Precambrian Eon

Plate Theory

- About 4 billion years ago the earth had cooled enough to form geological Plates.
- The original basaltic crust is strengthened by granite and intermediate rocks, thus forming the first stable masses, protocontinents
- These masses formed the nuclei around which the first continents developed

The oldest land surface

- A zone of petrified land (palaeosoil) was found in Australia at the age of 3.46 billion years. Thus continental masses above the sea surface.

- First signs of weathering, erosion, soil formation.

- The presence of zirconium mineral granules from W. Australia at 4.4 billion years suggests disintegration of already formed rocks and the presence of water in liquid form

Evolution of the atmosphere and the hydrosphere

The first atmosphere

- The first atmosphere of the earth did not contain free Oxygen.
- It originated from gases most likely associated with comets and meteorites that hit on the earth during the early stages of its formation.
- From volcanic activity

Comet gases

- Comets consist of frozen gases, ice and dust.

- The comet of Halley consists of:
  80% ice (water)
  Frozen CO_2 (dry ice)
  Cloud of H_2 encloses the comet
  The dust around the core contains Fe, O, Si, Mg, Na, S, C.

Meteorite gases

- Calcitic chondrites consist mainly of silicate minerals but also contain:
  N
  H_2
  water
  C in the form of complex organic molecules (proteins and amino acids)

- Water and gases were released from the newly formed earth by the heat caused by impacts and accretion, or by melting and volcanism during diversification.

Volcanic gases

- Hawaii volcanoes contain:
  70% water vapor (H_2O)
  15% CO_2
  5% N_2
  5% Sulfur (H_2S)
  Chlorine (HCl)
  H_2
  Ar

Water

- Most water on the surface of the earth and the atmosphere came from volcanism in the first billion years of the Earth.
- And this because the first marine sedimentary rocks that indicate the presence of oceans appear at 3.8 billion years.

Formation of the hydrosphere

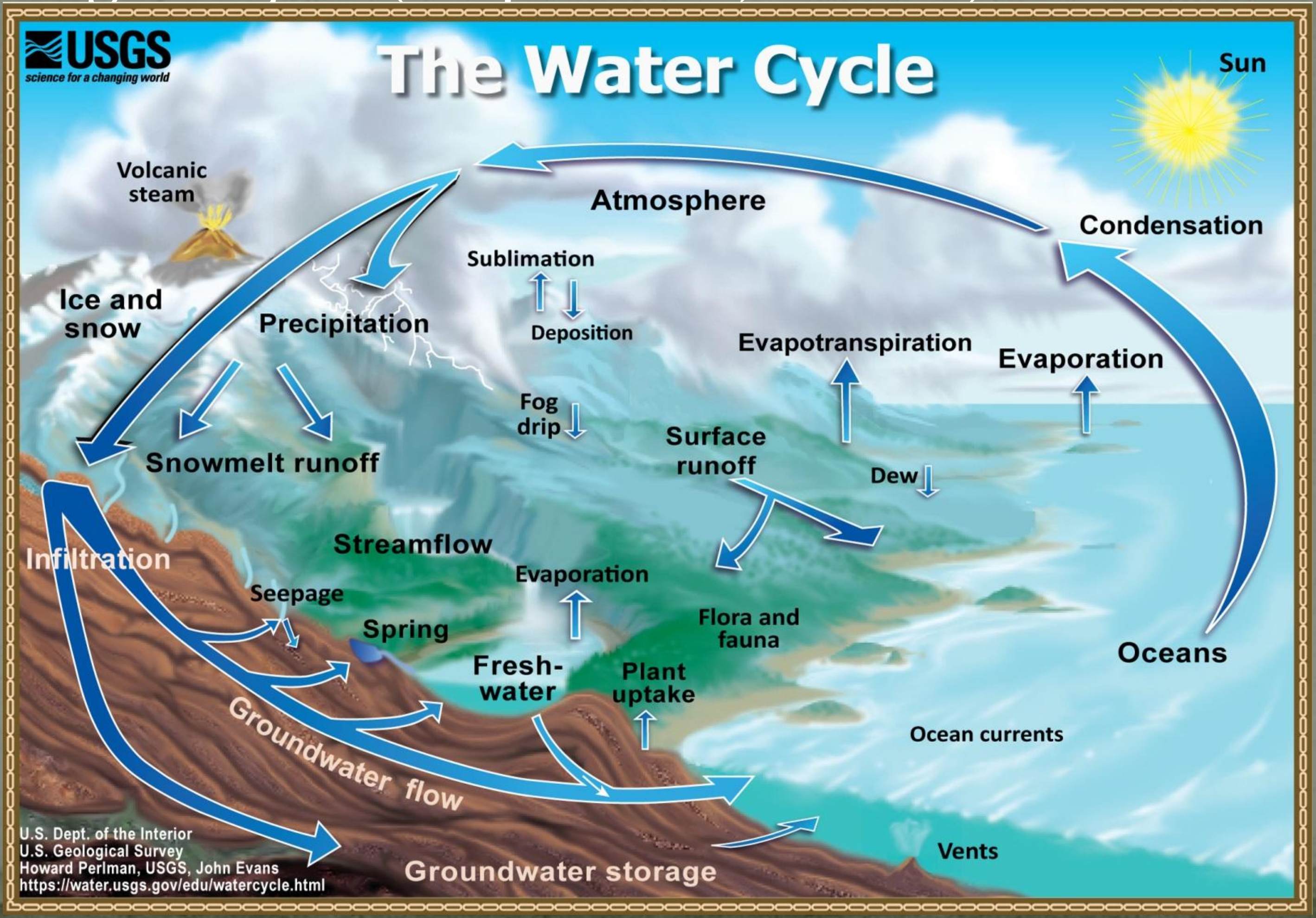
- The water vapor condensed and precipitated like rain.
- Liquid water began to drop to Earth at about 4.4 billion years.
- Rain water was concentrated in basins to form seas.
- The first seas consisted of fresh water.
- Carbon dioxide and other gases made water more acidic than today.
- Acidic waters caused the rapid chemical weathering of rocks by adding Na, Ca, K, and other ions to "seawater".
- Changing to more alkaline water had to happen quickly as large amounts of Ca, Na, and Fe have entered from underwater volcanism, neutralizing acidic water.

