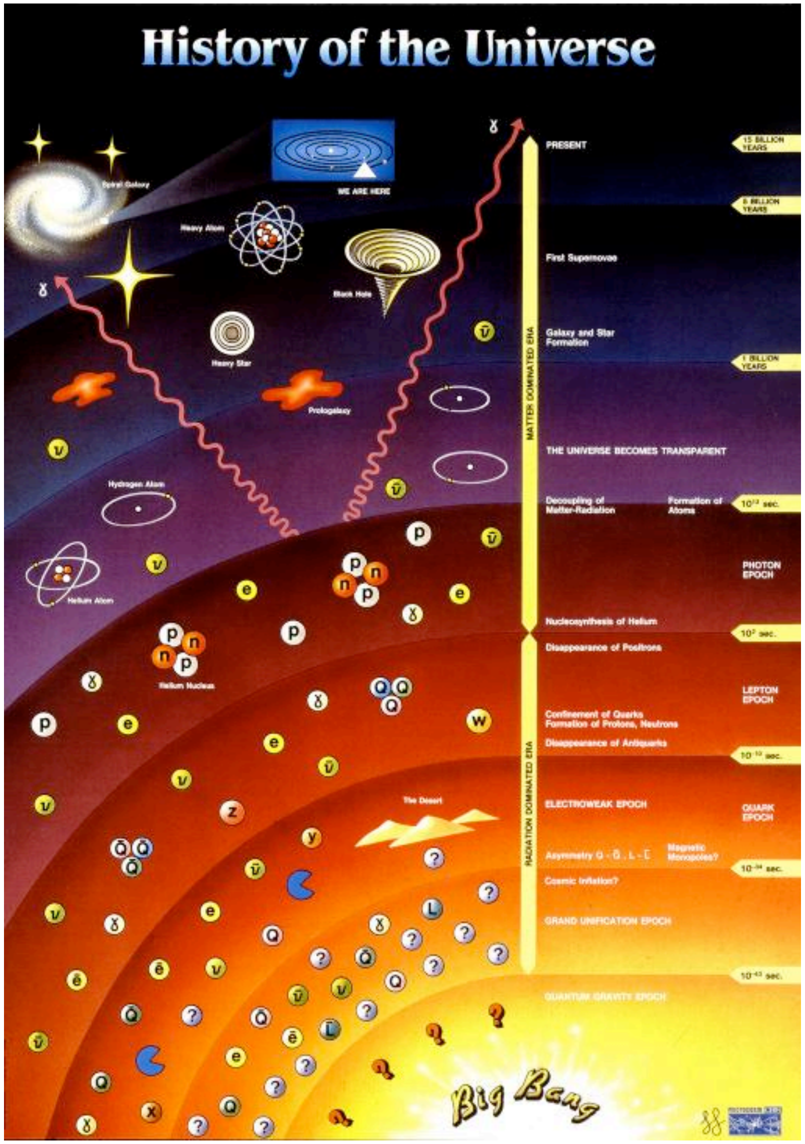
The Archean: 4.6-2.5bya

1-the formation of the Earth (the last stage of the formation of the solar system and the Big Bang

2- the evolution of the atmosphere and hydrosphere

3-the evolution of life

Our universe formed ~15by bp with the "big bang"



Step 5: at 3min, nuclei form

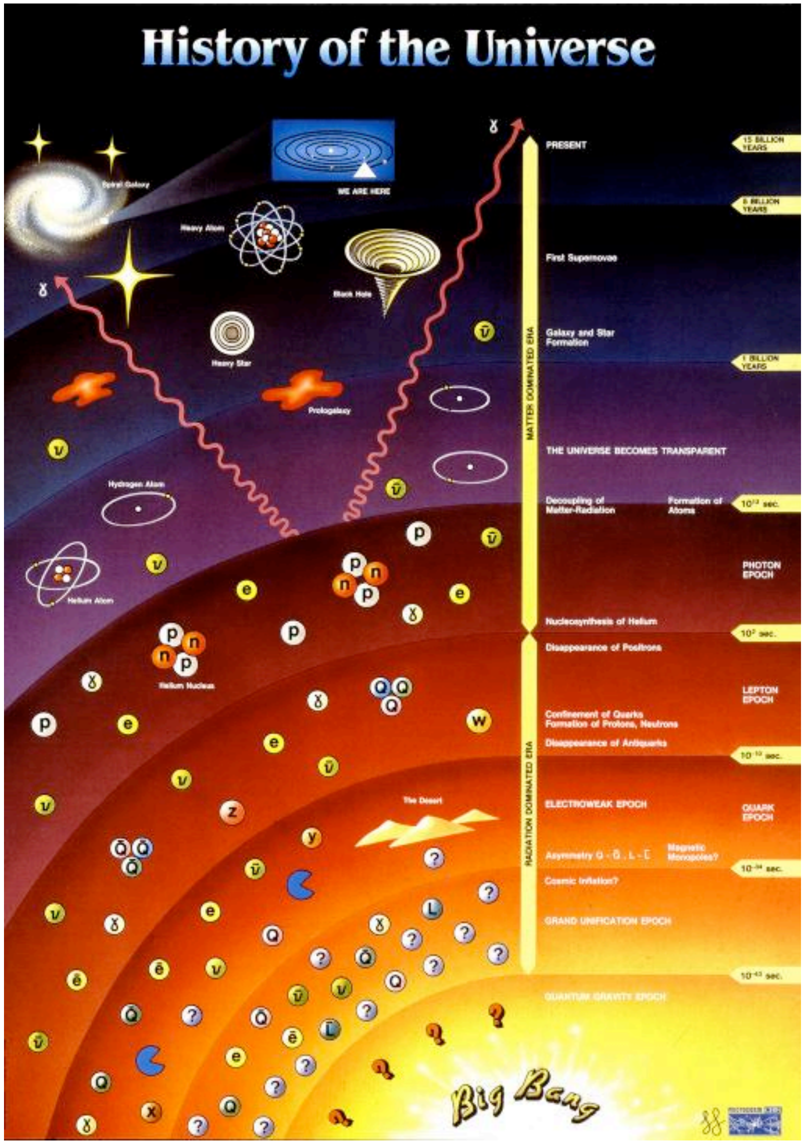
Step 4: at 0.01 sec protons & electrons form

