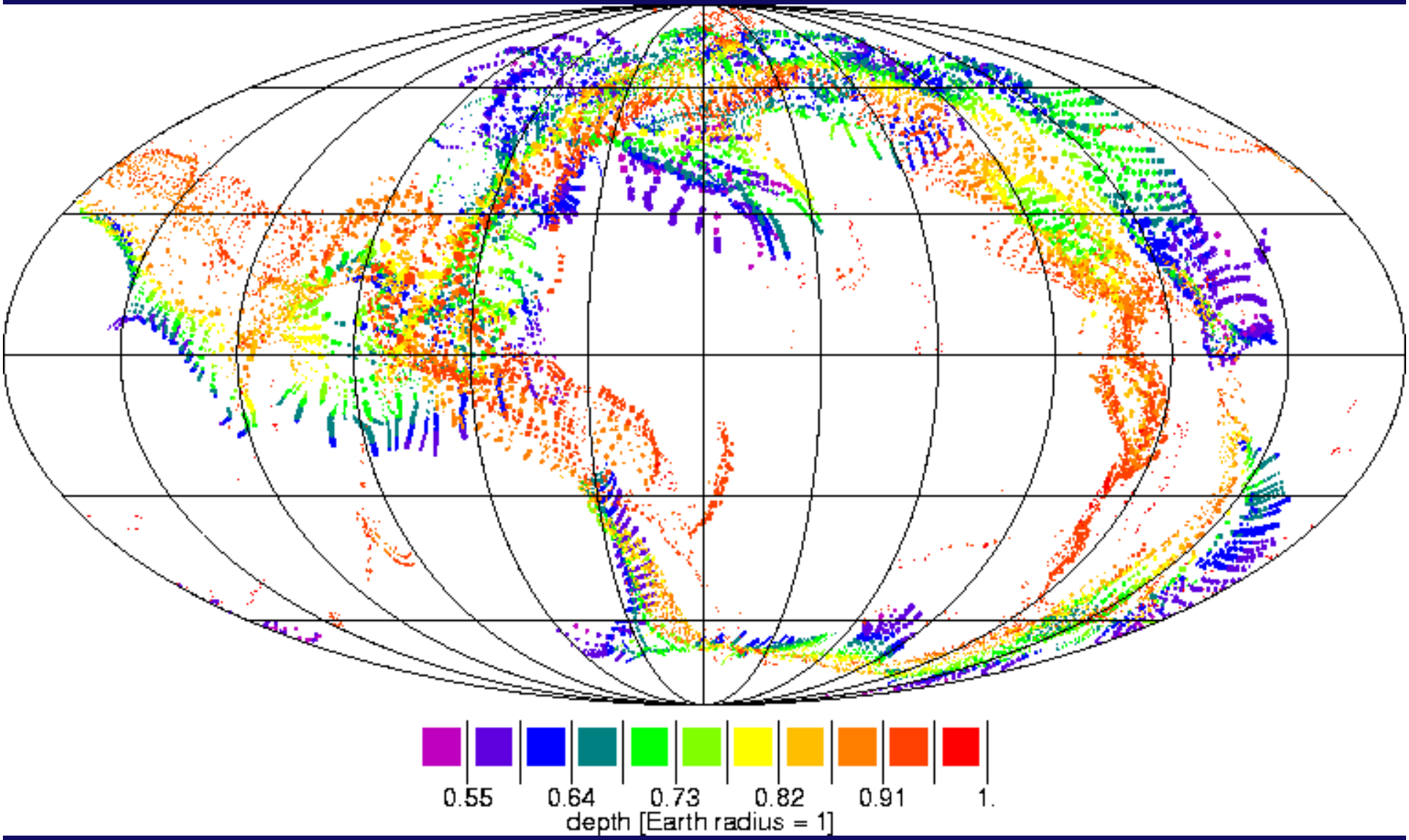


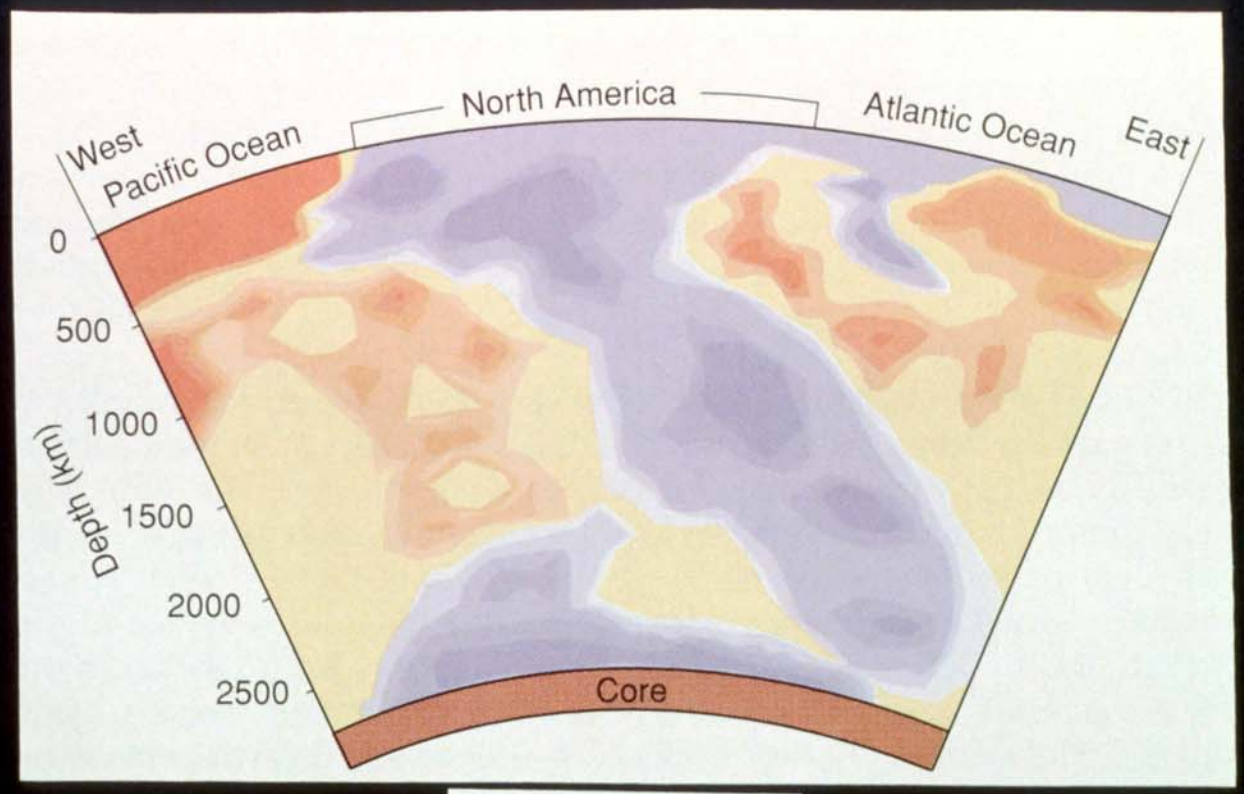

B
Depth (km)
Distance (deg)
High V_s
Low V_s

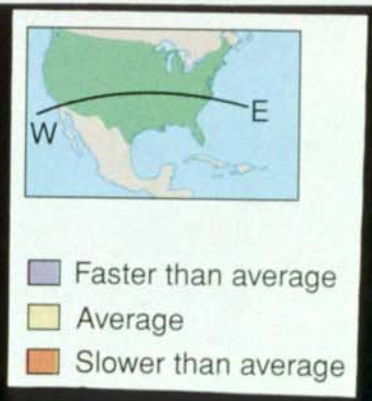

C
Depth (km)
Distance along MAR (deg)
CRM

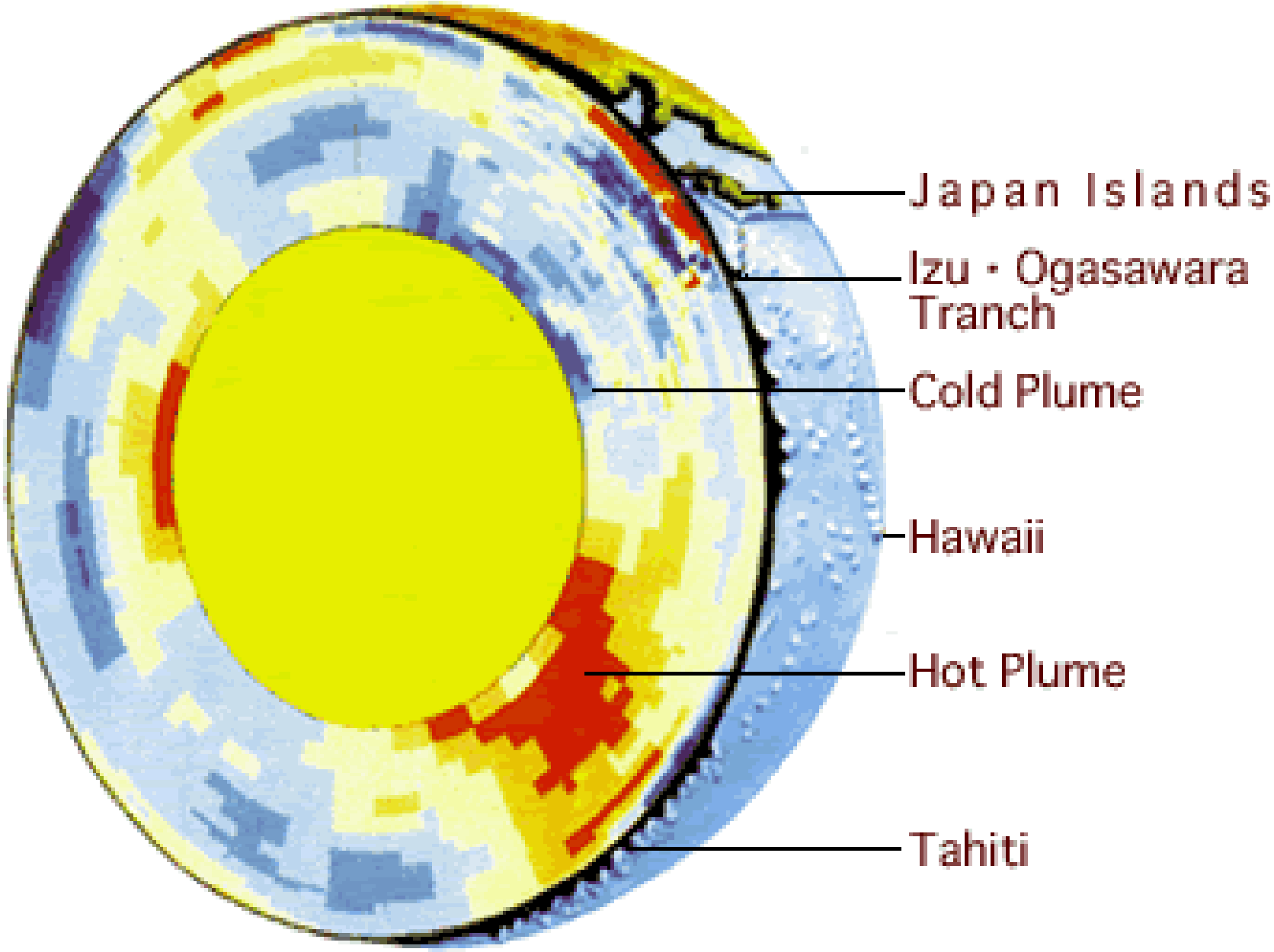

A
Japan sea
Volcanoes
NE Japan
Pacific ocean
Japan trench
A'
Moho
Pacific plate
DEPTH(km)
0
50
100
150
200
B
B'
C
C'
-6%
0%
6%

