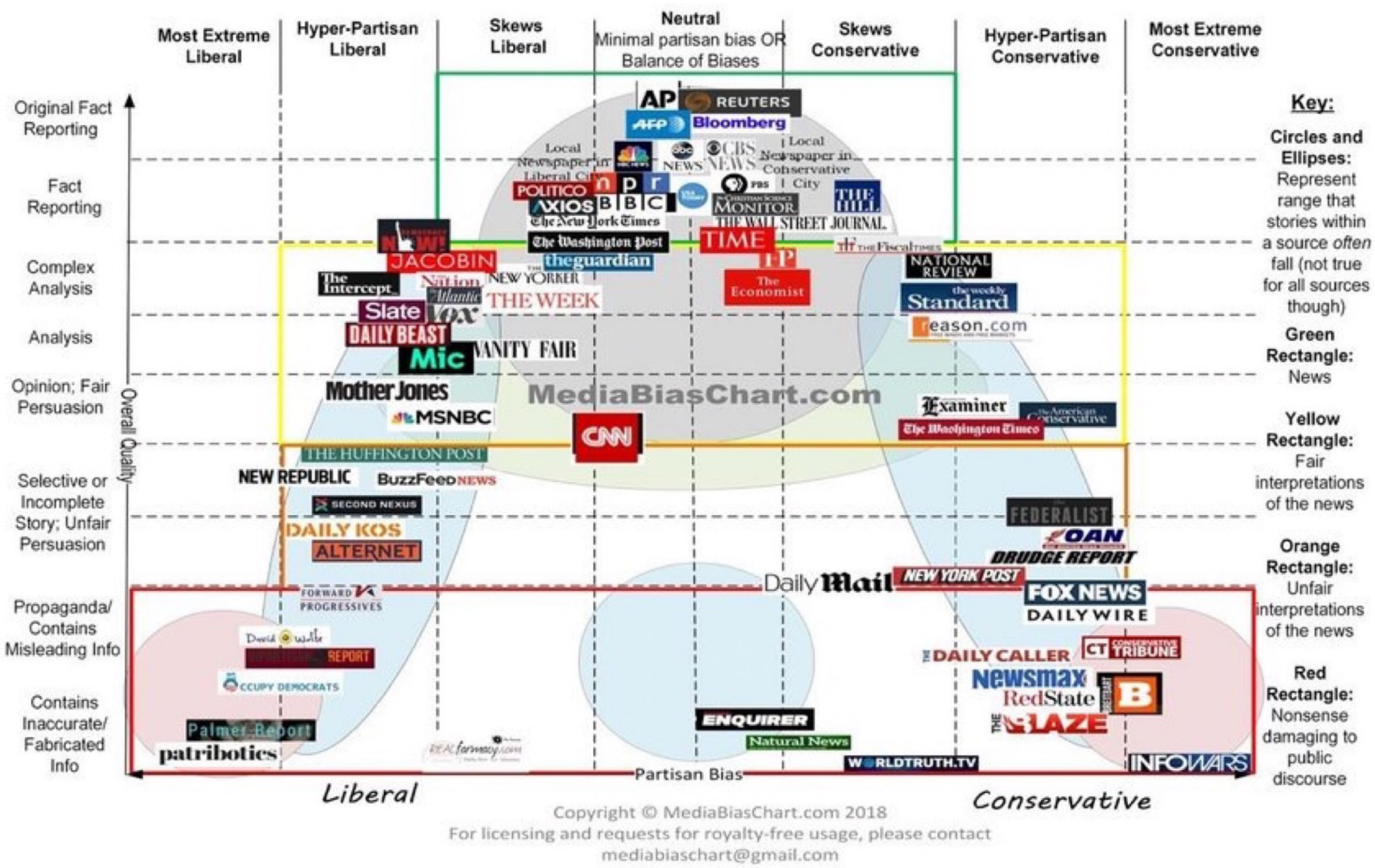
“Education is one of the great joys and solaces of life. It gives us a framework for understanding the world around us and a way to reach across time and space to touch the thoughts and feelings of others.“

Kent Nerburn Simple Truths 1996

What's in the news can depend on the source.
*So reader beware.*



# Why everyone should be interested in global ecology

The human influence on the global environment is changing our understanding of “nature”.

Our world is changing and is fundamentally different than the one we were born in to.

Our lives and livelihoods are threatened by actions that undermine the well being of our natural support systems.

Understanding global ecology is needed to assess & minimize our current and future impacts on natural support systems.

Ecological changes in the next 10 years will determine the type of world you and your children will live in.

Past ecological changes provide a context for current changes.

We won’t know what to do, if we don’t understand what’s going on

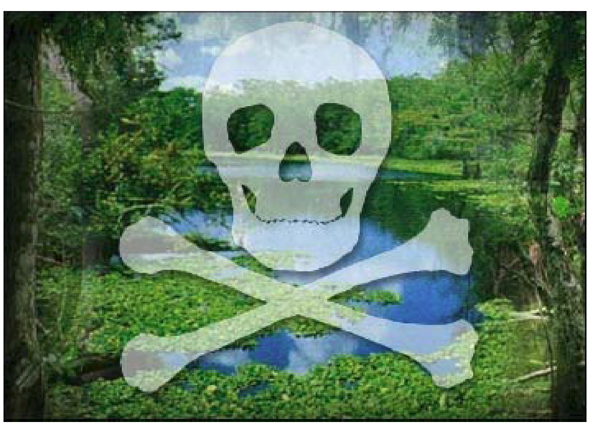
# Landscape in the Adirondacks

*Frederic Edwin Church*

1826-1900

# The Issues: Acid Rain

ADIRONDACK MOUNTAINS, N.Y., Oct. 20, 2004



(CBS/AP)

**(CBS)** ***CBS News*** *continues an election-year series titled "What Does It Mean To You?" focused on where the presidential candidates stand on major issues and how a vote for one or the other candidate might affect average people's lives.*

*In this report,* ***CBS News Correspondent Wyatt Andrews*** *compares the Bush and Kerry positions on reducing acid rain.*

**QUOTE**

**"Of 2,800 lakes in the Adirondacks, one quarter of them are biologically dead." Brian Houseal, Adirondack Council**

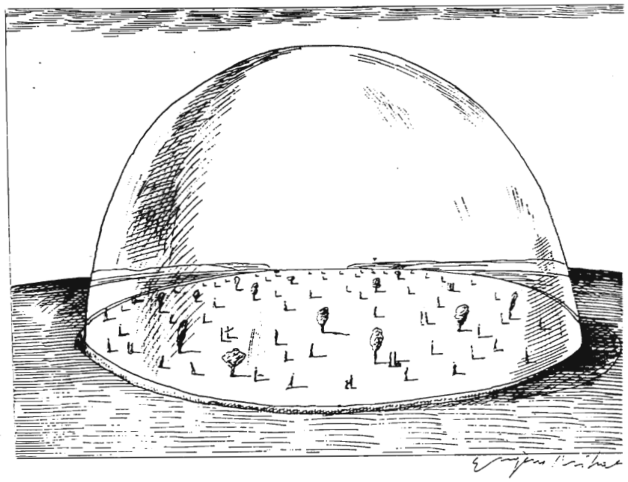
In the New York Adirondacks, a place so peaceful, in a wilderness so beautiful, you'd never suspect the damage beneath the surface.

Just looking at the water, it looks pristine.

"That's because there is no life in it," says Brian Houseal of the Adirondack Council. "Of 2,800 lakes in the Adirondacks, one quarter of them are biologically dead."

REFLECTIONS

THE END OF NATURE



NATURE, we believe, takes forever. It moves with infinite slowness through the many periods of its history, whose names we can dimly recall from high-school biology—the Cambrian, the Devonian, the Triassic, the Cretaceous, the Pleistocene. At least since Darwin, nature writers have taken pains to stress the incomprehensible length of this path. "So slowly, oh, so slowly, have the great changes been brought about," John Burroughs wrote in 1912. "The Orientals try to get a hint of eternity by saying that when the Himalayas have been ground to powder by allowing a gauze veil to float against them once in a thousand years, eternity will only have just begun. Our mountains have been pulverized by a process almost as slow." We have been told that man's but it is that vast day that has lodged in our minds. The age of the trilobites began six hundred million years ago. The dinosaurs lived for a hundred and fifty million years. Since even a million years is utterly unfathomable, the message is: Nothing happens quickly. Change takes unimaginable—"geologic"—time.

This idea about time is essentially misleading, for the world as we know it, the world with human beings formed into some sort of civilization, is of quite comprehensible duration. People began to collect in a rudimentary society in the north of Mesopotamia some twelve thousand years ago. Using twenty-five years as a generation, that is four hundred and eighty generations ago. Sitting here at my desk, I can think back five generations—I have think back one-ninety-sixth of th
to the start of civilization. A
genealogist could easily get me
fiftieth of the distance back. And
conceive of how most of those for
lived. From the work of archeol
and from accounts like those
Bible I have some sense of daily
least as far back as the time
Pharaohs, which is almost ha
way. Three hundred and twent
erations ago, Jericho was a wall
of three thousand souls. Three
dred and twenty is a large numb
not in the way that six hundred
is a large number, not insc
large. And within those twelve
sand years of civilization time
uniform. The world as we reall
it dates back to the Renaissance
world as we *really* know it dates

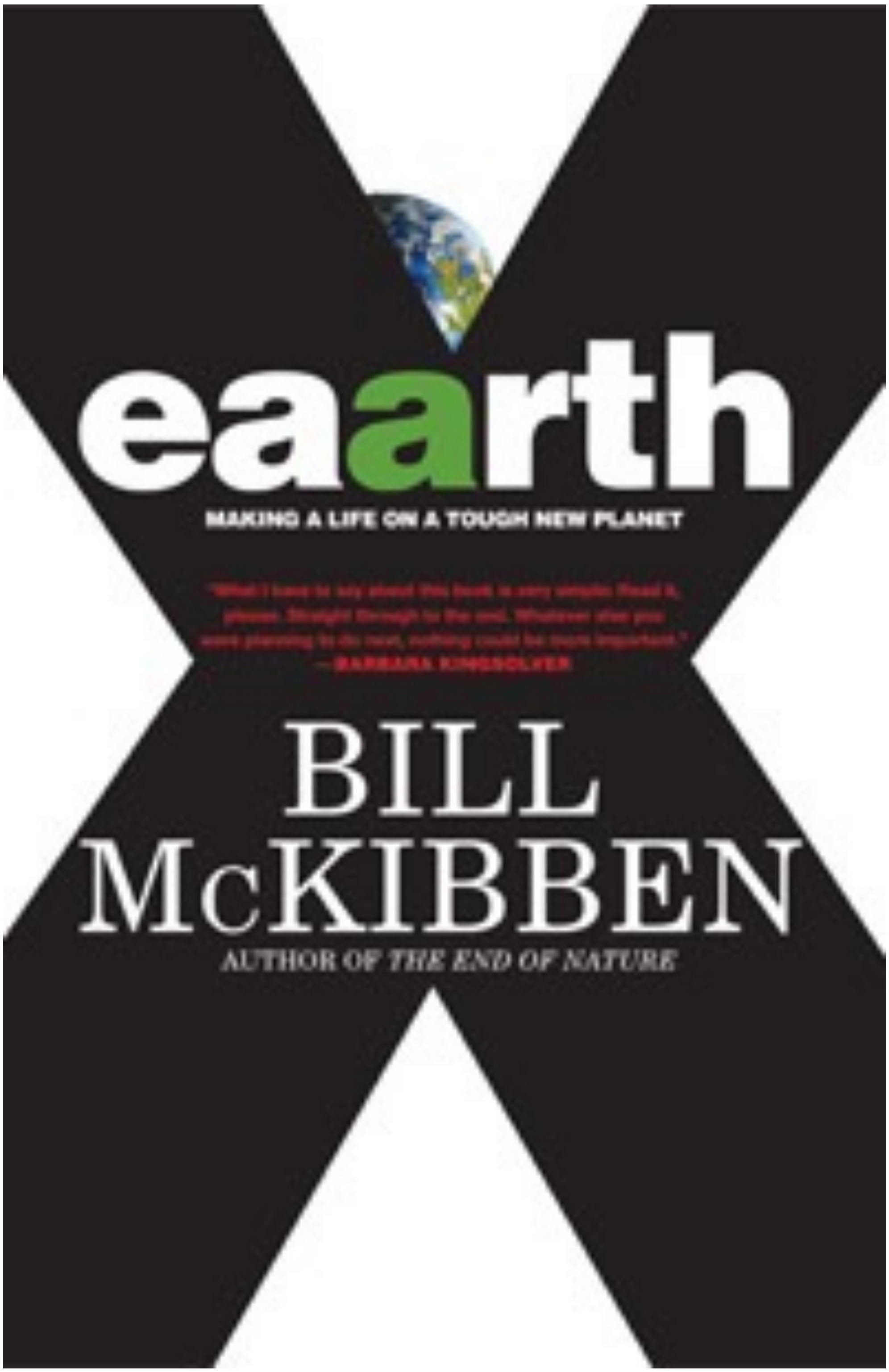
Bill McKibben
The New Yorker
Sept. 11, 1989

# The End of Nature

"… any clear dichotomy between pristine ecosystems and human-altered areas that may have existed in the past has vanished …"

*Peter Vitousek 1994*

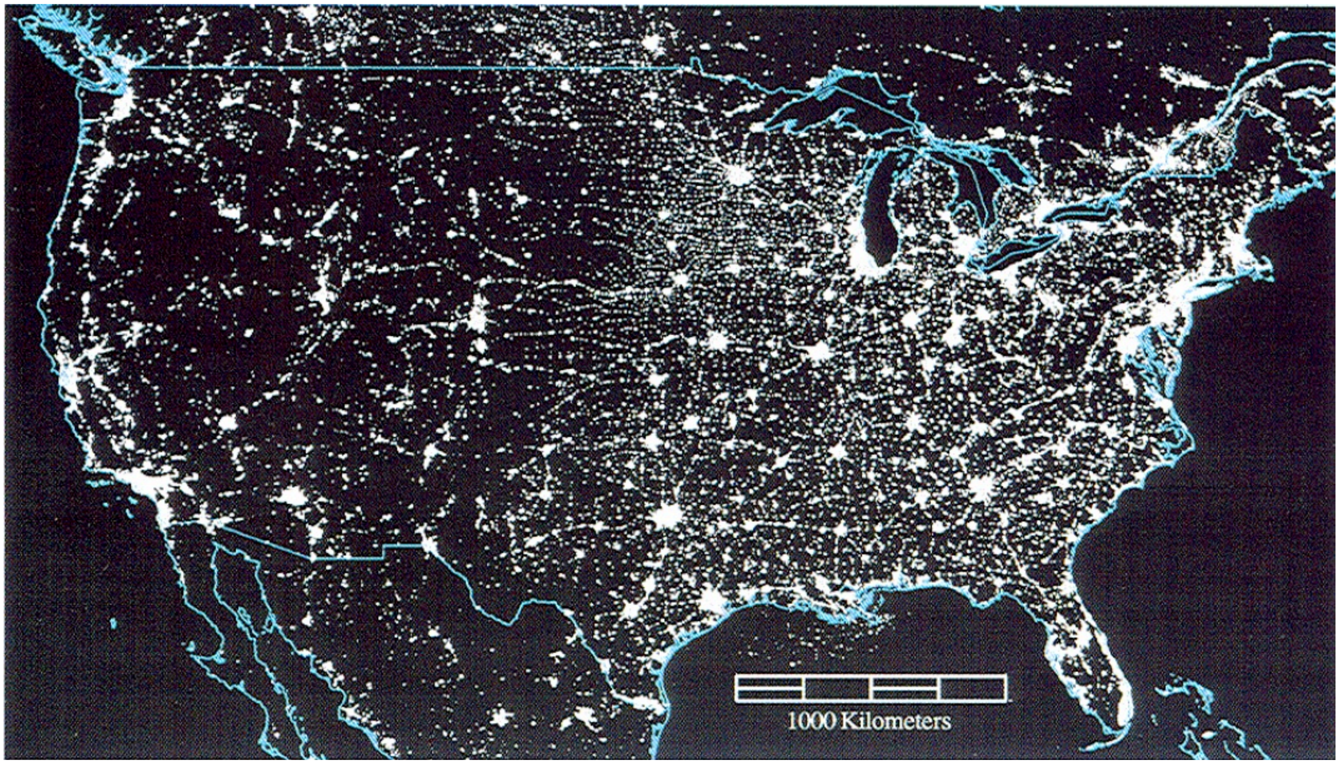
# Welcome to planet Eaarth!