Step 3: 10^{-12} to 0.01 sec: 4 forces become distinct

Step 2: 10^{-35} to 10^{-12} secs quarks & anti-quarks form

Step 1; the first 10^{-43} secs the 4 fundamental forces (gravity, weak,strong,electromagnetic form

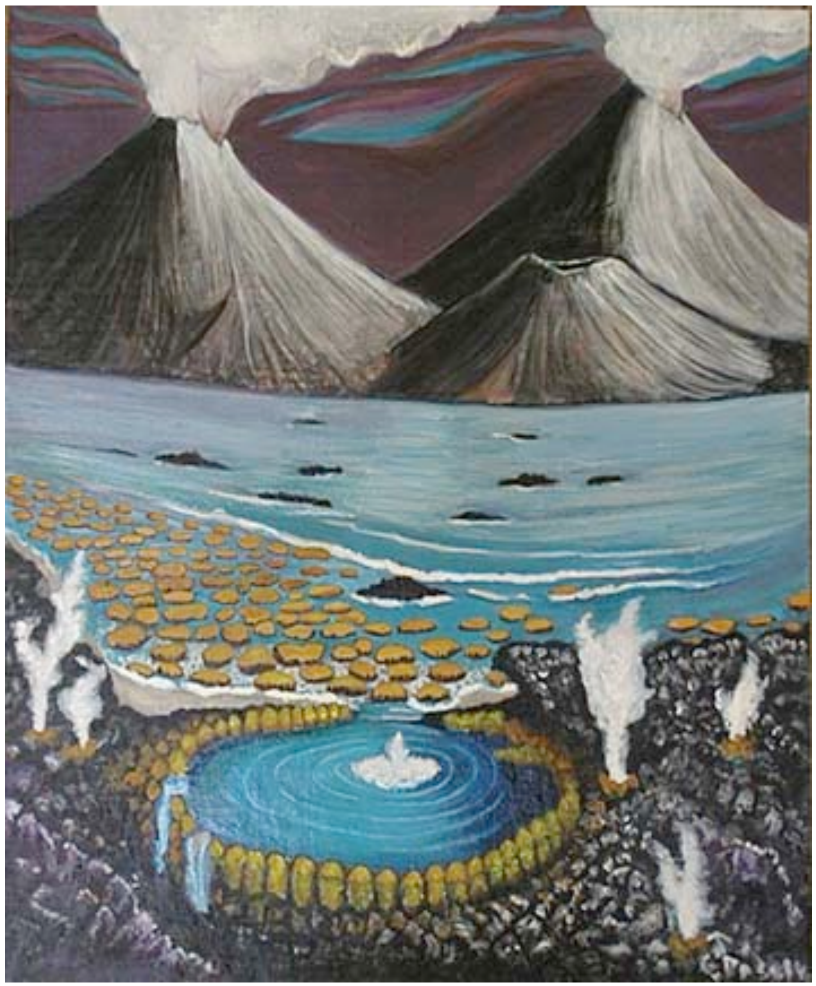
History,cont.



At 1 by after the Big Bang the galaxies and stars form from gravitational collapse
Our own galaxy forms ~10 by after the Big Bang (~4.6bybp)

What was happening on Earth between 10 by and 4.6by ? Condensation, cooling, differentiation of core, mantle, and crust.

Artist's rendition of the Archean world: shown in the background are abundant volcanoes, in the foreground are hot springs and stromatolites



The Archean included events such as:

- Formation of the moon, from the collision of a planetoid and the earth: 4.6-4.2 by bp
- Formation of crust: continents and ocean: oldest continental crust: 4.2-4.1by bp
- High rates of meteorite bombardment on the Earth's surface between 4.6-4.2 by bp
- Formation and evolution of atmosphere and hydrosphere between 4.6 and 3.1-2.6 by bp
- Evolution of life between 4.2 and 3.5 by bp: C_{13} indicates C_{12} uptake of life by 3.5by
- Ductile (non-brittle) deformation: pre-plate tectonics; major event ~ 2.7-2.3 by bp

Example of meteorites found on Earth, interpreted to represent material found in the Earth's core

Based on estimates of asteroid density in our early Solar system, we think impacts on early Earth were ~ 2000x more frequent than today!

What would Earth be like under constant bombardment?