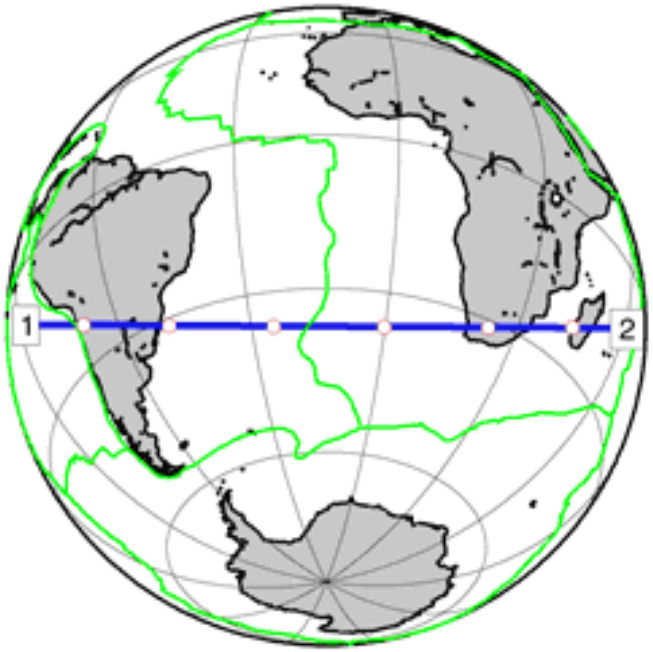
Projected locations of subducted lithosphere down into the mantle:

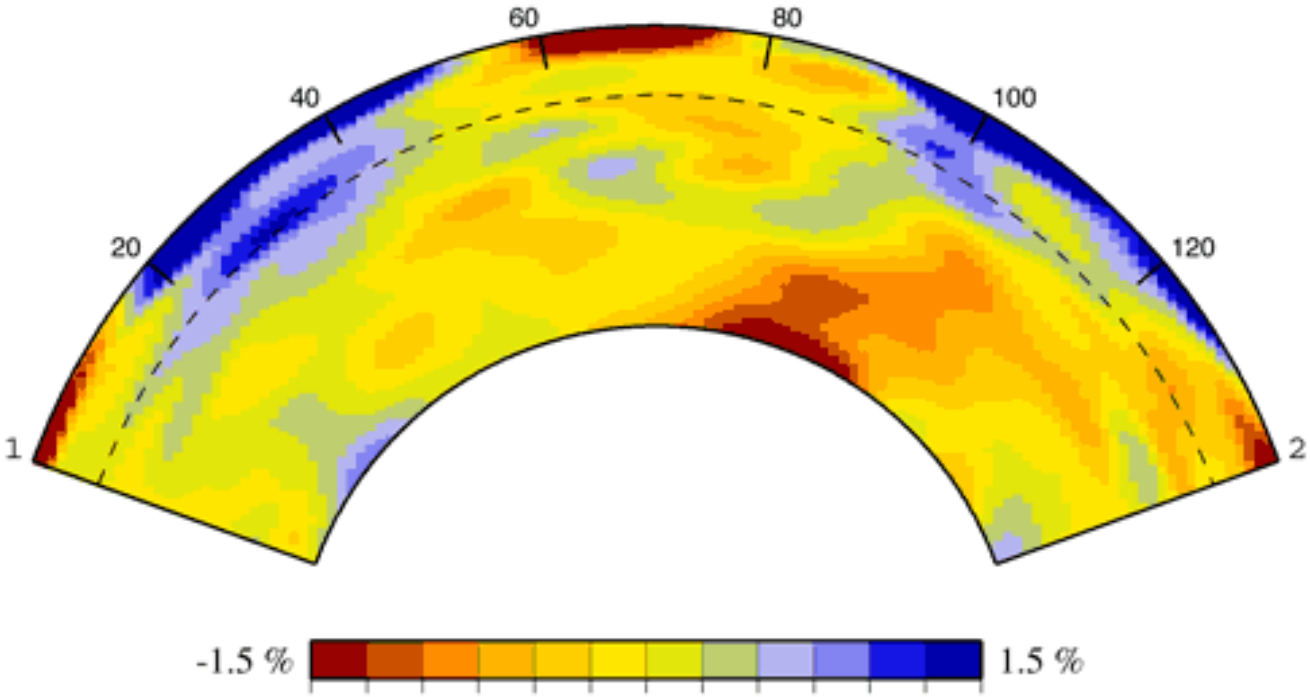


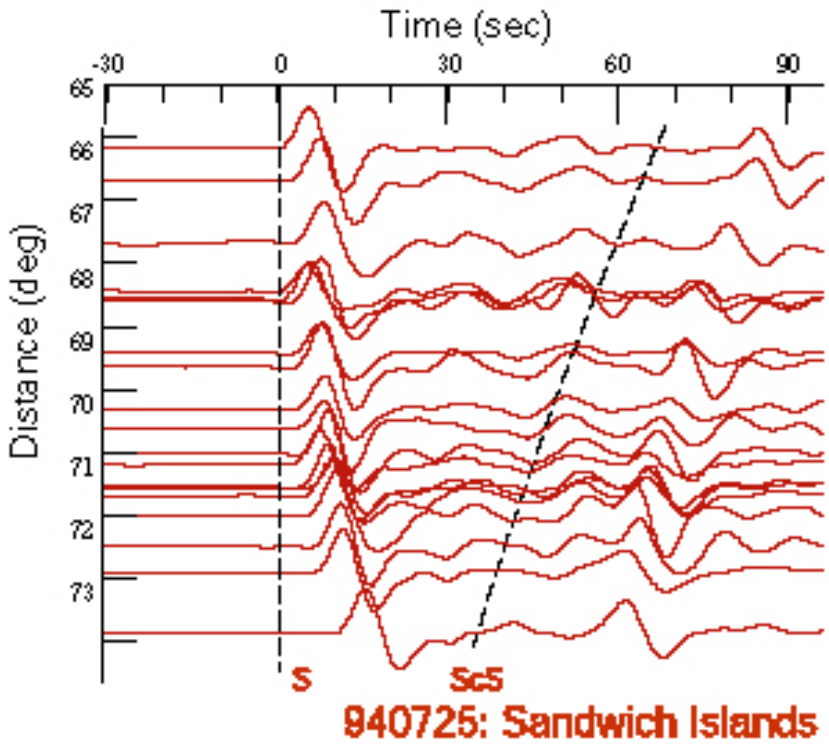

North America
West
Pacific Ocean
Atlantic Ocean
East
0
500
1000
1500
2000
2500
Depth (km)
Core