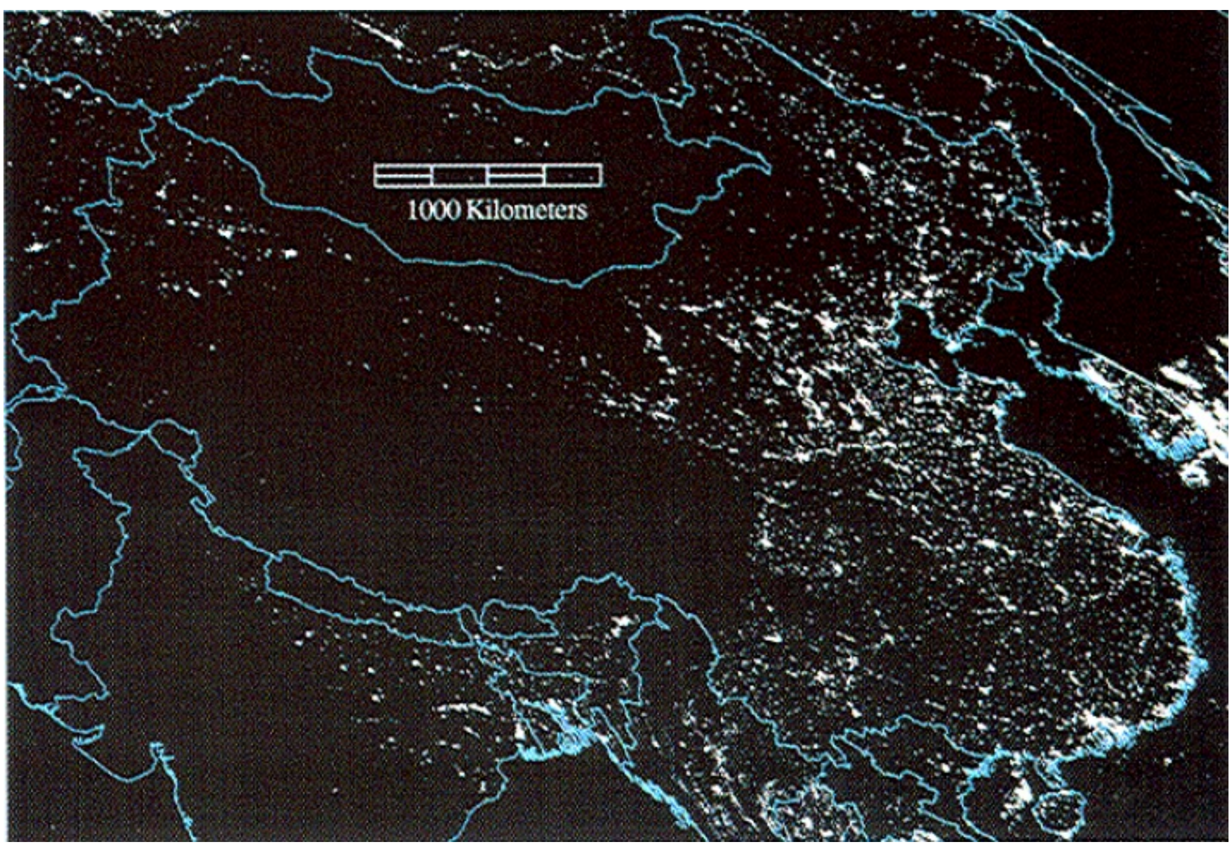



“The health of an economy cannot be separated from that of its natural support systems.”

***Lester R. Brown 2006 Plan B 2.0***

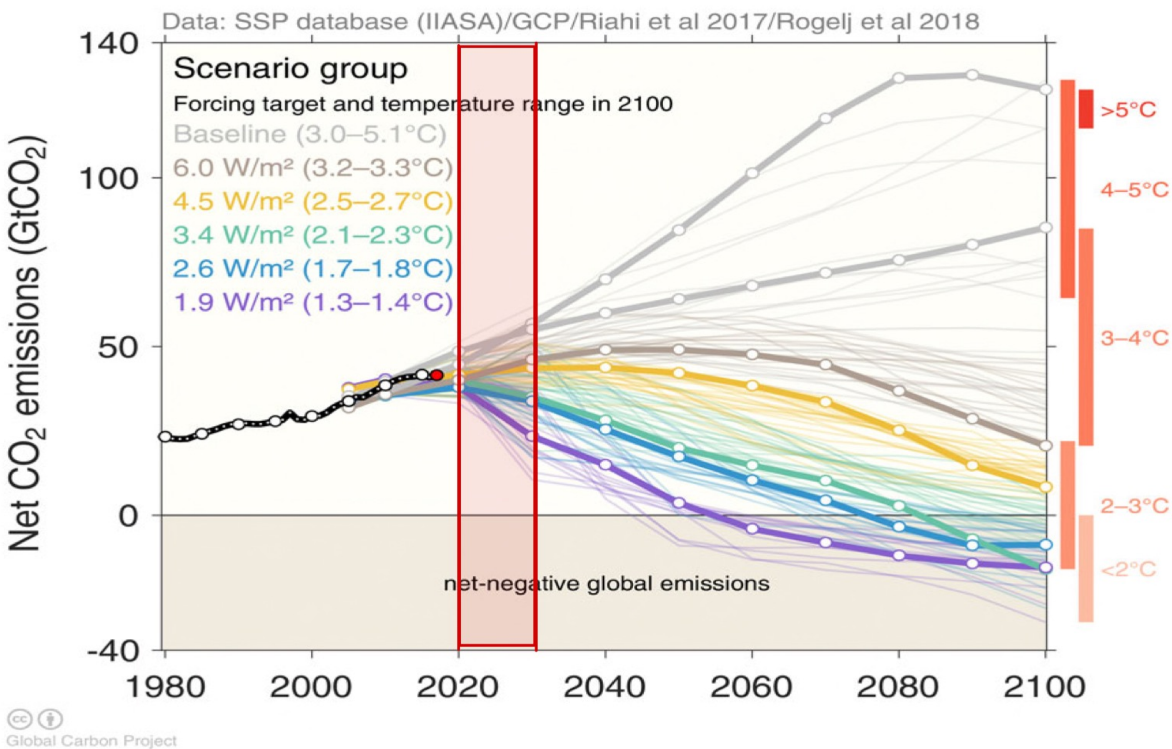
# I = P*A*T

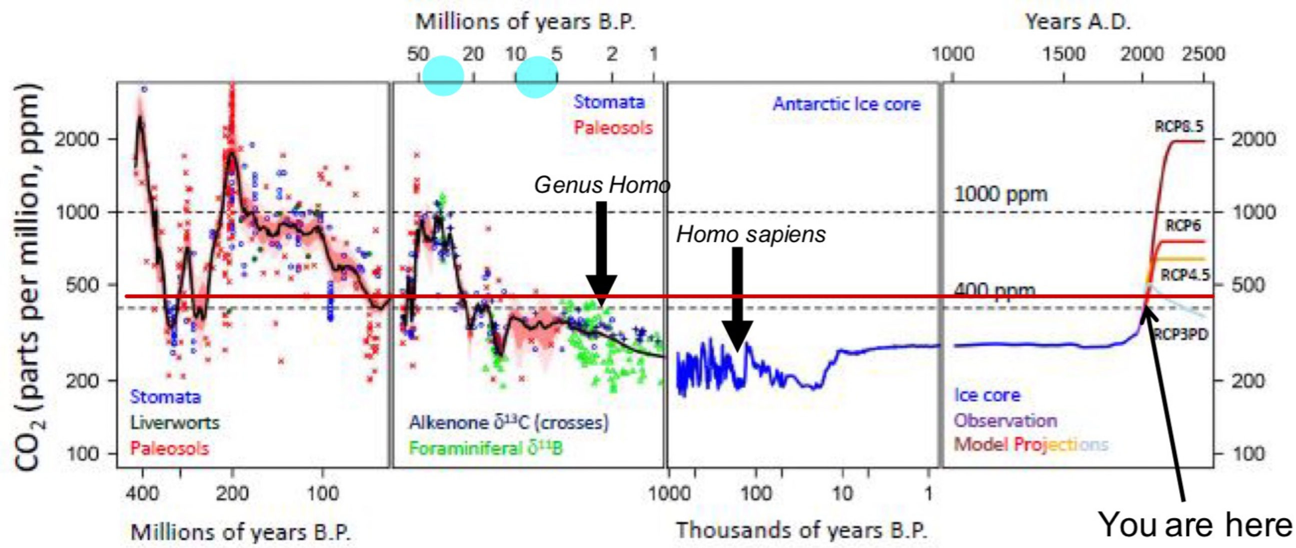



Elvidge et al. 1997

The next 10 years or so will determine the type of world you and your children will live in.



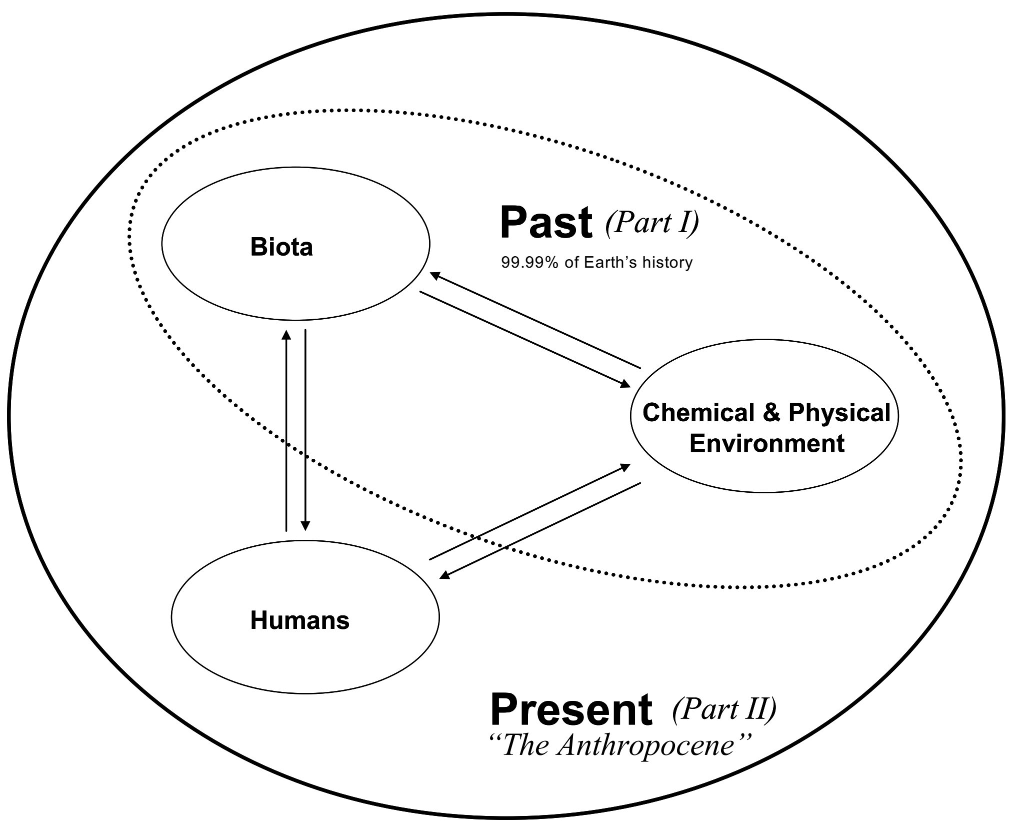

Millions of years B.P.
Years A.D.
50 20 10 5 2 1
1000 1500 2000 2500
$CO_2$ (parts per million, ppm)
Stomata
Paleosols
Antarctic Ice core
Genus Homo
Homo sapiens
1000 ppm
400 ppm
RCP8.5
RCP6
RCP4.5
RCP3PD
2000
1000
500
200
100
Stomata
Liverworts
Paleosols
Alkenone δ13C (crosses)
Foraminiferal δ11B
Ice core
Observation
Model Projections
400 200 100
1000 100 10 1
Millions of years B.P.
Thousands of years B.P.
You are here

# Our Capacity to Change the Earth Means We Must Manage it Wisely

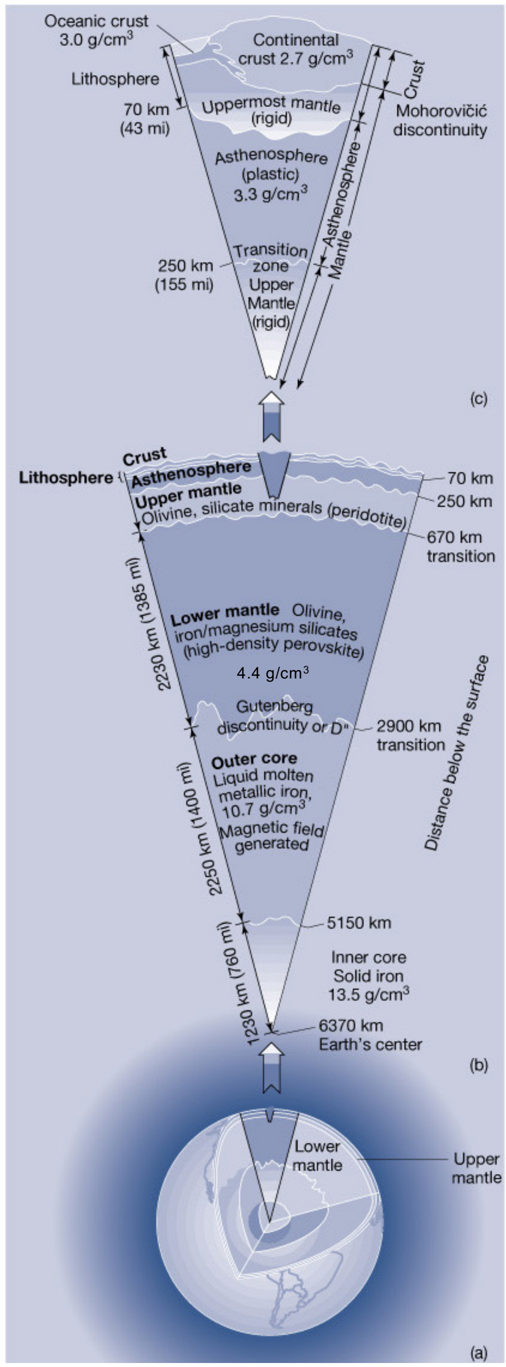
Paraphrased from
Peter Vitousek
Time Magazine
August 20, 2001

We won't know what to do, if we don't understand what's going on.