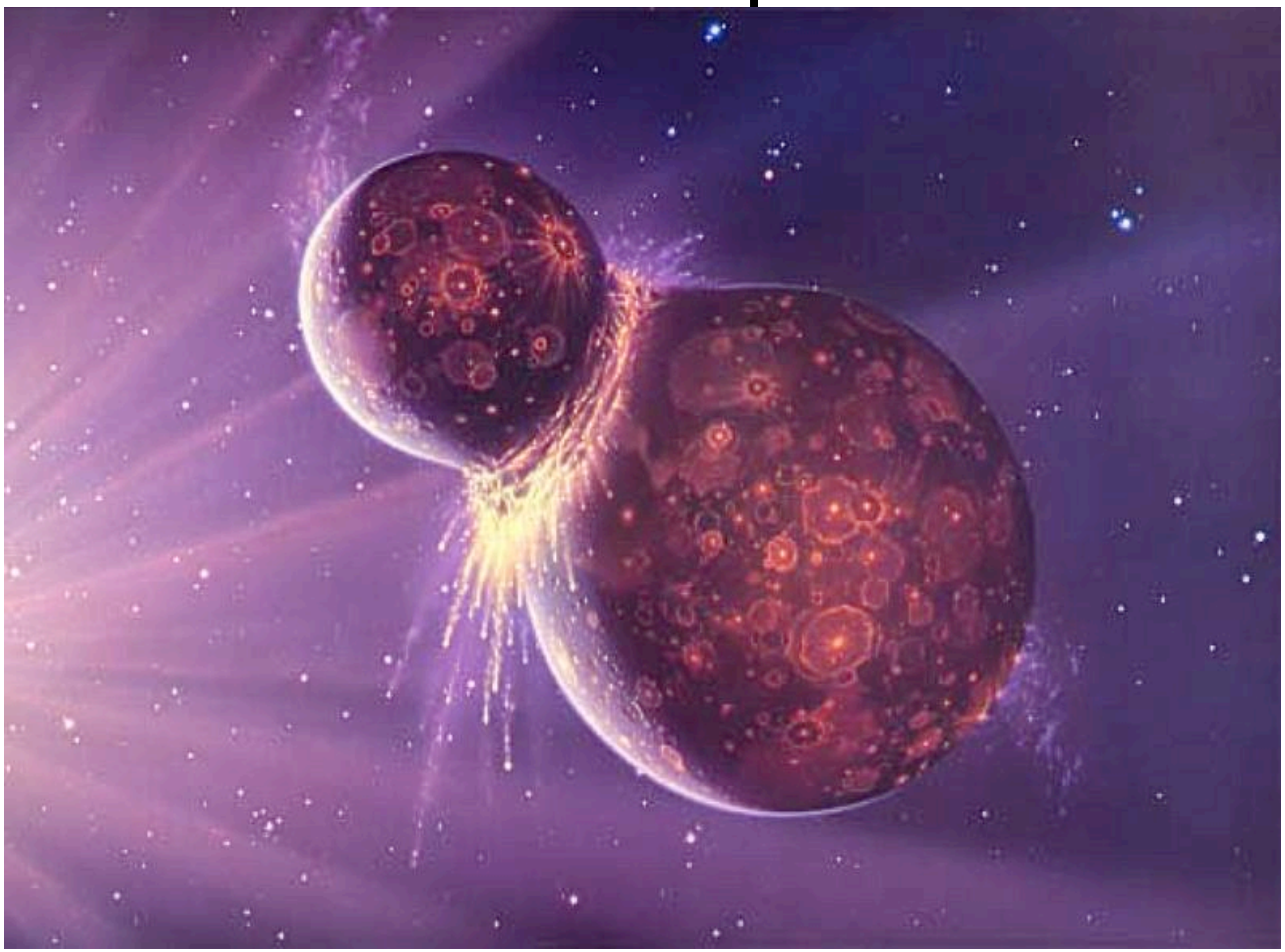
A new 1my old meteorite crater in northern Canada

Differentiation of Earth

- Dense material sinks to the Earth's interior: formation of the core and mantle;
- Less dense material rises towards the surface: formation of crust; degassing to form atmosphere and hydrosphere
- Heat source that drives differentiation is heat from condensation, radioactive decay, heat from bombardment by comets/meteorites

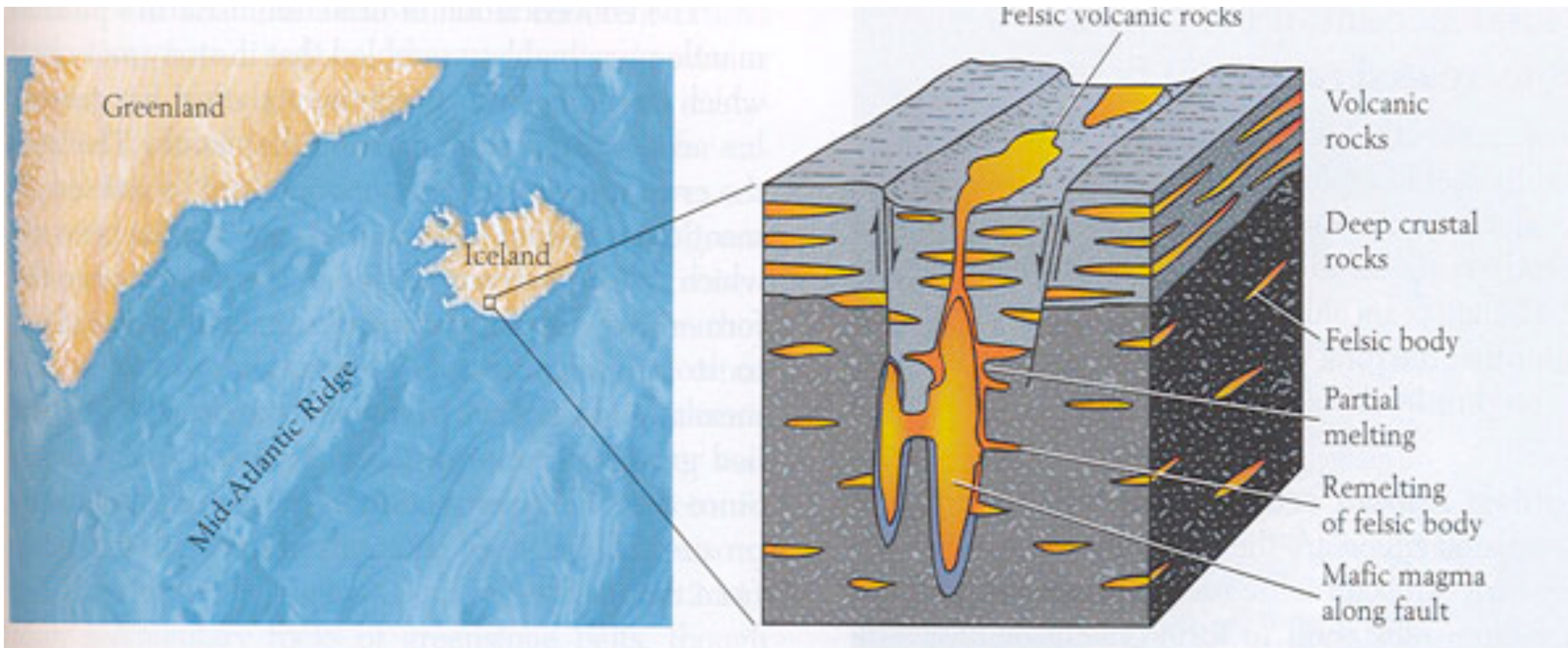
Another artist's rendition of the Archean world….