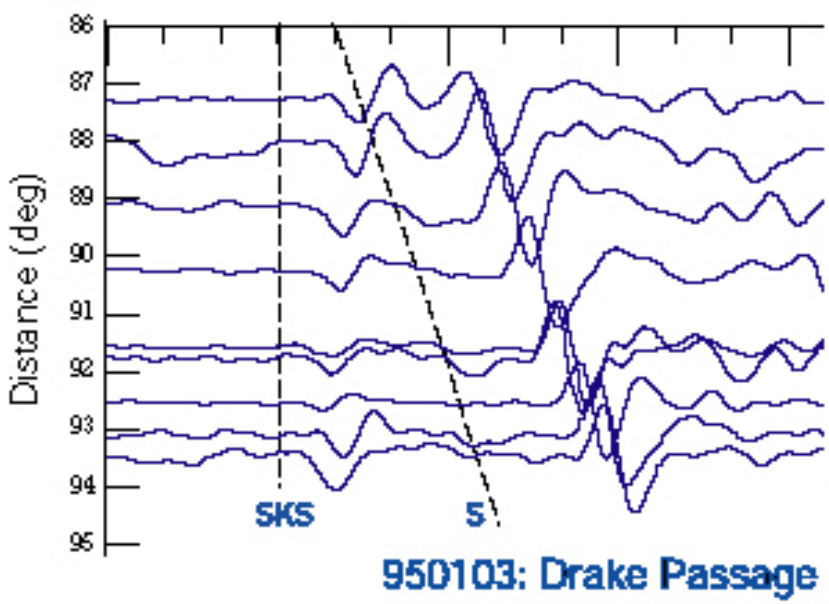

W
E
Faster than average
Average
Slower than average

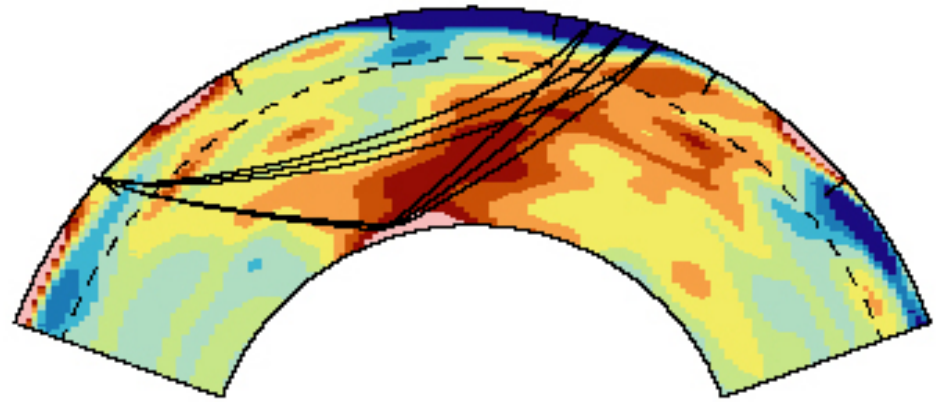

Japan Islands
Izu・Ogasawara
Tranch
Cold Plume
Hawaii
Hot Plume
Tahiti

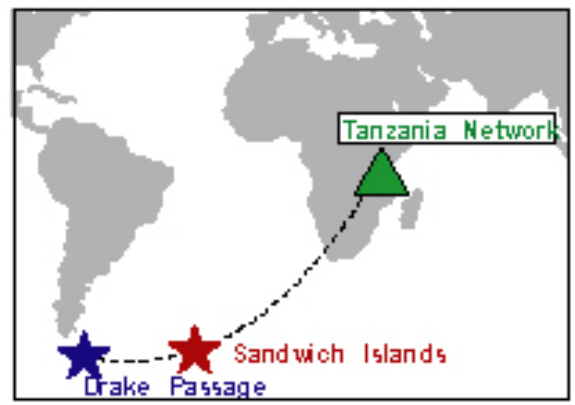

1
2

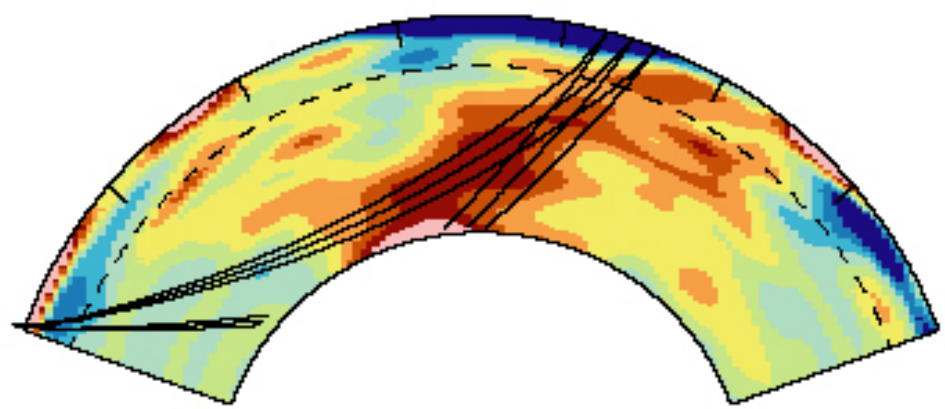

60
80
40
100
20
120
1
2
-1.5 %
1.5 %

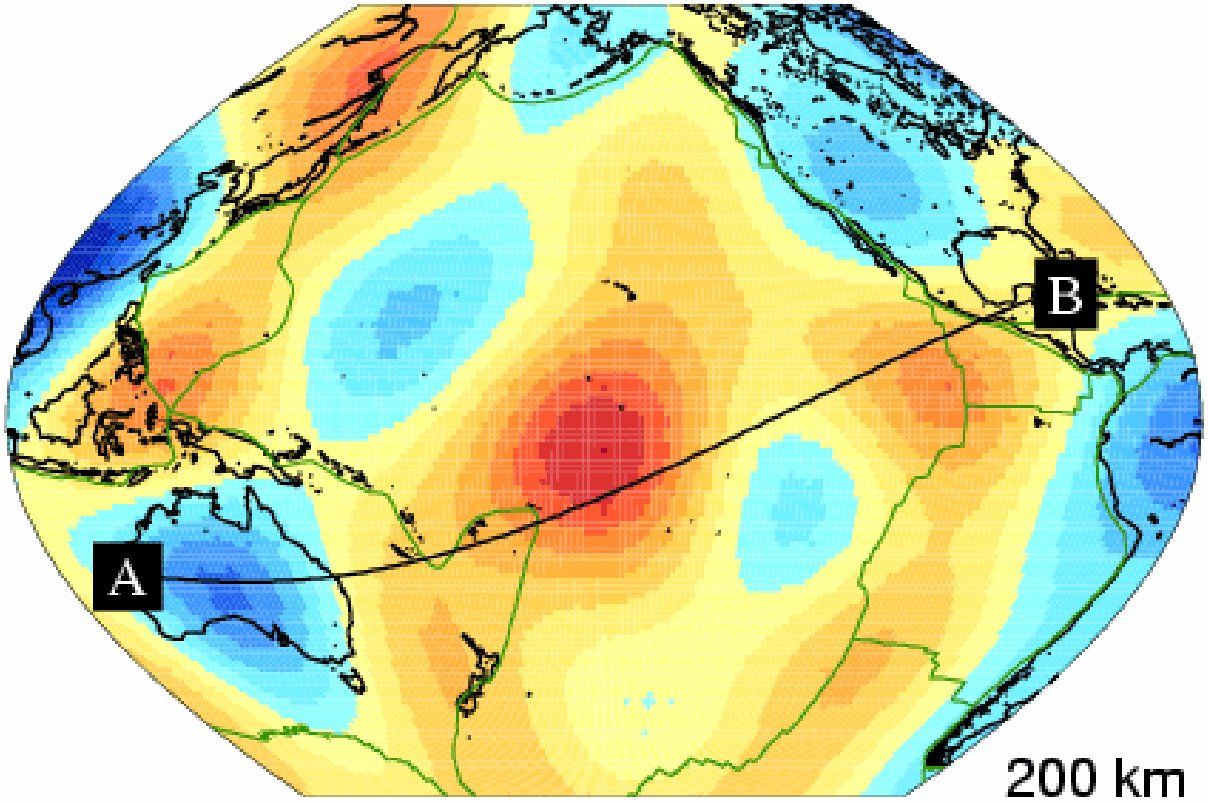

Time (sec)
-30
0
30
60
90
Distance (deg)
65
66
67
68
69
70
71
72
73
S
ScS
940725: Sandwich Islands

