Part 4: Our Solar System, Life in the Universe

Tuesday, April 11 — Reading: Chapter 15 (12th & 13th Edition of the textbook)
- Solar System: Introduction and Formation; Other Solar Systems

Thursday, April 13 — Reading: Chapter 18 (planets)
- Solar System: Jupiter, Saturn, Uranus, Neptune

Tuesday, April 18 — Reading: Chapter 18, 19
- Solar System: Outer Solar System, Pluto, Kuiper Belt, Comets, Satellites

Thursday, April 20 — Reading: Chapter 16, 17, 18, 19
- Solar System: Satellites, our Moon, Mercury, Asteroids

Tuesday, April 25 — Reading: Chapter 17
- Solar System: Mars and Venus

Thursday, April 27 — Reading: Chapter 16
- Solar System: Earth

Monday, May 1 — Help Session from 4 to 6 PM in RLM 4.102

Tuesday, May 2 — Exam 6

Thursday, May 4 — Reading: Chapter 20
- The history of life on Earth; Life in the Universe

Venus and Mars

Venus and Mars
are opposite extremes of planetary evolution
away from conditions that support life.

Mars is a little too low in mass and a little too far from the Sun.
It got too cold: It lost its air and water
to space,
to the soil,
and
to permafrost.

Venus is a little too close to the Sun. It got too hot:
It baked too many gases out of the soil and into the atmosphere,
producing a runaway greenhouse effect.

Earth

We shall not cease from exploration,
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.

T. S. Eliot
Little Gidding


Image by: Stöckli, Nelson, Hasler
Hurricane Linda west of Mexico

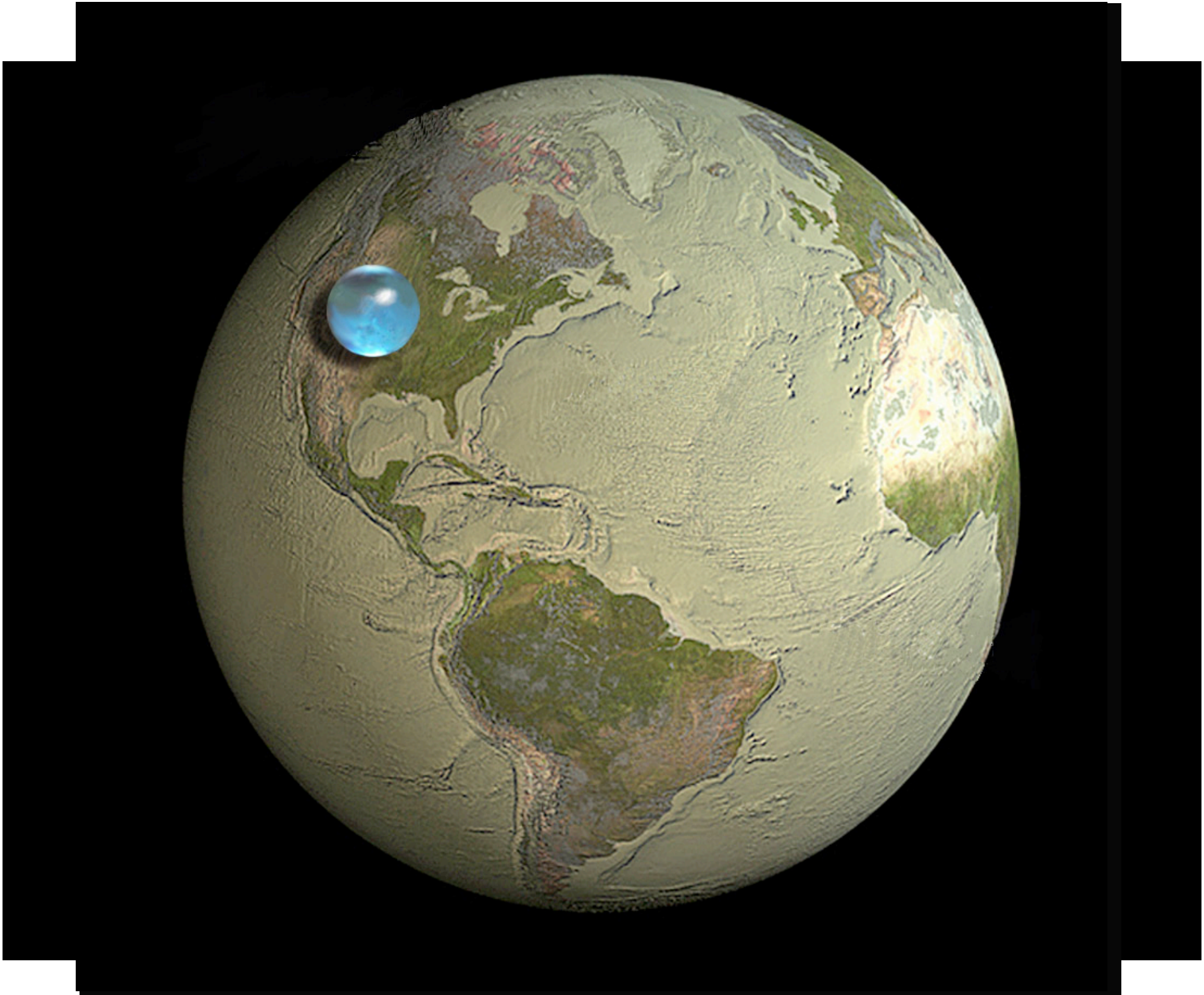


Image by: **Stöckli**, Nelson, Hasler

Hurricane Linda west of Mexico

The Inner Solar System

Planet	Semimajor axis (AU)	Period (year)	Diameter (km)	Mass (M_{Earth})	Composition	Atmosphere
Mercury	0.39	0.24	4878	0.055	metal, rock	—
Venus	0.72	0.62	12102	0.814	rock, metal	CO_2, SO_2
Earth	1.00	1.00	12756	1.000	rock, metal	N_2, O_2, H_2O
Moon			3476	0.012	rock	—
Mars	1.52	1.88	6787	0.107	rock, metal	CO_2, N_2, Ar

78 % 21 %

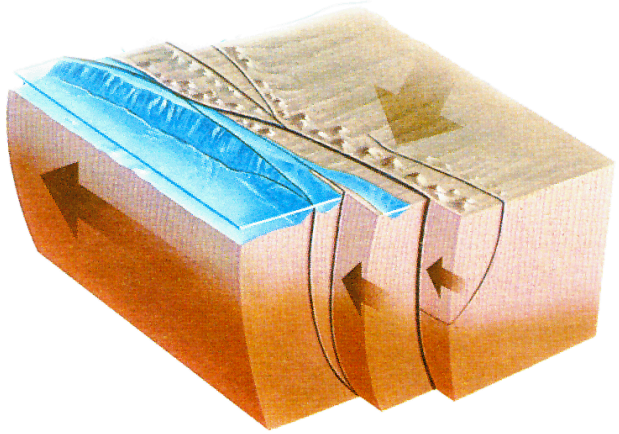
Average density = 5.52 g / cm³ Compare: water 1 g / cm³
rock 3 g / cm³
iron 8 g / cm³

Interesting features: Continental drift
Oxygen atmosphere!
Water!
Life!

Earth shows few impact craters because it is heavily eroded and resurfaced.

Manicougan crater in Canada (42 miles diameter, 200 million years old)

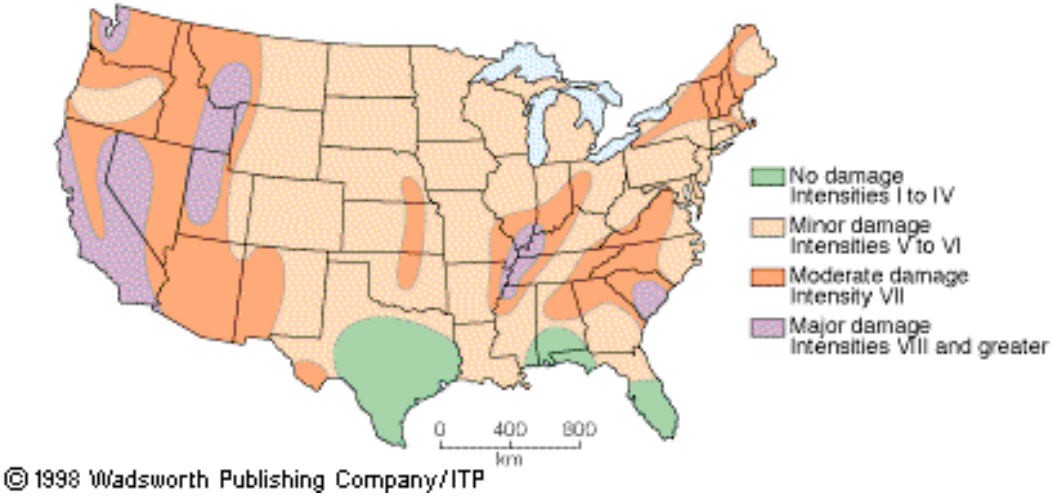
Faults are cracks in the Earth's crust.
Earthquakes happen when rock on one side of a fault moves suddenly with respect to the other side.



FAULTING

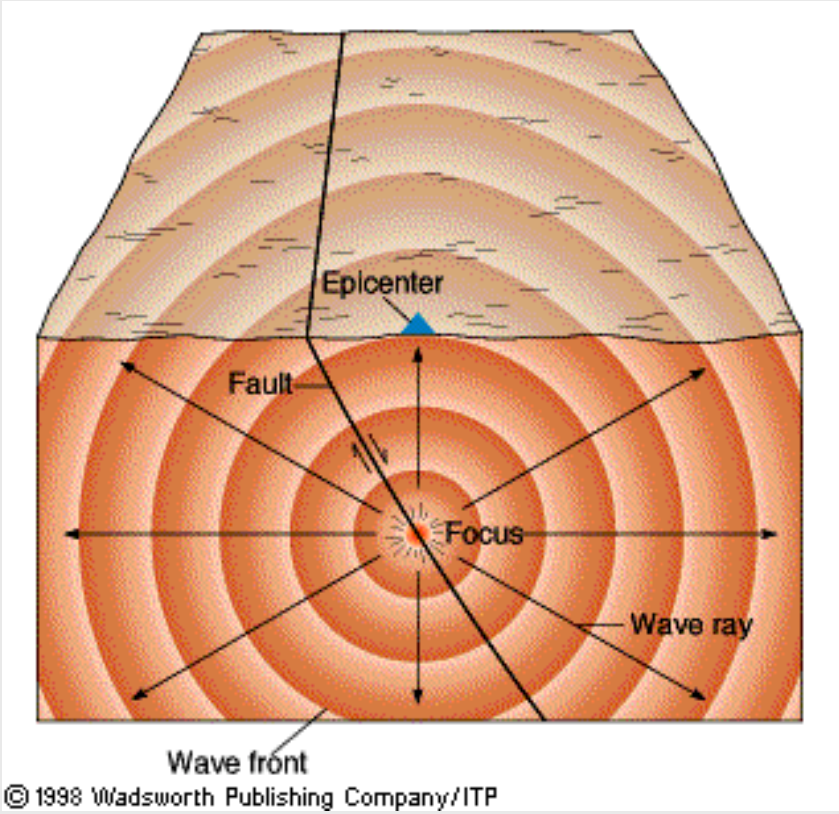
GRINDING past each other in fits and starts, the plates leave great rips, or faults, in their journey. Strain builds up along "locked" plate edges; the stress can be released gradually by thousands of tiny earthquakes or unleashed in a single disastrous jolt. Parts of California along the San Andreas Fault lurched northward as much as six meters (20 feet) during the 1906 San Francisco quake. Such transform faults also link segments of spreading centers (thick black lines) as Earth's rigid skin adjusts to movement. These highly active fault zones form huge canyons cleaving the seafloor. As the plates move outward, the deep canyons survive as scars, or fracture zones (thin black lines), often thousands of kilometers long.

Earthquakes — South Texas is pretty safe!



See http://www.geo.wvu.edu/~wilson/Geol1/lec39/lec392.htm

Earthquakes happen when rock on one side of a fault slips with respect to the other side. The location of the break is the "focus". Primary ("P") and secondary ("S") waves are emitted in all directions from the focus.



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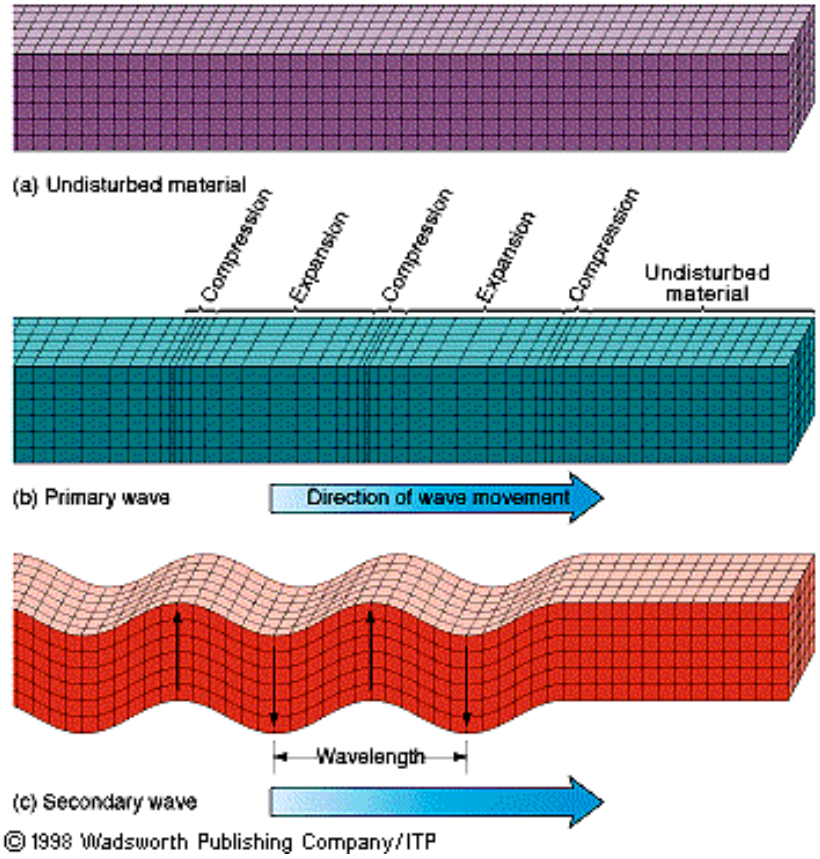
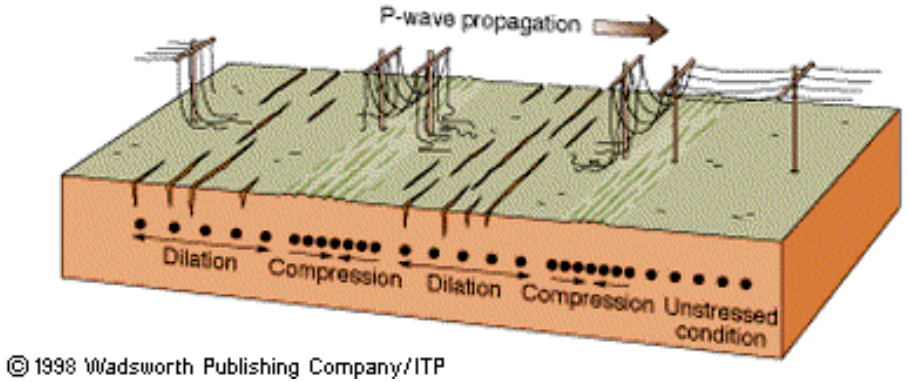
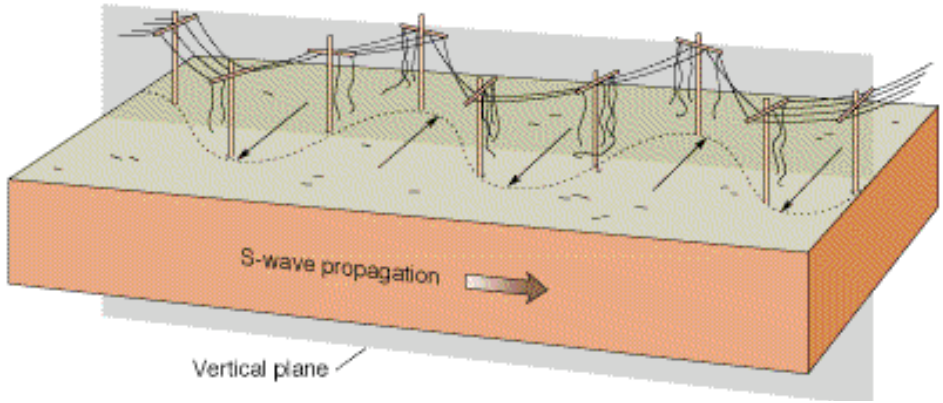
Earthquakes