Formation of the moon, ~4.5 by: collision with a planetoid



The Moon is depleted in Fe, which tells us that when it formed the Earth had already differentiated to produce its core.

As the Earth differentiated, less dense felsic material accumulates to form the continents: a modern example: Iceland



Even though Iceland sits on the mid-Atlantic ridge, the volume of magma is so large, and spreading rates relatively slow, so differentiation of the magma can occur and become more felsic. Oldest continental crust ~ 4.2 - 4.1by; 3by old Pongola Supergroup records shallow water envs (=stable craton)

How did the oceans form?

- Sources of water: volcanic degassing during the differentiation of the Earth; water arriving from meteorites
- The Earth's ocean is ~ 10^{21} kg of water (one billion trillion kg), and a typical comet has ~ one billion billion (10^{15}) kg of water, so only one million comet impacts (10^{6}) are required to generate the present ocean waters (and this assumes no contribution from degassing, which has occurred). Considering that comet/meteor impacts have been 2000x times greater in the Archean, delivery of water to Earth is reasonable.

Evolving oceans

- Early ocean water began a long period of chemical reactions with rocks and gas to come to its present composition, probably by the end of the Archean (2.6by) (since then it's been in chemical equilibrium)
- Over Earth history tidal friction of the Earth/Moon system has slowed the Earth's rotation, so that a day in the Archean was only ~20 hours long; a year was ~450 days. (how do we know this? (1) theoretical calculations based on what we know about today's gravitational forces of the Earth-Moon-Sun system; (2) geologists have identified rocks that they believe represent tidal cycles…

Another artist's view, this one focusing more on the atmosphere, which would have, due to its different composition, diffracted light differently. The sky would not have been blue

The Archean sun was dimmer than today's sun by ~25% - less incoming solar radiation would have Made for a colder Earth's surface, yet we think the early Earth was quite warm. Why? The density of the atmosphere would lead to extreme "greenhouse" conditions (trapped heat). By the end of the Archean (2.6by the Sun was only 16% less luminous than today

How we know the composition of the early atmosphere?

* The presence of un-oxidized minerals- ex, detrital pyrite FeS_2, uranium oxide UO_2 (uranite)
- Formation of banded iron (BIFs): iron dissolved in seawater precipitates out, forming thin layers of unoxidized hematite alternating with chert; iron only goes into solution in the absence of O_2
- The paucity of photosynthesizing organisms to produce oxygen
- Models for the evolution of life require the absence of oxygen to prevent early decay of organic compounds
- Models based on the composition of present day volcanic eruptions: CO, CO_2, SO_4, etc
- The same comets/meteorites that delivered H_2O ice also delivered CO_2

BIF's
(where a lot of the Earth's iron ore comes from)

- "banded iron formations": BIFs
- Made of hematite layered with Fe-rich chert. The hematite is Fe_2O_3. In the presence of free O_2 in the atmosphere ferrous iron (FeO)- the only form of iron that can dissolve in water- would oxidize to make ferric iron and not go into solution. If there was any O_2 gas dissolved in sea water you wouldn't be able to dissolve ferrous iron, and therefore no BIFs

Filling the sinks for oxygen before it can accumulate in the atmosphere

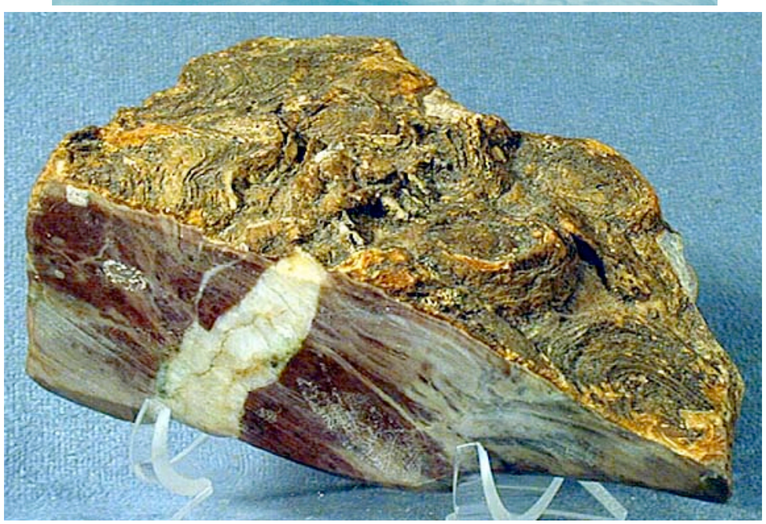
- Before oxygen can accumulate in the atmosphere O_2 sinks or reservoirs on Earth must be filled (chemical reactions on Earth would occur before O_2 could accumulate in the atmosphere)

When did the atmosphere Become oxygenated? What is the youngest age of BIFs and UO_2?