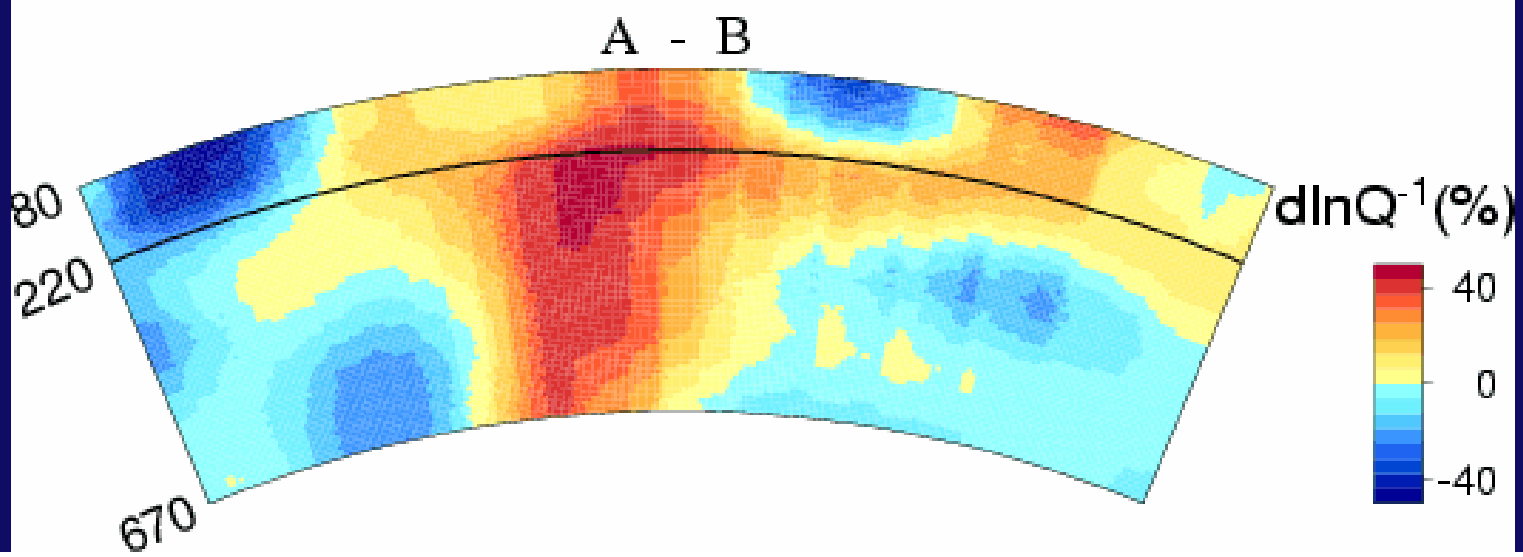

Distance (deg)
86
87
88
89
90
91
92
93
94
95
SKS
S
950103: Drake Passage

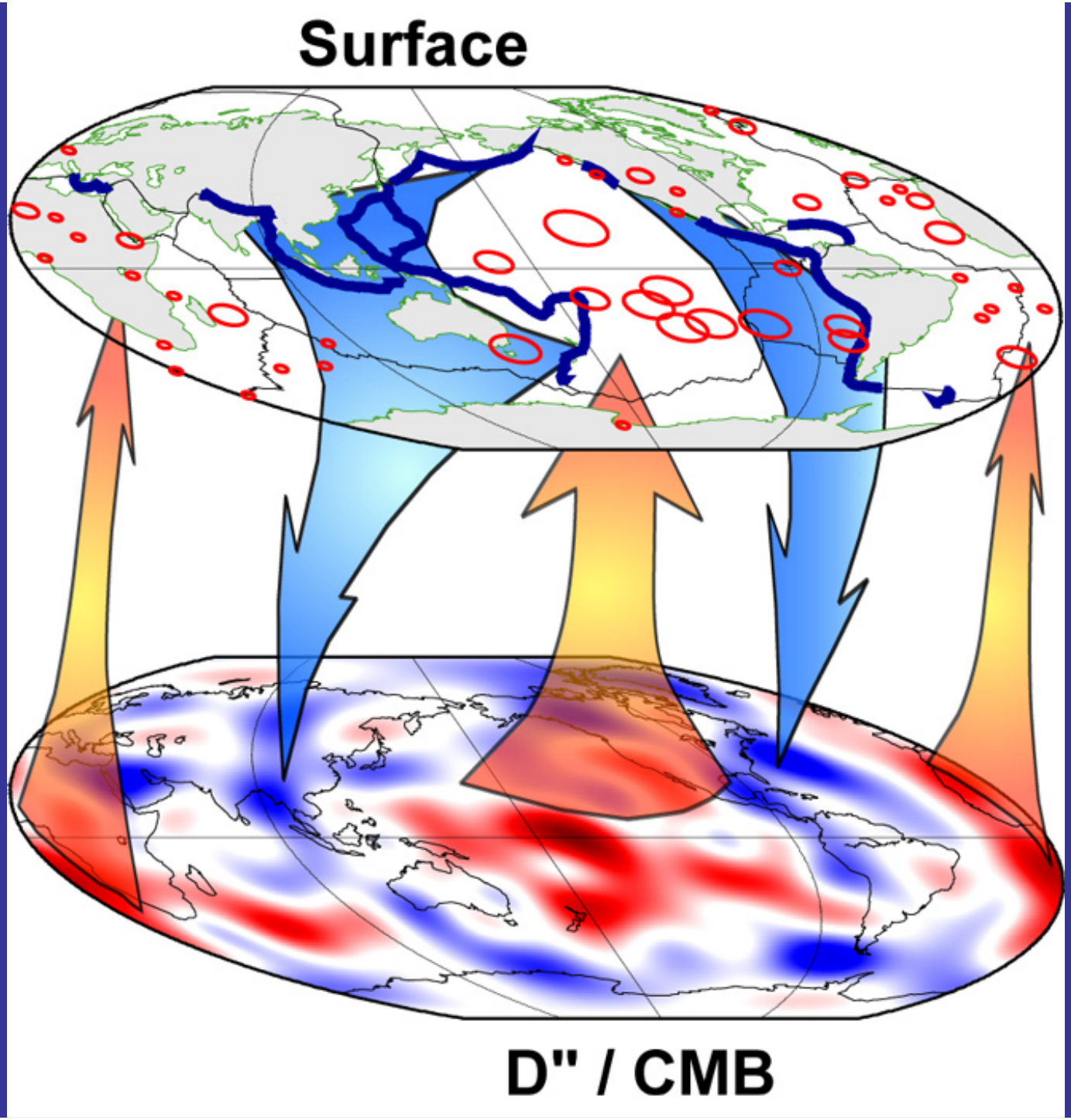



Tanzania Network
Sandwich Islands
Drake Passage



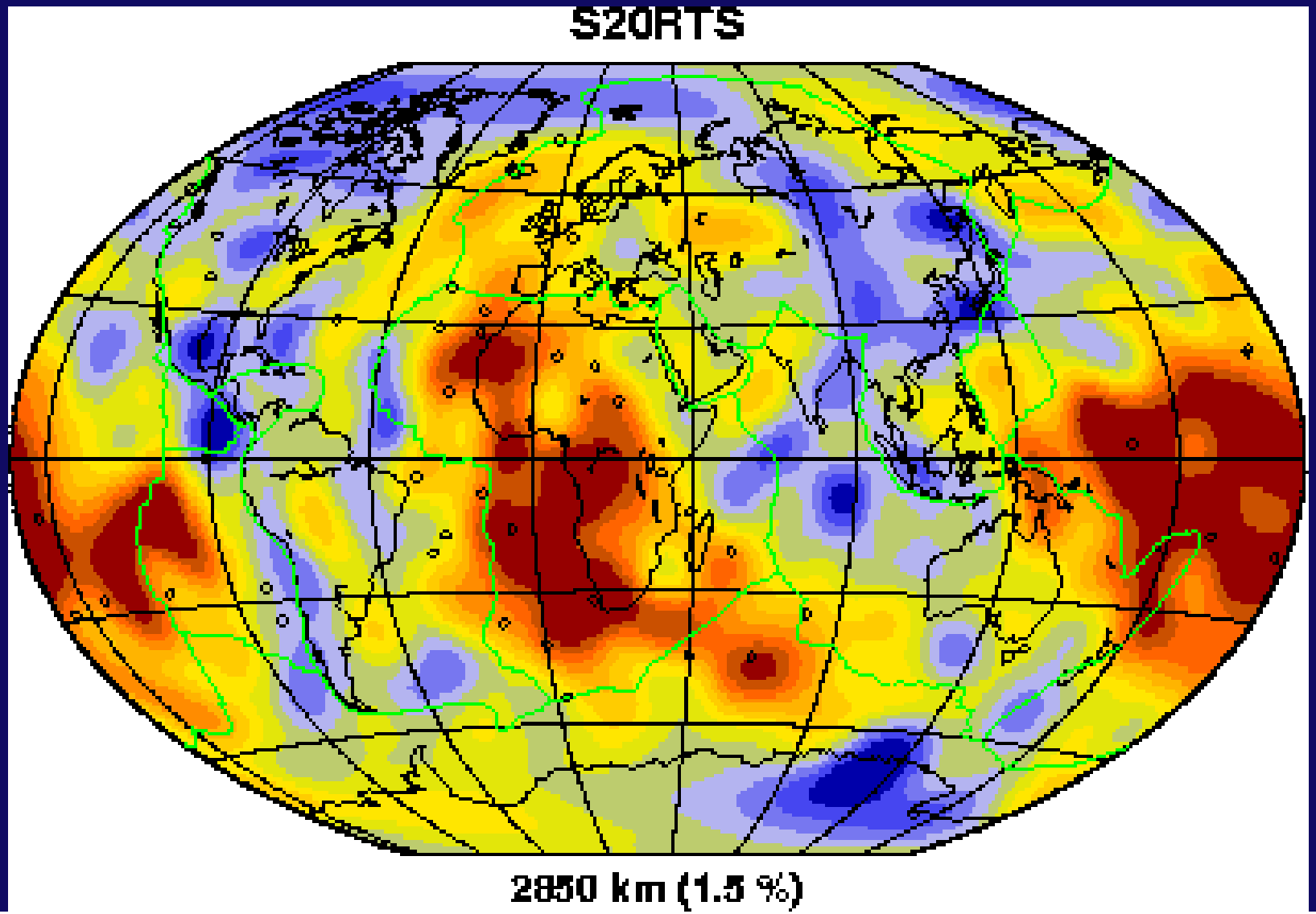

B
A
200 km


A - B
80
220
670
dlnQ^{-1}(%)
40
0
-40

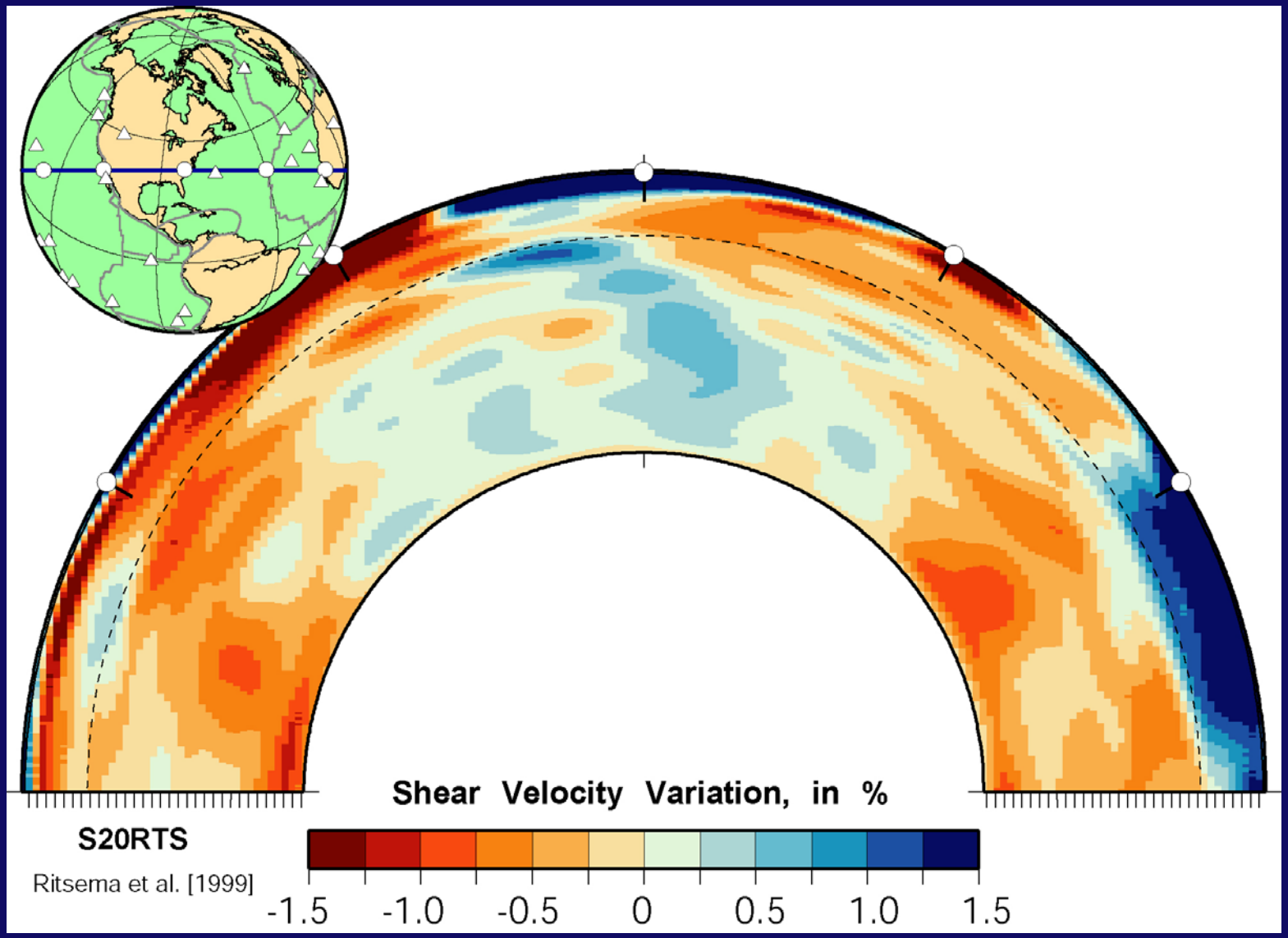

Surface
D" / CMB

D″ Lateral S-Velocity Heterogeneity *(Long Wavelength)*

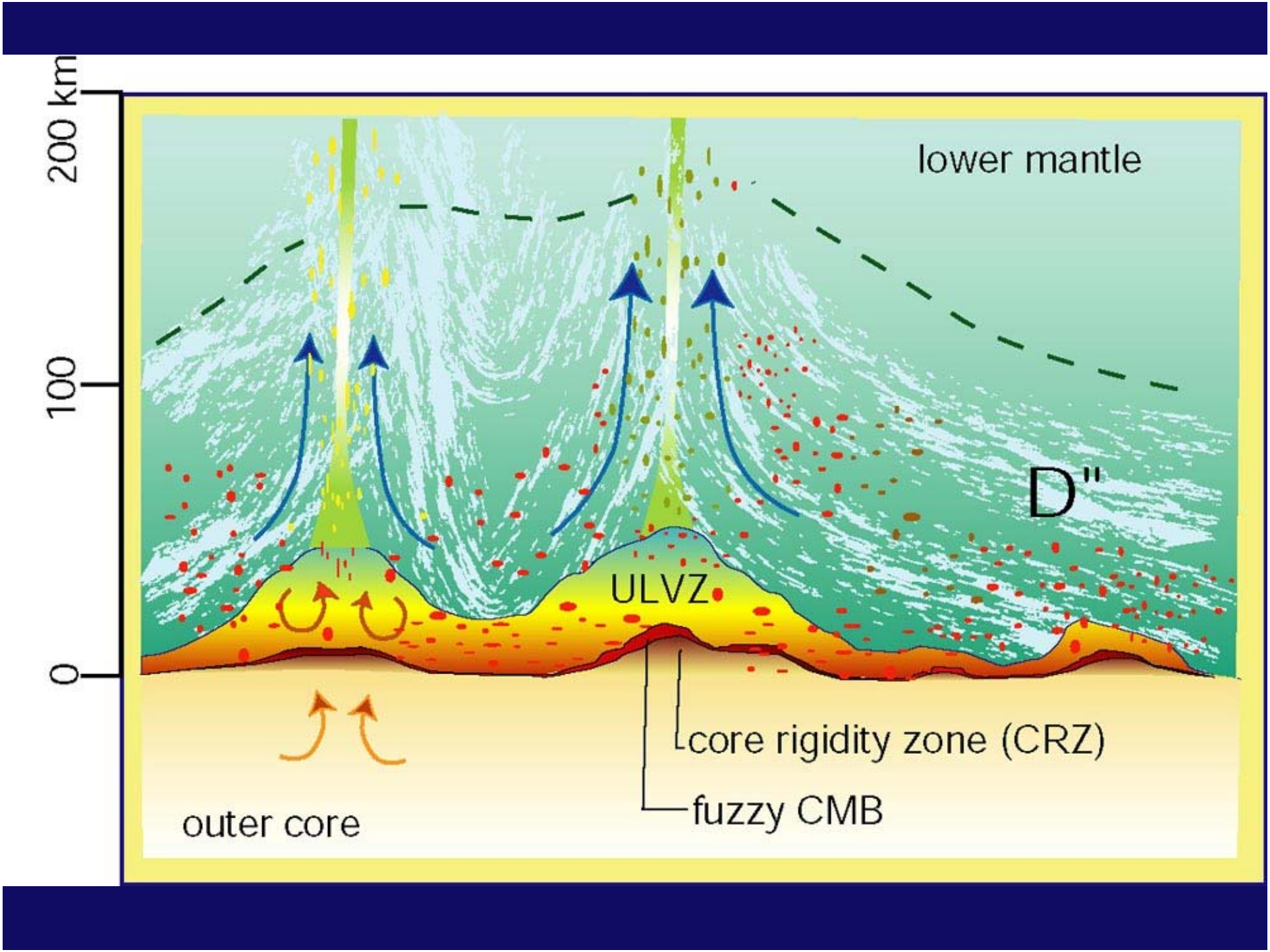
- (Fast velocities beneath the circum-Pacific)
- (Slow velocities beneath Africa and the Pacific)