Formation of the hydrosphere

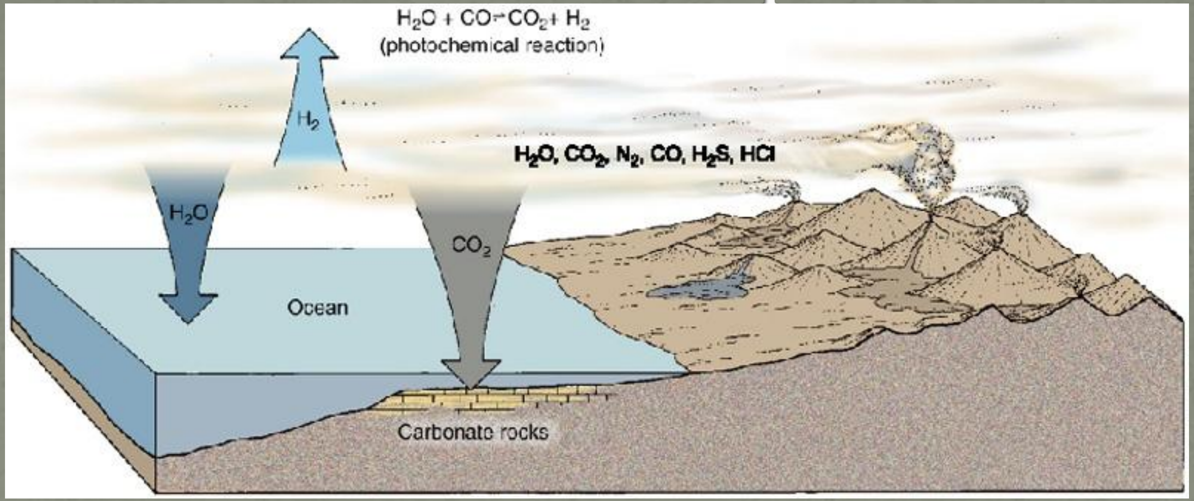
- Ions gathered in the seas making salinity. Today Salinity must remain relatively constant because the salts are precipitating at the same rate as entering the sea. Na stays in water due to its high solubility.
- Later, when the seas became less acidic, Ca ions were combined with CO_2 to form shells of organisms and limestones. ($CaCO_3$).
- The presence of marine fossils suggests that sodium has not significantly changed over the last 600 million years.

The hydrological cycle

Today the water of the earth is recycled through the hydrological cycle (evaporation, rainfall).



Evolution of the atmosphere



Gases are released from volcanoes, condensation, precipitation, water concentration, photochemical reactions in the atmosphere, limestone formation (later when the seas became less acidic)

The first anoxic atmosphere

- The first atmosphere of the earth was strongly reducing and anoxic (lack of free O), and consisted of:
  water vapor (H_2O)
  CO_2
  N_2
  CO
  H_2S
  HCl