How did oxygen accumulate on Earth?

Marine plants: stromatolites = the plant that produced O_2 through photosynthesis

Modern stromatolites in warm, shallow marine water



A fossil stromatolite of ~3by age from Canada

Until stromatolites became

abundant on earth around 2by ago, there was no mechanism to produce O_2 in any quantity

Oldest stromatolites ~3.5by

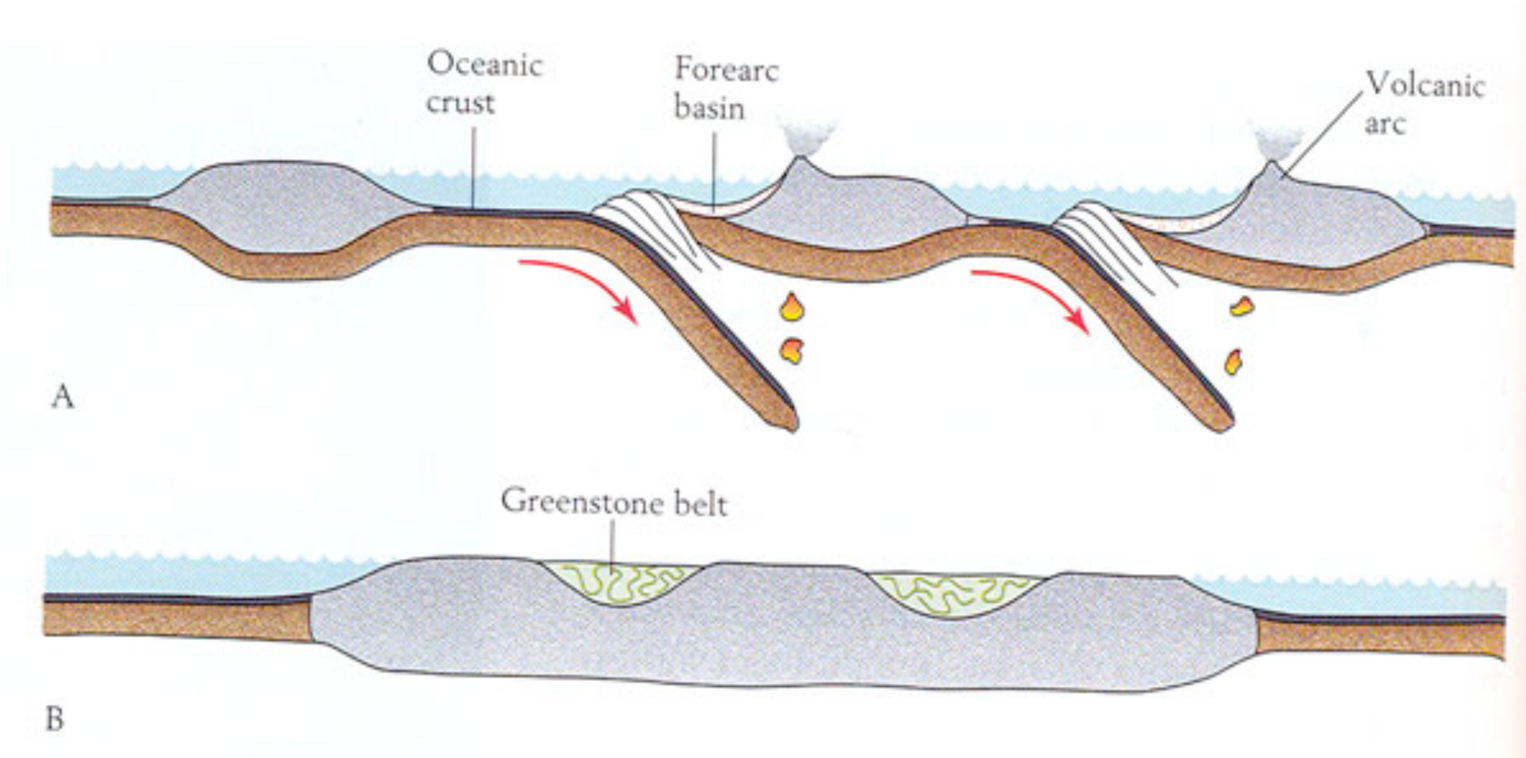
Oxygenating the atmosphere: 3 stages

- The reducing world: atmospheric O_2 levels 10^{-8} to 10^{-14} present day. BIF's, UO_2 form; ~4.56 - 2.6 by
- The oxidizing world: pyrite, UO_2 unstable, ferrous iron doesn't dissolve in seawater, but not enough O_2 to sustain aerobic respiration; hypothesized to be ~2.2 - 2by ago.
- The aerobic world: enough atmospheric O_2 to sustain aerobic respiration; possibly around 1.7 by- in the Proterozoic Eon

Not only were the Archean atmosphere and hydrosphere different, so was the lithosphere

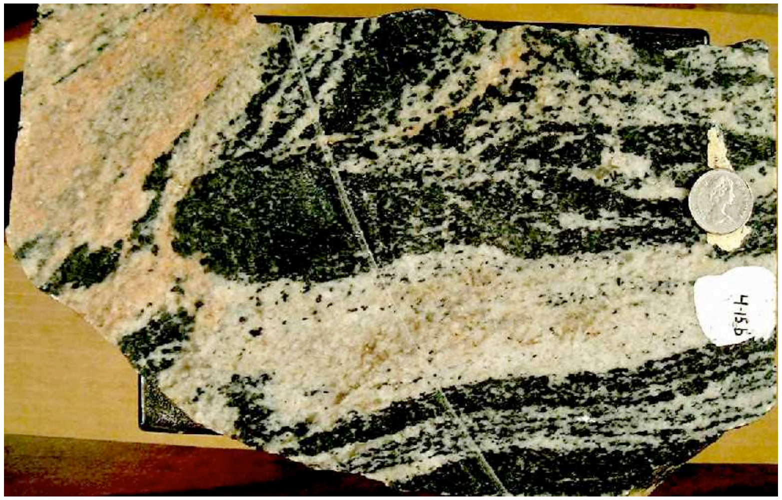
- When the Earth formed, it was hot, as rocks formed they were not cold enough to be brittle: when stressed they would flow, not break…..no plate tectonics!