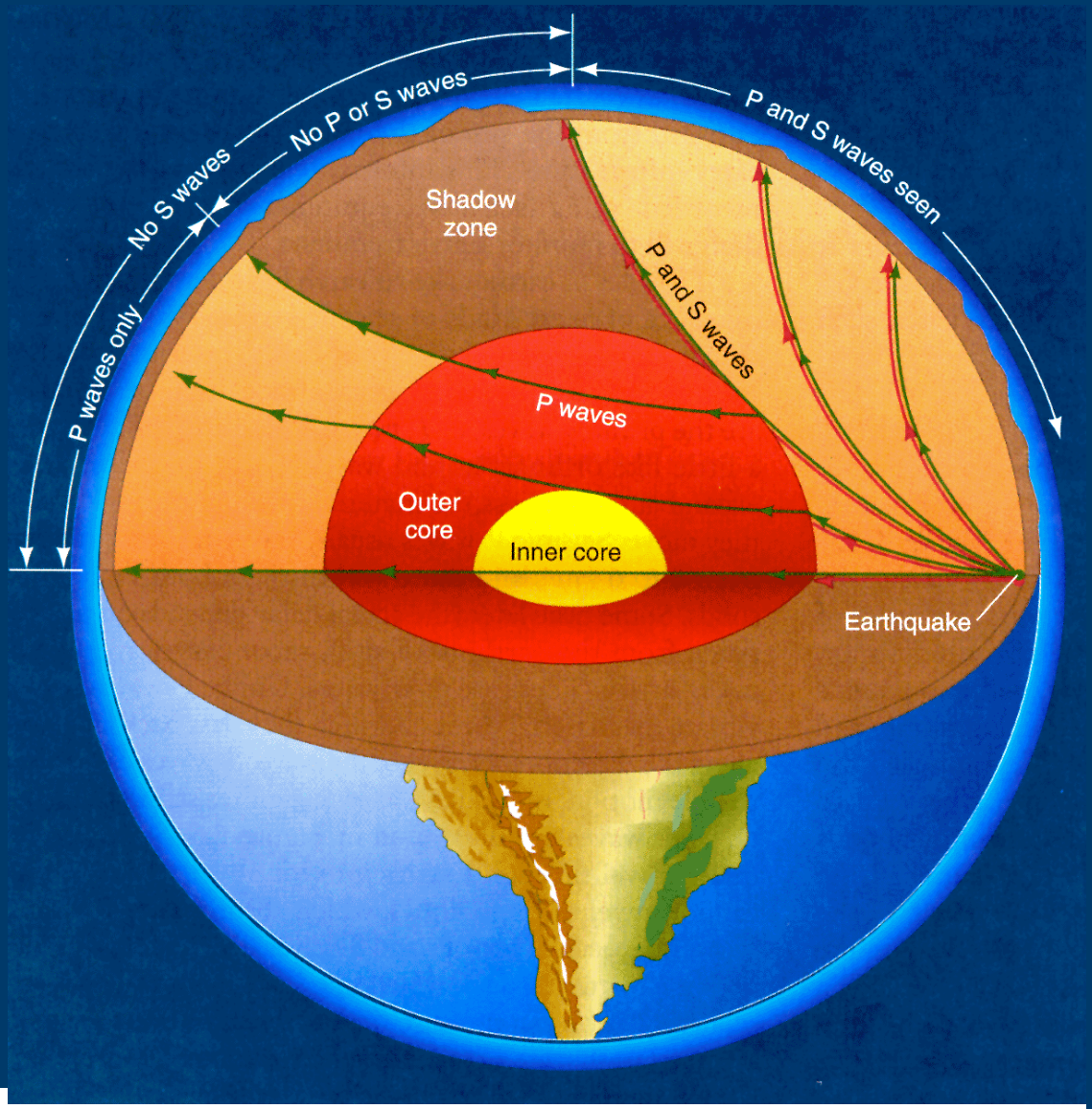






See http://www.geo.wvu.edu/~wilson/Geol1/lec39/lec392.htm

P and S waves bend as the density of rock through which they travel changes. Transverse S waves can't travel through a liquid, so only P waves go through the molten outer core of the Earth. This is how we know that the outer core is liquid.

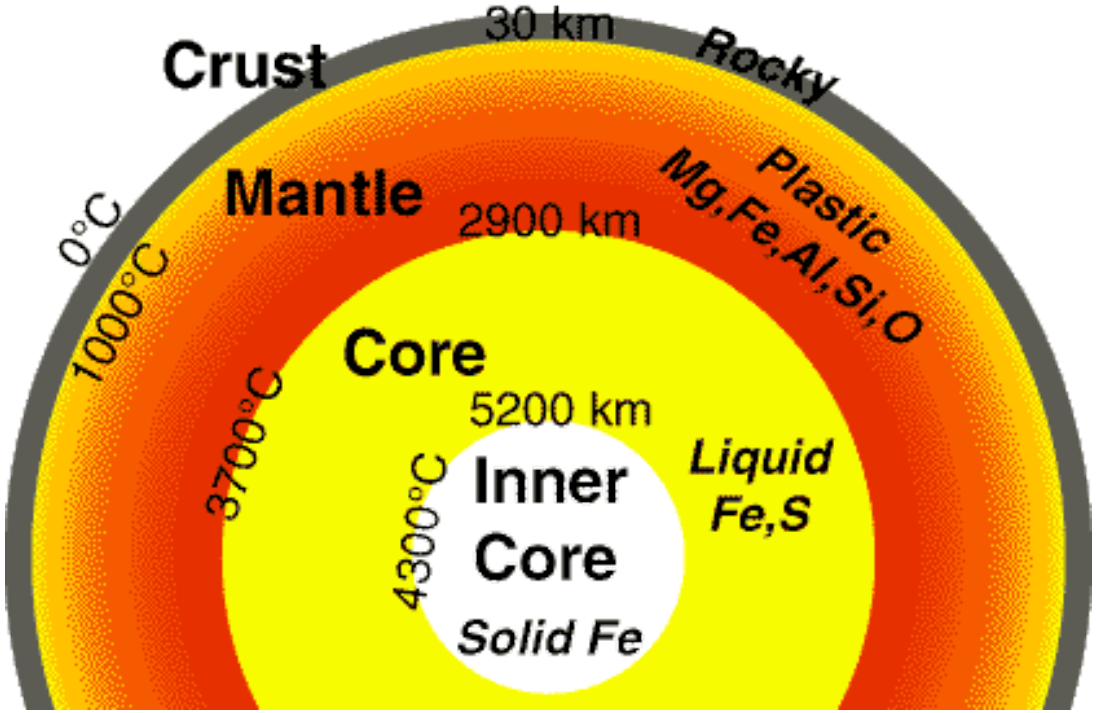


Earth's Interior

The Earth's crust is up to 60 km thick under continents but only about 10 km thick under the oceans.

The mantle is plastic — it is almost a solid, but it flows under pressure.

The inner core is nickel-iron compressed to ~ 14 g/cm^3.
Its temperature is about 6000 K — the same as the surface of the Sun.
But it is solid because of the high pressure.



Earth's Magnetic Field

There are 2 reasons why the Earth's magnetic field can't be due to permanent magnetism.
1 — A permanent magnet gets weaker with time.
2 — Earth's magnetic field occasionally switches direction, which a bar magnet never does.

The dynamo effect

A dynamo converts mechanical energy to electromagnetic energy. To make a dynamo, Earth's core must be (1) electrically conducting, (2) rotating, and (3) undergoing convection. The molten outer core of the Earth does all this. It creates the Earth's magnetic field. But the convection currents change every ~ 500,000 years in a way that reverses the polarity.

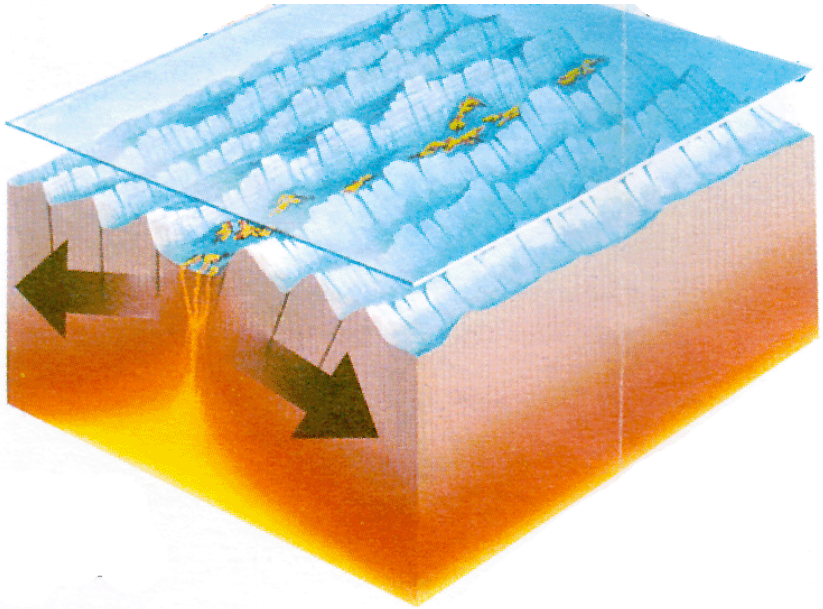
Alfred Wegener

Continental Drift

The crust of the Earth consists of rigid plates that float on a partly molten mantle. Driven by convection, the plates move around.

On Earth, continental plates move around, pushed by convection in the molten interior. The motion is seen in laser measurements of the distance to the Moon (accurate to 1 mm). The rift zones where ocean floor is being created are clearly seen.

Figure 17-3 If we could drain the Atlantic Ocean, we would see the midocean rift snaking



SPREADING

RISING through rifts in the crust, dense magma from Earth's interior creates new surface at the Mid-Ocean Ridge, a rugged undersea mountain range stretching 74,000 kilometers (46,000 miles). The injections widen the seafloor as much as 22 centimeters (8 inches) a year, a rate that could have formed the 7,000-kilometer-wide Atlantic in only 30 million years instead of the 165 million it has already taken. The process is not constant. The ridge itself is largely composed of short segments, each releasing irregular bursts of magma. Where the ridge runs into the northern end of the East African Rift System, the spreading action is opening a new ocean. Millions of years from now, eastern Africa may drift out into the Indian Ocean as a new continent.

How do we know that the Atlantic Ocean is getting wider?

Evidence that ocean floor is created on the mid-ocean ridge line as the ocean floor plates pull apart:

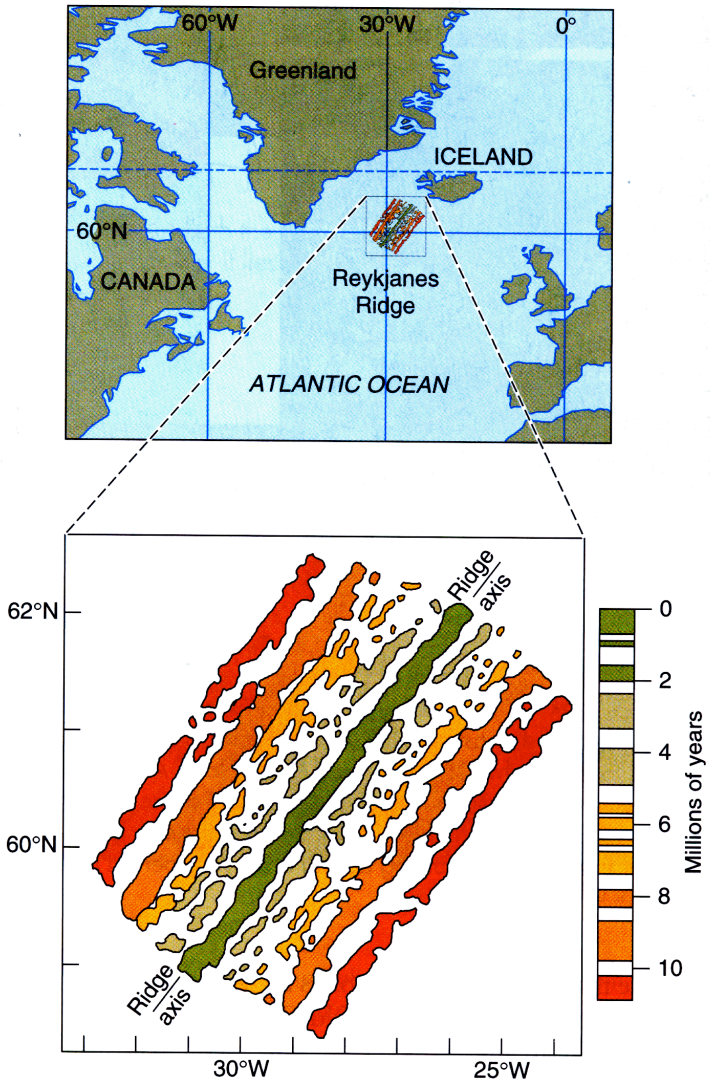
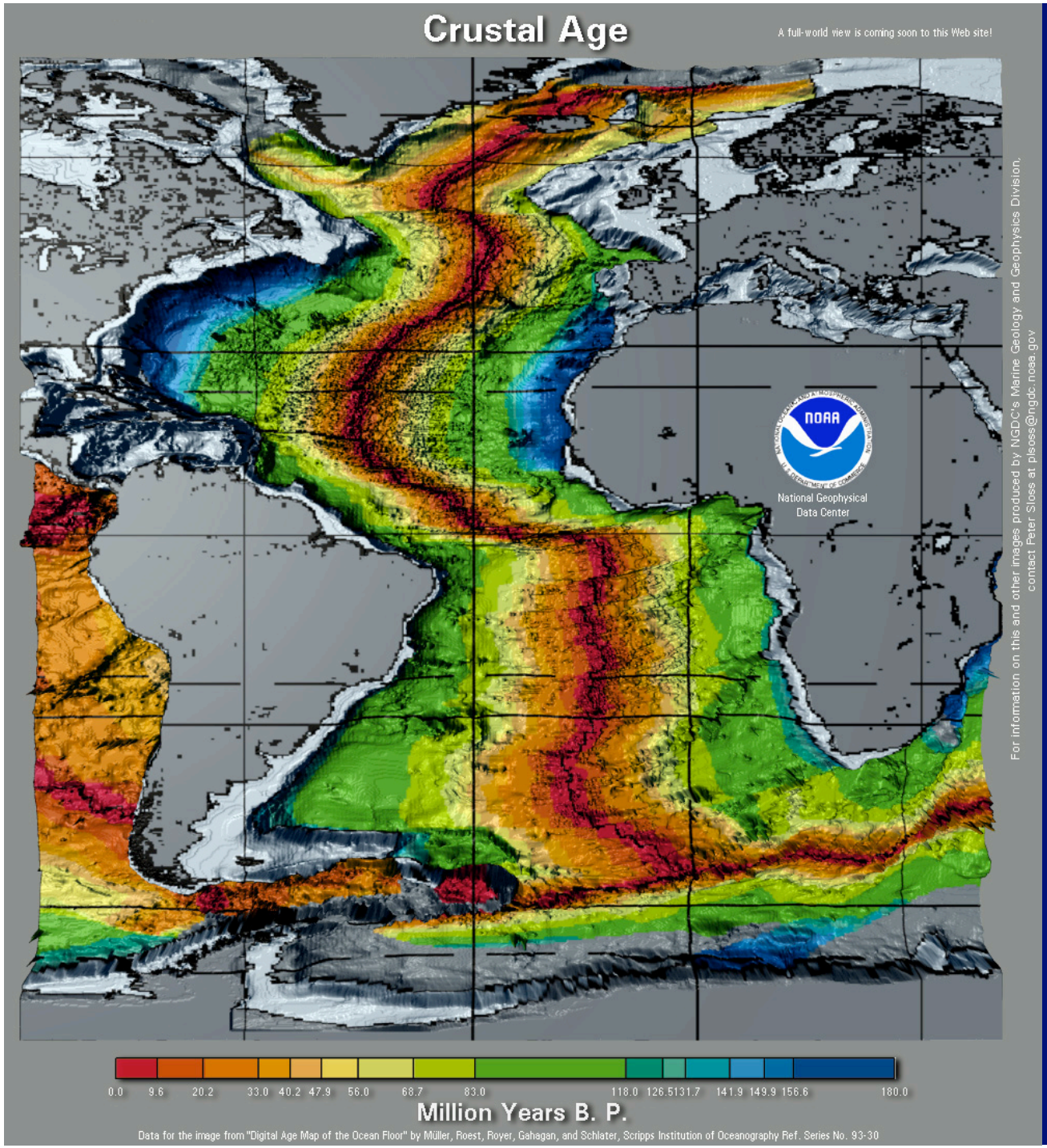


Figure 7.19 Samples of basalt retrieved from the ocean floor often show Earth's magnetism to have been oriented oppositely from the current north–south magnetic field. This simplified diagram shows the ages of some of the regions in the vicinity of the Mid-Atlantic Ridge (see Figure 7.14), together with the direction of the fossil magnetic field. The colored areas have the current orientation; they are separated by regions of reversed magnetic polarity.