The first anoxic atmosphere

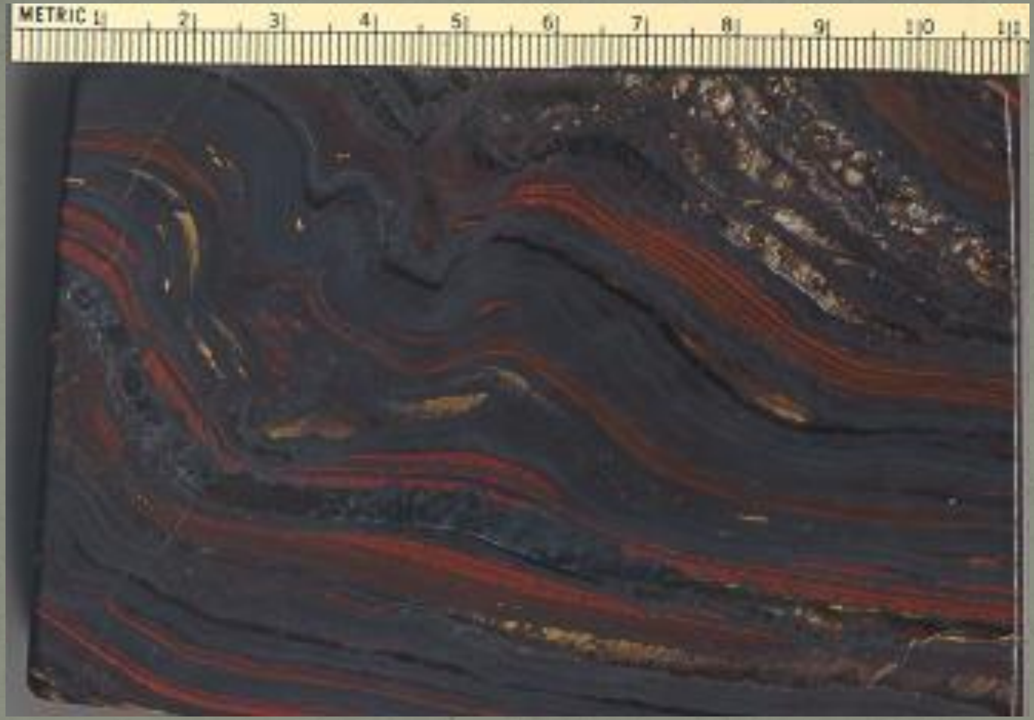
- The composition of the atmosphere would be similar to that of today's volcanoes, with perhaps more H_2 and possibly traces of methane and ammonia.

- If there was free O_2, it would be directly bound by metal oxidation reactions.

Evidence for anoxic atmosphere

- Lack of oxidized iron (sulphurous iron minerals, such as iron pyrite, are formed in anoxic environment)
- Pyrite and Uranite are currently very easily oxidized, but in Precambrian sedimentary rocks are found non-oxidized.
- Archaic sedimentary rocks are usually black due to the presence of carbon, which would oxidize if there was O_2.
- In archaic sedimentary rocks calcareous rocks are absent but contain cherts, due to the acidic and CO_2-rich atmosphere.
- Iron Formations with bedding (red oxidized iron in alternations with gray non-oxidized). From precipitation of iron to shallow sea.

Bedded iron deposits



Further evidence

- The simplest organisms today have anaerobic metabolism, and are killed by O_2. The first organisms would have had the same metabolism.
- The basic building blocks of life could not be formed in the presence of O_2.

Archaic Era (4000-2500 my)

- More stable conditions on earth
- First extensive rocks
- Liquid water on the surface
- Atmosphere rich in CO_2, enough N_2 and CH_4 and a little O_2
- Meteorite and comet impacts have dropped significantly
- Stable environments

Formation of atmosphere rich in oxygen

- The change from a poor to an oxygen-rich atmosphere occurred at the end of the Archaic century.

Formation of atmosphere rich in oxygen

- It was a result of:
  Photochemical separation - Decomposition of water molecules in H and O in the upper atmosphere from ultraviolet radiation from the sun.
-
  Photosynthesis - The process by which photosynthetic bacteria and plants produce oxygen (the main process).

Evidence for the presence of free oxygen in the atmosphere

- Red layers - sedimentary rocks with iron oxides, appear in rocks more than 1.8 billion years old (proterozoic).
- Calcareous rocks - appear for the first time at the same time as the red layers.
- So, less CO_2 in the atmosphere and the oceans, so the water was no longer acidic.