We need to come up with other models to explain what we see in rocks 3.6 - 2 by old



A model for pre-plate tectonics deformation: greenstone belts. Small, scattered volcanoes and proto-continents, deep ocean basins between them, high temperatures and metamorphism as accretion occurs. The metamorphosed basalts and ocean sediments are green (chlorite-rich)

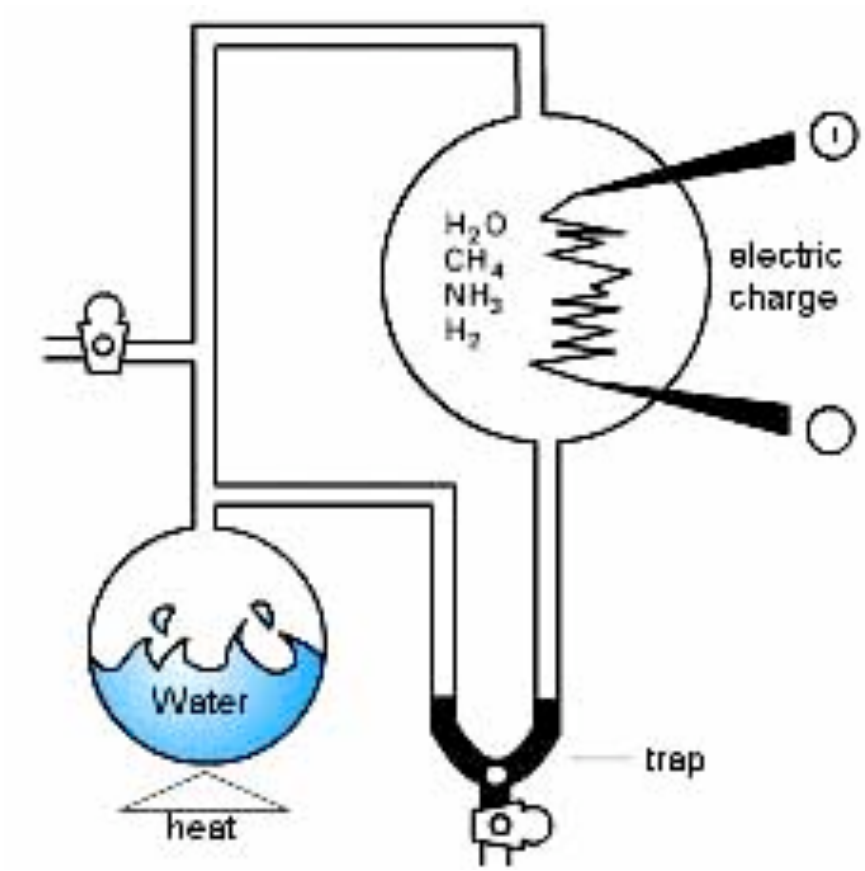
Examples of deformed Archean rocks



Earliest forms of life: some important terms

- Bacteria - simplest form of life; 1 of 6 kingdoms of life
- archaebacteria = the most primitive bacterial form (modern forms are eubacteria)
- Procaryote: "pre-nucleus". Cells which lack organized reproductive and metabolic cell of a nucleus containing RNA &DNA
- Eucaryote: "true nucleus" more advanced cell organization; the basis to advanced life

How did life evolve on Earth?
The 1953 Miller and Urey experiment



What do we need to have “life”?

- Metabolize
- Reproduce
- Cell wall for protection
- Key elements: P, trace Ni, Zn

The chemical compounds that perform metabolism and reproduction are proteins, which are built from more simple chemical compounds termed amino acids. Proteins combine to form nucleic acids, including RNA,DNA

Amino acids are simple to produce in the lab; they have been found in meteorites from space

The first forms of life on earth were cyanobacteria

- Shown below are drawings of inter-twined growths of bacteria which contain primitive chloroplasts for photosynthesis. Shown above is a photograph of a modern example of this from the Black Sea

A modern analogue for where life may have evolved

- Shown below is a photo of a modern "black smoker" - an undersea hydrothermal vent associated with a mid-ocean rift. The gasses spewing from the undersea volcano are sulfur, methane, and CO_2-rich.
- Upper photo of life forms living around black smokers; adapted to a sulfur-rich environment

chemosynthesis

- Life forms that use the energy generated from chemical reactions to metabolize
- $S + H_2 = H_2S$ + energy or

$CO_2 + 4H_2 = CH_4 + 2H_2O$ + energy

An example of *heterotrophy*- assimilating chemical compounds from the surrounding water

Versus: organisms that photosynthesize use sunlight to drive metabolic reactions or are *autotrophic*

Evidence that life may have evolved around "black smokers"

- Abundance of mid-ocean ridges and their size = lots of niches
- Easy dissolution of chemicals in warm sea water
- Reducing conditions
- Protection from UV radiation
- Abundance of phosphorus, metals (Ni, Zn)
- Abundant clays: sites for adsorption
- See modern examples