## Two Main Themes of the Course



Mean density of Earth  ~ 5.5 g/cm3

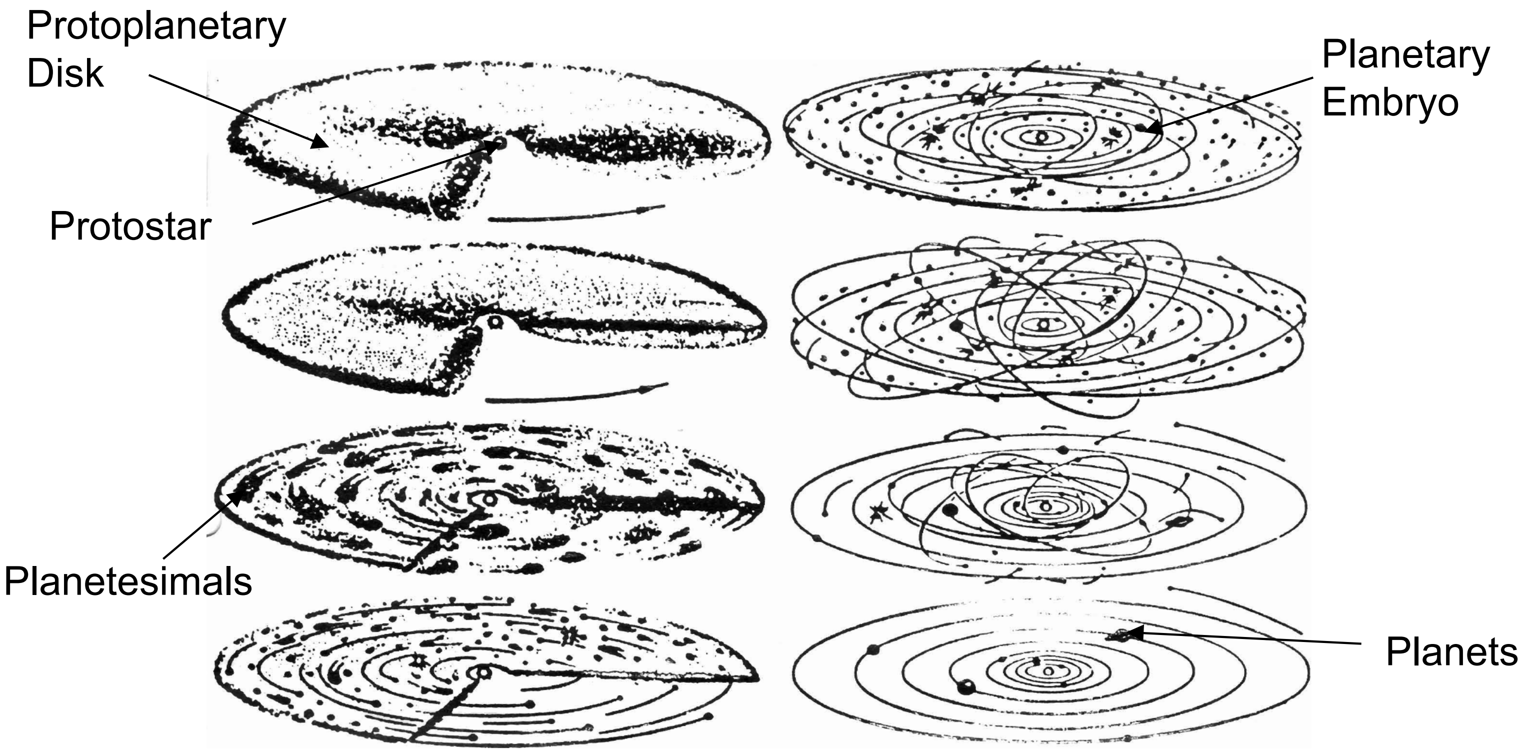



Kump et al. 2004

# Standard Model of Planet Formation

**Accretion**
**4.6-4.5 BYBP**

**Bombardment**
**4.5-3.8 BYBP**




Dust -> Planetesimals
Planetesimals -> Planetary Embryos
(~ 1-10 % Mass of Earth)

Planetary Embryos -> Planets

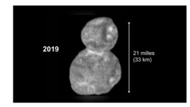
**Ahrens 1994**

# Brief History of our Solar System

Supernova – stellar explosion

Pre-solar Nebular – slowly spinning cloud of gas & micron-sized condensates (i.e., star dust)

A high-resolution image of asteroid Bennu taken by the OSIRIS-REx spacecraft on 2 December from a distance of about 24 kilometers. Bennu is covered with large boulders, and a particularly large rocky outcropping can be seen at lower right. Credit: NASA/Goddard/ University of Arizona




New Year's Eve 2018
Most distant object NASA has ever imaged up close - 2014MU69 (a contact binary).
Taken by New Horizons spacecraft when 4 billion miles from Earth.

Encounter velocities ca. miles/hr to thousands of miles/hr

***Dust => Particles => Gravels => Small Balls => Big Balls => Planetesimals***

Non-gravitational cohesion (i.e., sticking) & gravitational instabilities form **planetesimals** (rocky bodies 1-10 km in diameter)

If planetesimals had similar composition, then planets formed by **homogeneous accretion**. If composition differed, then planet formed by **heterogeneous accretion**.

In computer models, when diameter > ca. 1 km, then increased gravitational attraction results in collisions of planetesimals.

With the largest planetesimals growing the fastest.

Planetesimals swept up within zones defining present-day orbits and continues accretion leads to moon-sized bodies (radius ~ 1,700 km) called **planetary embryos**.

Once lunar size, gravitational attractions result in inter-orbital collisions (crossing orbits)

As Earth grew it probably experienced impacts from:

Hundreds of bodies with a radius of 10 km
Tens of bodies with a radius of 100 km
Several bodies with radius of 1,000 km

For perspective: The K-T (Cretaceous-Tertiary) impact had radius of ~ 5 km (Earth's radius is ~ 6,000 km) => extinction of ~75% of all species

~4,474 mph

When impactors > lunar size, then impact velocities are > 2 km/sec and collisions have enough E to devolatilize minerals contained in the impactor.

Volatilized impactors release $CO_2$ and water vapor to create protoatmosphere.

Supergreenhouse forms and traps heat released from collisions & radioactive decay.


Temperatures increase to > 2000 K creating "magma ocean"

Separation of lithosphere into density layers.

Molten iron coalesced & sinks through molten silicate magma to form core.

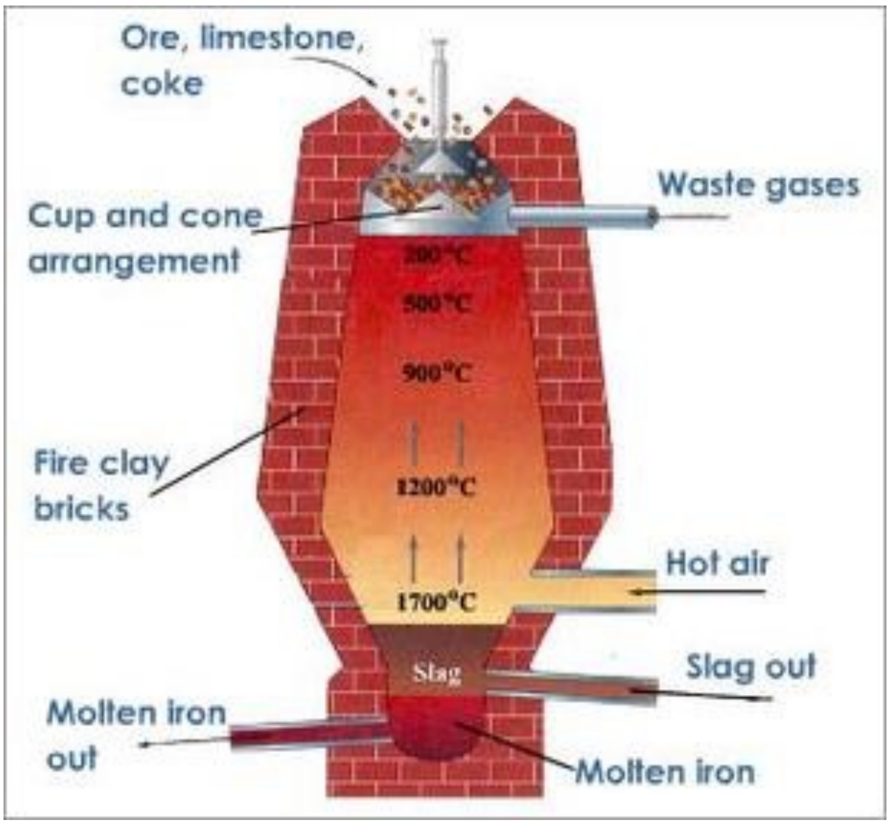
Separation of lithosphere into density layers.

Infrequent impacts from the larger planetesimals erode portions of the atmosphere.

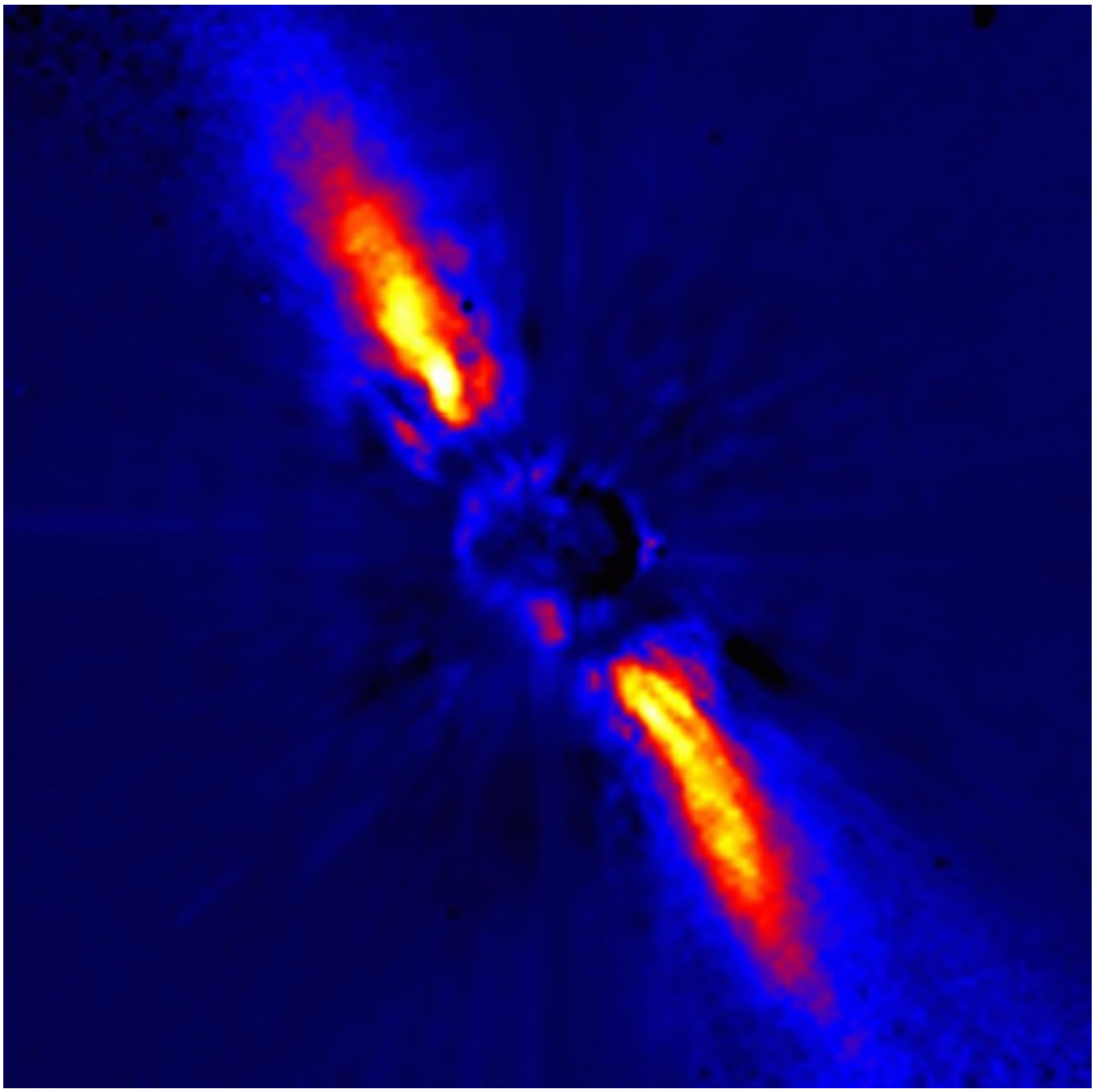
Rare and extremely large impacts (> 3000 km radius) have enough E to eject the entire protoatmosphere.

Bombardment slows; rate of impacts decrease; volatilization, supergreenhouse and magma ocean no longer occur; Earth cools.

# The Density Structure of the Lithosphere Appears to be Due to "Planetary Smelting"

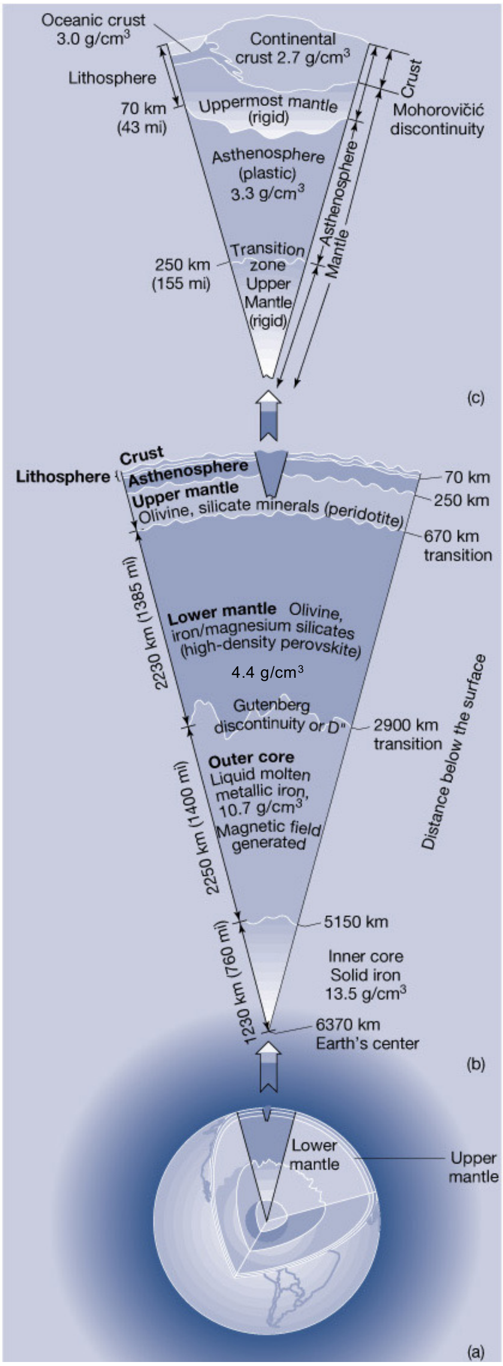


# Beta Pictoris and its emerging solar system



The circumstellar disk shows (in false colors) the light reflected by dust around the young star

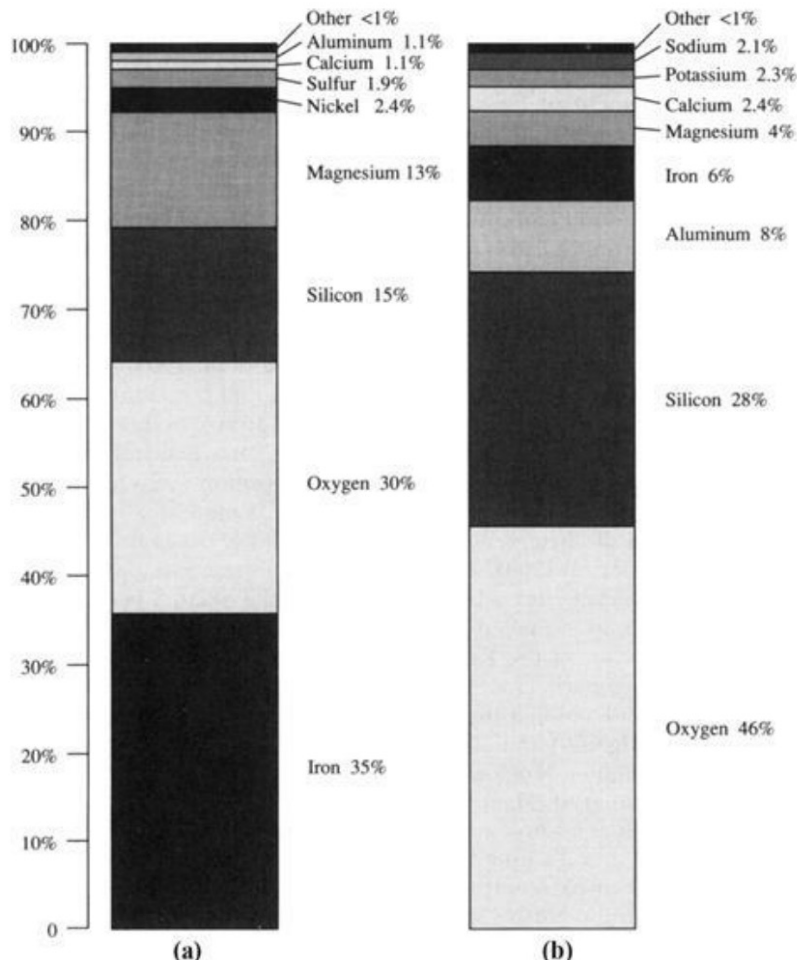
Mean density of Earth ~ 5.5 g/cm3




Kump et al. 2004

Whole Earth

Crust Only




Schlesinger 1997

# Core

- Composition
  - –Iron
  - –Nickel (~6 %)
- •Inner solid core
- •Outer liquid core
  - –Convective mixing