We can measure the ages of rocks on the ocean floor. We find that the ages increase in both directions from age zero on the mid-ocean ridge line.

Measurements of the direction of the magnetic field that is frozen into the rock when it cools agree with the ages:

A strip of given age & magnetic polarity is matched on the other side of the ridge line by another strip of the same age and polarity.

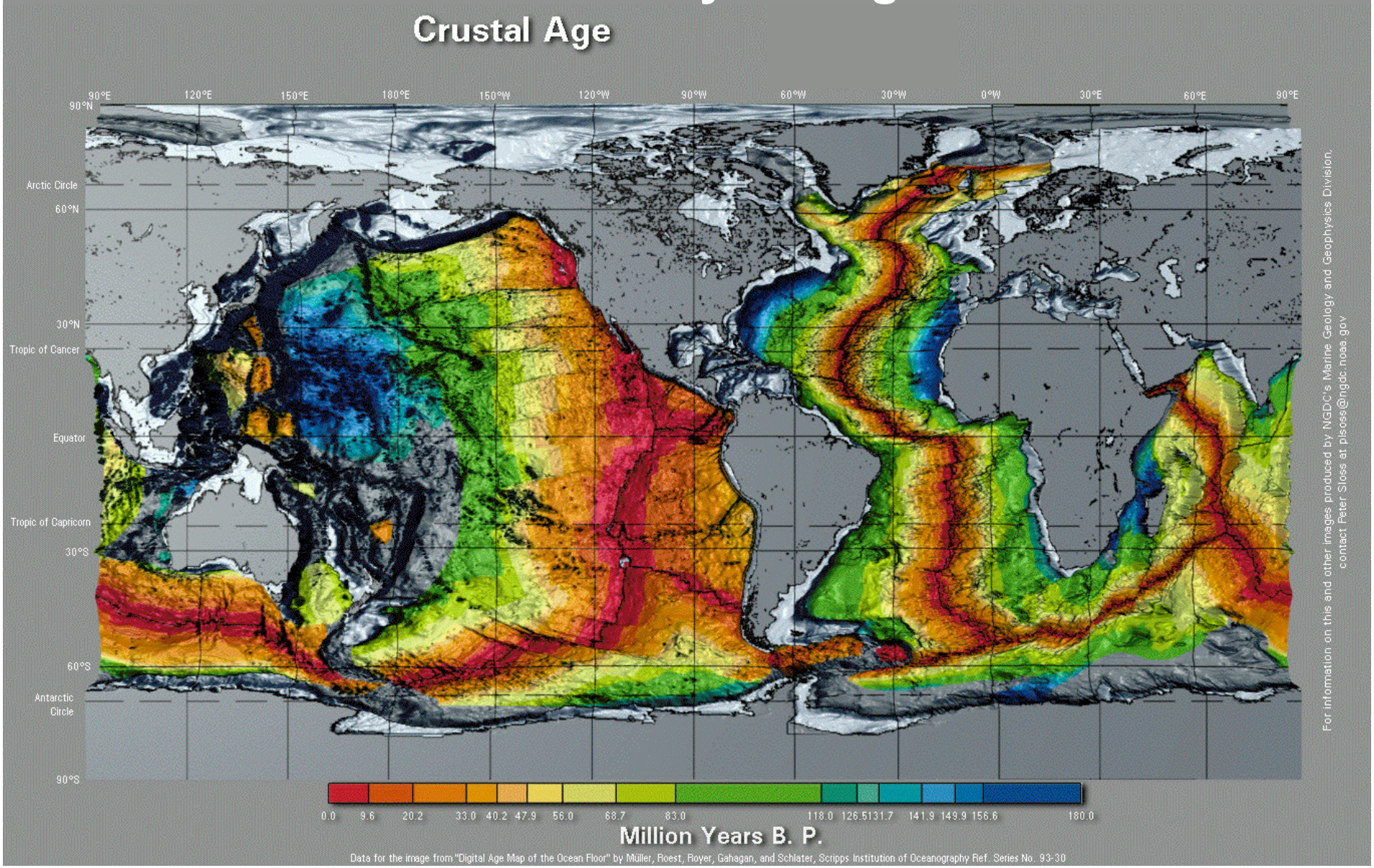


Note: the North Atlantic ocean started to open up ~ 180 million yr ago, 50 million yr before the South Atlantic ocean.

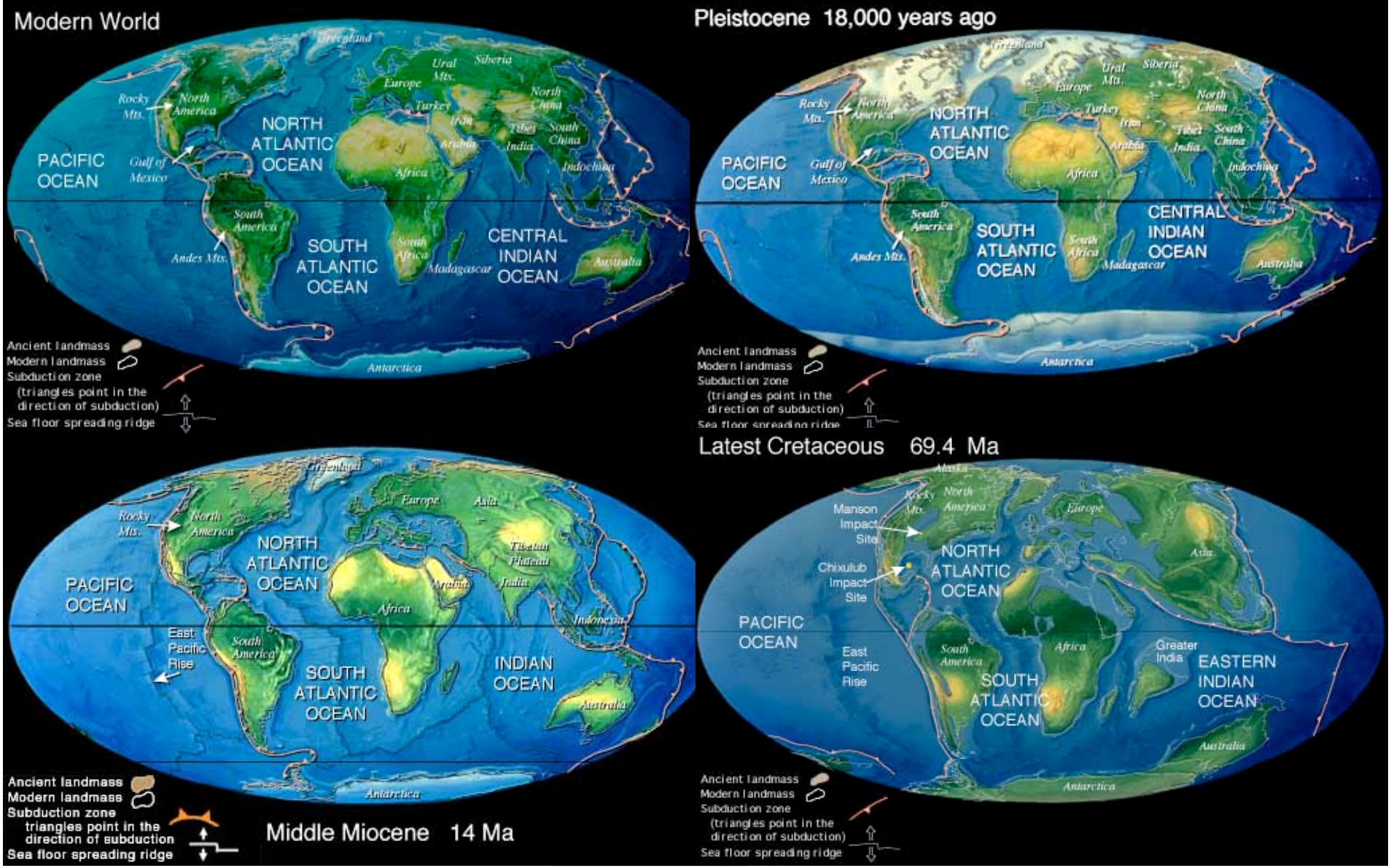
When the dinosaurs became extinct about 65 million yr ago, the South Atlantic ocean was about half as wide as it is now.

ftp.ngdc.noaa.gov/MGG/images.html

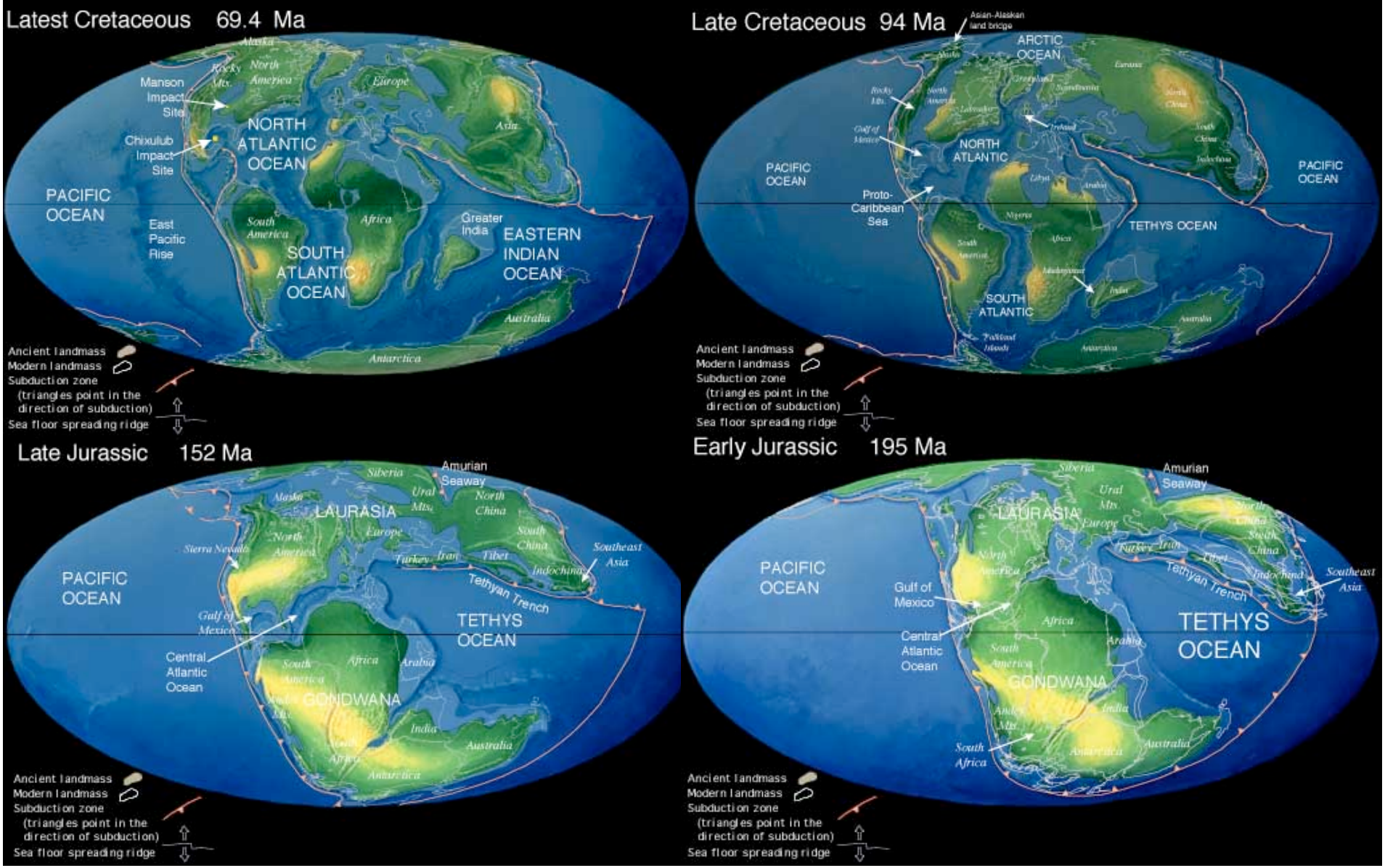
All oceans are nearly the same age. Also, all continental plates were connected into one super continent about 200 million years ago.



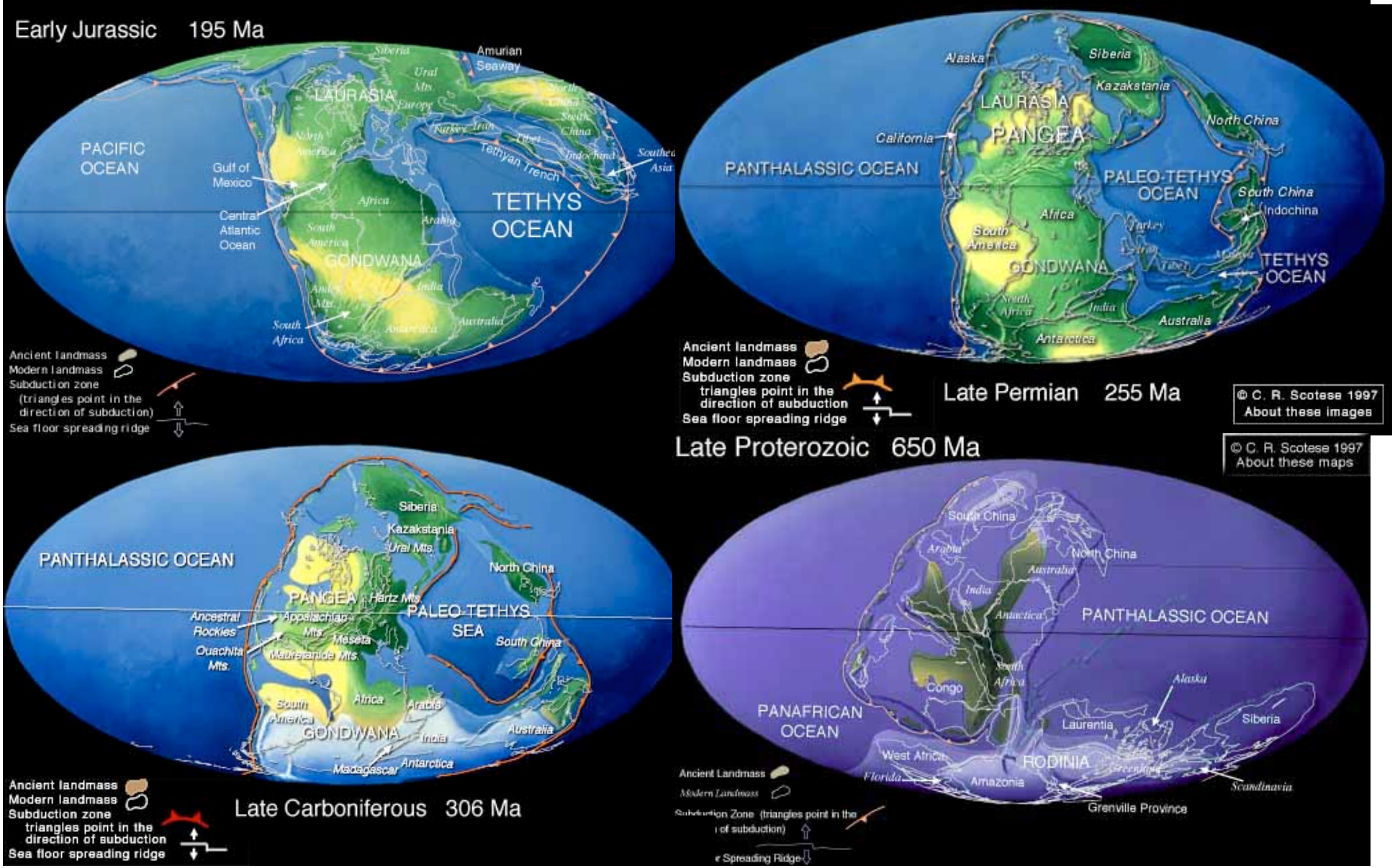
Notes: Latest ice age 18000 yr ago: sea level was very low.
The Atlantic ocean was much narrower 69 M yr ago.
India had not yet collided with Asia 69 M yr ago.