Proterozoic Era

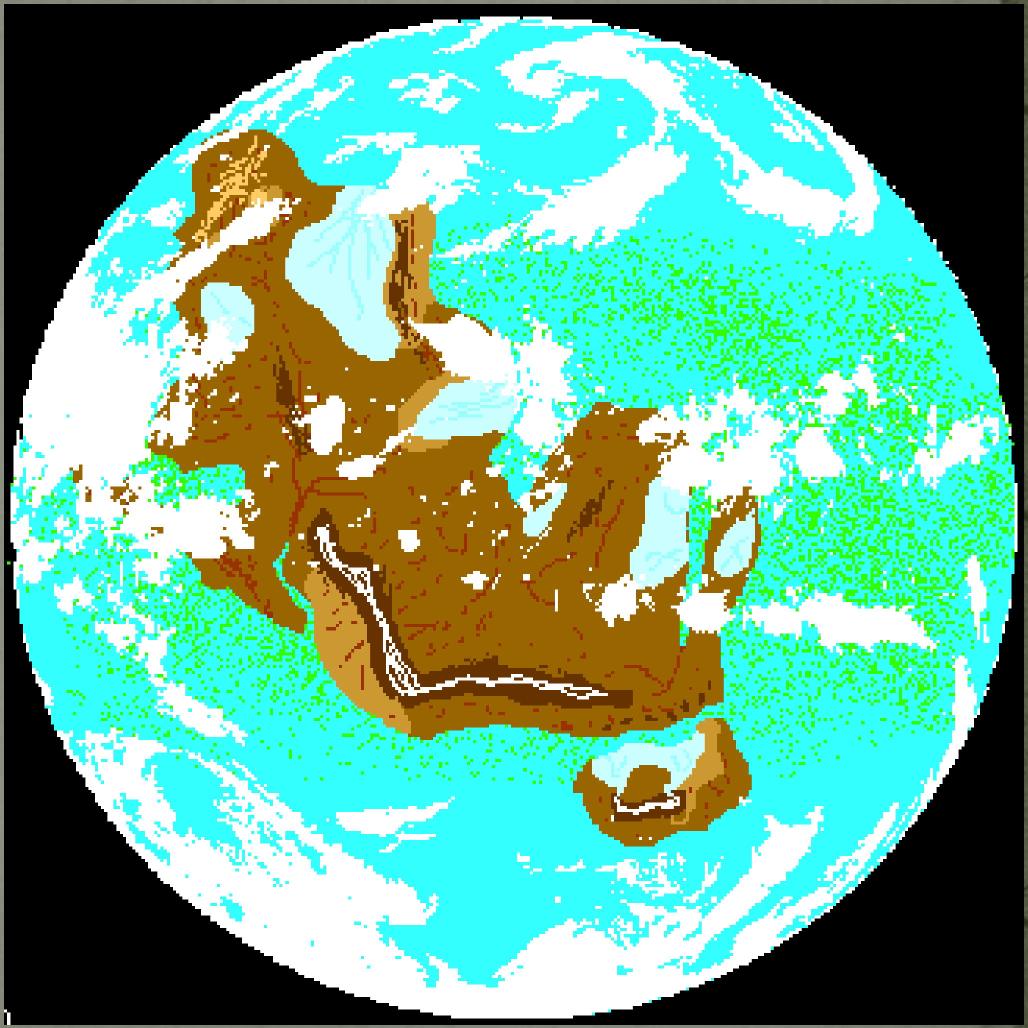
- 2500 - 541 my
- 42% of the earth history
- Separated into 3 suberas:
  - Paleoproterozoic era (2.5 - 1.6 by)
  - Mesoproterozoic era(1.6 - 1.0 by)
  - Neoproterozoic era (1000 – 541 my)

At the beginning of the Proterozoic

- More contemporary plate tectonics
- More contemporary sedimentation
- More modern climate with glaciers
- The beginnings of an atmosphere rich in Oxygen
- The appearance and prevalence of eukaryotic organisms

At the beginning of the Proterozoic

Large parts of the crust (slabs), also known as Precambrian provinces, at the beginning of the Proterozoic, joined together to form the first large and unified continent of the earth, the Kenorland.



At the beginning of the Proterozoic

- Conjunction ("seam") of continental plaques occurs along mountain ranges or orogenetic zones.
- Up to about 1.7 billion years ago, the formation of the Kenorland had been completed.
- Kenorland continued to grow throughout the Proterozoic, with the welding of new parts in its margins.

Paleoproterozoic era (2.5 - 1.6 by)

Active tectonics
Orogenesis
The first glaciers
Volcanism (with continental basalt)
Increased Oxygen in the atmosphere
High concentrations of organic matter in sediments (2000 million years), and the creation of the first "oil".
The oldest phosphate rocks

sentimentation

- The first extensive deposits of sand (seawater classics) and carbonate deposits on continental shelves and continental seas

climate

- The first glacial periods:
  In Palaeoprotozoic, about 2.45-2.22 billion years, Huronian
  In the Neoprotozoic, 850-600 million years, Varangian,