Convection in outer core creates the Earth’s magnetic field

# Mantle

## Mafic in composition

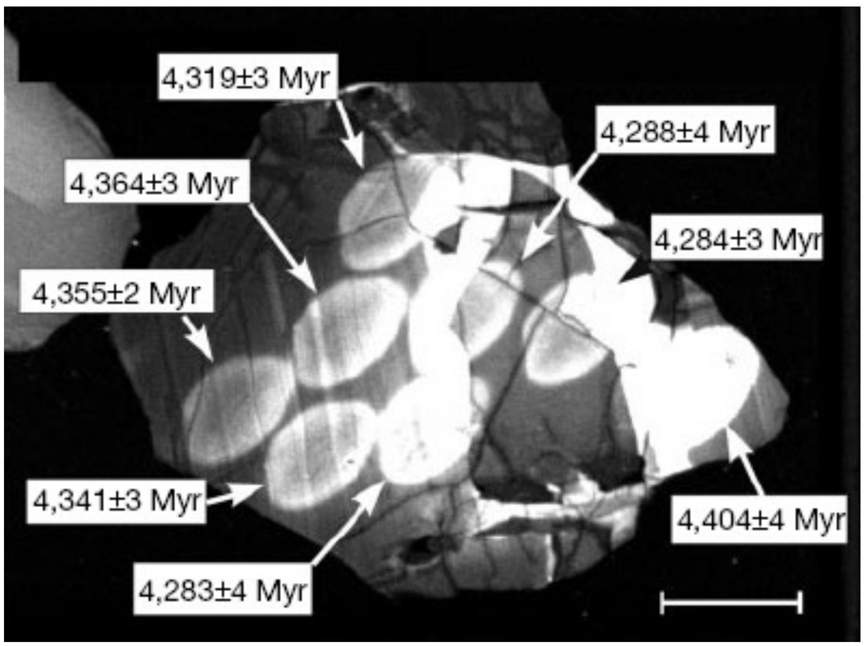
- Pyroxene (Mg, $FeSiO_3$)
- Olivine ($Mg_2$, $Fe_2SiO_4$)

# Two types of crust

| Continental Crust | Oceanic Crust |
|---|---|
| 1/3 of Earth surface | 2/3 of Earth surface |
| Higher elevation<br>(126 m above sea level) | Lower elevation<br>(3.7 km below sea level) |
| Thicker<br>(15-70 km)<br>(average = 35-40 km) | Thinner<br>(6 km thick) |
| Wider mountain belts | Narrower mountain belts |
| Felsic composition<br>"granitic rocks"<br>quartz, plagioclase,<br>alkali-feldspar **(e.g. $Ca\ Al_2\ Si_2\ O_8$)**<br>(rich in Si, K, Na) | Mafic composition<br>"Basaltic rocks"<br>pyroxene, plagioclase<br>**(e.g. $Mg, Fe\ Si\ O_3$)**<br>(rich in Mg, Fe, Ca) |
| Never subducted<br>Less dense<br>Older on average | < ~ 200 MYBP |

Can be > 2 BYBP

# When the lithosphere form?




Cathodoluminescence and back-scattered electron images of zircon crystal W74/2-36.

With portions dated at 4.404 billion years.

Wilde S.A., Valley J.W., Peck W.H. and Graham C.M. (2001). "Evidence from detrital zircons for the existence of continental crust and oceans on the Earth 4.4 Gyr ago". Nature 409 (6817): 175–8. doi:10.1038/35051550. PMID 11196637.

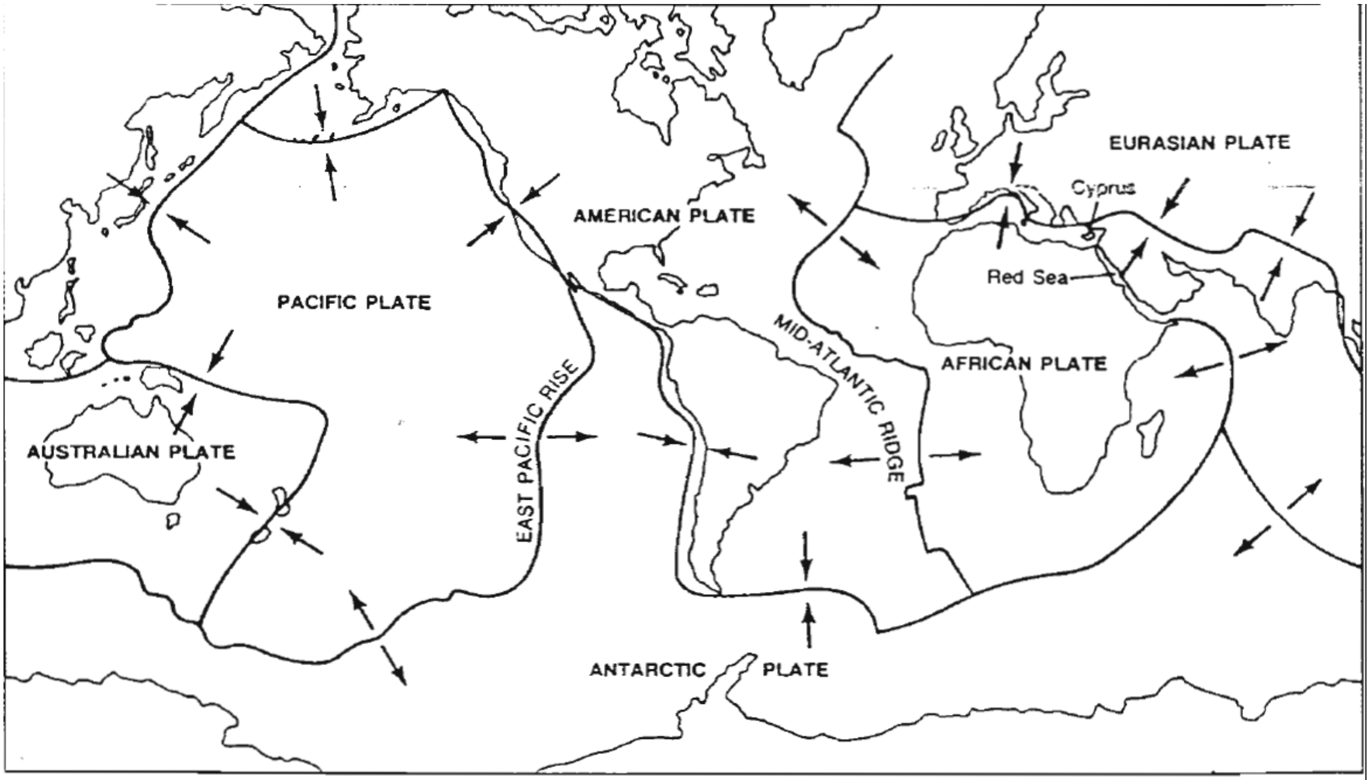
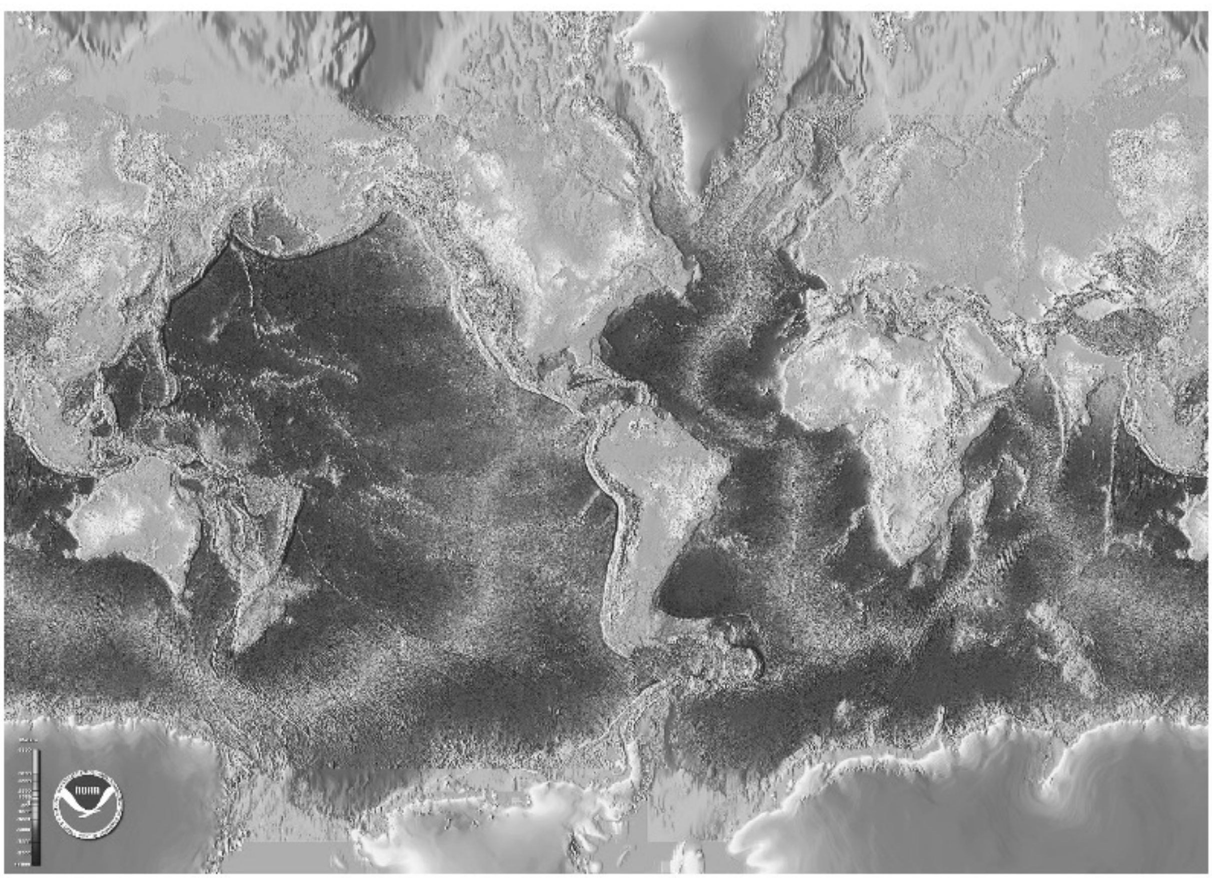



FIGURE 2-3

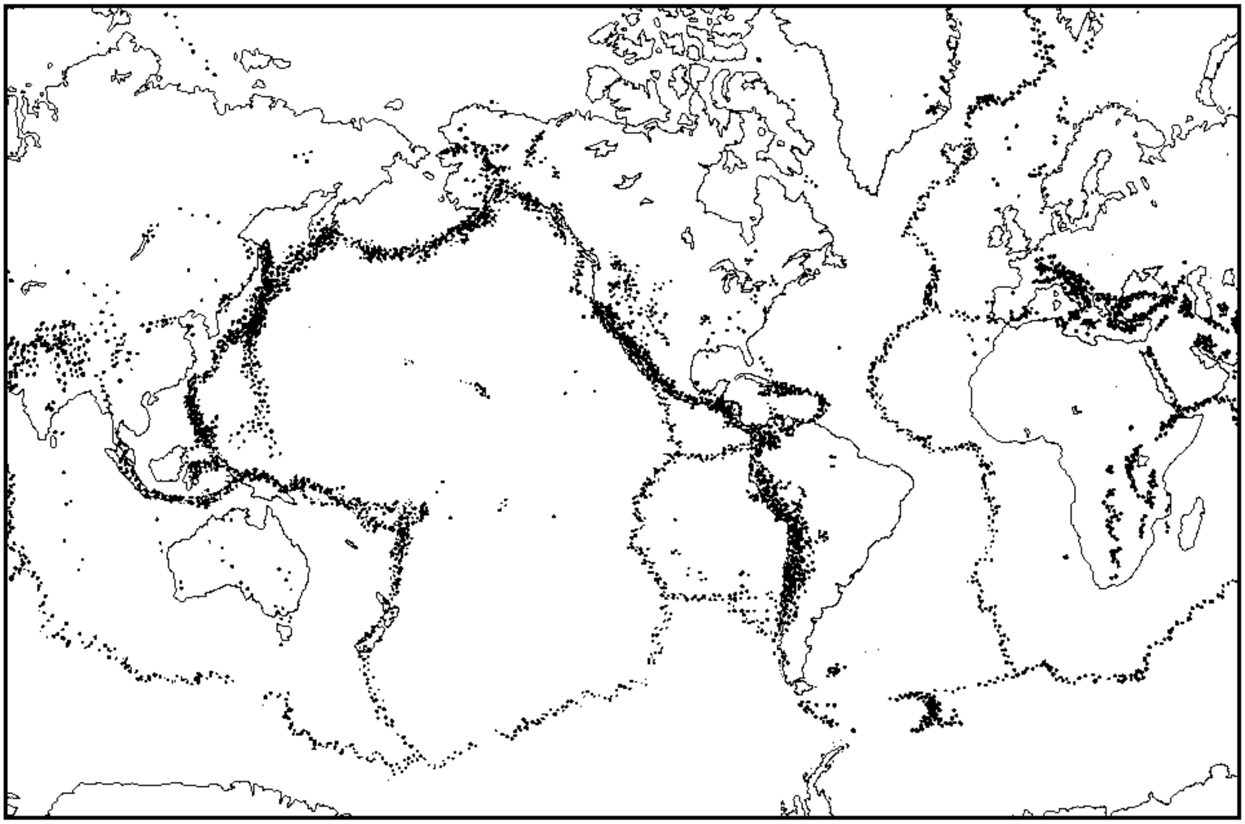
Six principal tectonic plates of the lithosphere.

Ehrlich et al. 1977





Kump et al. 2004



The world distribution of earthquakes. Earthquakes cluster along subduction and collision margins.