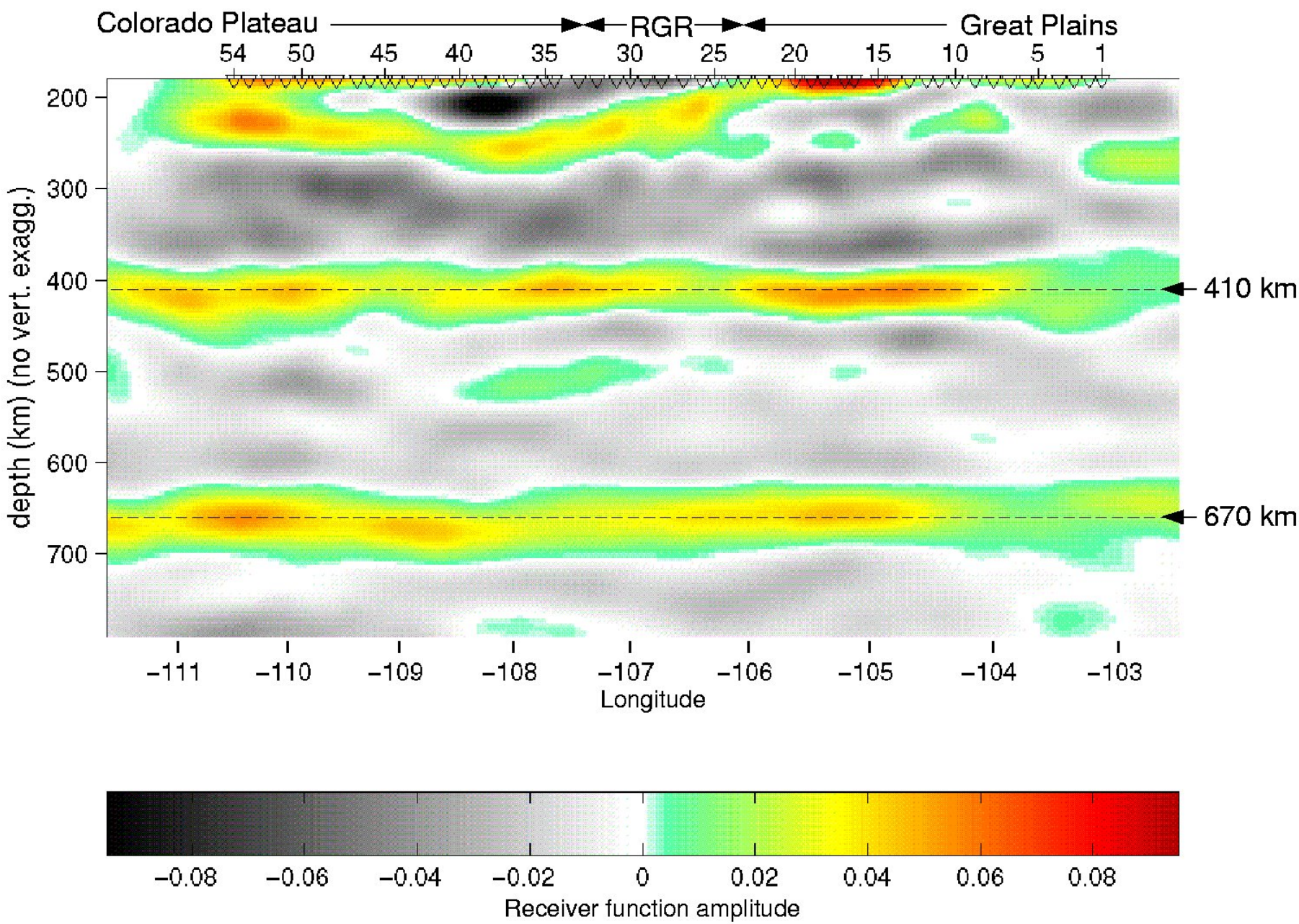


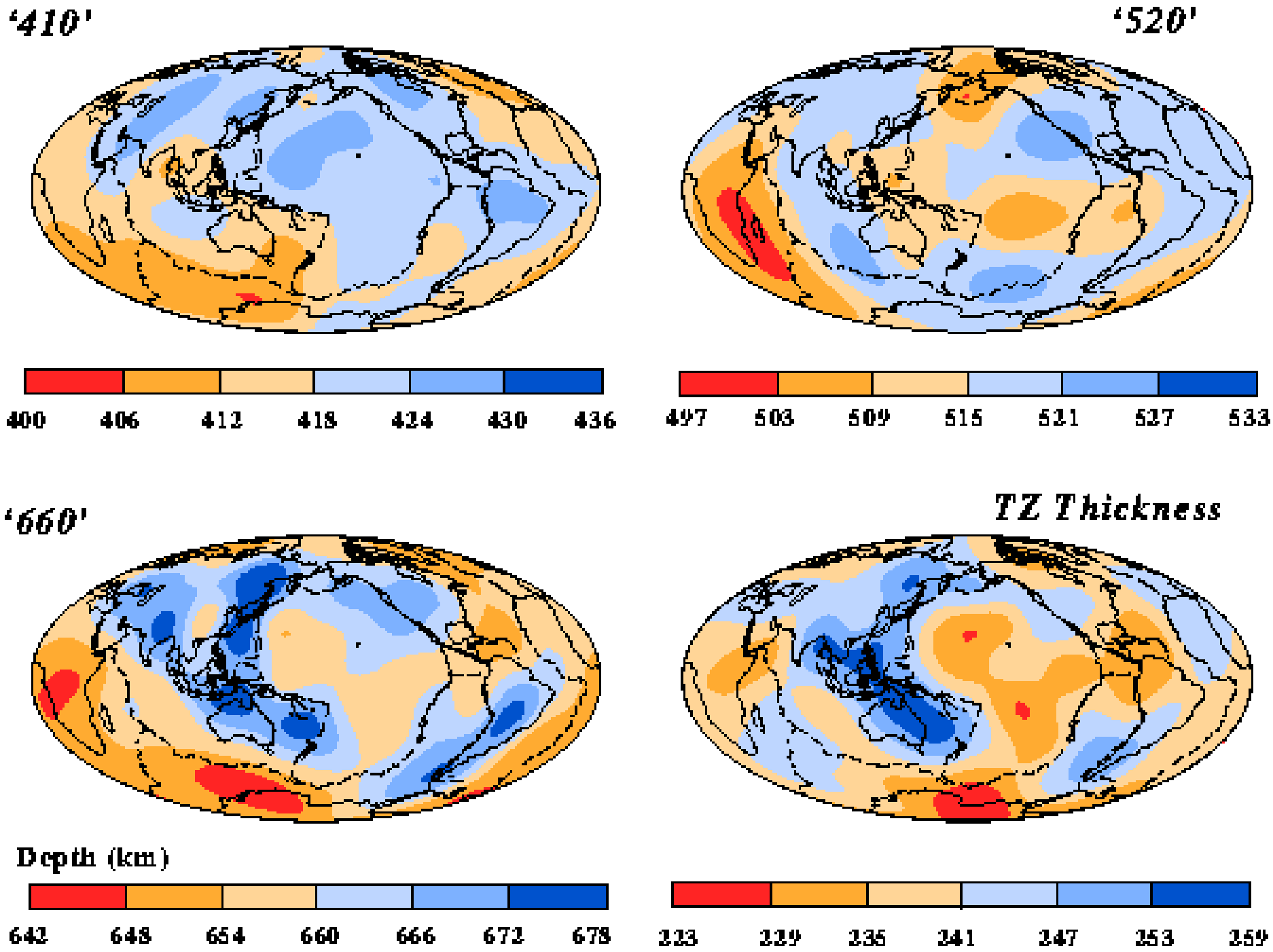
A map of “anti-continents” at the core-mantle boundary – graveyard of subducted slabs, birthplace of hot spot plumes.



An artist's rendition of the core-mantle boundary.