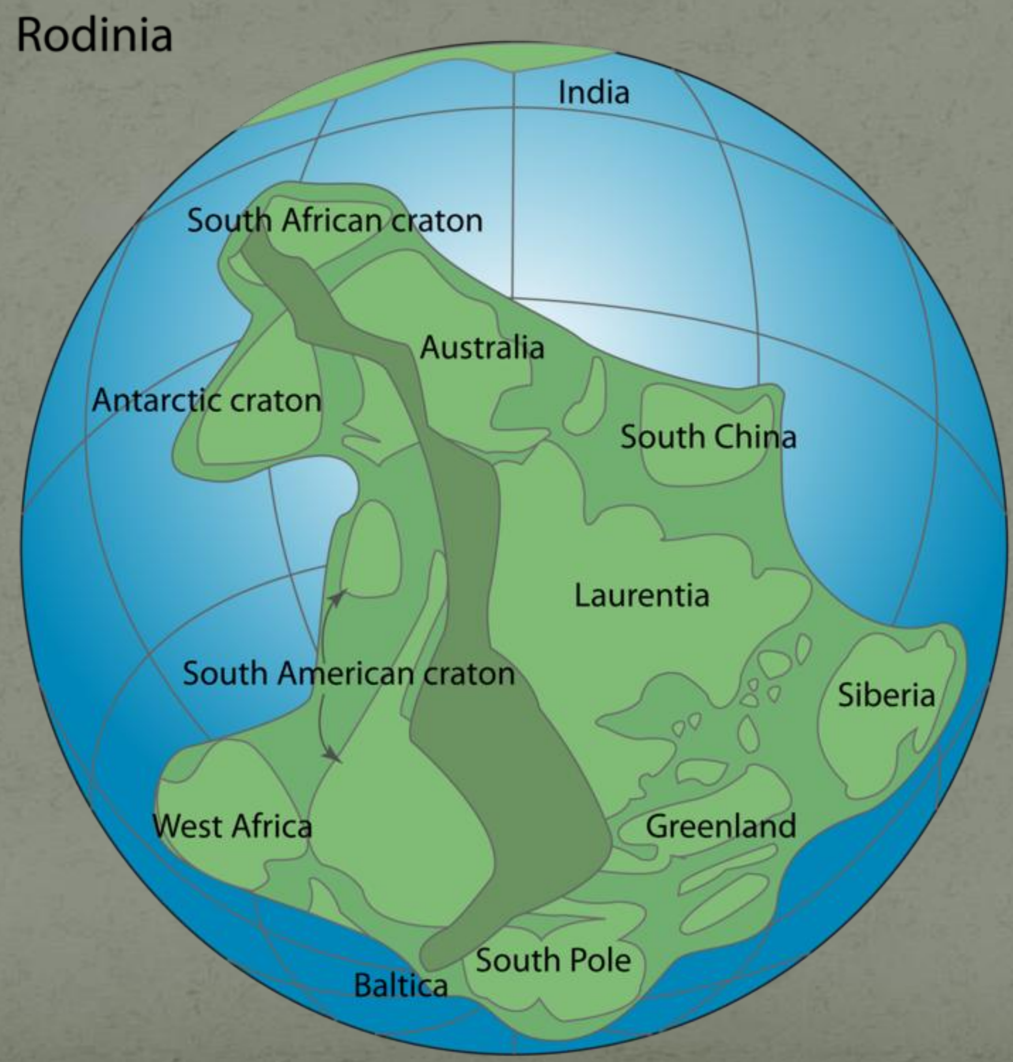
Huronian Ice age (2450-2220 εκ. έτη)

- Suddenly started from the then stable conditions
  Iliolites showing seasonality
  Tilites, agglomerates of coarse grained sediments.
  Typical lineation on pebbles from ice movements.
  It has had a large global spread, glacier deposits have been found in North America, Europe, South Africa, India.

Mesoproterozoic era(1.6 - 1.0 by)

- Formation of ocean.
  Then Grenvilian orogenetic event 1.2 - 1.0 billion years
  The collision of continents formed the supercontinent Rodinia.