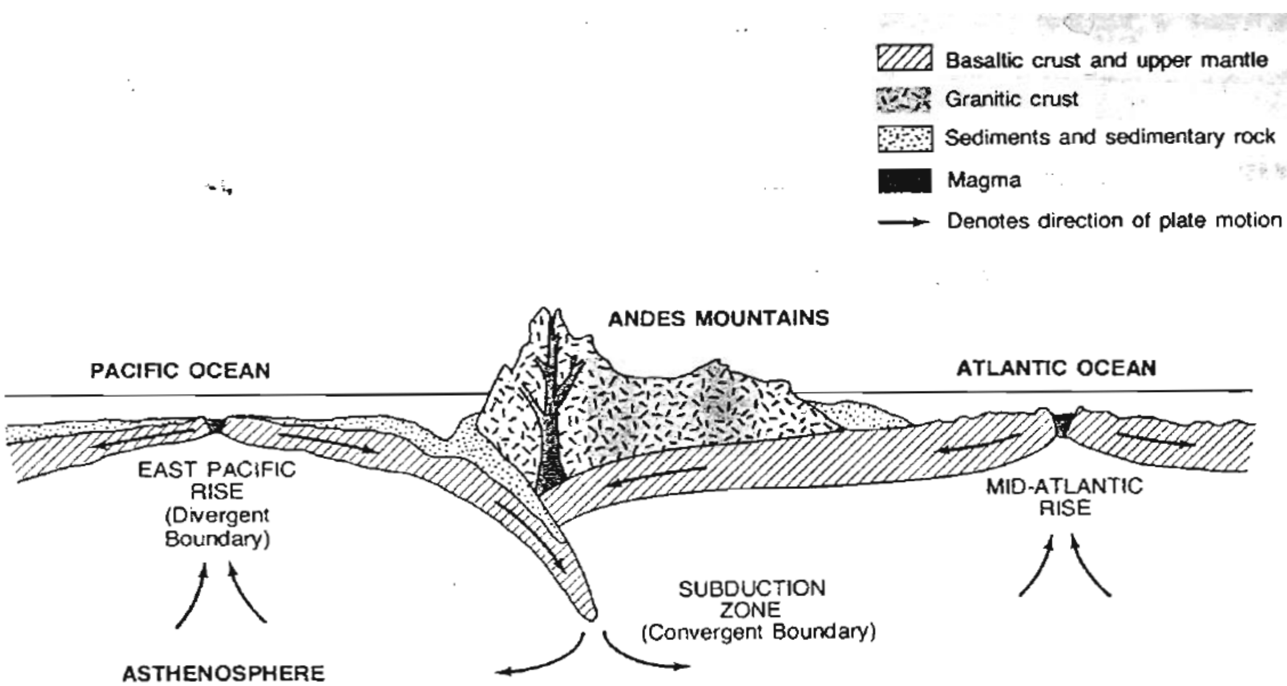
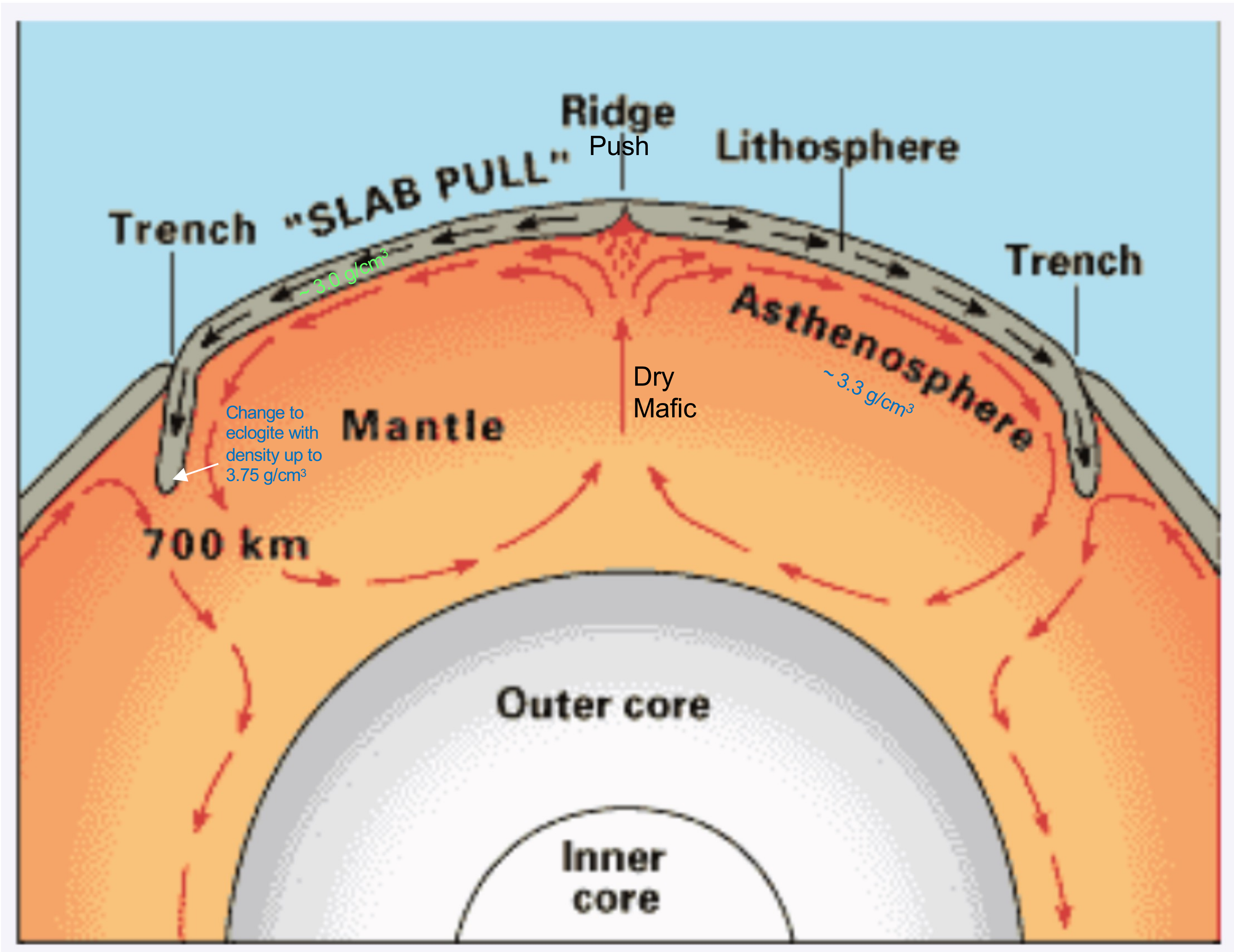



FIGURE 2-2

Tectonic processes and the Earth's surface. (From Rona, 1973.)

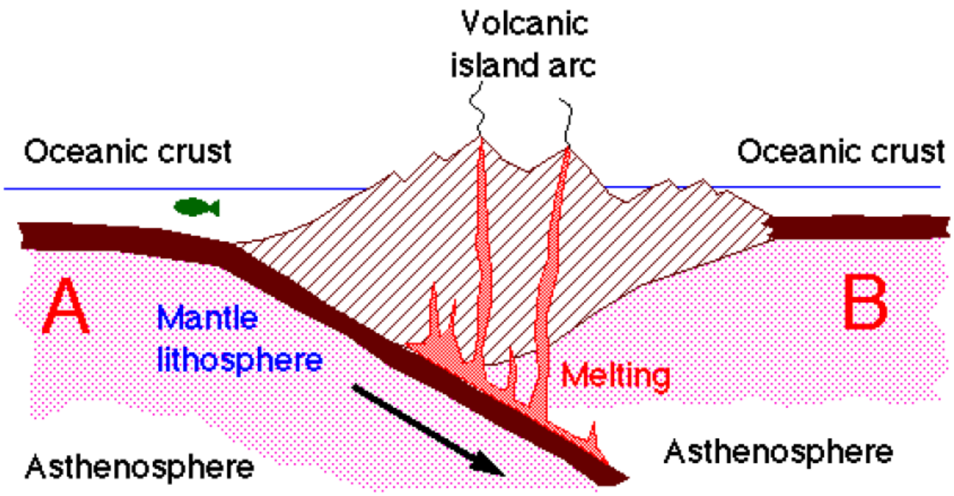
# What drives plate movement?



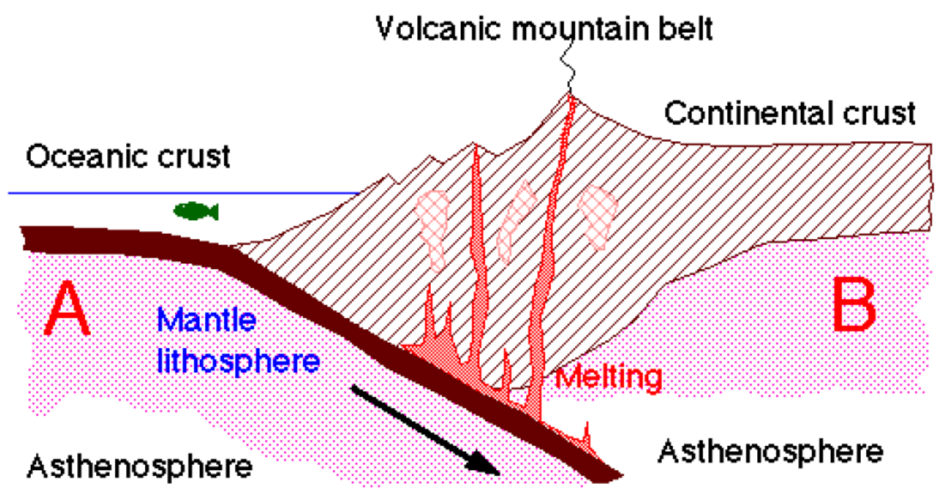

https://pubs.usgs.gov/gip/dynamic/unanswered.html

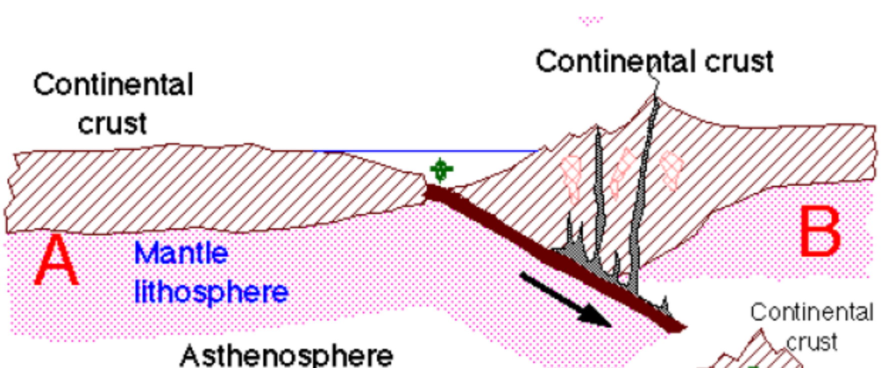
https://upload.wikimedia.org/wikipedia/commons/c/c0/Mid-ocean_ridge_topography.gif

**Ocean-Ocean Convergence**

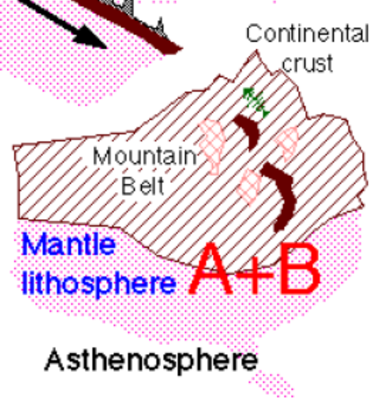



**Ocean-Continent Convergence**




1. Plate A subducts under Plate B until the oceanic crust is consumed.
2. Continental crust can not subduct.
3. The continents collide to produce a single Plate A+B with a mountain belt in the centre. e.g., Himalayas.



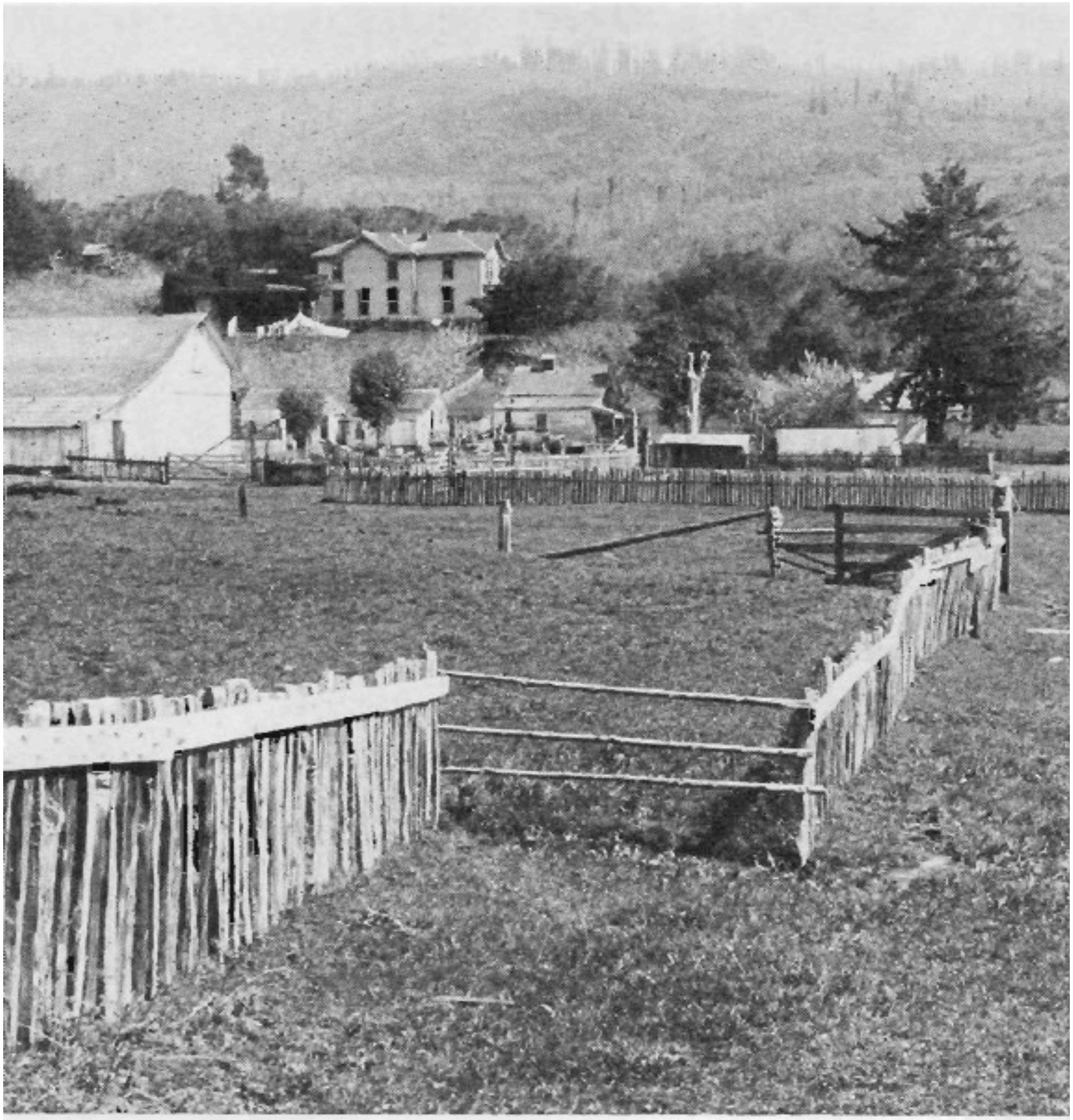
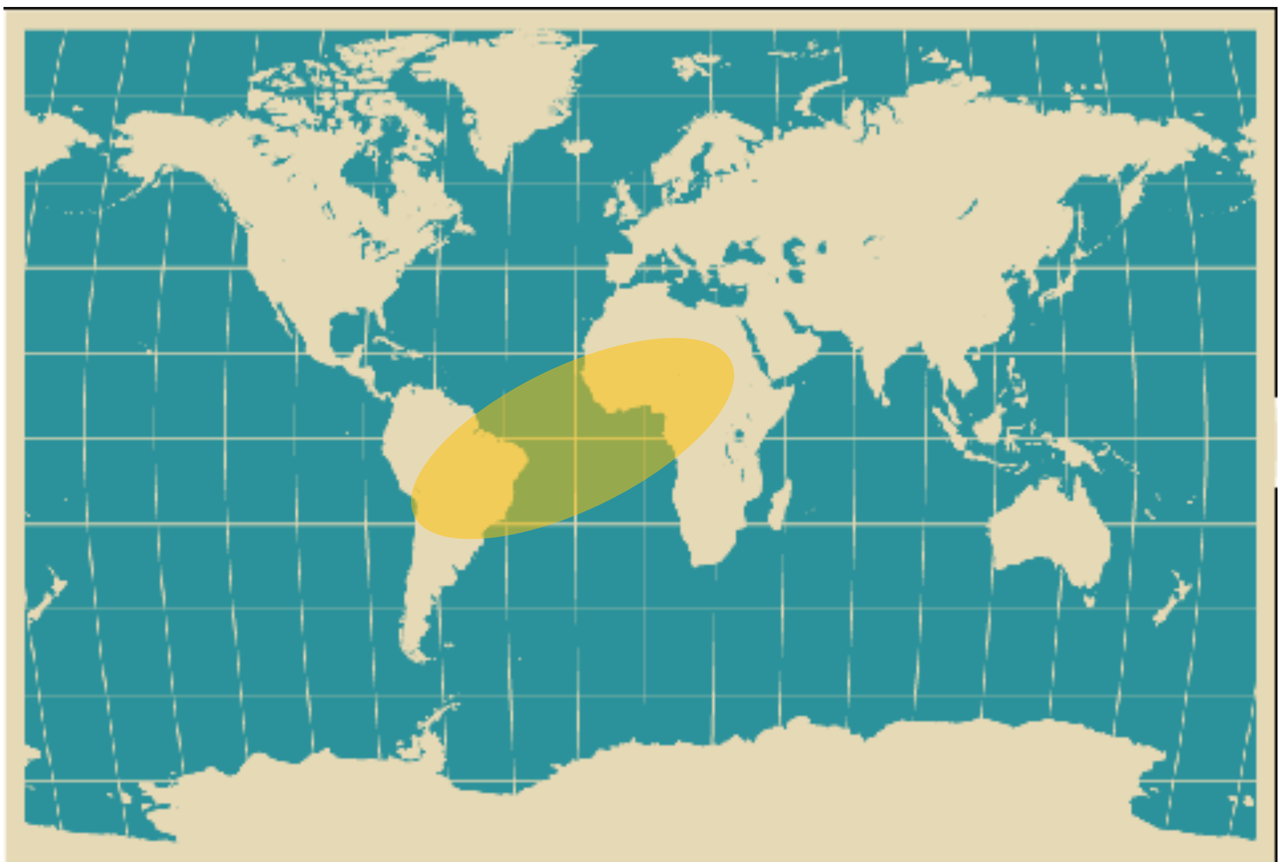


