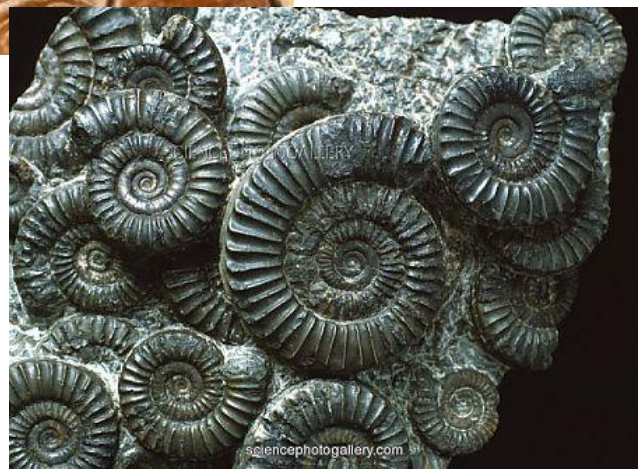
About the Earth, its origin, composition and evolution – i.e. geology



Kuressaare 11.8 2014
Olav Eklund
Åbo Akademi
Geology & Mineralogy

The science of the Earth

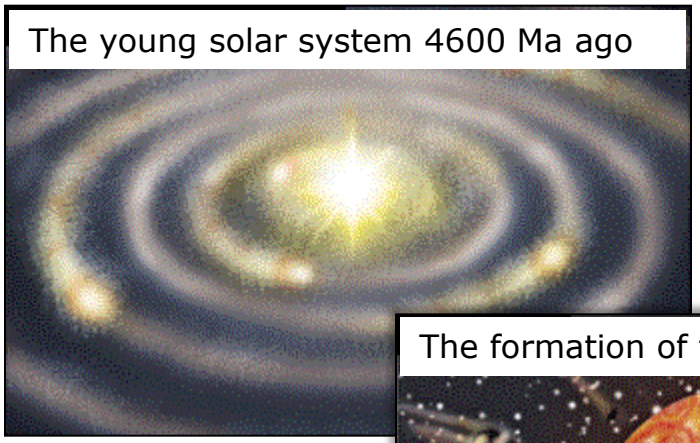
Geosphere
Uppkomst
Uppbyggnad
Sammansättning
Utveckling
Plattektonik
Jordbävningar
Vulkanutbrott

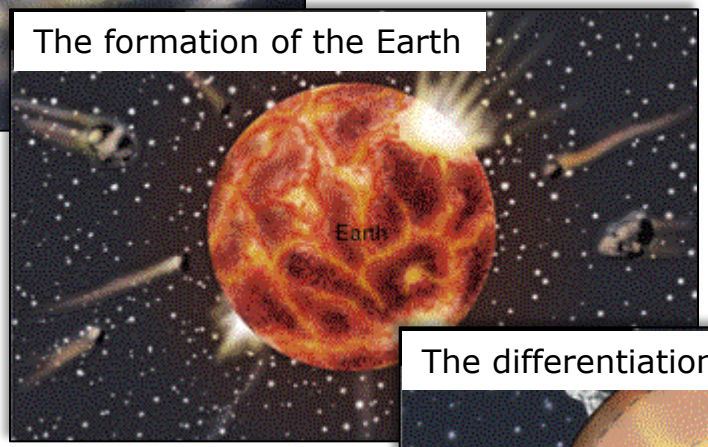
Biosphere
Livets uppkomst
Livets utveckling
Massutrotningar
Fossil

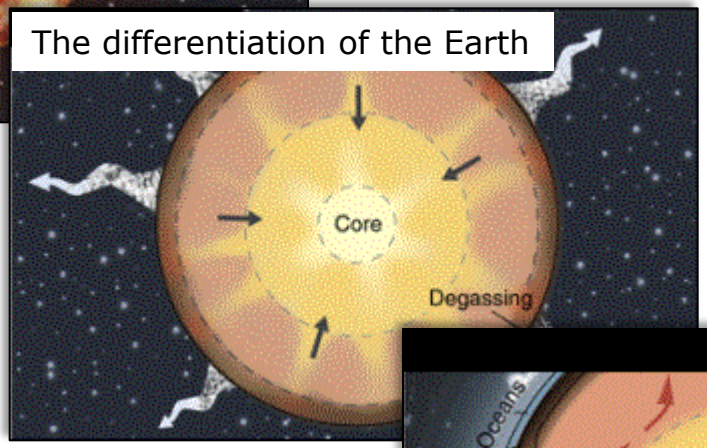
Hydrosphere
Uppkomst
Sammansättning
Utveckling
Klimatförändringar
Istider