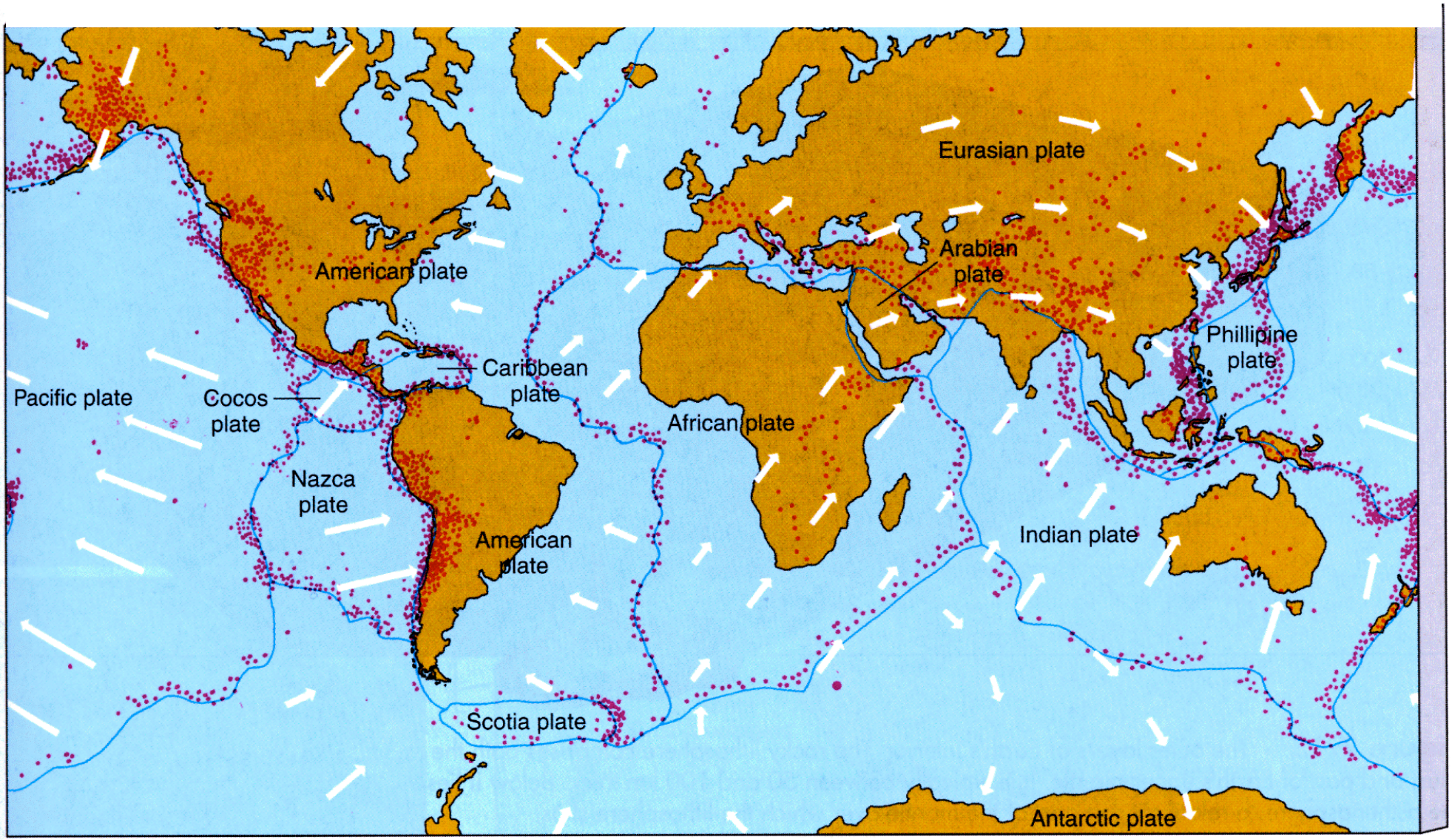
Sea levels were very high between ice ages.
The Himalayas were not present before India collided with Asia.
All major plates were assembled into Pangaea 200 million years ago.

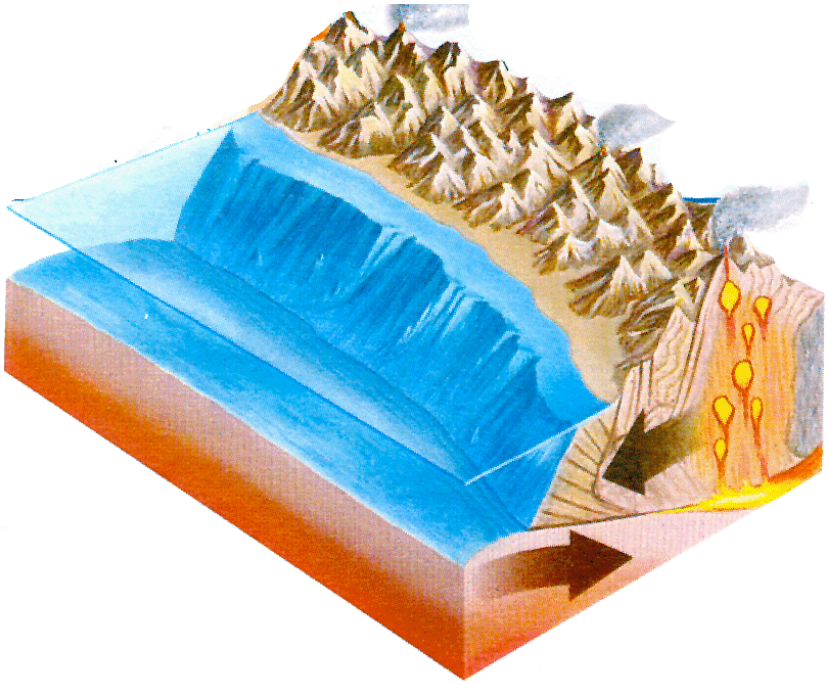


Pangaea was complete ~ 255 million years ago. Its assembly created huge mountains. Ecological stress caused many extinctions. There were more ice ages 306 million yr ago and another supercontinent, Rodinia, 700 million yr ago.



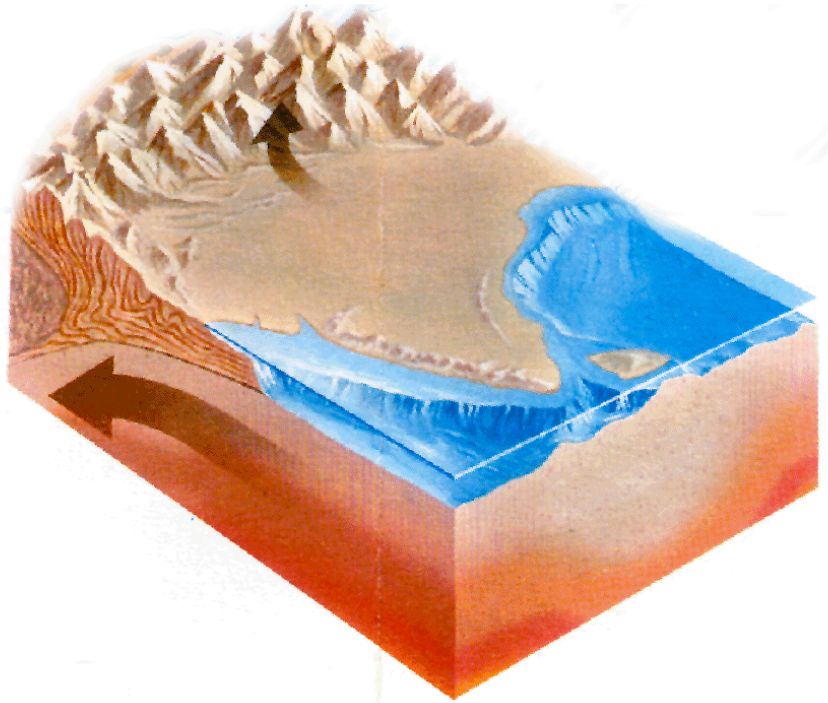
Earth's main crustal plates and how they move
(Red dots are strong earthquakes.)





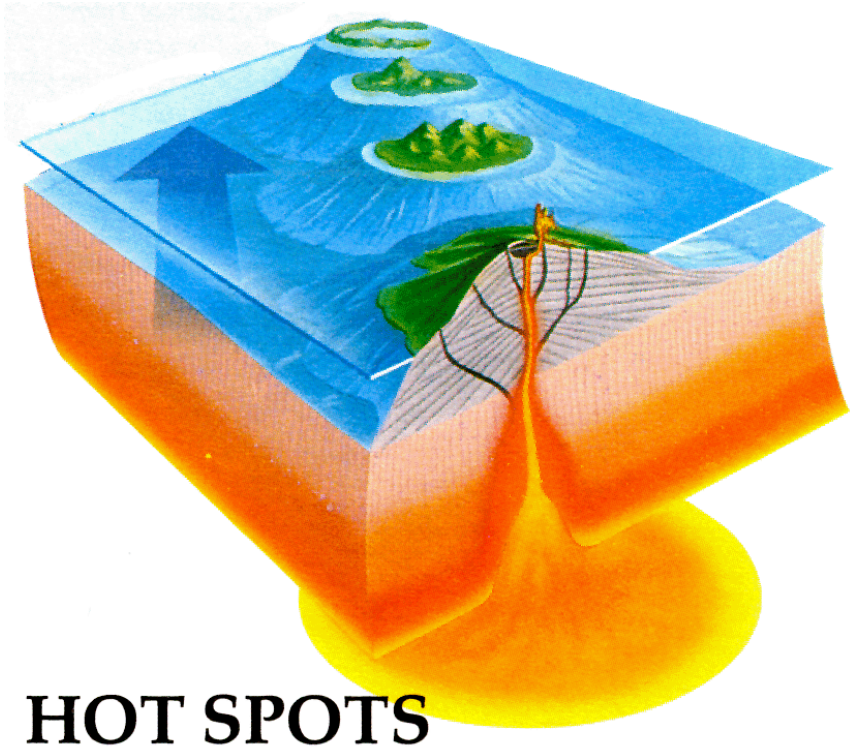
SUBDUCTION

COLLIDING with the edge of a continent, old, cold, heavy seafloor dives back into the interior of the Earth and forms an ocean trench. Setting off deep-seated earthquakes, the plunging slab also generates heat that melts through the overlying plate, allowing fingers of magma to rise. These fingers form chains of volcanoes like those of the Andes or island arcs such as the Aleutians and the Antilles. The overriding continent also compresses near the trench, lifting mountains. The destruction of ocean crust—nowhere older than 200 million years—balances creation at the ridge. Subduction can also stretch and thin the overlying plate behind the row of volcanoes, allowing magma to rise and forming a zone where new crust and mountains are created.



COLLISION

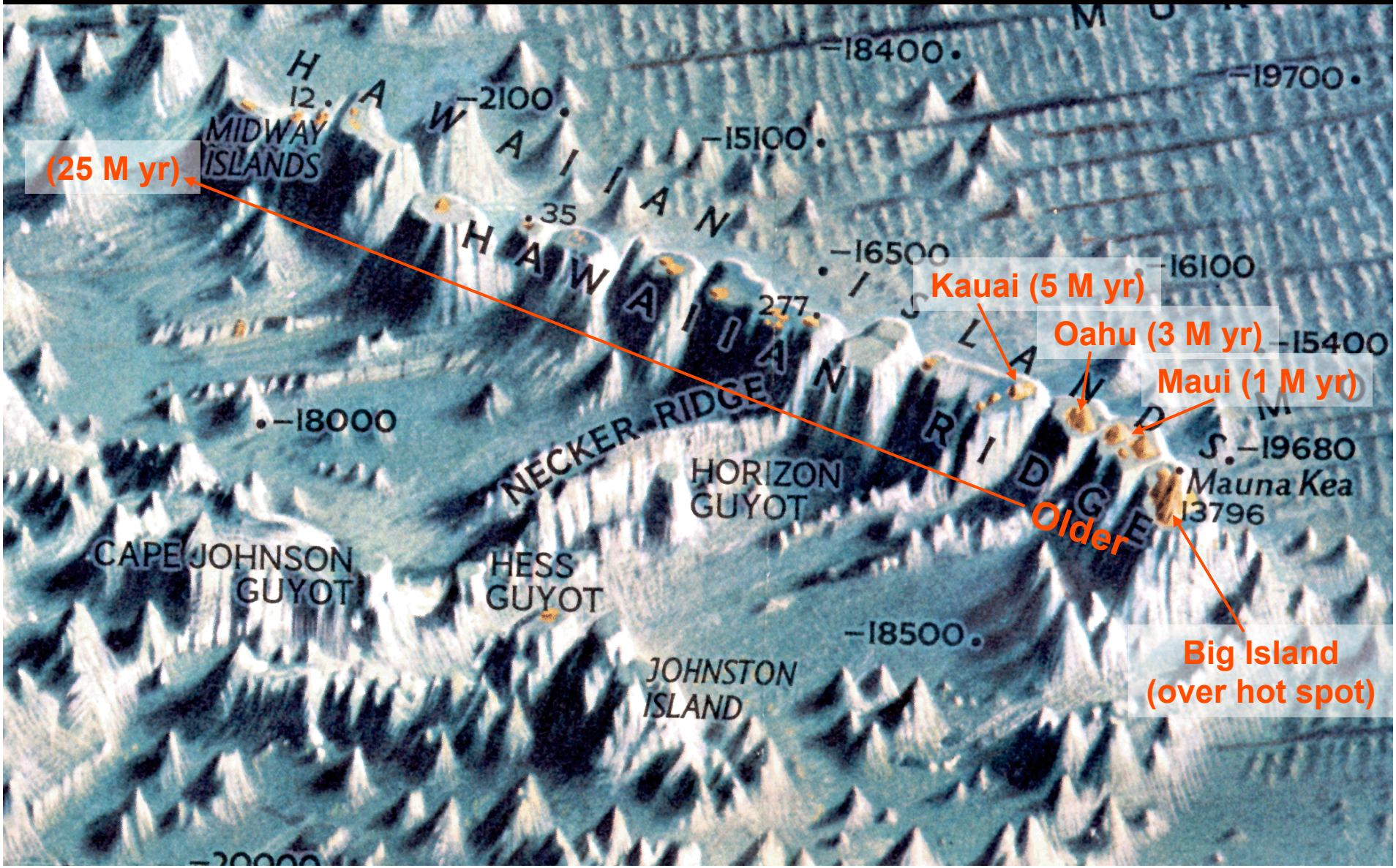
IN THE GREATEST mountain-making process on Earth, the Indian subcontinent rams into Eurasia, creating the Himalayas. Since both continents are too light to subduct, the older, heavier Indian mass wedges under Eurasia and thrusts up the high plateaus and massive folds of the mountain range. India, once far south of the Equator, moved north in only 30 million years—a speedy trip by the geologic clock. The subcontinent continues to underthrust Asia, setting off frequent and sometimes devastating earthquakes. Some 450 million years ago the collisions forming the supercontinent Pangaea (inset maps) began to raise the 5,000-kilometer-long Appalachian and Caledonian ranges as the Atlantic Ocean's predecessor disappeared.