**Figure 18-8**

The earthquake of 1906 was caused by slip along the San Andreas fault. The offset fence shown here shows a slip of nearly 3 m. The scene is near Bolinas, California. [Photo by G. K. Gilbert; courtesy of R. E. Wallace, U.S. Geological Survey.]

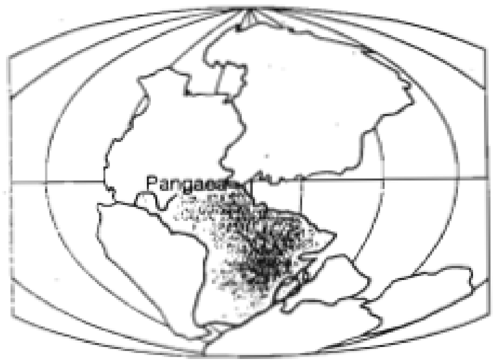
Press and Siever 1986

Have you ever noticed that the shape of eastern S. America could fit into the shape of western Africa?

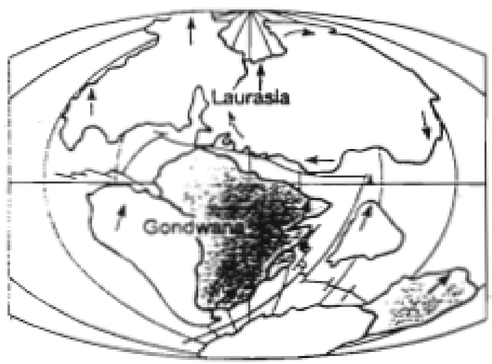


*Alfred Wegner did along with the correspondence of geological features, and fossils*

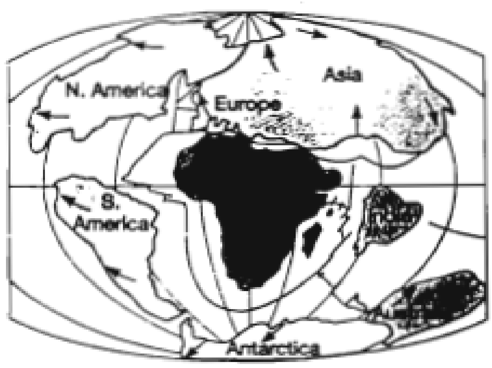
# We now know that ~ 250 MYBP they did fit together to form Pangea



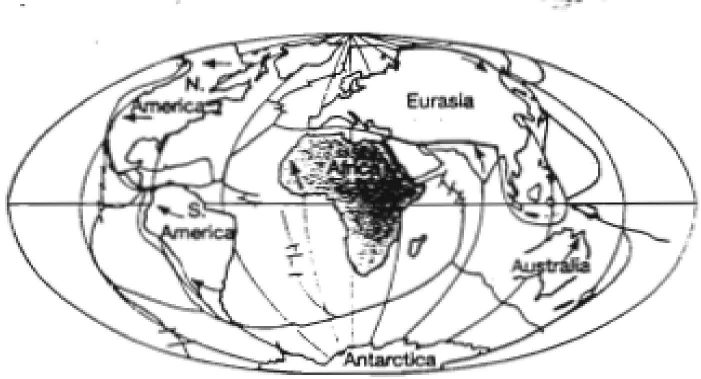

(a) 240 million years ago (Triassic period)




(b) 120 million years ago (Cretaceous period)

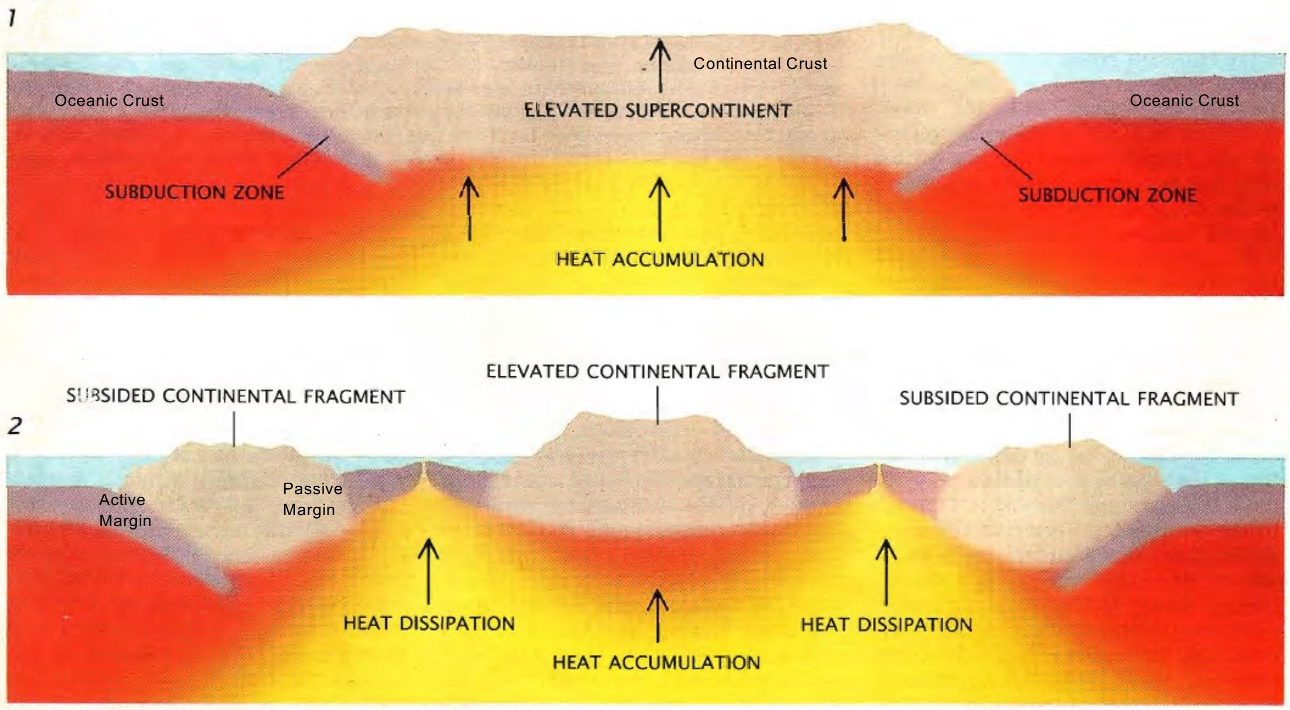



(c) 60 million years ago (early Tertiary period)




(d) Today

Solomon 1996

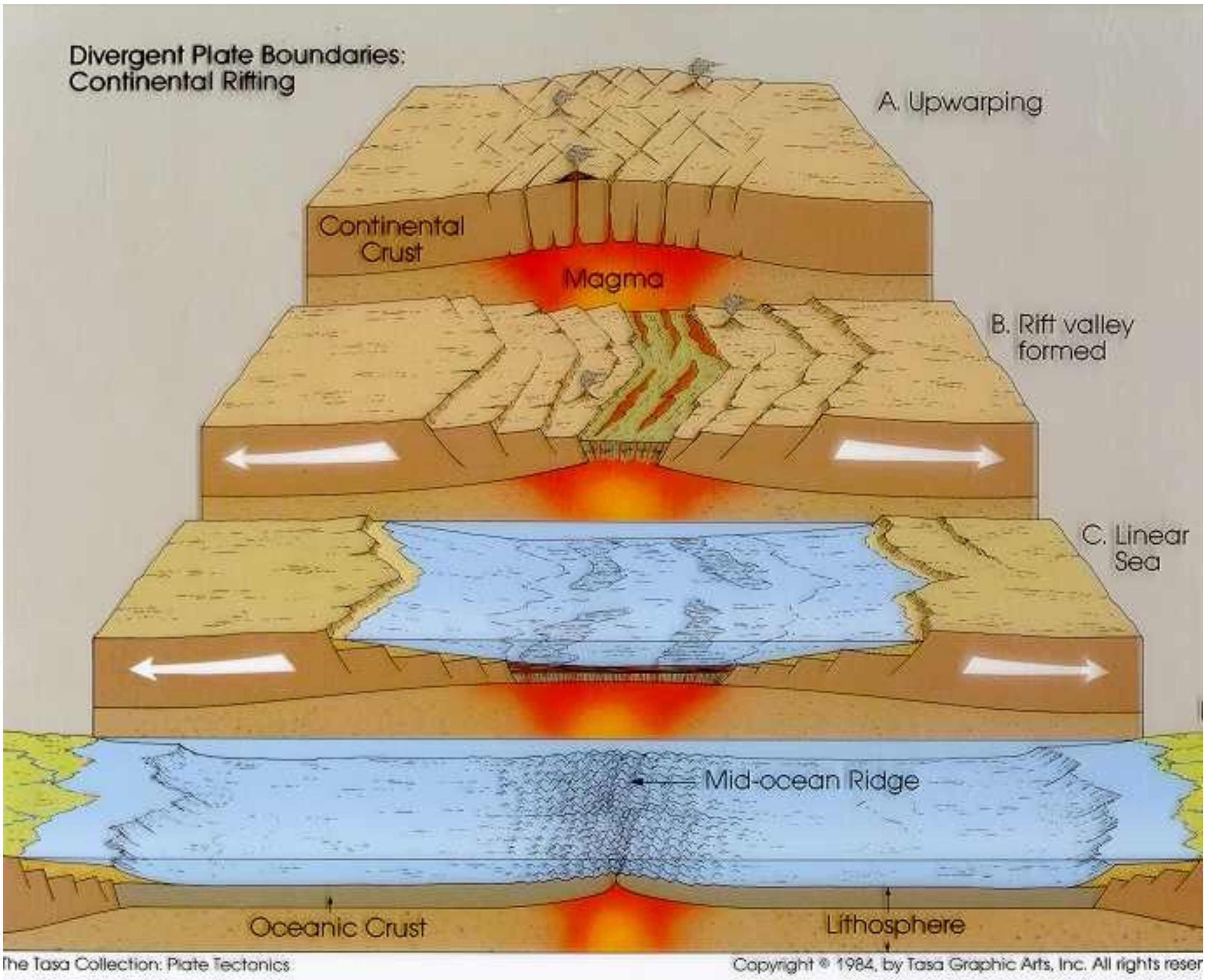



**HEAT** controls the elevation of a supercontinent and its fragments. A supercontinent (*1*), surrounded by subduction zones (where sea-floor material sinks under the continent), remains stationary in relation to the underlying mantle. Heat accumulates under it, buoying it upward. After the supercontinent breaks up (*2*), fragments subside as they drift away. A fragment that stays in place (*center*) remains elevated. Present-day Africa is one example of such a stationary fragment.

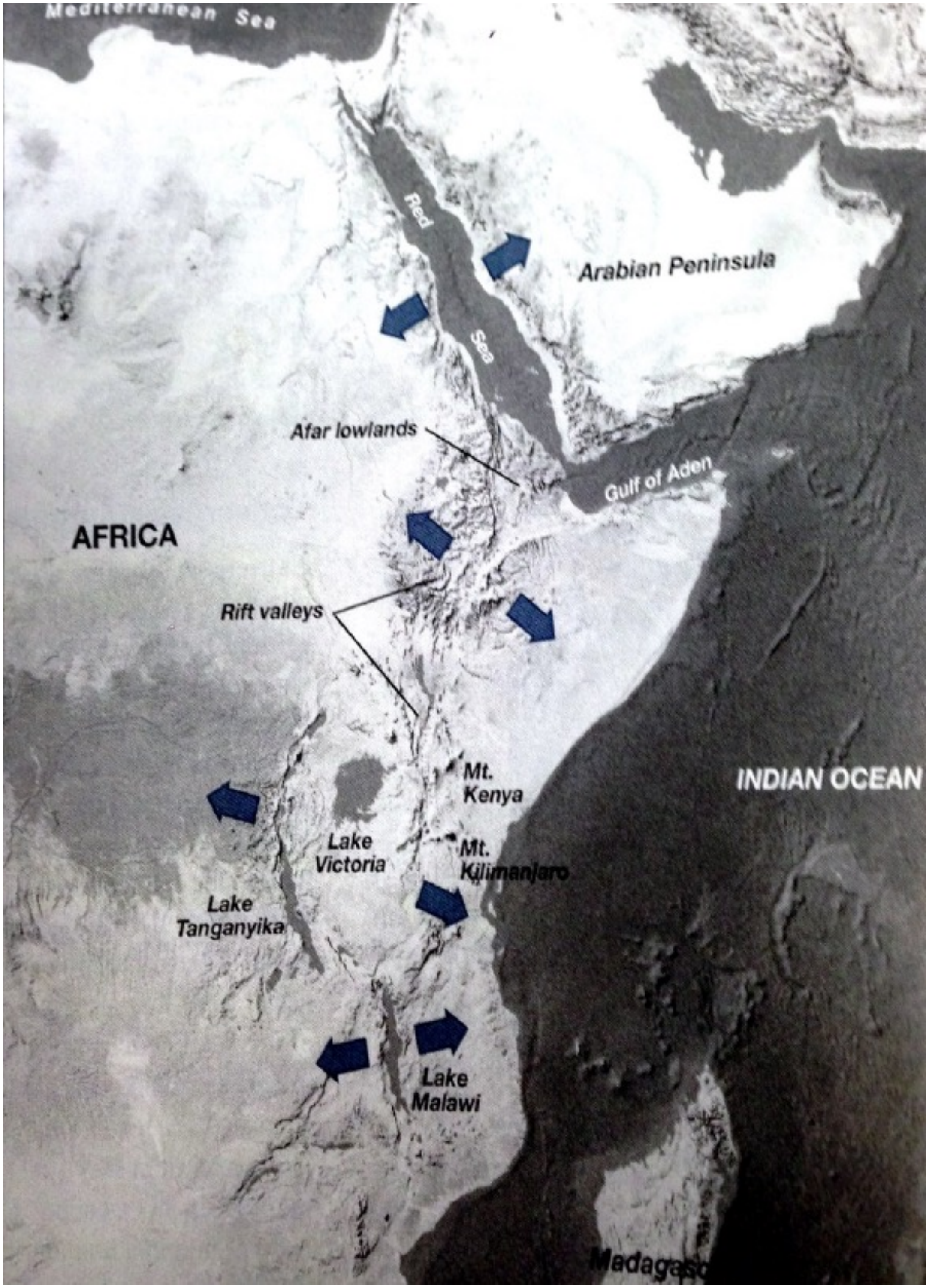


Nance et al 1988

# Rift Valley Formation



# Rift Valleys of East Africa



| event | years before present |
|---|---|
| breakup of Pangea | ~200 million |
| assembly of Pangea | ~300–250 million |
| breakup of Pannotia | ~550 million |
| assembly of Pannotia | ~600 million |
| breakup of Rodinia | ~760 million |
| assembly of Rodinia | ~1.1 billion |
| assembly of Nuna/Columbia | ~1.8 billion |
| assembly of Kenorland | ~2.5 billion |
| assembly of Ur | ~3.0 billion |