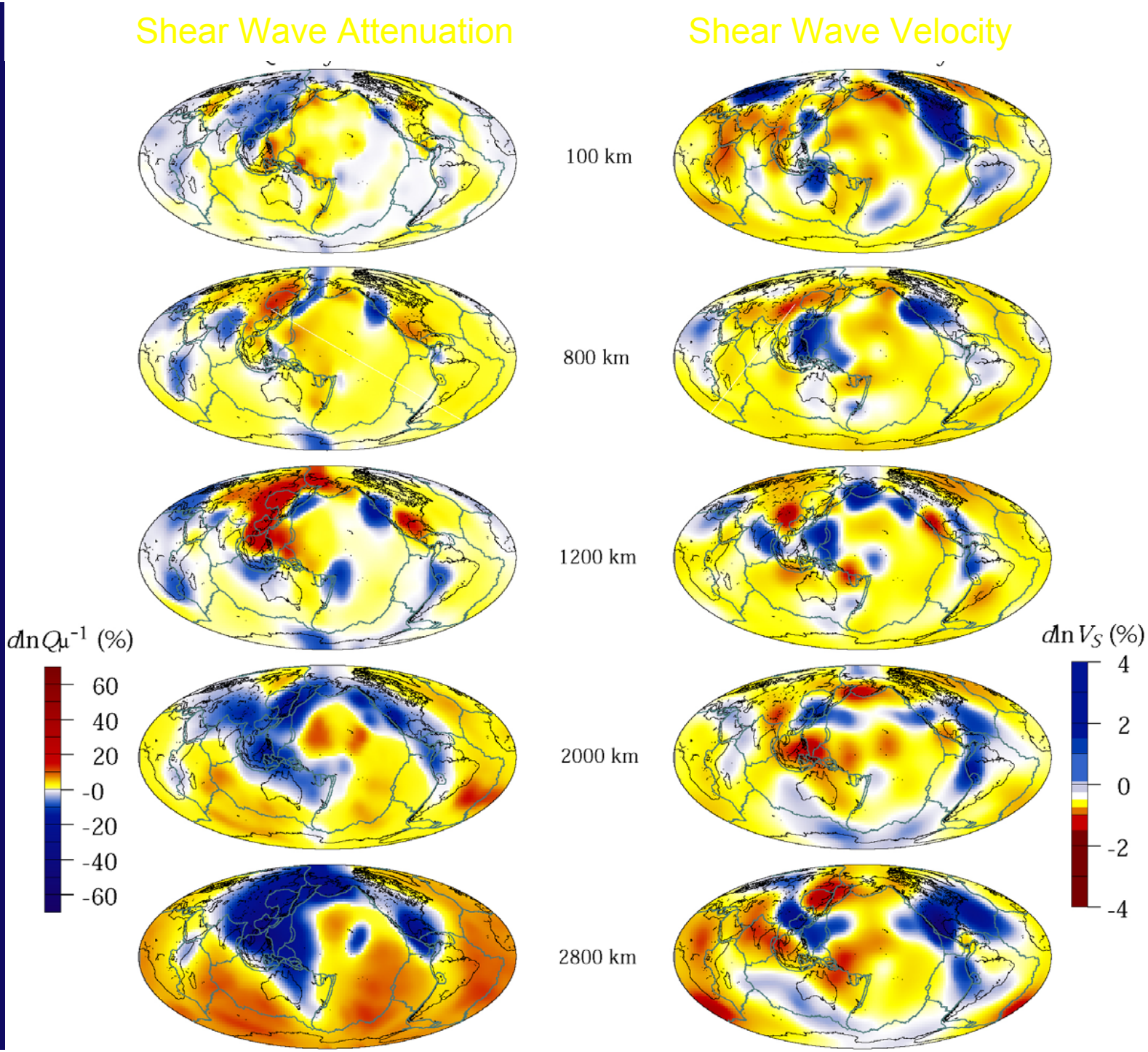

200 km
100
0
lower mantle
D"
ULVZ
core rigidity zone (CRZ)
fuzzy CMB
outer core

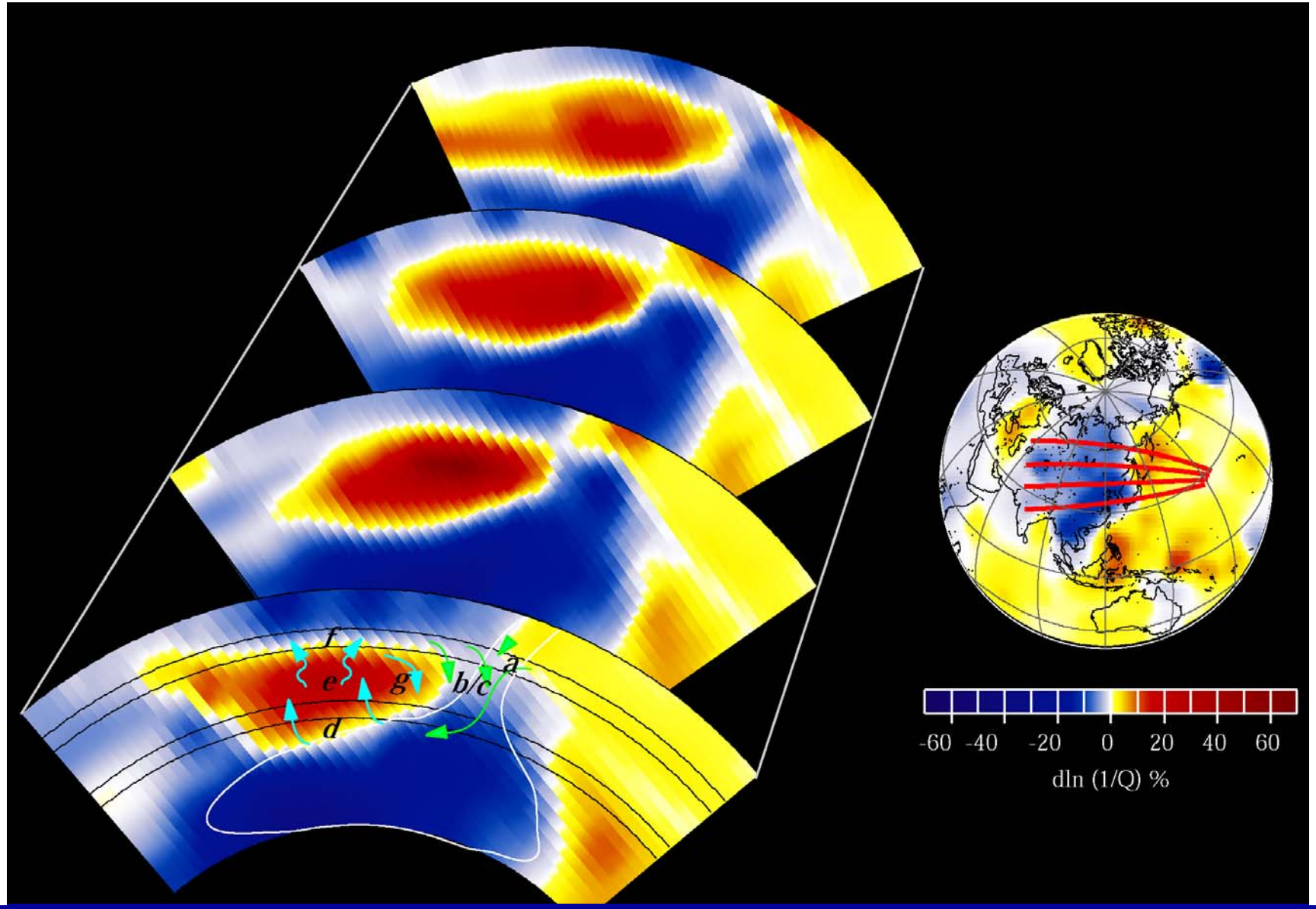

Colorado Plateau
RGR
Great Plains
54
50
45
40
35
30
25
20
15
10
5
1
200
300
400
500
600
700
depth (km) (no vert. exagg.)
410 km
670 km
−111
−110
−109
−108
−107
−106
−105
−104
−103
Longitude
−0.08
−0.06
−0.04
−0.02
0
0.02
0.04
0.06
0.08
Receiver function amplitude


'410'
400
406
412
418
424
430
436
'520'
497
503
509
515
521
527
533
'660'
Depth (km)
642
648
654
660
666
672
678
TZ Thickness
223
229
235
241
247
253
259

Depth Slices Through the Earth:

VERY large attenuation anomalies in the lower mantle

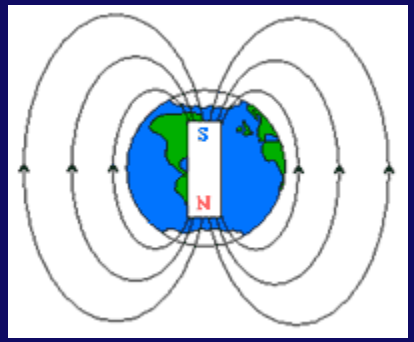


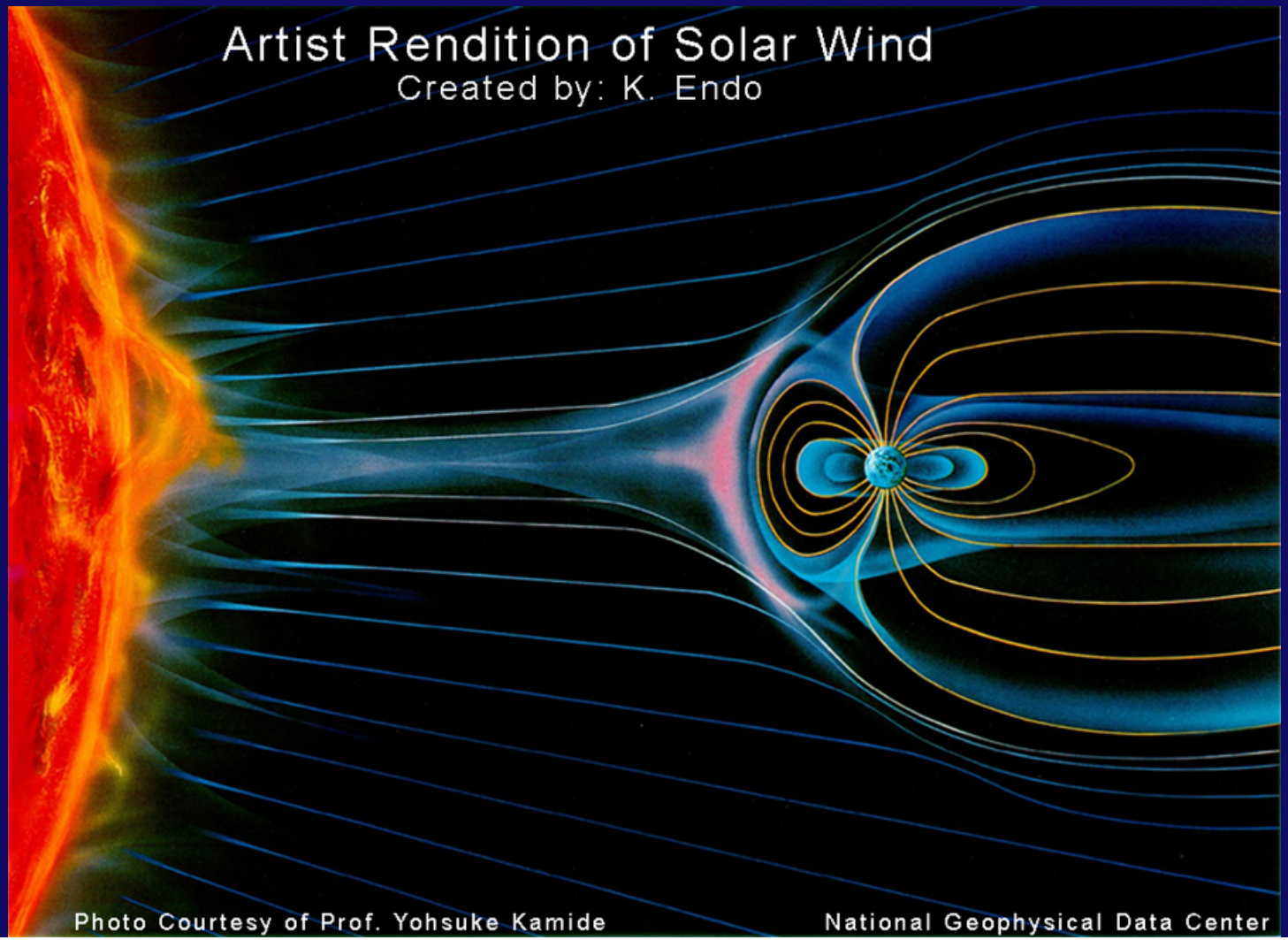


Water Might be Continually Pumped Into the Lower Mantle Via Sinking Ocean Seafloor

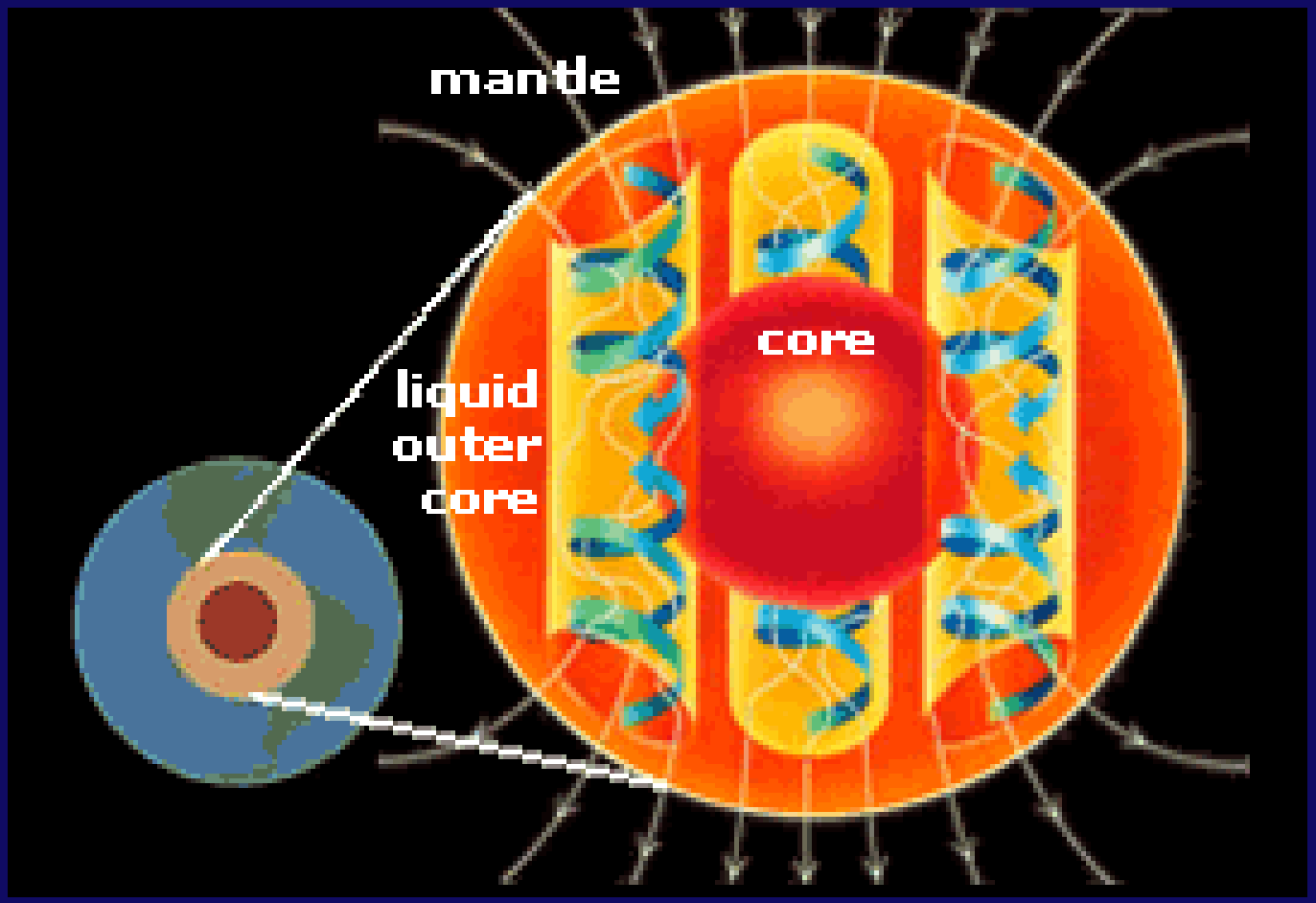
Earth has a strong magnetic field.