Atmosphere
Uppkomst
Sammansättning
Utveckling
Klimatförändringar

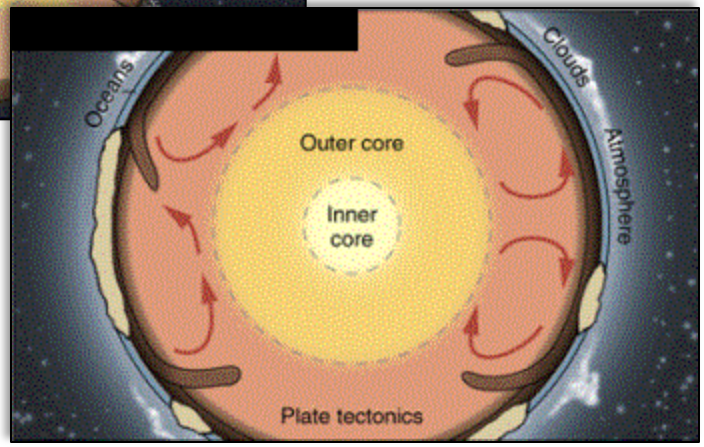
The physics, chemistry and history of the Earth







Ma = Mega anno = million years

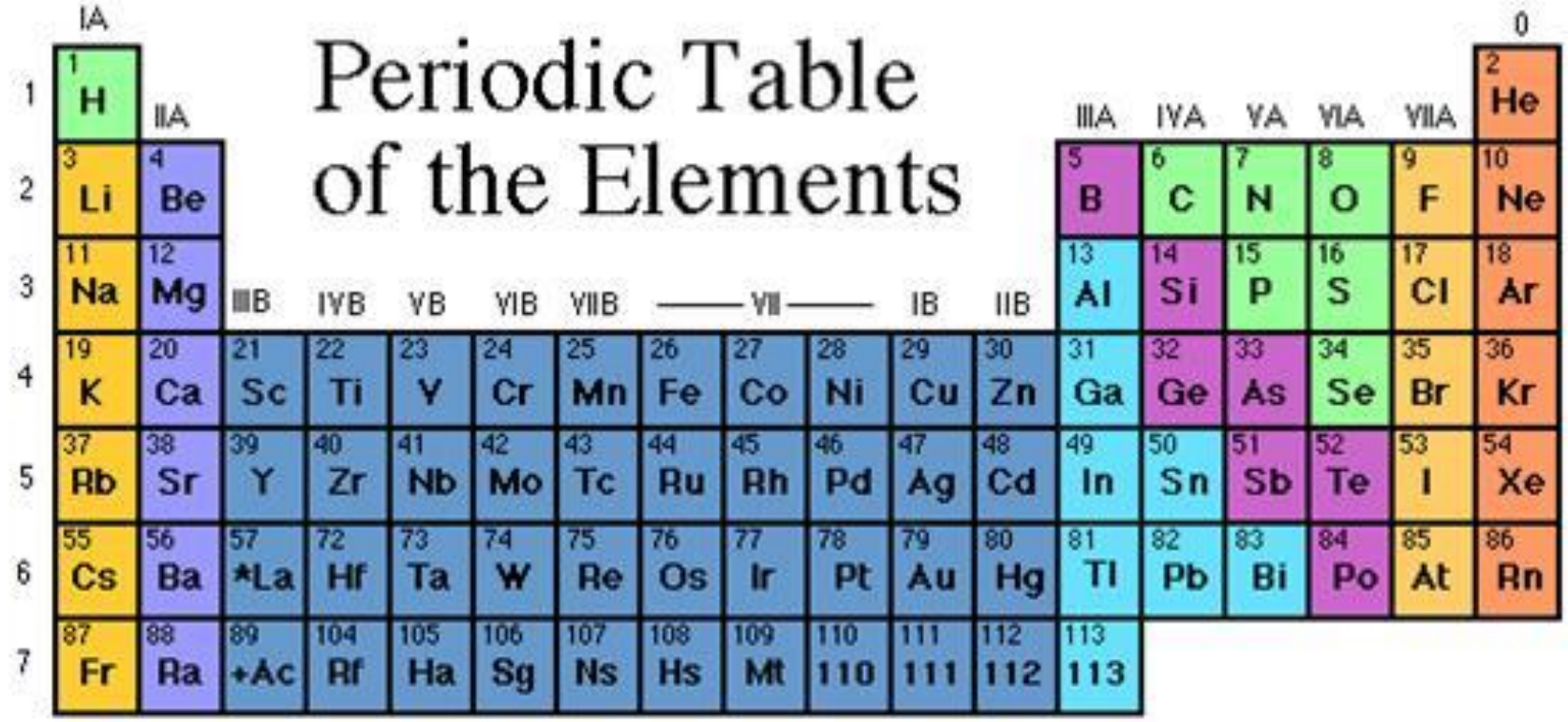


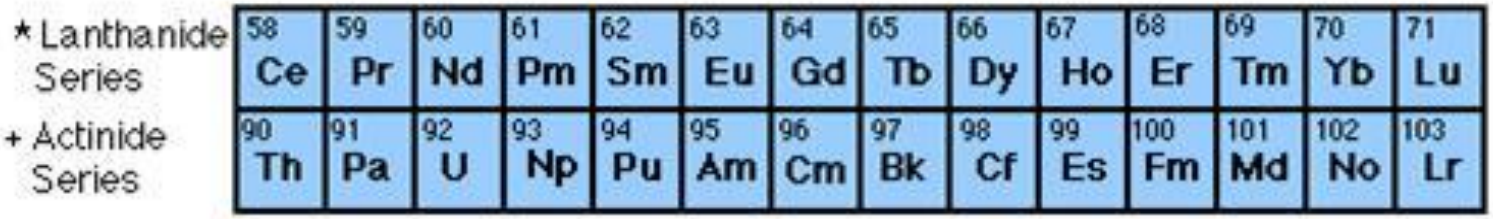
The formation of the hydrosphere and the atmosphere