supercontinent timeline

**Figure 3. At least six supercontinents have assembled through geologic history.**

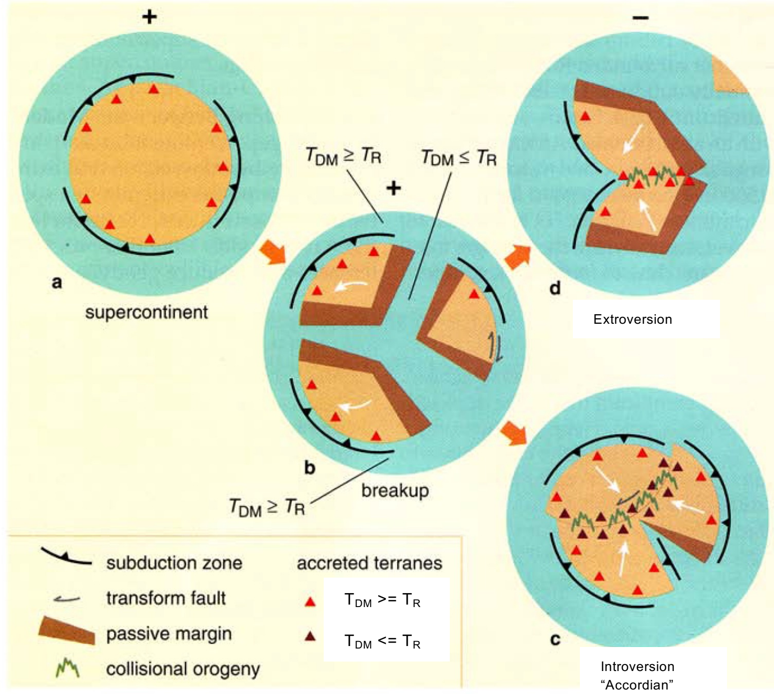
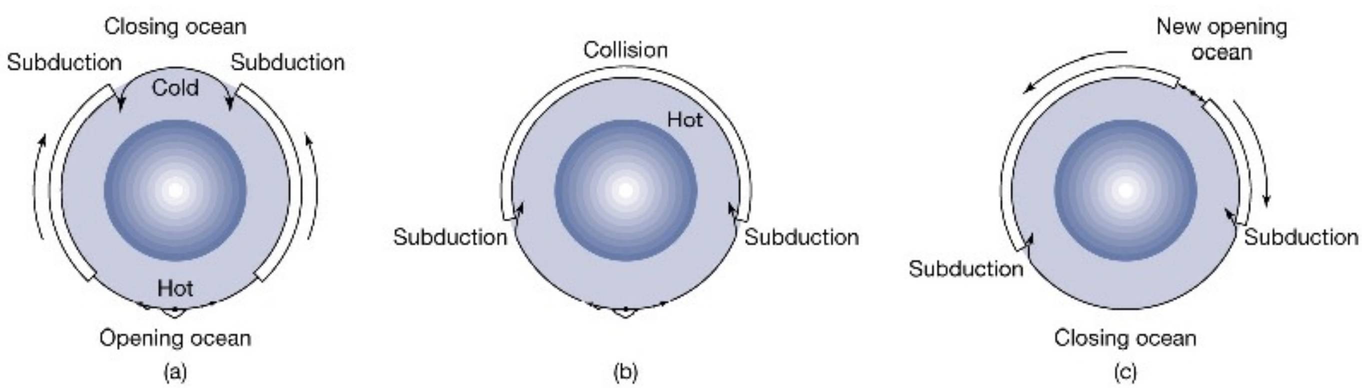



**Figure 5. Schematic shows the possible stages in supercontinent breakup and amalgamation. The supercontinent is flanked by an exterior ocean with subduction zones and volcanic complexes *(red triangles)* around its margins *(a)*. At the time of rifting ($T_R$), the breakup of the supercontinent creates a new interior ocean *(b)*. At this stage, there are two distinct types of oceans: An exterior ocean surrounds the dispersing continental fragments and contains oceanic lithosphere with a depleted mantle age ($T_{DM}$) older than $T_R$, and an interior ocean consists of relatively new oceanic lithosphere with $T_{DM}$ younger than $T_R$. The age of the fragments of oceanic lithosphere accreted to the continents when they reunite thus holds the key to the mechanism of amalgamation. If the interior ocean closes so that the next supercontinent is formed by introversion (accordion motion), then accreted oceanic lithosphere will be younger than $T_R$ *(c)*. But if an exterior ocean closes so that the next supercontinent is formed by extroversion, then accreted oceanic lithosphere will be primarily derived from exterior ocean, and will be older than $T_R$ *(d)*.**

Murphy & Nance 2004

Extroversion



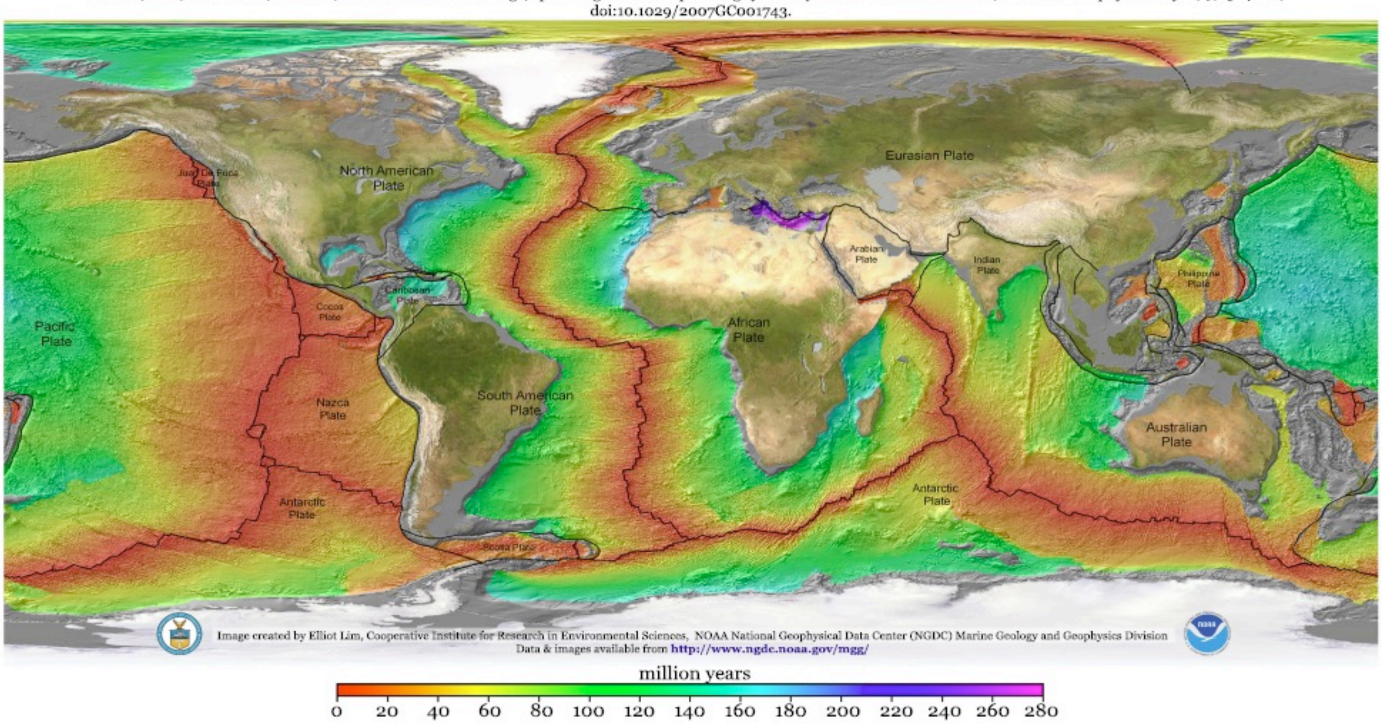


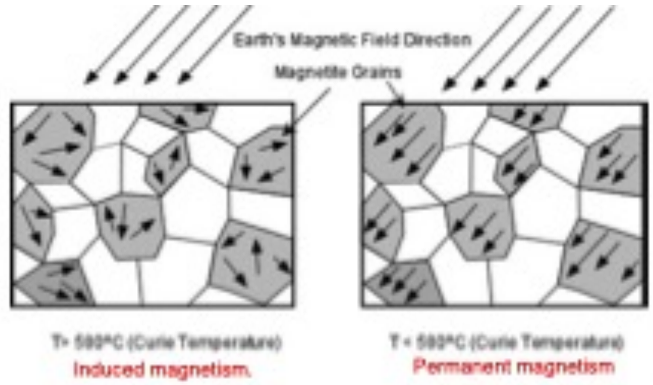

Kump et al. 2004

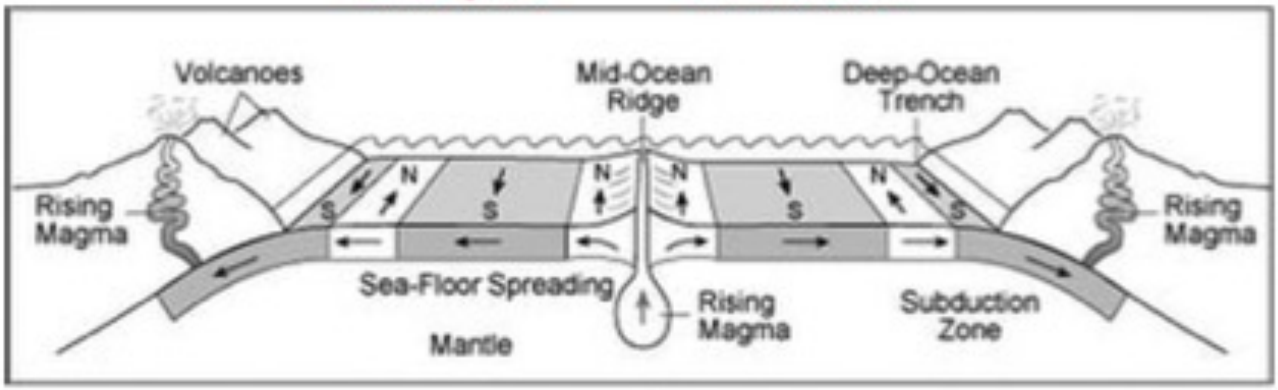
# Age of Oceanic Lithosphere (m.y.)

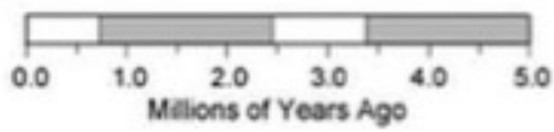
**Data source:**

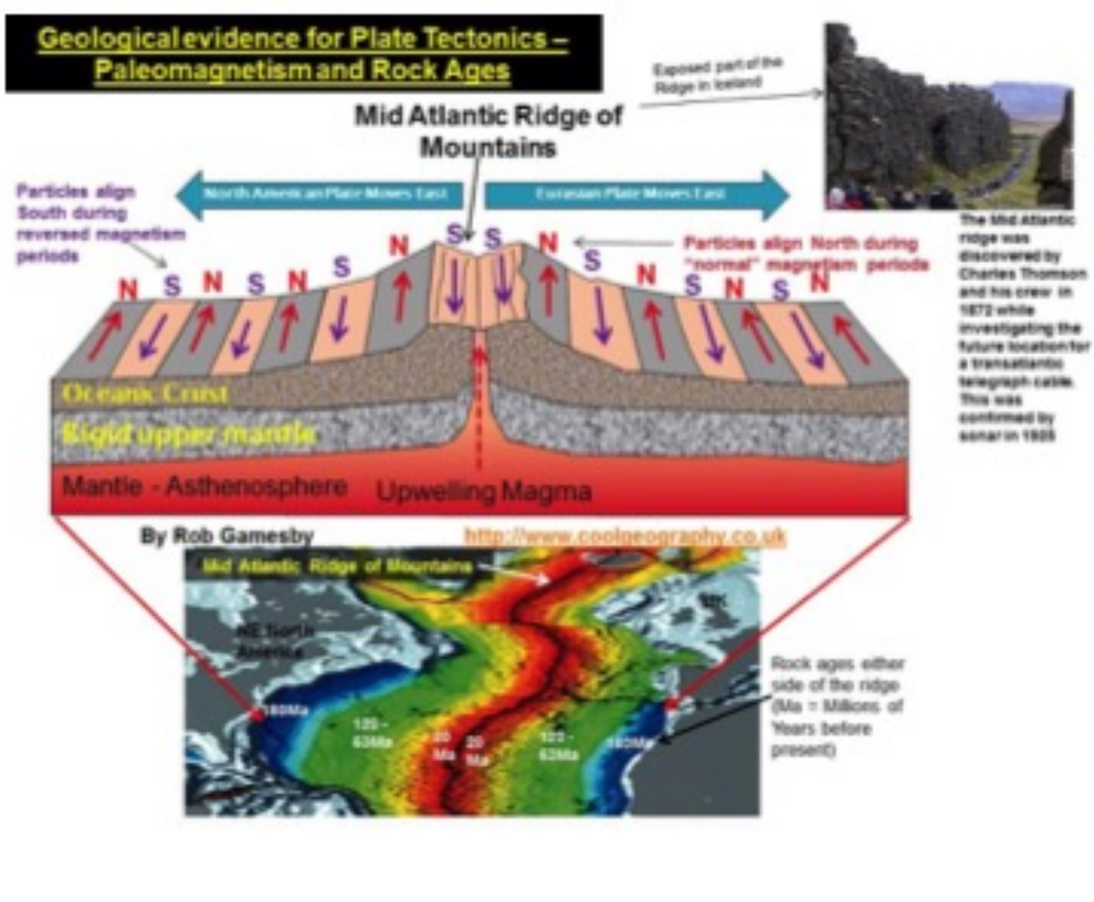
Muller, R.D., M. Sdrolias, C. Gaina, and W.R. Roest 2008. Age, spreading rates and spreading symmetry of the world's ocean crust,Geochem. Geophys. Geosyst., 9, Q04006, doi:10.1029/2007GC001743.