Even though earliest life forms are preserved in shallow water rocks, life may have evolved in deep water env., which is not preserved

The sequence of steps (5) in the evolution of life

- The **pre-biotic world**:

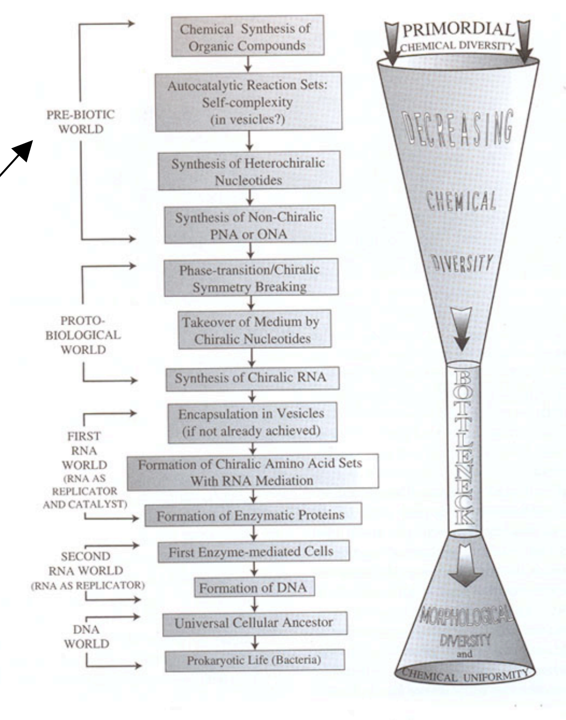
 1. The chemical synthesis of organic compounds

 2. “autocatalytic” reactions - fm of proteins

 3. Chemical synthesis of

 nucleotides; requires “vesicles”

(possibly sites on clay grains?)



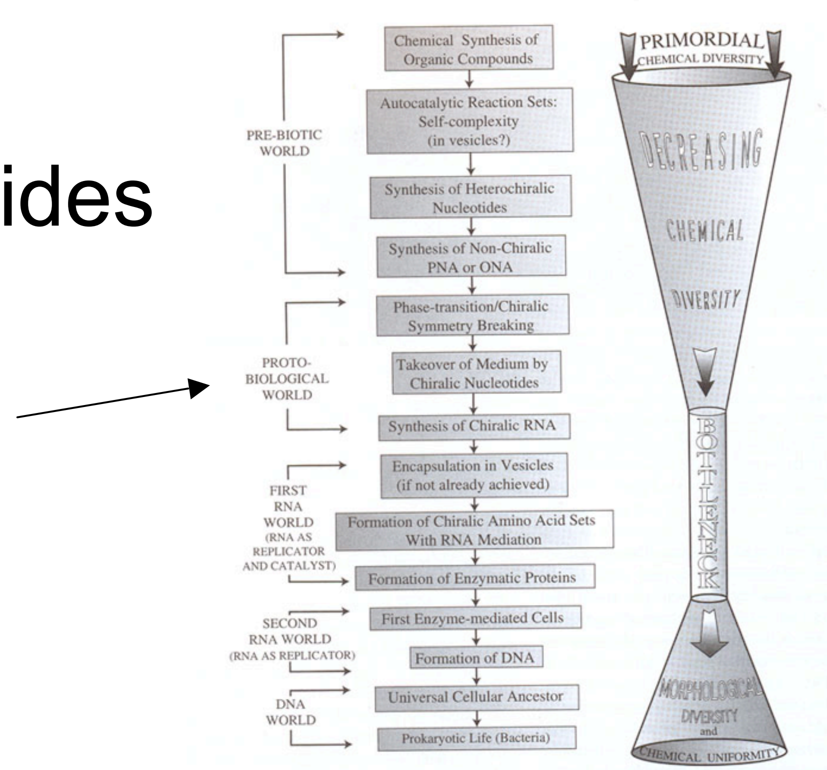
Cont..

- **Proto-biological world**

1. Symmetry of protein chemical compounds

2. Symmetry breaking dominated by nucleoutides

3. Development of RN



Cont….

- **RNA world**

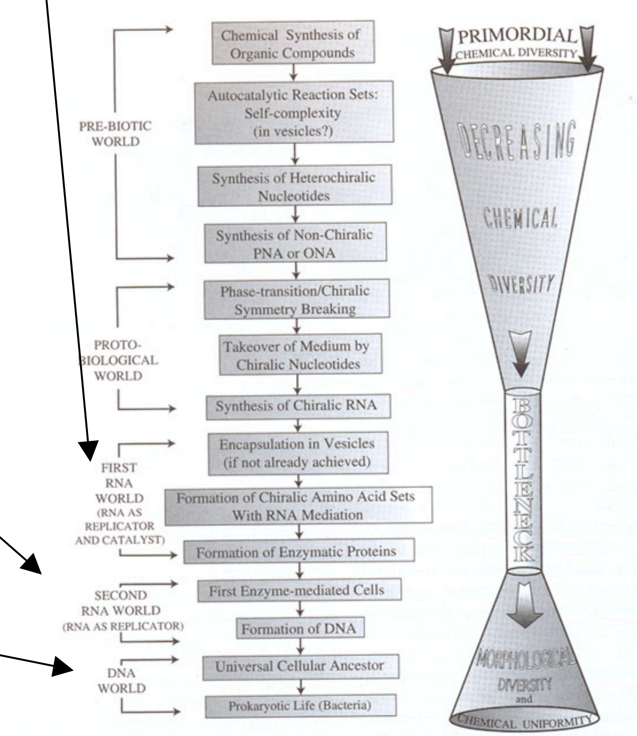
  1. Encapsulation in vessicles (proto-cell)
  2. Diversification of amino acids with RNA mediation
  3. Formation of enzymatic proteins