Supercontinent Rodinia

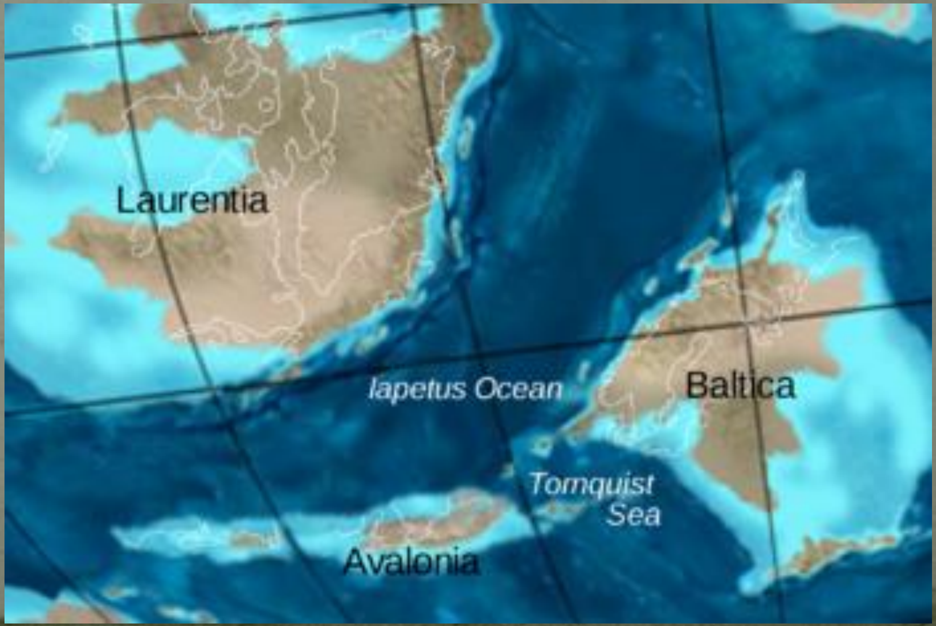


Supercontinent Rodinia

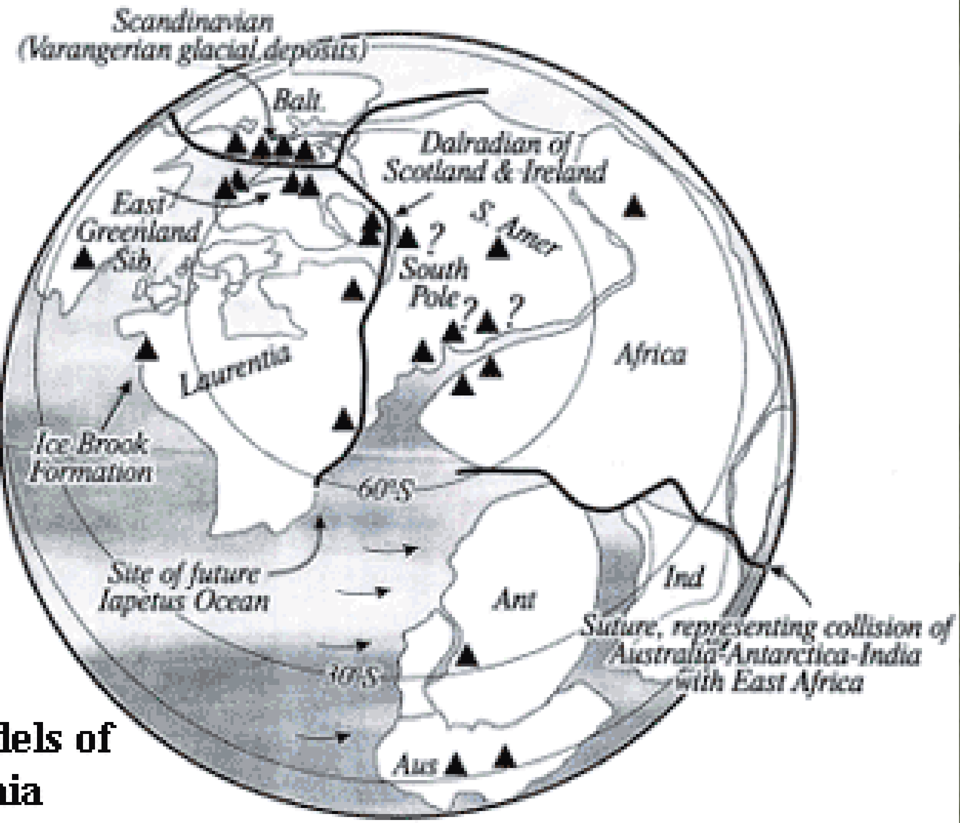
- It remained as a supercontinent for about 350 million years.
  It was surrounded by the ocean of Mirovia.
  It began to open and to divide and form 750,000 years in the Panthalassa (protopacific).

Neoproterozoic era (1000 – 541 my)

- Widespread glaciers
- At 570 million years, the oceans were reopening, once the South American block began to separate from that of the North the ocean of Iapetus was formed (protoatlantic).

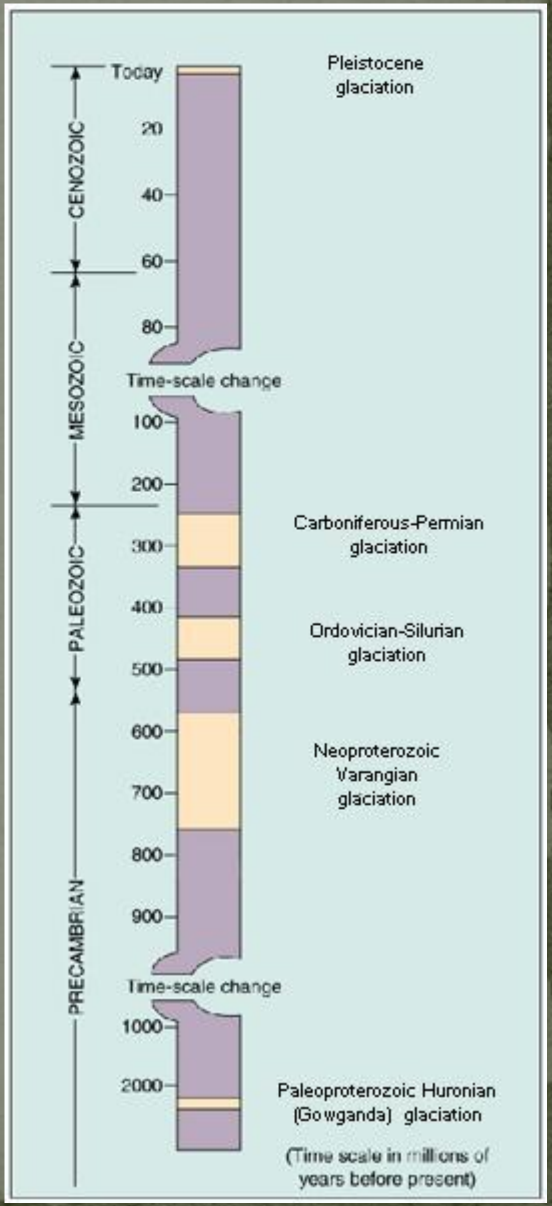


Two models of Rodinia



The Varangian glacial period (850 – 600 my)

- Known also as ‘snowball Earth’ due to the widespread glacial deposits.
- It lasted for 250 my, the biggest one in the history of the earth.
- Rocks with glacial deposits are found around the earth (tillites etc.)



What caused it?

Plate tectonics may have affected the cooling of the planet.
The continents were around the equator and thus no tropical ocean.
Reflection of heat on the surface of the rocks (continents naked).
When the first glaciers formed, the snow and ice reflectance was further reduced.
Glaciers are associated with a CO_2 reduction and an increase in O_2.
CO_2 greenhouse effect. Reduce cooling.
The reduction is probably due to an increase in the number of photosynthetic organisms (cyanobacteria, stromatolites).