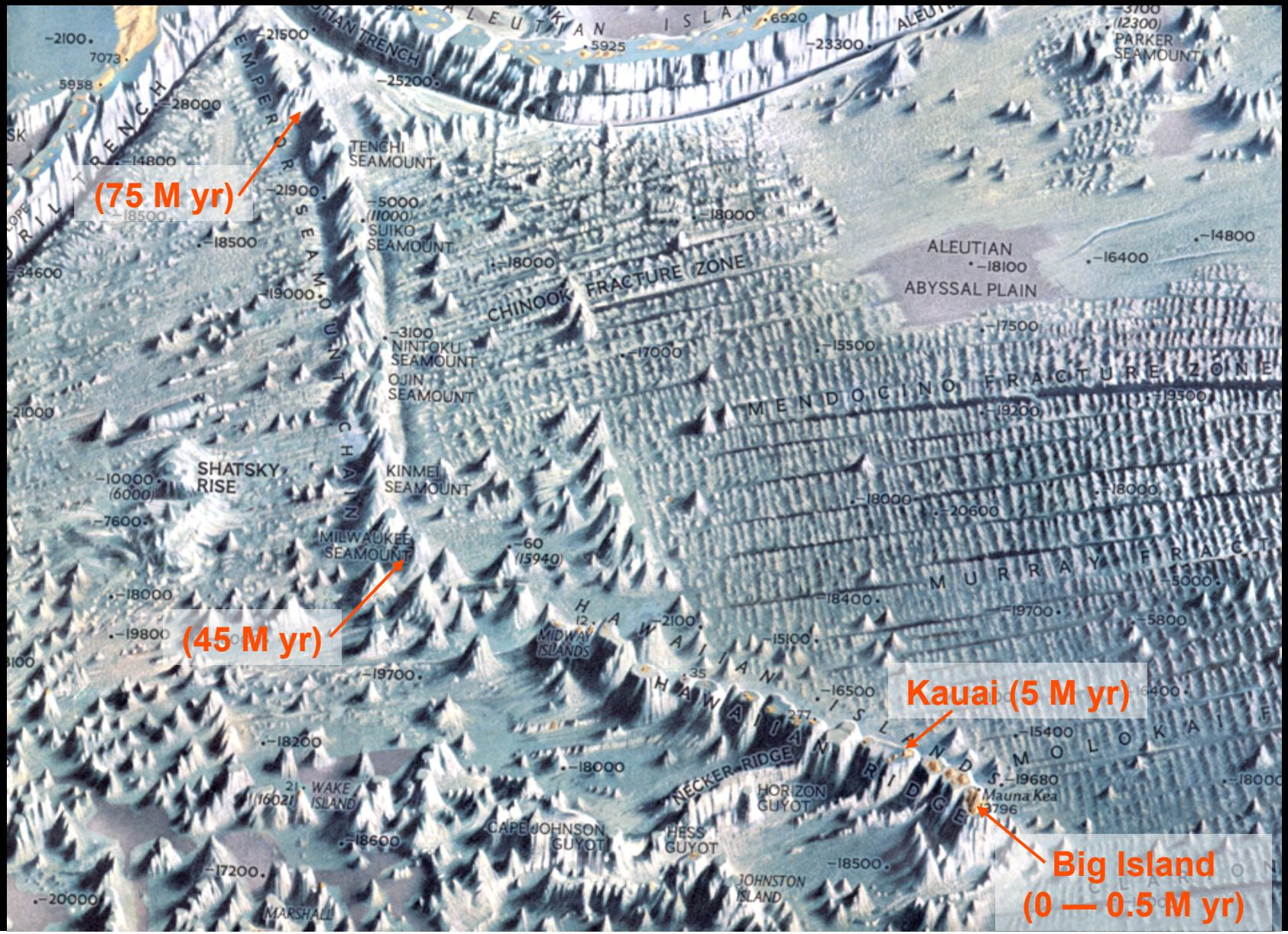
HOT SPOTS

BURNING through the crust like blasts from a flamethrower, magma floods to the surface to build massive assembly-line volcanoes like the Hawaiian Islands. Tallest mountains in the world, the islands rise 6,000 meters (19,700 feet) to the surface and as much as 4,200 meters more above the sea. A future Hawaiian island, Loihi, is still a seamount 950 meters down. Numerous strands of islands and seamounts mark the path of the plates over hot spots—each strand bent as the plates changed direction 43 million years ago. Iceland has formed within the past 55 million years as a magma plume pumps up a seemingly endless supply of rock. Yellowstone's geysers and mud pots mark North America's current position over a hot spot.

The Islands of the Hawaiian chain were made successively at the hot spot and then were carried NW away from it.
The Big Island is over the hot spot now.



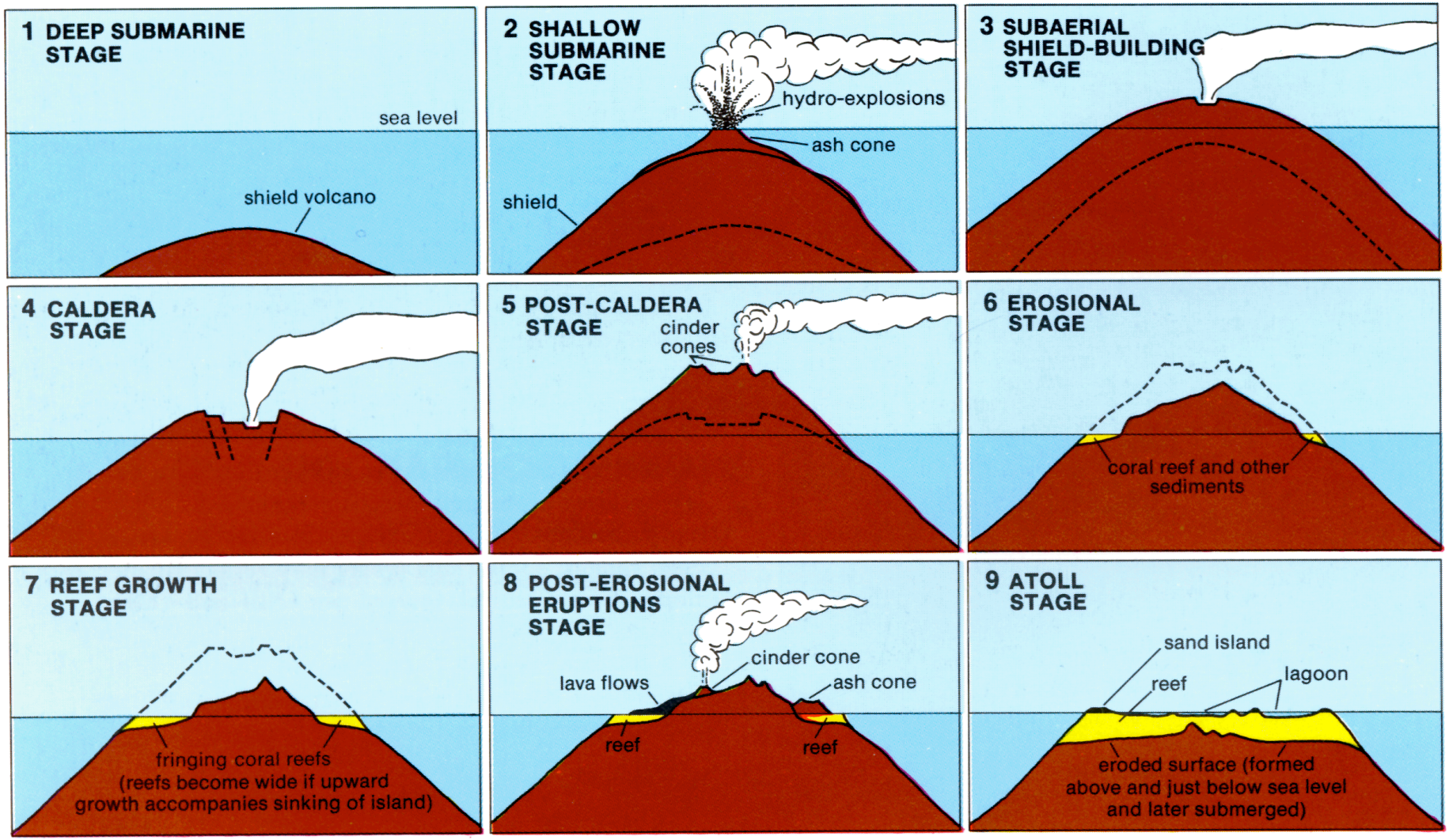
About 45 million years ago, the Pacific plate changed its direction of motion.



Evolution of a Tropical Island Volcano

In Hawaii, Loihi is stage 1, Mauna Loa is stage 4, Mauna Kea is stage 5,

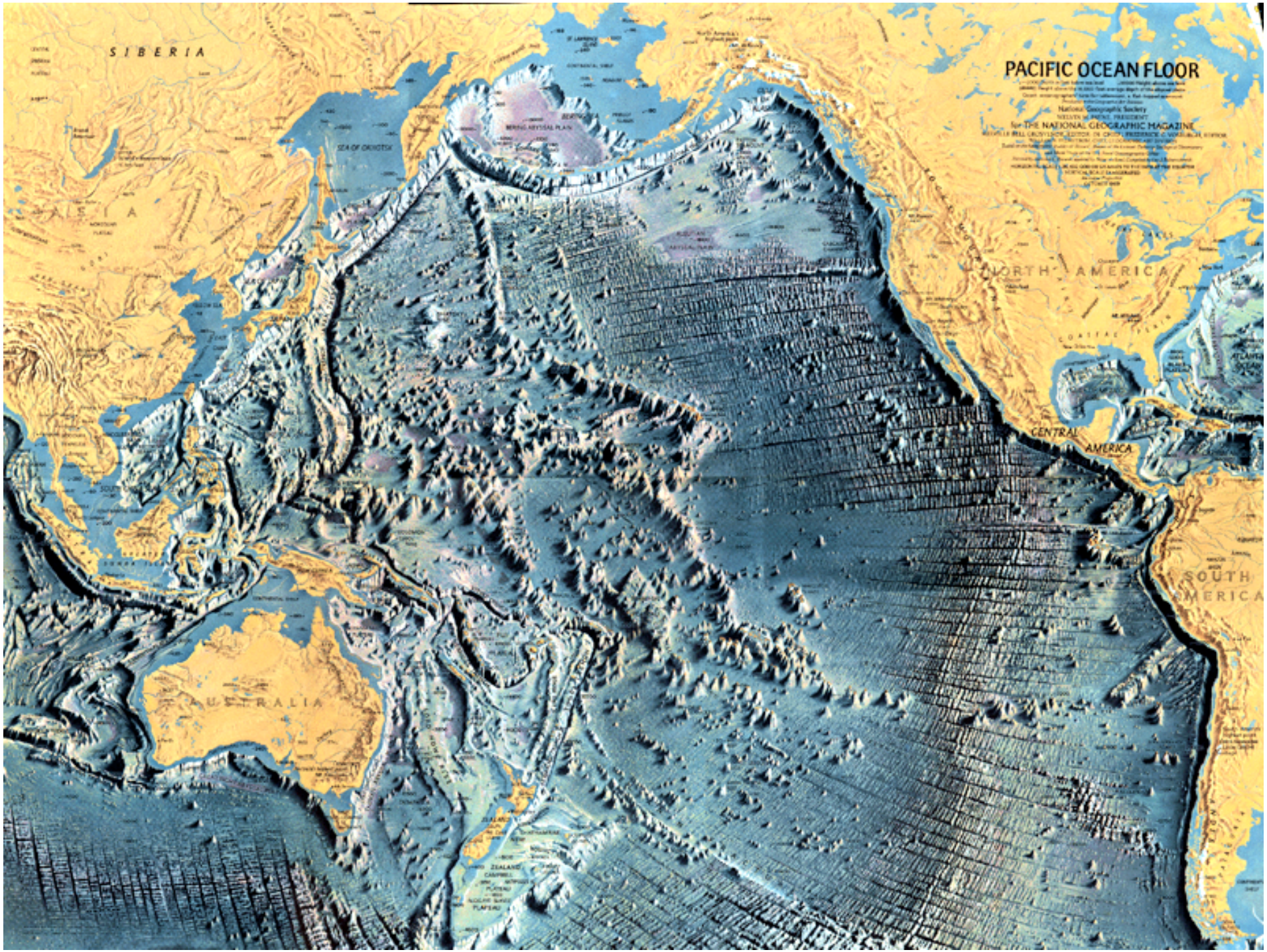
Oahu and Kauai are stage 6, Midway is stage 9.



Source: modified after H.T. Stearns, 1946

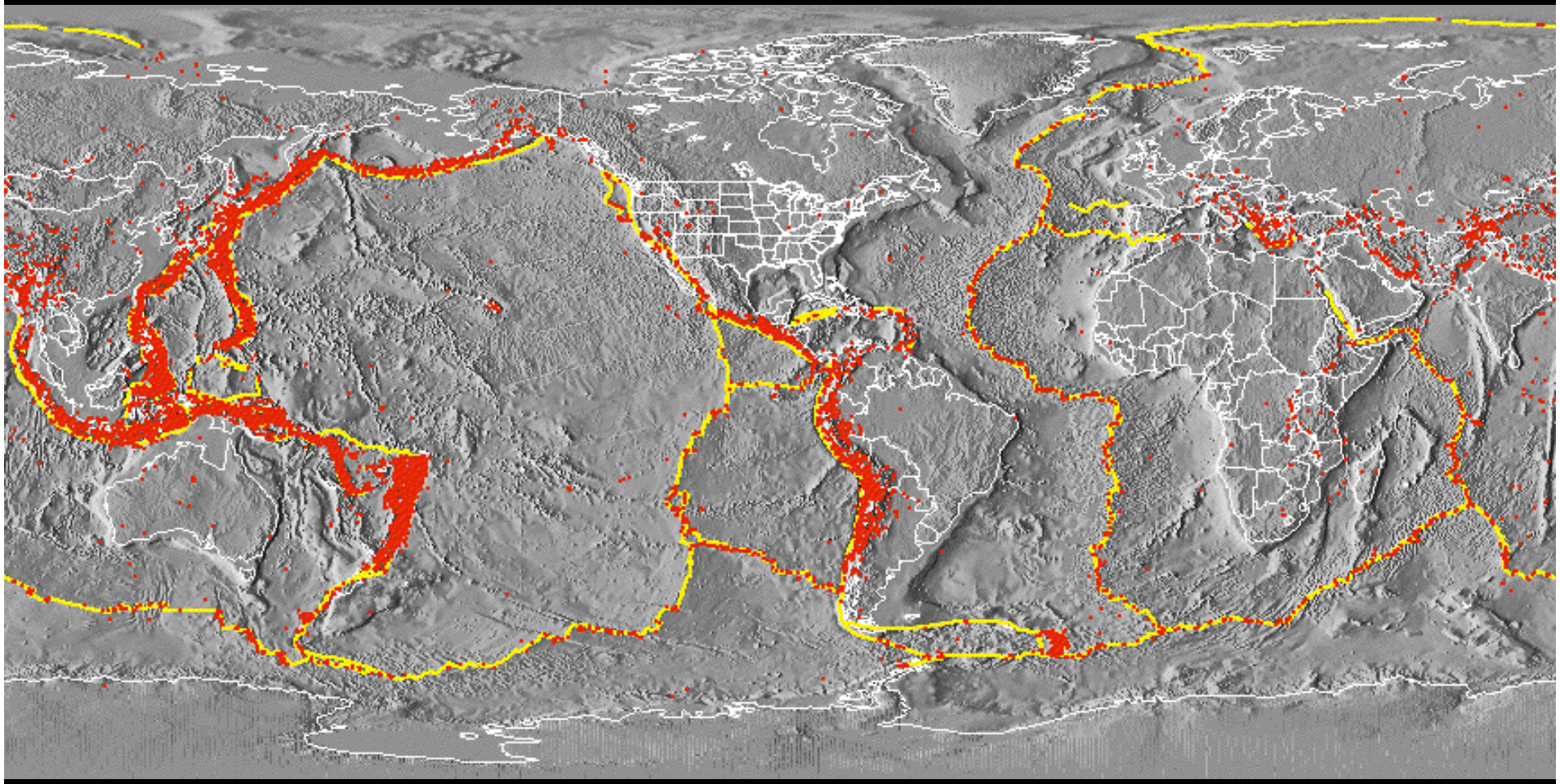
Iceland sits on a hot spot.