- **Second RNA world**

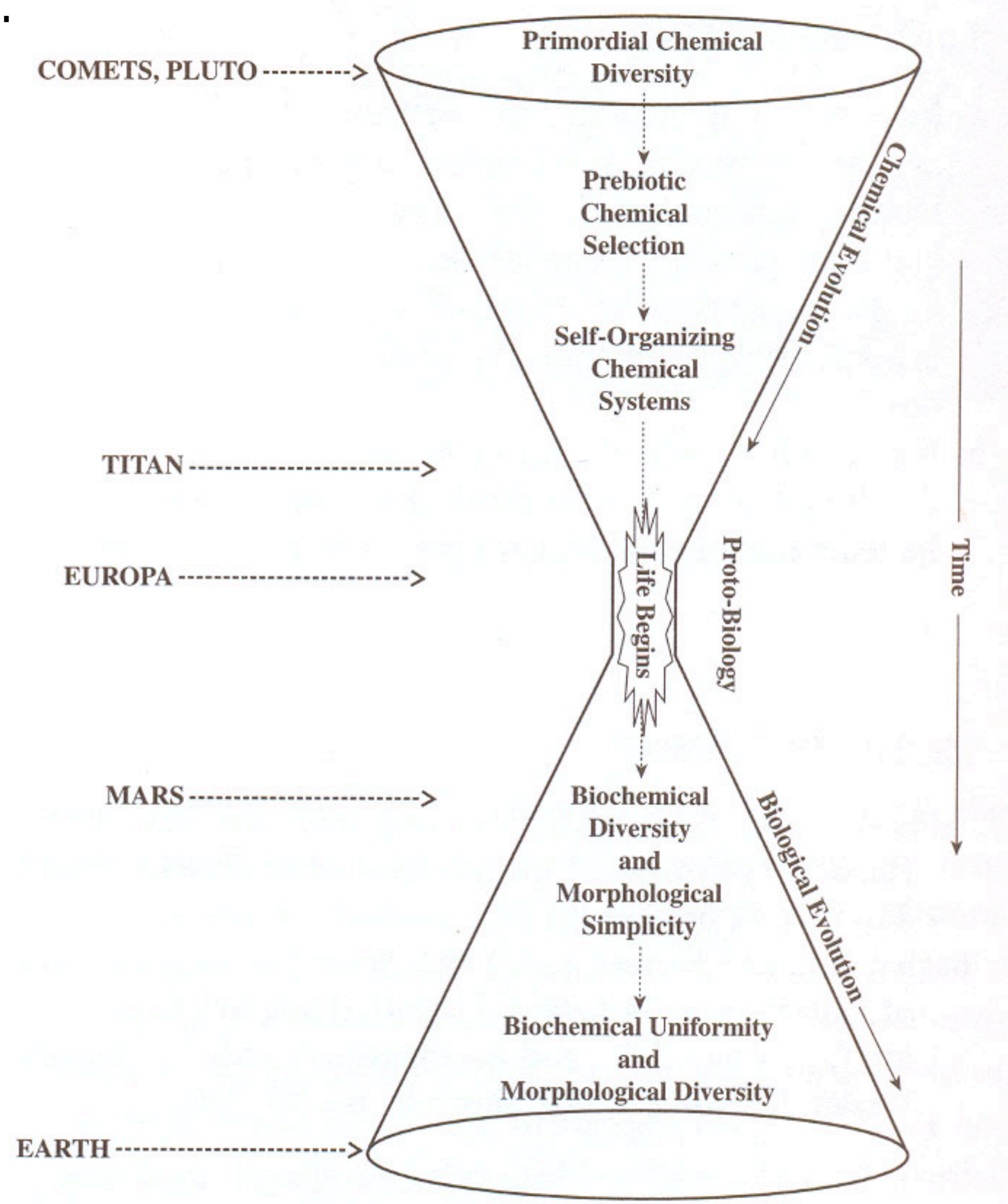
  1. First enzyme-mediated cells
  2. Formation of DNA

- **DNA world**

  1. Universal cellular ancestor
  2. Procaryotic life (archaeobacteria)



If we translate the sequence of steps necessary to form life to the solar system……

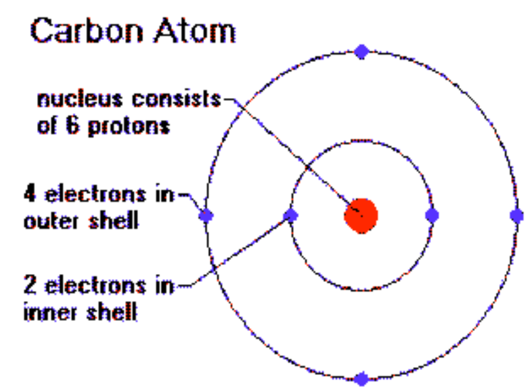


Why carbon-based life forms?

- Of all elements, C possesses the greatest tendency to form covalent bonds, including bonding with itself
- Relatively small size atom
- Builds a variety of bond structures: long-chains, sheets, rings (= wide variety of structures = greater potential information content, or diversity). Alphabet analogy:

  26 characters to make words and sentences whereas a computer uses binary code (0,1) to carry information. It can convey the same information as the 26 letter code, it just needs to string together longer "sentences")
- 4th most abundant element on Earth,

being made from helium fusion in stars



Why water?

- Exists in all states of matter on Earth
- Hydrogen bonds are strong
- Catalyst for chemical reactions - the medium within which reactions take place; transport of reactants

Light? Oxygen?