Where does it come from?

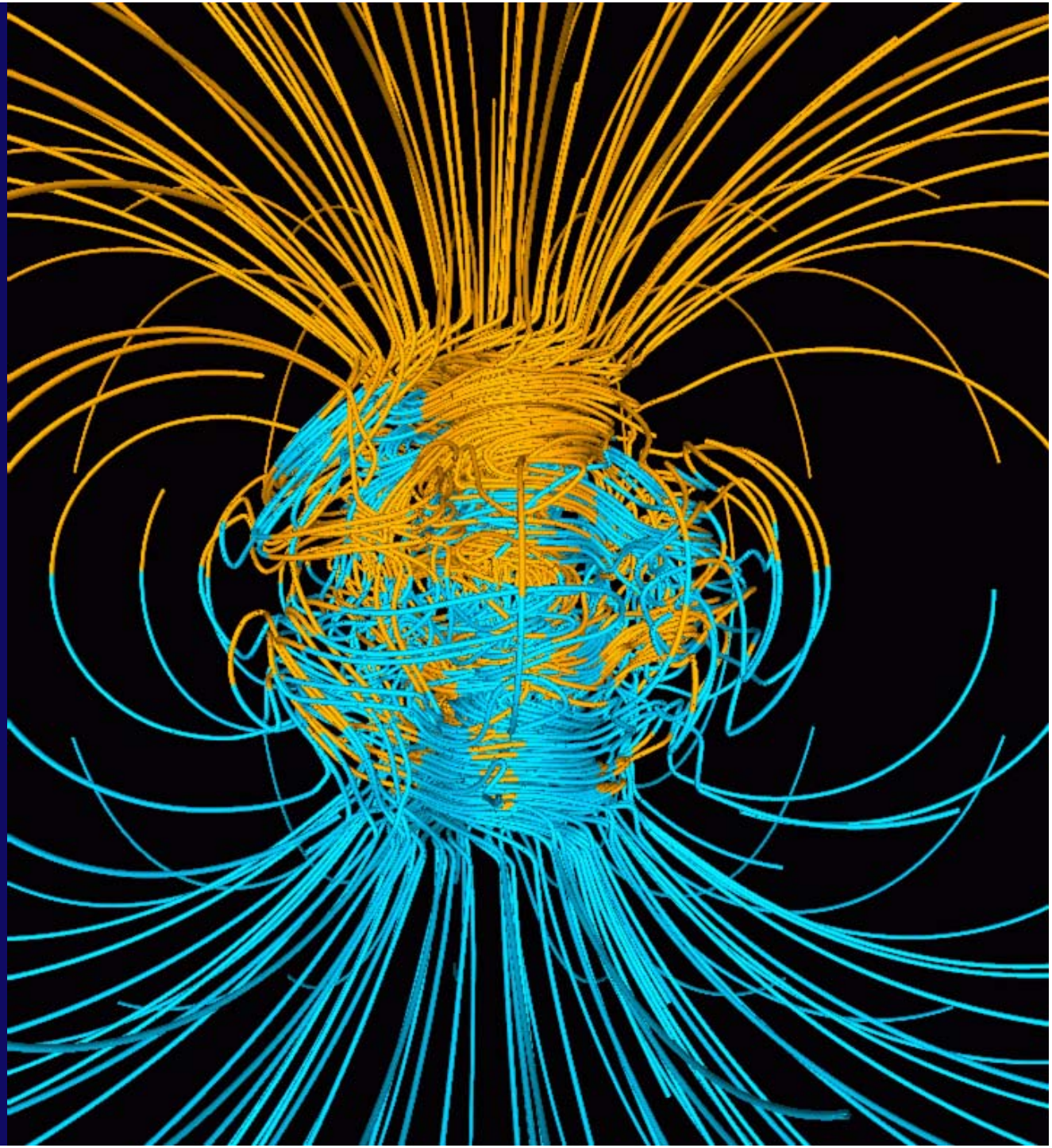




Convection of liquid iron in Earth's core creates Earth's magnetic field.



Magnetic Field Lines in Earth's Iron Core

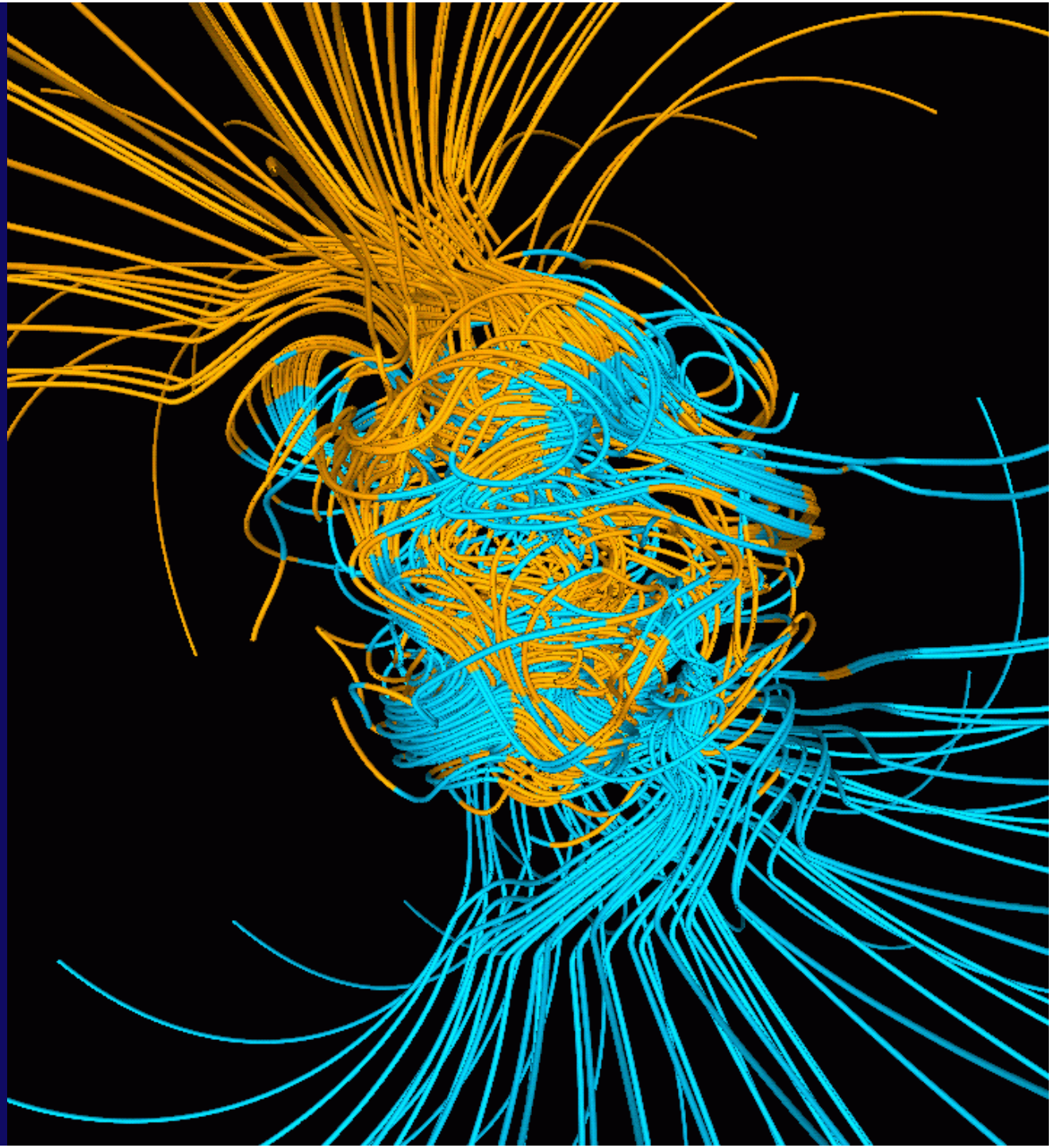


Courtesy of G. Glatzmaier

Magnetic Field Lines in Earth's Iron Core

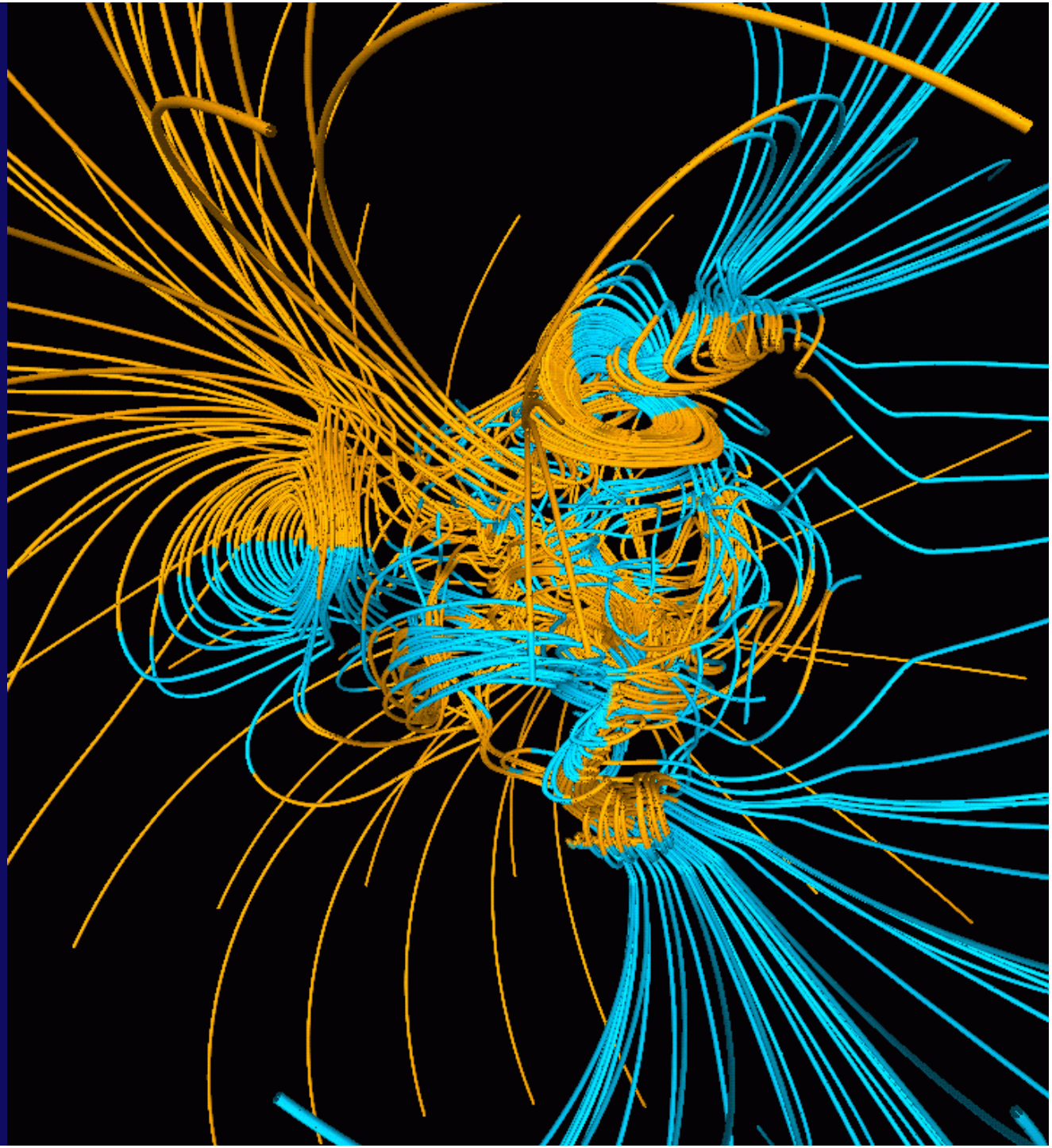
The Field *FLIPS RANDOMLY* Every Few 100,000 Years (or so)!