This is the birth of Surtsey in 1963.


PACIFIC OCEAN FLOOR
SIBERIA
SEA OF OKHOTSK
BERING ABYSSAL PLAIN
NORTH AMERICA
CENTRAL AMERICA
SOUTH AMERICA
AUSTRALIA
NEW ZEALAND

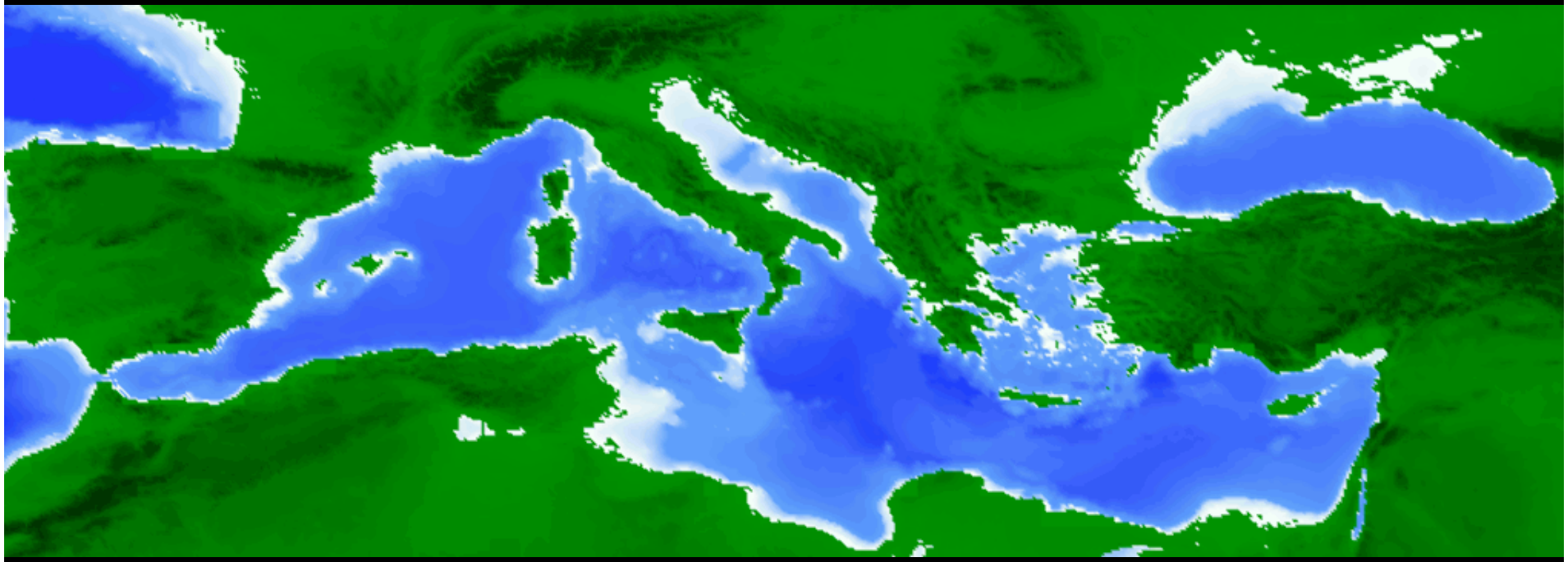
Earth's Main Crustal Plates

Red dots are strong earthquakes.



YESTERDAY'S "DEATH VALLEY" ?

The Mediterranean Sea may have been a desert depression (like Death Valley or the Dead Sea now) until the Atlantic Ocean breached the Strait of Gibraltar in a magnificent waterfall ~ 5.5 million years ago.

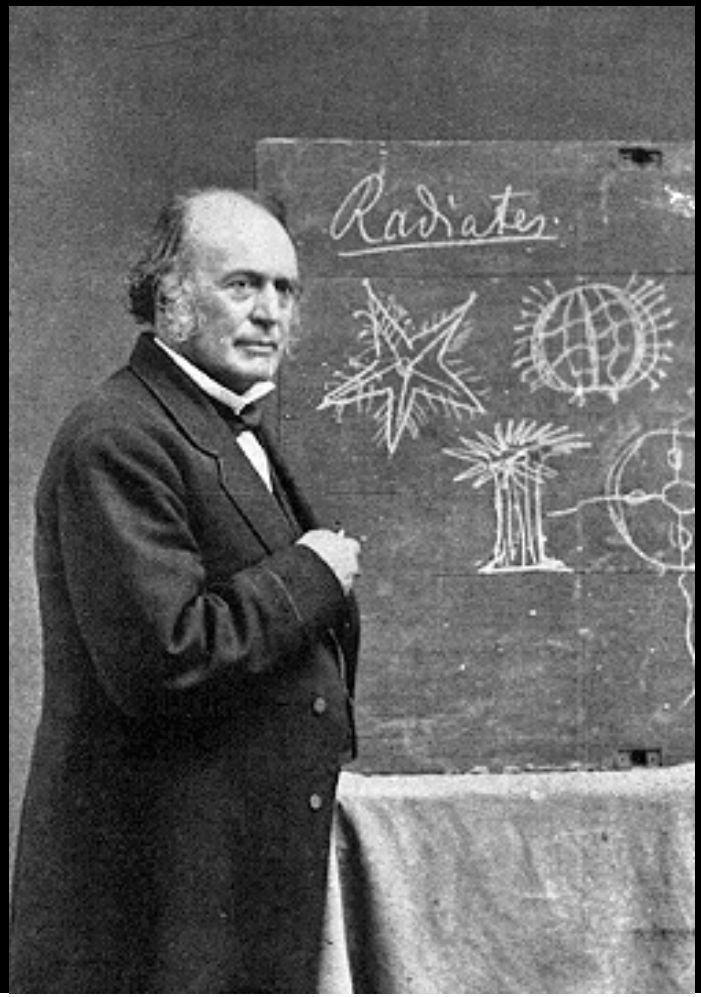


AN OCEAN OF TOMORROW

Earth's crust is breaking apart along a line from southern Turkey — Jordan river valley — Gulf of Aqaba — Red Sea — African rift valley.

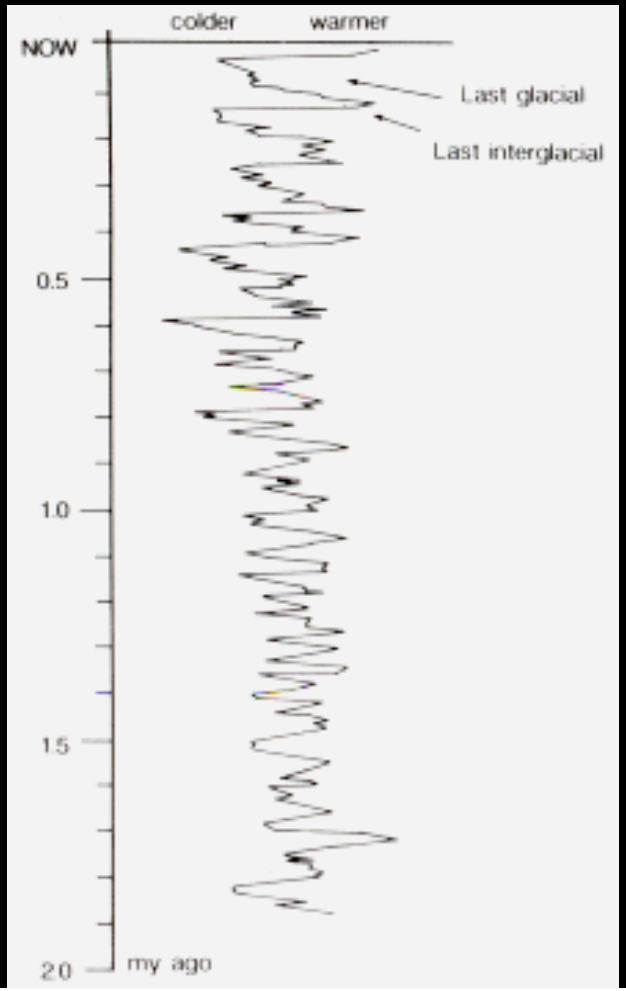
ICE AGES

Louis Agassiz suggested in 1830 that we live in a glacial age — a period of unusual cold with recurring ice ages. Convincing people took many years.



ICE AGES

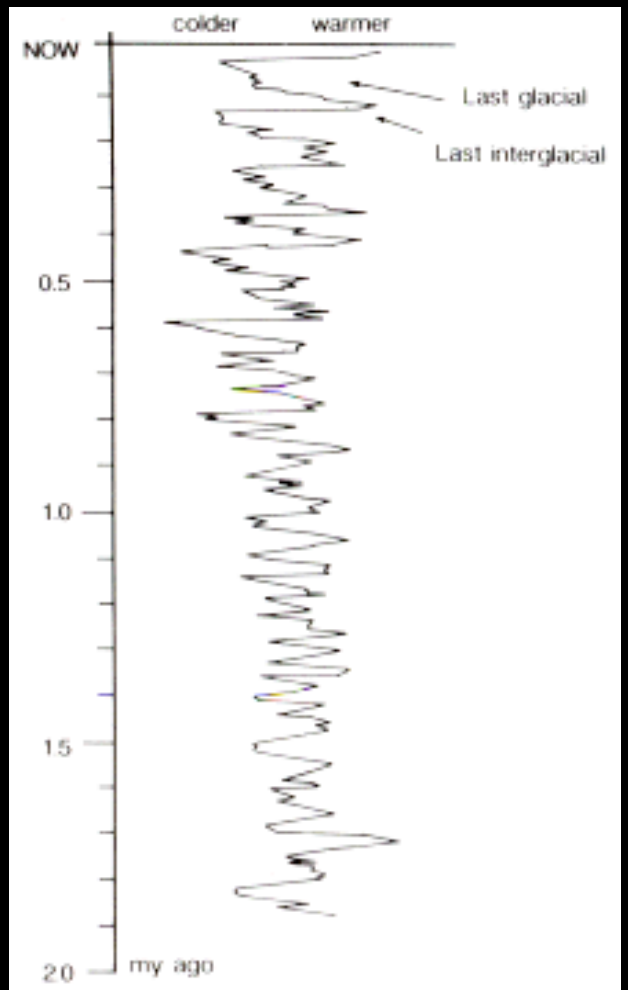
Temperature chronology for the past 2 million years from $^{16}O/^{18}O$ ratio in sediments. How it works: ^{16}O preferentially evaporates from the oceans and is depleted when locked up in glaciers instead of returned in rivers.



ICE AGES

Early on, glacial cycles were not extreme.
Warm and cold periods lasted about 40,000 years.

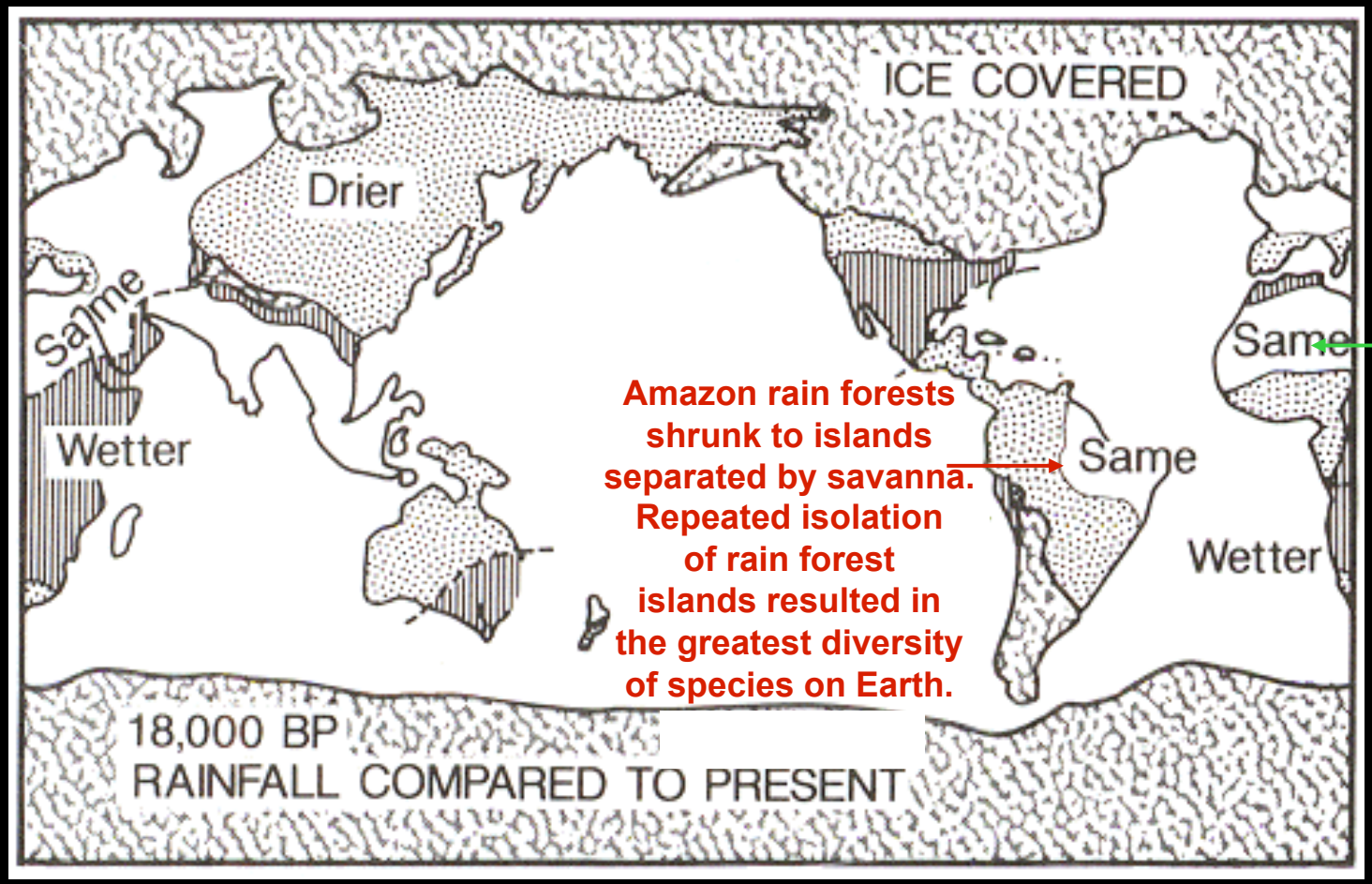
In the last million years, the temperature swings have grown more severe.