Impact

- Drop of sea level
- Reduced lithification of cyanobacteria
- Low production of acritarhs
- Abandoned Stromatolites
- Decrease of $\delta^{13}C$
- Decrease of CO_2 in the atmosphere
- Higher erosion (indications of increased amounts of ^{87}Sr / ^{86}Sr in carbonate rocks) and hence an increase in P in ocean water

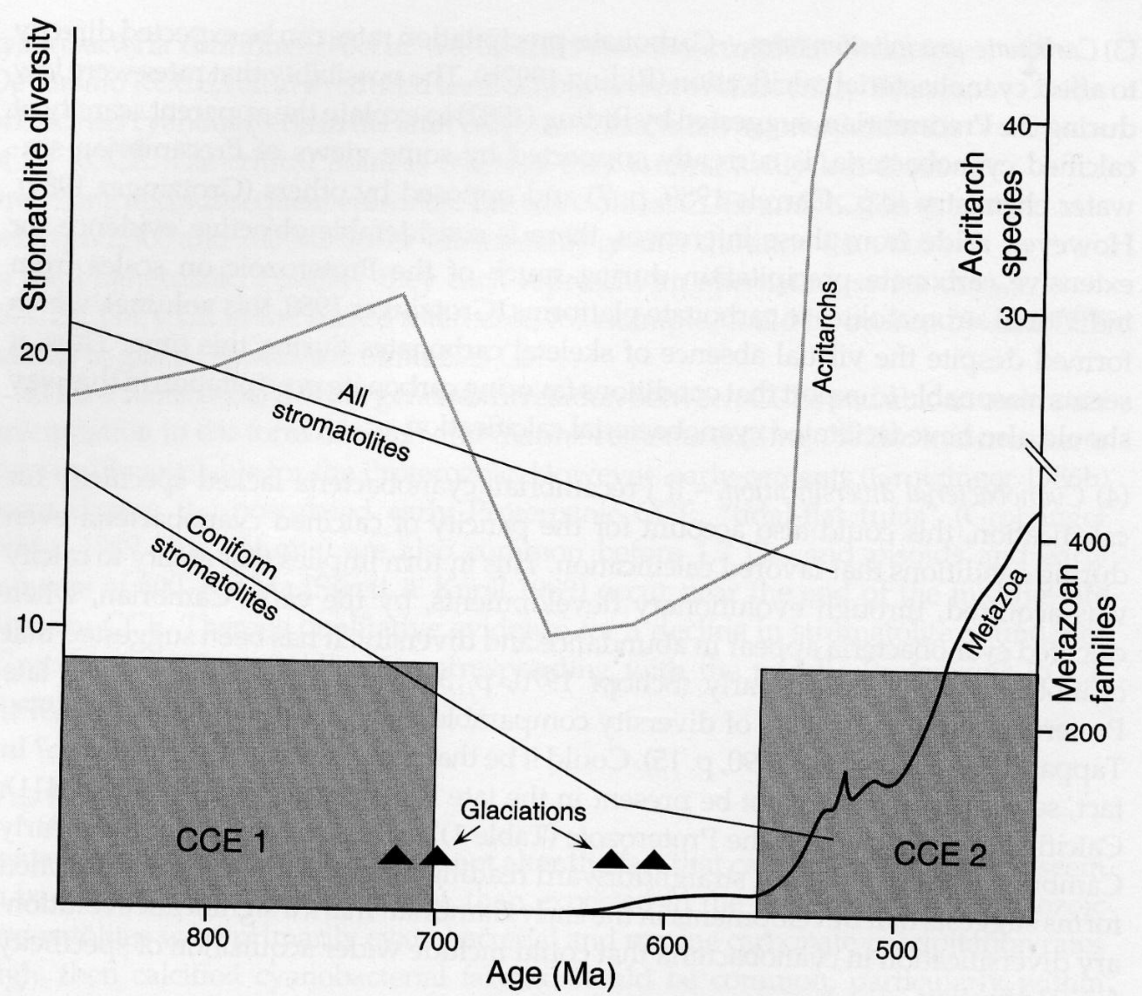


FIGURE 3 Synthesis of events at the Proterozoic–Palaeozoic transition. It is proposed that (a) decline in stromatolite and acritarch diversity and termination of the middle–late Riphean CCE (CCE1) are linked to temperature fall in the latest Proterozoic also reflected by glacial episodes around 700–600 Ma, and (b) commencement of the Cambrian – early Ordovician CCE (CCE2) near the beginning of the Tommotian is linked to temperature rise which also stimulated acritarch, metazoan, and cyanobacterial diversification. CCE1 and CCE2 are separated by an RCCE. During CCE2 calcified cyanobacteria created widespread dendrolite and skeletal thrombolite fabrics in reefs. Biomineralization also took place in a variety of metazoan groups during the early Cambrian. (Sources: acritarchs – Vidal 1984, p. 54; stromatolites – Walter & Heys 1985, Fig. 5B; metazoan diversity – Sepkoski 1979, Fig. 7; glaciations – Harland *et al.* 1990; CCE's – Riding 1992b, this paper.)