Courtesy of G. Glatzmaier



Magnetic Field Lines in Earth's Iron Core

The Field *FLIPS RANDOMLY* Every Few 100,000 Years (or so)!



Courtesy of G. Glatzmaier

Magnetic Field Lines in Earth's Iron Core

The Field *FLIPS RANDOMLY* Every Few 100,000 Years (or so)!

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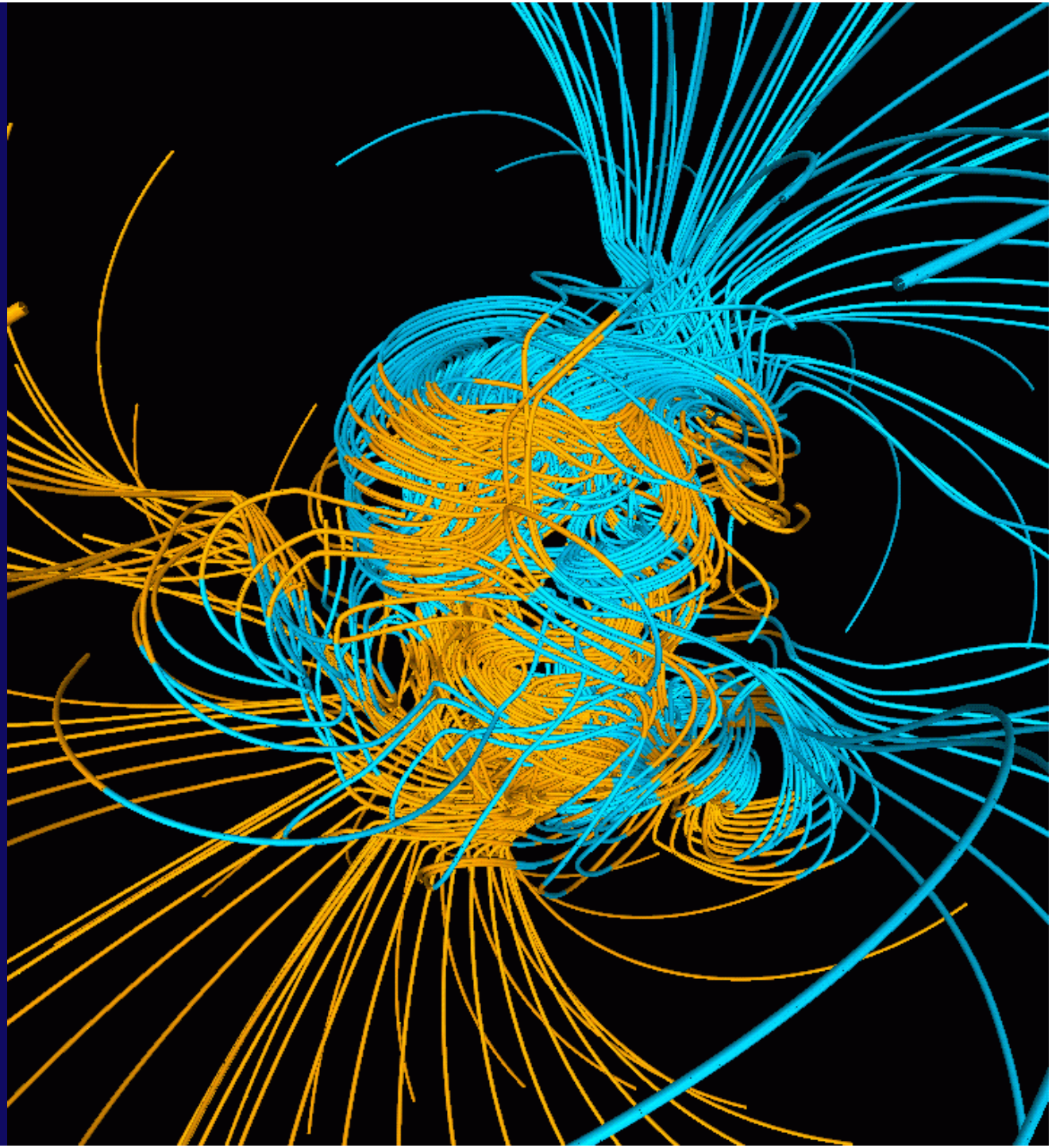
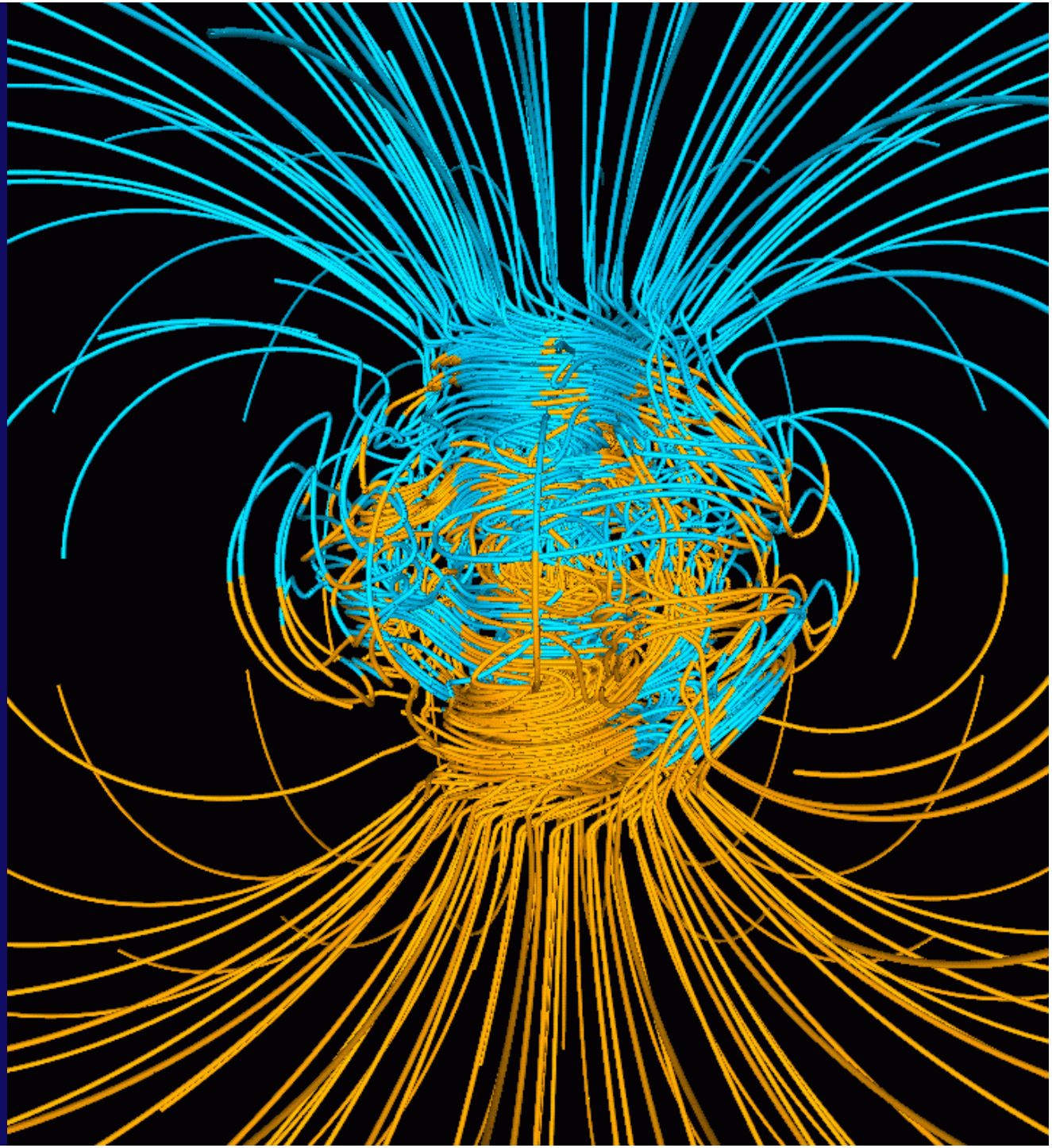


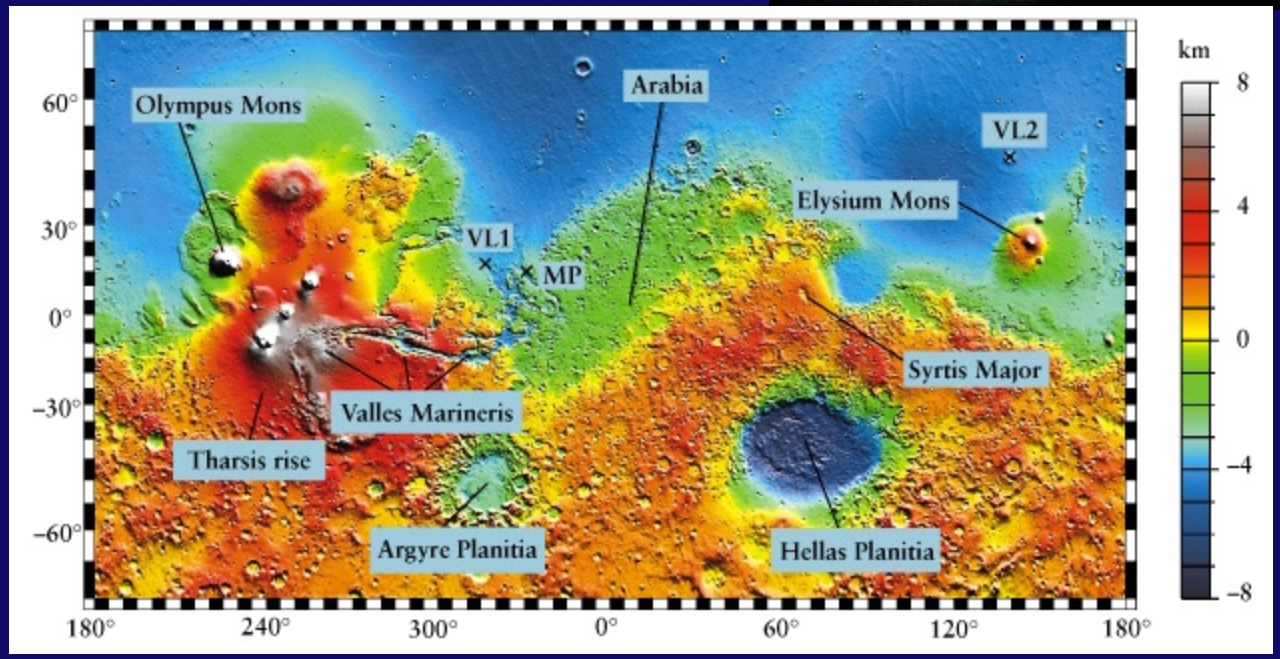
Magnetic Field Lines in Earth's Iron Core

The Field Strength has recently decreased by 10%. Are we beginning a new field reversal??

Courtesy of G. Glatzmaier



Mantle convection on *Mars*



Convection in the *Sun*

Figure 4 The sun has an interior and an atmosphere. The interior consists of the core, radiation zone, and convection zone. The atmosphere consists of the photosphere, chromosphere, and corona.
Interpreting Diagrams ***What is the diameter of the sun's core?***