Maximum Ice Extent 18,000 Years Ago

Maximum Ice Extent 18,000 Years Ago

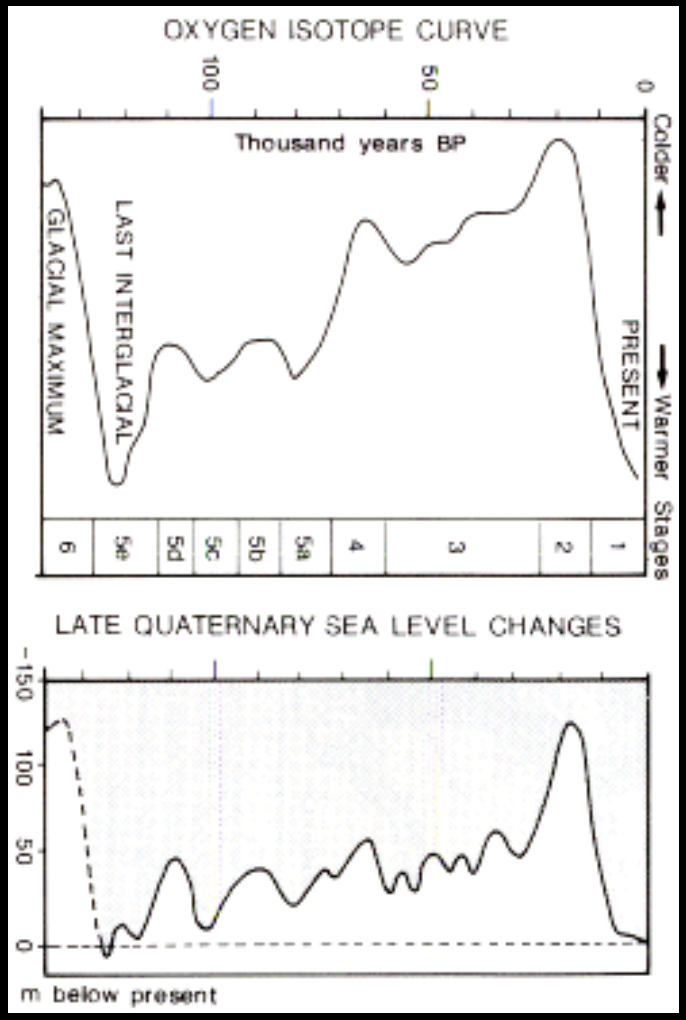
Some places were much wetter and others were much drier than now.



The Sahara was lush and rich in game.

http://www.carleton.ca/~tpatters/teaching/climatechange/glacial/glacial18.html.

Depending on how much water was locked up in ice, sea levels have been as much as 130 m lower than they are now. Now, sea levels are rising even without our contribution to global warming.



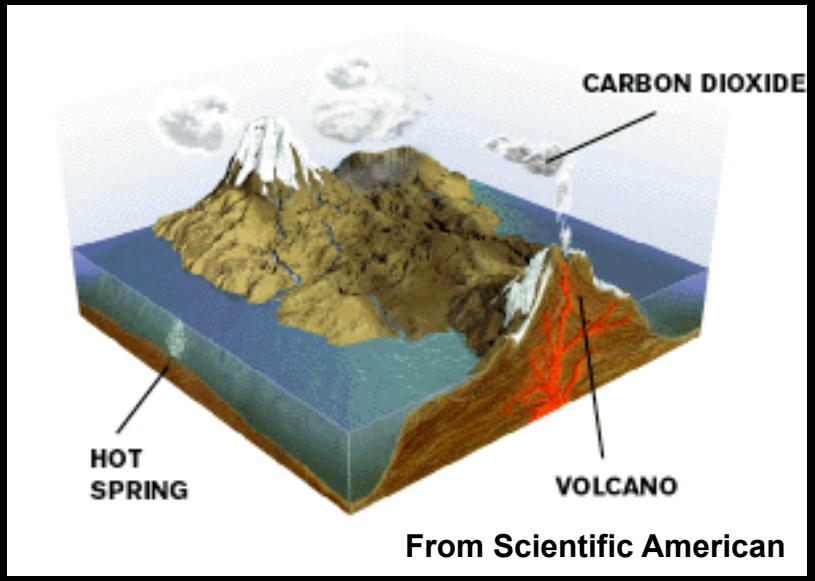
http://www.carleton.ca/~tpatters/teaching/climatechange/glacial/glacial35.html

Snowball Earth

Snowball Earth

Earth went through several "snowball" periods ~ 600 million years ago when surface water was completely frozen.

Suggestion:



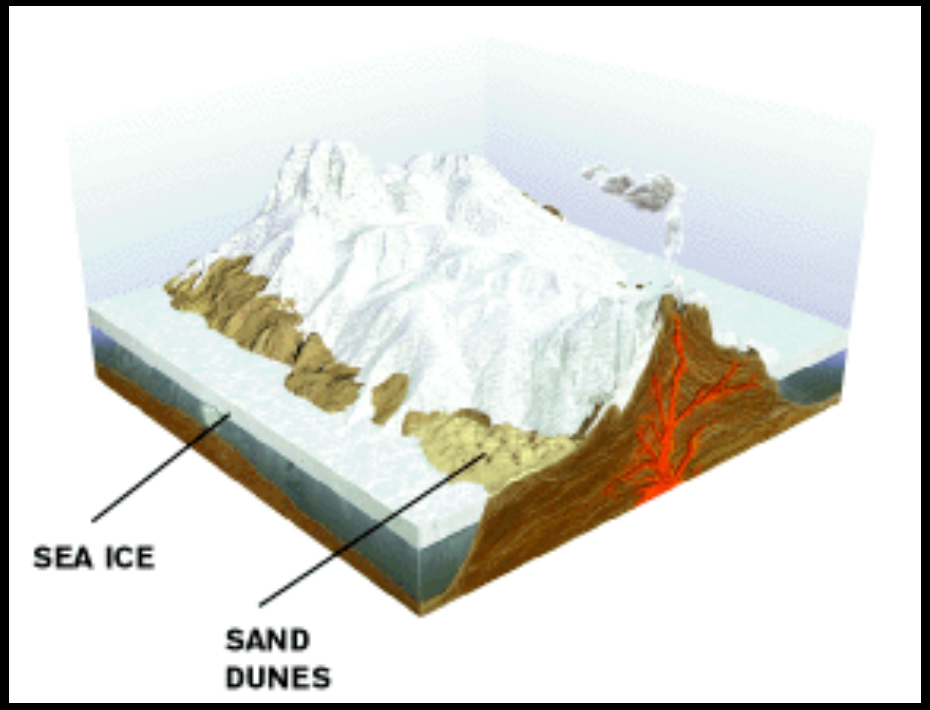
From Scientific American

The breakup of a supercontinent about 600 million years ago left small continental pieces, all near the equator.

Widespread tropical rains scrubbed CO_2 out of the atmosphere, cooling it and depositing ice near the poles.

Snowball Earth

Earth went through several "snowball" periods ~ 600 million years ago when surface water was completely frozen.

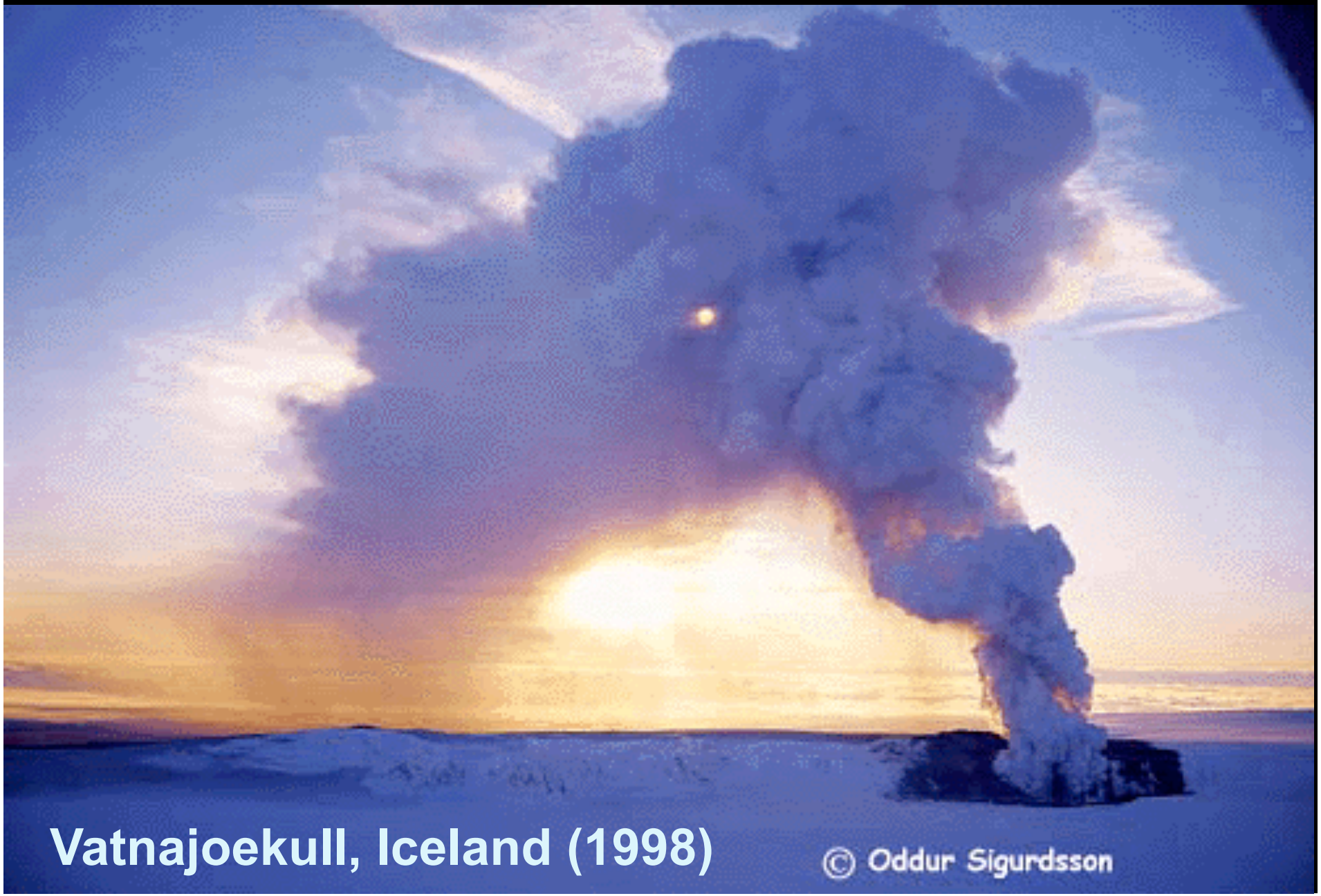


In Namibia, a student stands in front of boulder-studded rock called glacial diamictite--evidence of an ice age more than 700 million years ago.

Ice reflects sunlight, so the temperature went into a runaway drop. Most or all oceans froze over, even at the equator.

Evidence: 1 — drop in biological component in seafloor sediments; 2 — layer of dropstones in seafloor sediments.

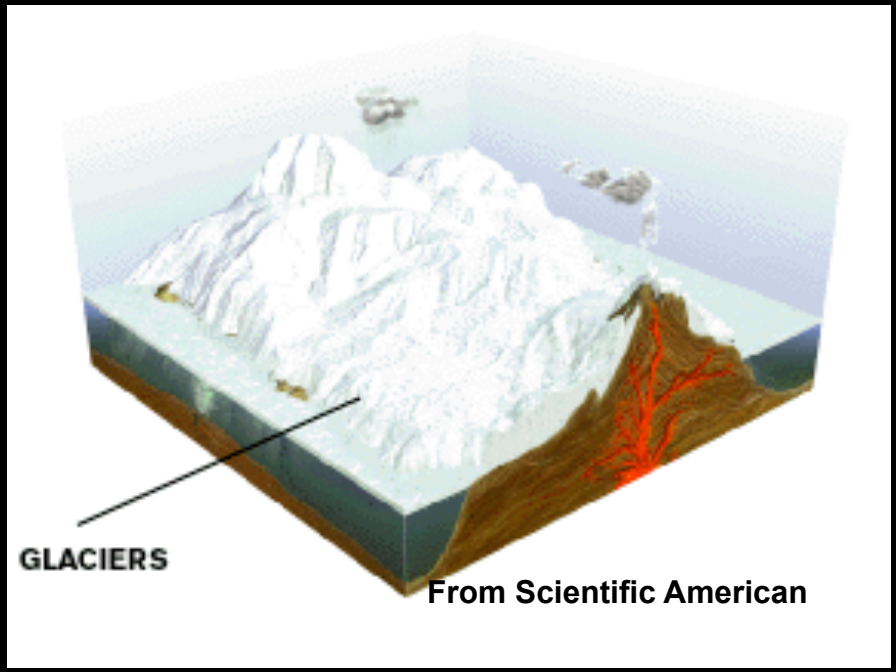
Volcanoes easily erupt through glaciers.



Eyjafjallajoekull, Iceland (2010)

Snowball Earth

Snowball Earth ~ 600 million years ago: surface water was completely frozen.

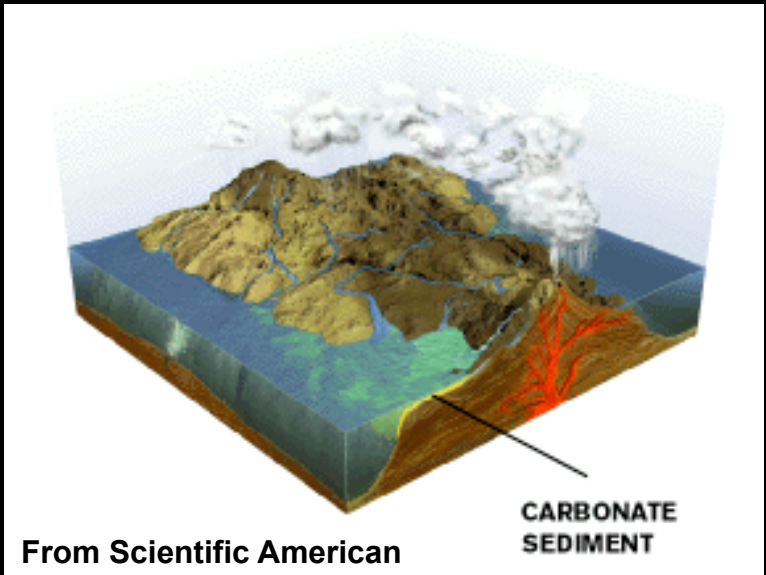


From Scientific American

The climate got too dry for precipitation. So 10 million years of normal volcanic activity increased the CO_2 concentration in the air by more than 300 times. Then a runaway greenhouse effect melted the glaciers and produced a hothouse Earth.