At the beginning of the Proterozoic life is the same as the Archaic

- Archaeobacteria in hydrothermal vents
  Planktonic prokaryotic organisms in seas and lakes
  Anaerobic prokaryotic organisms in anoxic environments
  Photosynthetic cyanobacteria that make stomatolites
  Eukaryotic organisms

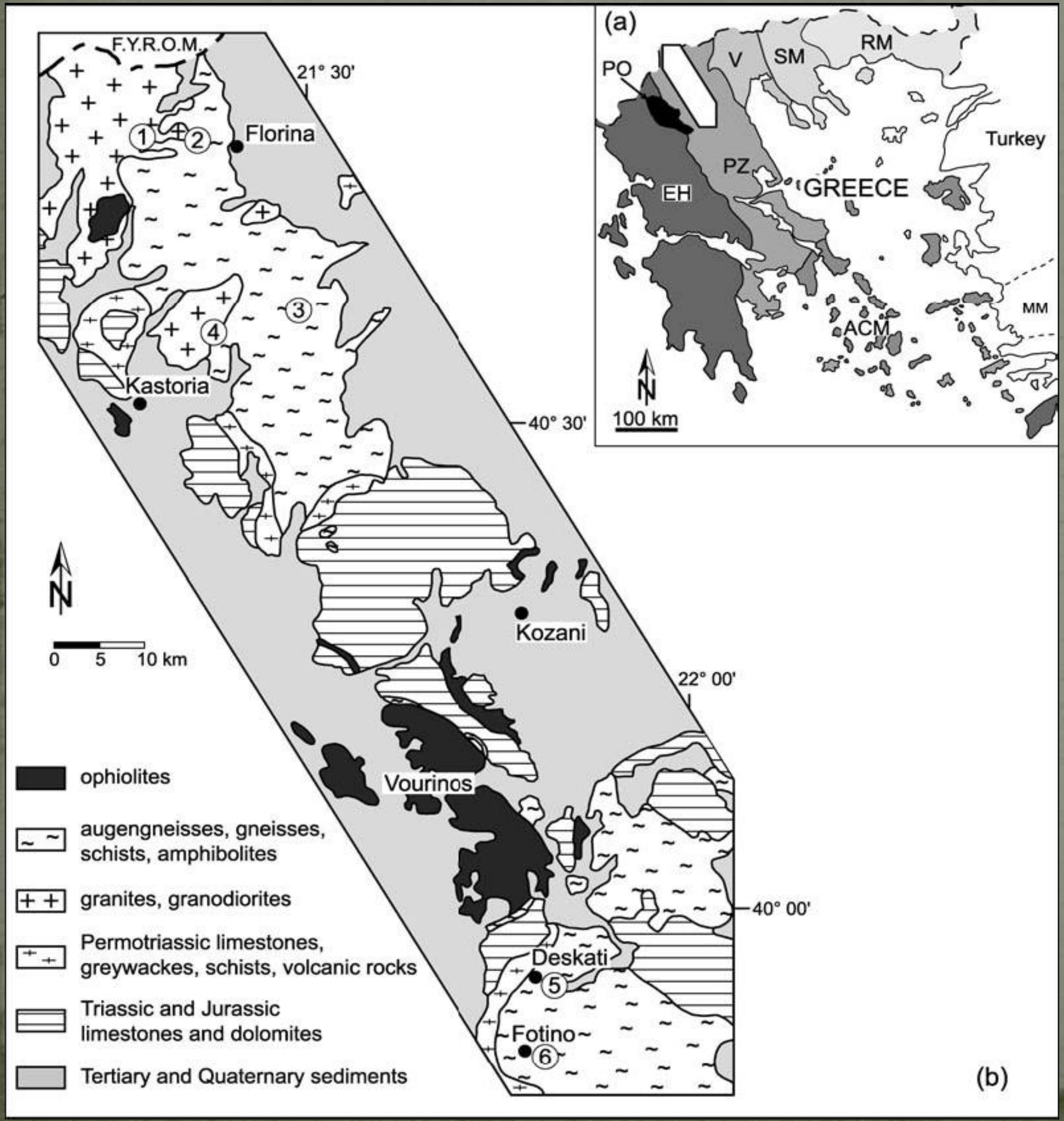
New forms of life

- Acritarhs
- Metazoa or multicellular animals with soft bodies
  Metazoa with microscopic tubes of calcium carbonate or shells
  Metazoa that left burrows in the sediment

The first Metazoa

- Multicellular animals with various types of cells organized into tissues and organs.
  The first of these metazoa appeared for the first time in the Neoproterozoan, about 630 million years (at the end of Varangian). They were retained as casts of organisms with soft parts on sandstone.

Oldest rocks of Greece (Anders et al., 2006)



- Age: 699±7 - 713±18 my
- Part of Godwana

The day in the Proterozoic

- From coral growth lines
  In Devonian the year had 398 days
  In the Neoproterozoic the day had 18.2 hours
  the earth was turning faster in the past and over time is slowing down