Earth's Magnetic Field Direction
Magnetite Grains
T> 580°C (Curie Temperature)
Induced magnetism.
T < 580°C (Curie Temperature)
Permanent magnetism


Volcanoes
Mid-Ocean Ridge
Deep-Ocean Trench
Rising Magma
Rising Magma
N
S
Sea-Floor Spreading
Rising Magma
Subduction Zone
Mantle


0.0
1.0
2.0
3.0
4.0
5.0
Millions of Years Ago


Geological evidence for Plate Tectonics – Paleomagnetism and Rock Ages
Exposed part of the Ridge in Iceland
Mid Atlantic Ridge of Mountains
Particles align South during reversed magnetism periods
Particles align North during "normal" magnetism periods
The Mid Atlantic ridge was discovered by Charles Thomson and his crew in 1872 while investigating the future location for a transatlantic telegraph cable. This was confirmed by sonar in 1925
Oceanic Crust
Rigid upper mantle
Mantle - Asthenosphere
Upwelling Magma
By Rob Gamesby
http://www.coolgeography.co.uk
Mid Atlantic Ridge of Mountains
Rock ages either side of the ridge (Ma = Millions of Years before present)

# Appalachians Triggered Ancient Ice Age

By JR Minkel

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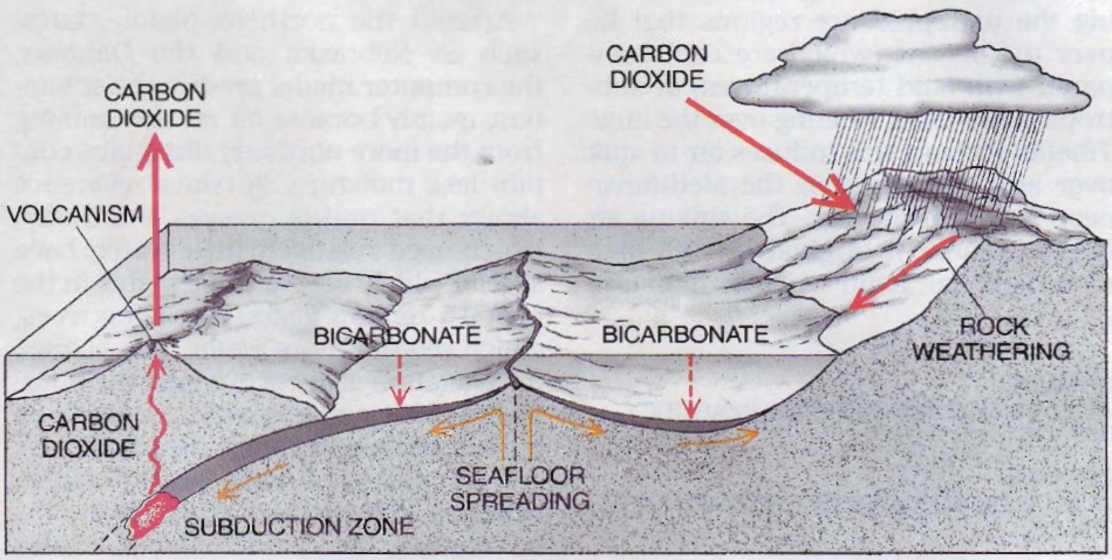
**COLD SNAP:** The rise of the Appalachians seems to have sucked carbon dioxide from the atmosphere, triggering a previously puzzling ice age 450 million years ago.


The rise of the Appalachian Mountains seems to have triggered an ice age 450 million years ago by sucking $CO_2$ from the atmosphere. Researchers report evidence that minerals from the mountain range washed into the oceans just before the cold snap, carrying atmospheric carbon dioxide with them. The result clarifies a long standing paradox in the historical relationship between $CO_2$ and climate, experts say.

At the start of the so-called Ordovician ice age, about 450 million years ago, the planet went from a state of greenhouse warmth to one of glacial cold, culminating in mass extinctions of ocean life. This period has always posed a problem for climate modelers, notes geologist Matthew Saltzman of Ohio State University. "The models for $CO_2$ that span that interval have always shown levels that are much too high to have an ice age," he explains. "That was a real paradox." Researchers believe that the last ice age, which began 40 million years ago, was kicked off by the rise of the Himalayas during the collision of tectonic plates and a corresponding plunge in atmospheric carbon dioxide. Ocean deposits of calcium carbonate, or limestone, indicate that $CO_2$-rich rainwater stripped calcium and strontium from the Himalayan rock; these elements fused with the carbon dioxide and spilled into the sea, effectively pulling carbon from the atmosphere.

The same chemical weathering commenced before the Ordovician ice age, Saltzman and his student Seth Young reported today at a meeting of the Geological Society of America. The pair analyzed the ratio of strontium isotopes in rocks from Nevada and Europe that date to the Ordovician climate reversal. Right before the ice age begins the ratio becomes low in strontium 87, which accumulates as rock ages, suggesting weathering of relatively young rock. And indeed at that time the Appalachians would have been forming from a Japan-like arc of islands smashing onto what is now North America. "We have pretty good evidence that in fact there was a weathering event that had to involve a significant removal of carbon dioxide," Saltzman says. "If you include the strontium data [in $CO_2$ models] then you can very easily force the drop in $CO_2$ that hadn't been there."

The result helps clear up a "particularly enigmatic" ice age, says geoscientist Lee Kump of Pennsylvania State University. "Solving the enigma is an important step forward" in building confidence in the relationship between $CO_2$ and climate change, he says.




**CHEMICAL WEATHERING occurs when atmospheric carbon dioxide dissolved in groundwater attacks silicate and other rocks to form bicarbonate, which is carried into the ocean and incorporated into the shells of marine biota. The carbon dioxide reenters the atmosphere many millions of years later in the cycle of subduction and seafloor spreading. Plateau uplift in the past 40 million years could have accelerated the chemical weathering cycle by creating monsoon rains and rapid runoff on freshly faulted slopes. These changes may have significantly decreased atmospheric carbon dioxide levels, lessened the greenhouse effect and cooled the climate worldwide.**

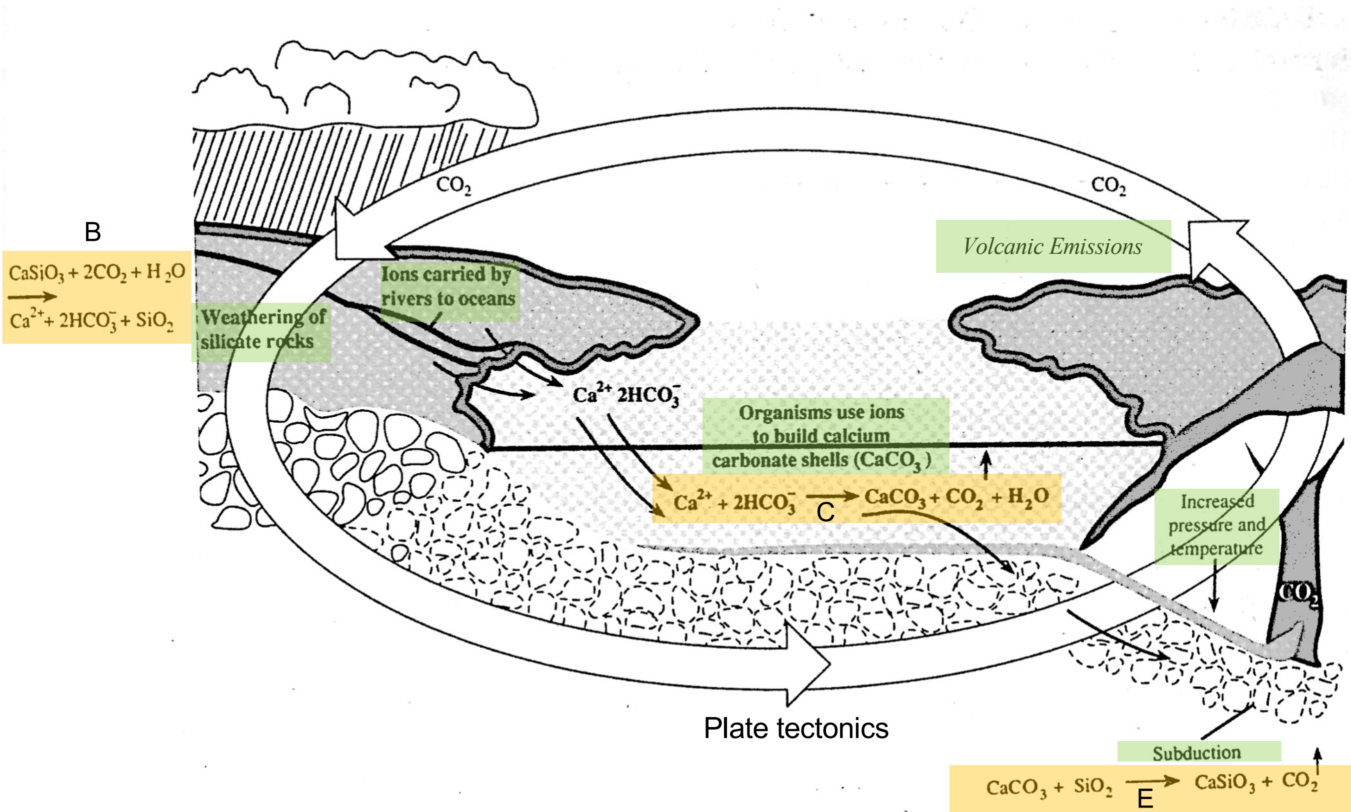


Ruddimann and Kutzbach 1991

Berner and Lasaga 1989

# The silicate weathering $CO_2$ thermostat

*Regulates atmospheric $CO_2$ and climate on geologic time scales.*




Only works for silicate rocks!

*Doesn't work for limestone.*

**A** CARBONATE ROCK WEATHERING

$CO_2 + H_2O + CaCO_3 \rightarrow Ca^{++} + 2HCO_3^-$

**B** SILICATE ROCK WEATHERING *Temperature, moisture, & $CO_2$ sensitive*

$2CO_2 + H_2O + CaSiO_3 \rightarrow Ca^{++} + 2HCO_3^- + SiO_2$

**C** CARBONATE FORMATION IN OCEANS

$2HCO_3^- + Ca^{++} \rightarrow CaCO_3 + CO_2 + H_2O$

**D** SILICATE WEATHERING PLUS CARBONATE FORMATION (REACTIONS B + C)

$CO_2 + CaSiO_3 \rightarrow CaCO_3 + SiO_2$ ⇦ ***Urey Reaction***

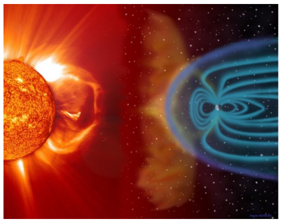
Igneous Rock Sedimentary Rock

**E** METAMORPHIC/MAGMATIC BREAKDOWN OF CARBONATE

$CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$

***Rate of tectonic activity (mtn. uplift & volcanic degassing) controls the set-point of the "thermostat" creating hot-house or ice age conditions***

Protection from solar wind.



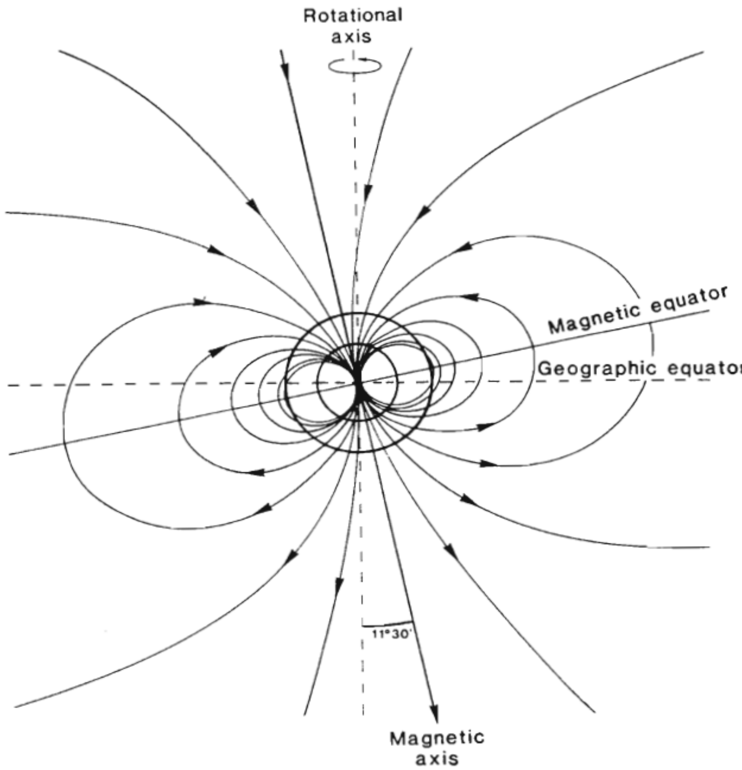
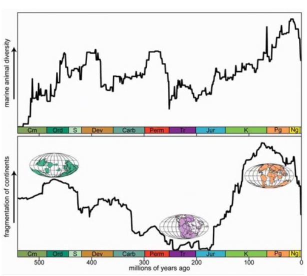


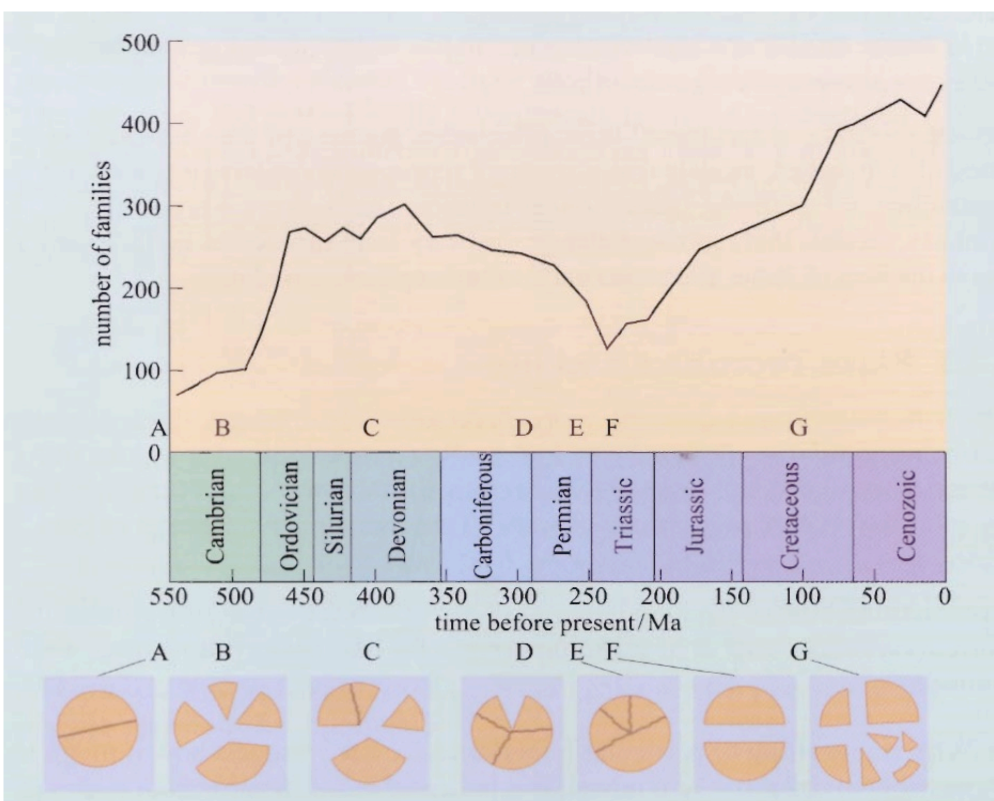

FIGURE 10.16 The earth's geomagnetic field. The geomagnetic field is derived from the observed magnetic field by removing irregularities. The geomagnetic field is a dipole field with the north geomagnetic pole in Antarctica (78°30′S, 110°10′E) and the south geomagnetic pole on the northwestern coast of Greenland (78°30′N, 68°50′W). The geomagnetic axis forms an angle of 11°30′ with the rotational axis.

Emiliani 1995

Diversity of benthic shelf-dwelling invertebrates



Zaffos et al. 2017 PNAS




Valentine and Moore 1970
Adapted by Cockell et al. 2007