Snowball Earth

Recovery from Snowball Earth:



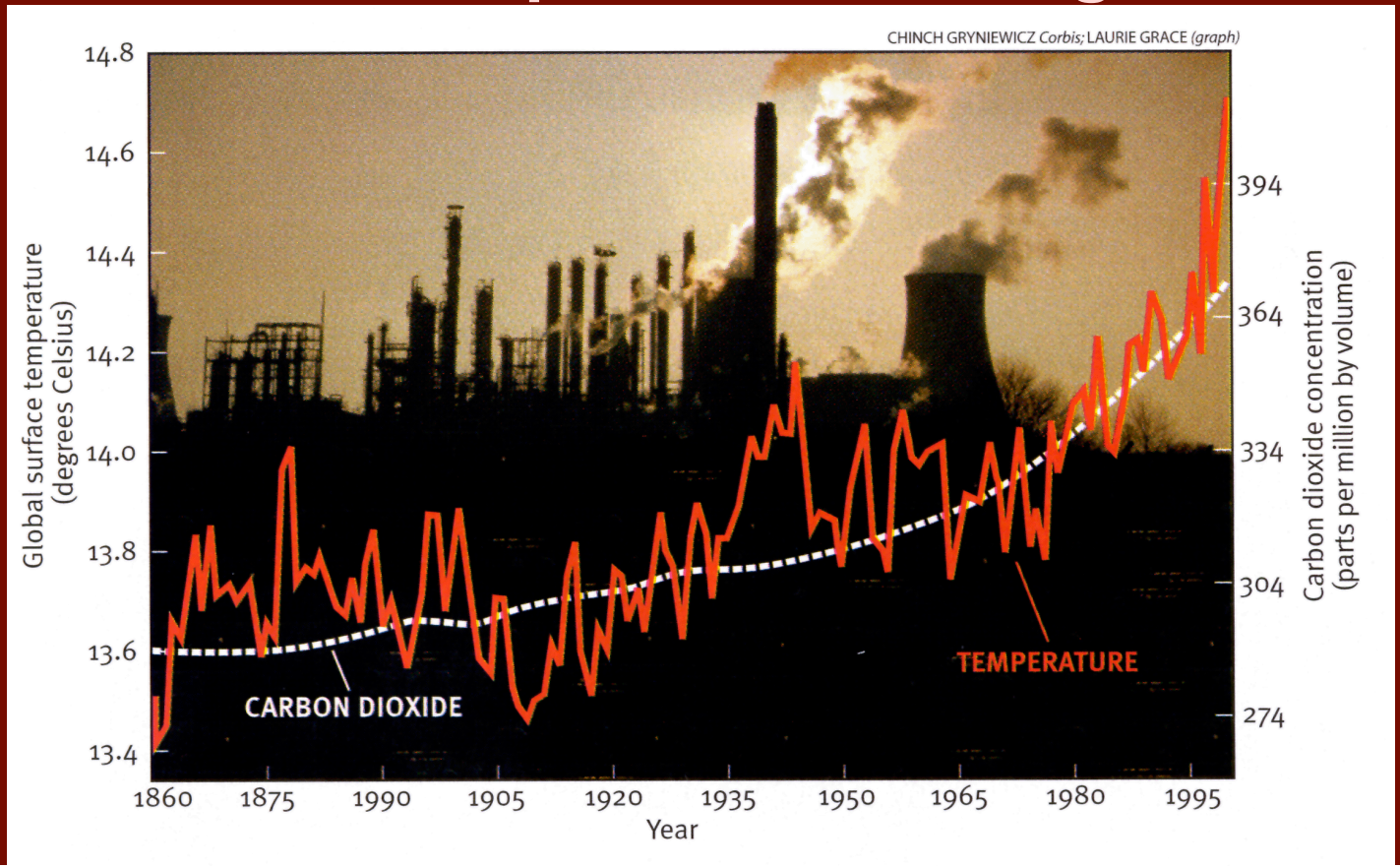
From Scientific American

Hothouse Earth torrential carbonic acid rains deposited deep carbonate sediments that immediately overlie the glacial deposits.

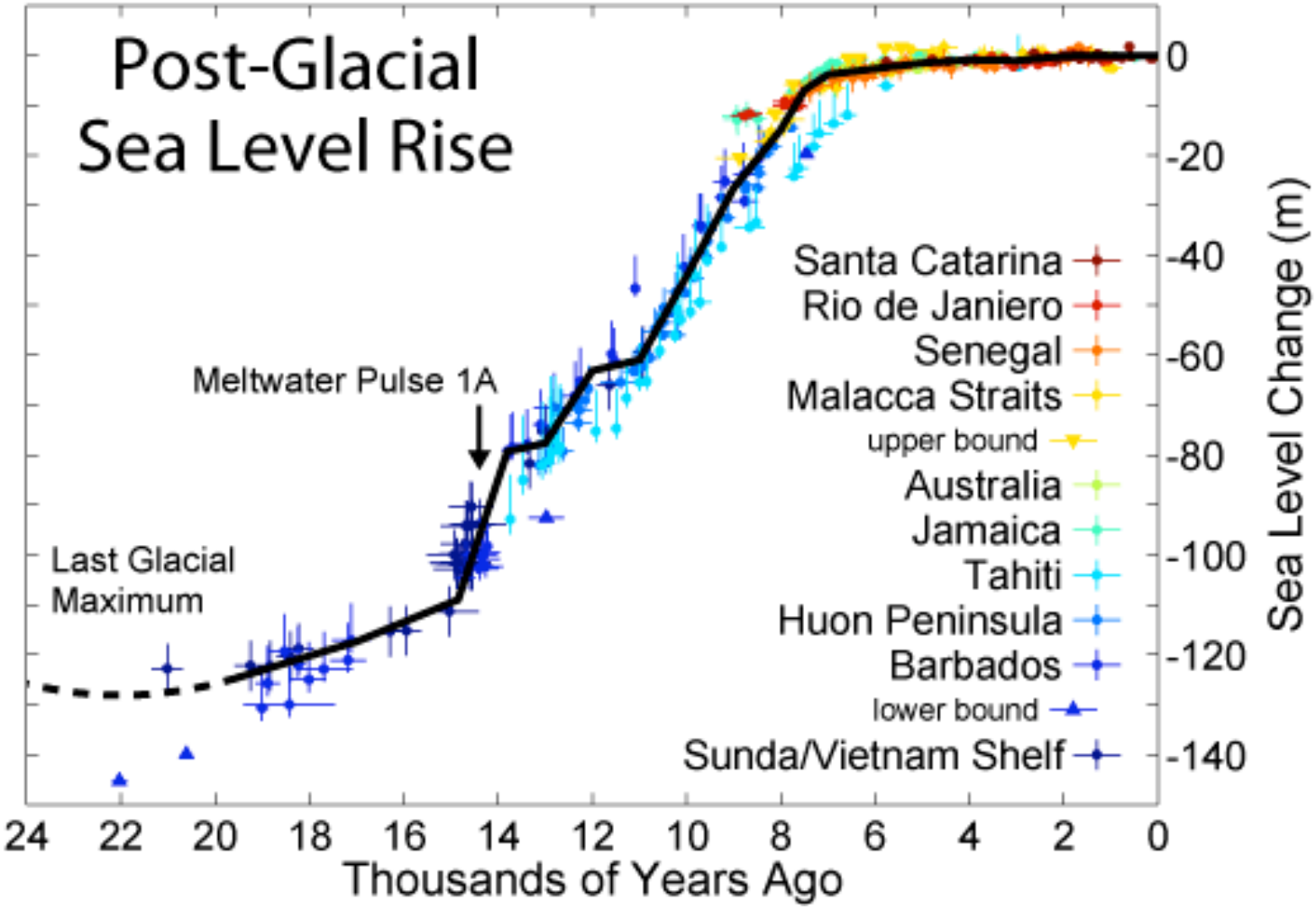
Climate returned to a benign norm. Supercharged biological activity may explain the biological big bang 550 million years ago.

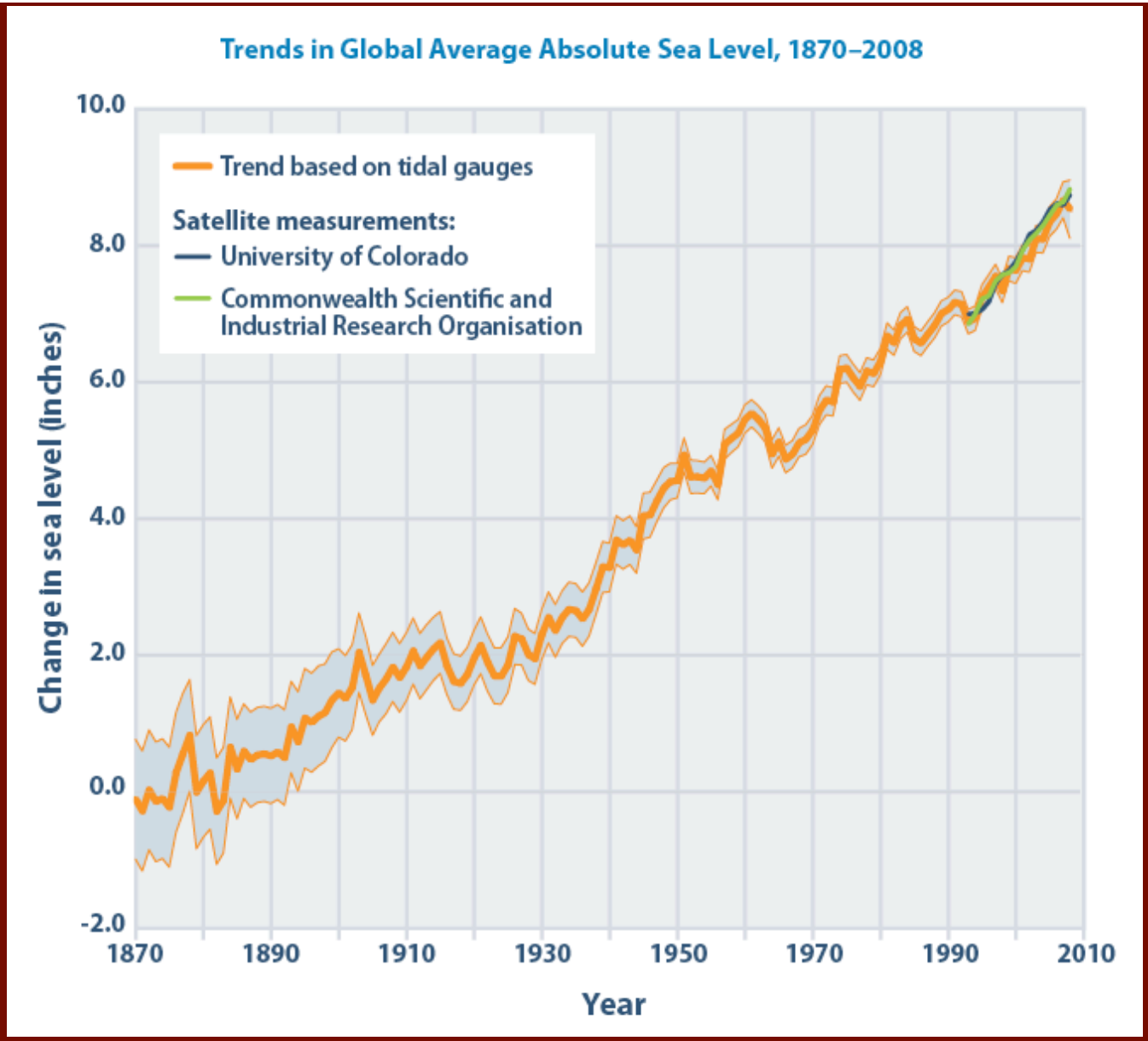
GLOBAL WARMING

We are changing Earth's climate by adding greenhouse gases to the atmosphere. The temperature is rising.



The main rise in sea level associated with the end of the most recent ice age was largely finished about 7000 years ago. A slower trend continued.





We are contributing to a continued rise in sea levels. The rise is faster in recent years.

GLOBAL WARMING

We are changing Earth's climate
by adding greenhouse gases to the atmosphere.

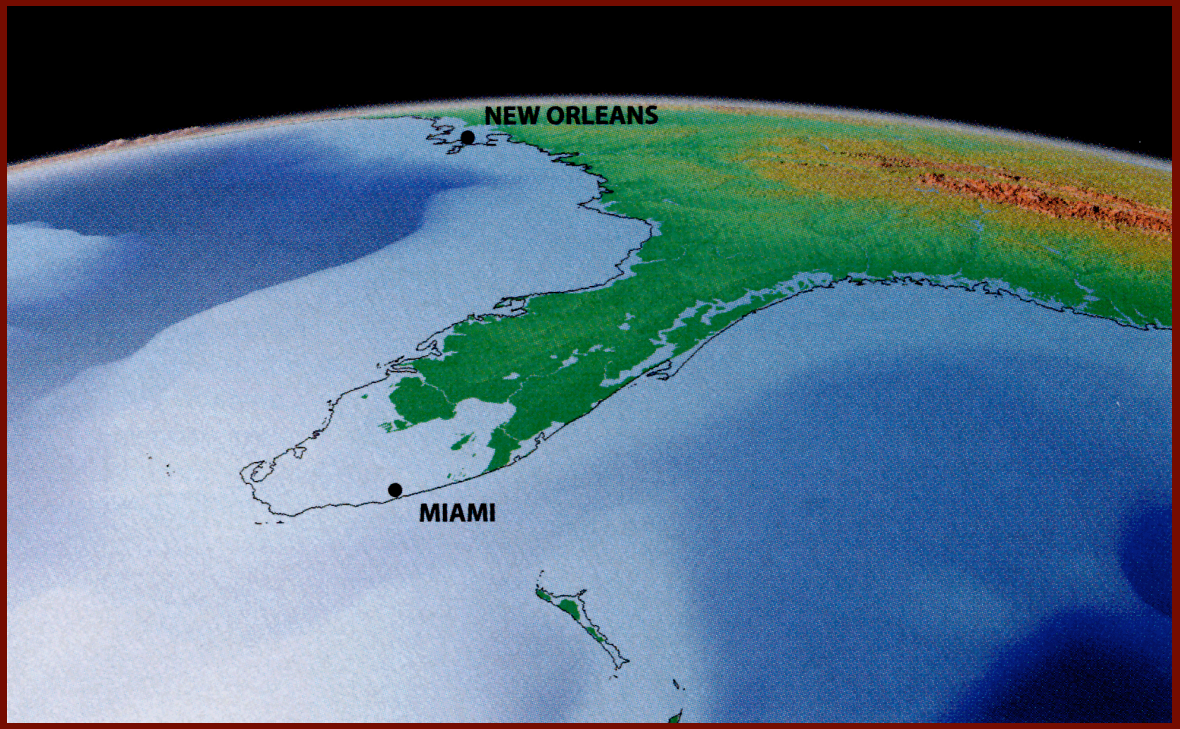
The temperature is rising.

There is much debate about whether we are
at fault or whether the climate is fluctuating by itself
or both. Probable answer: both.

The result can be catastrophic:
the West Antarctic ice sheet can slide into the ocean,
melt, and raise sea levels by ~ 15 feet.

GLOBAL WARMING

If sea levels rise and coastal regions are flooded, it won't matter whether we were completely at fault or whether we only made the situation worse. This argues for caution!



Earth: Summary

Like the other terrestrial planets, Earth's interior is differentiated. Iron and nickel, which are heavy, sank to the center and formed a core about 3500 km in radius. Rock, which is light, floated to the surface and formed a mantle that is about 3000 km thick and a still lighter crust that is only about 10 km thick under the oceans.

Convection currents in the molten outer core create a dynamo that gives the Earth a magnetic field.

Earth suffered many meteorite impacts until about 4 billion years ago, but few craters survive because most of the planet has been resurfaced.

Earth's crust consists of separate rigid plates about 50 km thick; they float on the underlying mantle and slowly get pushed around by mantle convection currents. “Plate tectonics” or “continental drift” has repeatedly reshaped the continents on time scales of 200 million years. When two plates collide, one slips under the other and pushes up mountains like the Himalayas (Asia), the Rockies (North America), and the Andes (South America).

Hawaii was formed by volcanic eruptions from a hot spot in the mantle. Currently the Big Island is over the hot spot and continues to grow because of active volcanoes. The Pacific plate is moving NW and carrying the islands away from the hot spot. Therefore islands that are farther NW are older. Other hot spots sit under Yellowstone National Park and Iceland.

Earth has had many ice ages; it is warming up from one now. As the ice melted, sea levels rose by several hundred feet. They are still rising and so is the temperature of the Earth. We are contributing to global warming by adding greenhouse gases to the atmosphere. Glacial melting can be very fast, so we would be wise to reduce our effects on the atmosphere.

The Earth has an unusual atmosphere: 78 % is nitrogen and 21 % is oxygen. Oxygen is very reactive. It would long ago have been removed from the atmosphere if it were not maintained by plant photosynthesis. This emits oxygen as a byproduct. Oxygen is required for life, and life preserves the oxygen. Unless we wreck it.

The Earth is spectacularly unusual because it has lots of liquid water on its surface. Water is liquid over only a tiny range in temperatures that are very unusual in the Universe. Without liquid water, life as we know it would be practically impossible.