The most important episodes in Earth history (that we can sit here and enjoy Estonia)

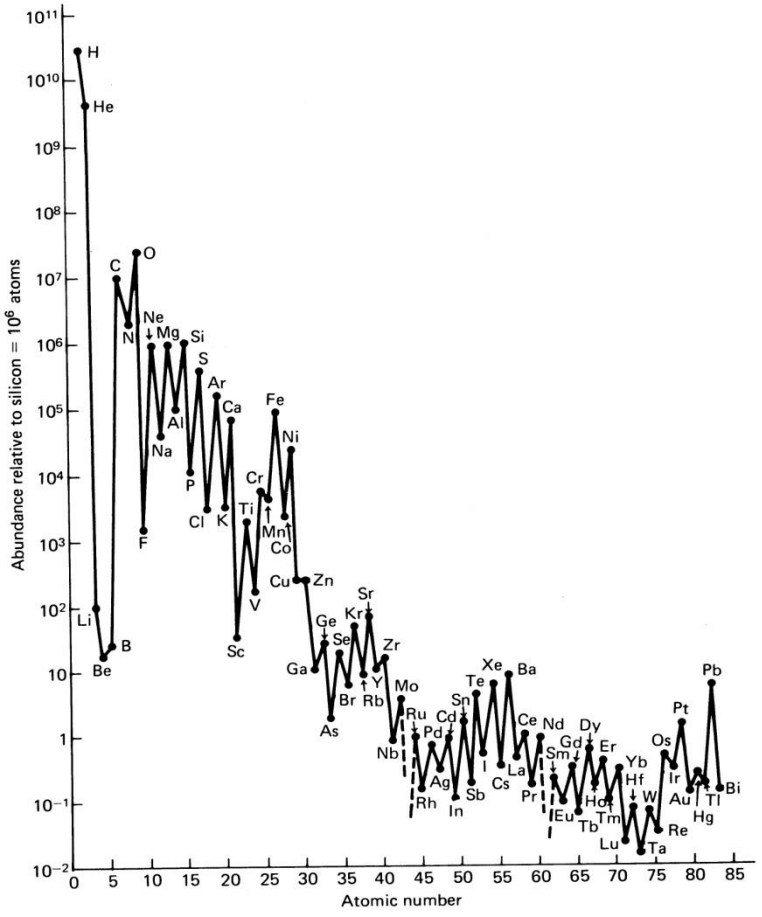
- The Earth developed in the life zone from the sun
- Plate tectonic started and put all materia into the great circulations
- The great oxygen event (GOE) 2400 Ma ago
- Periods of Snowball Earth
- The origin of the ozon shelter 400 Ma
- Massextintion

Periodic Table of the Elements

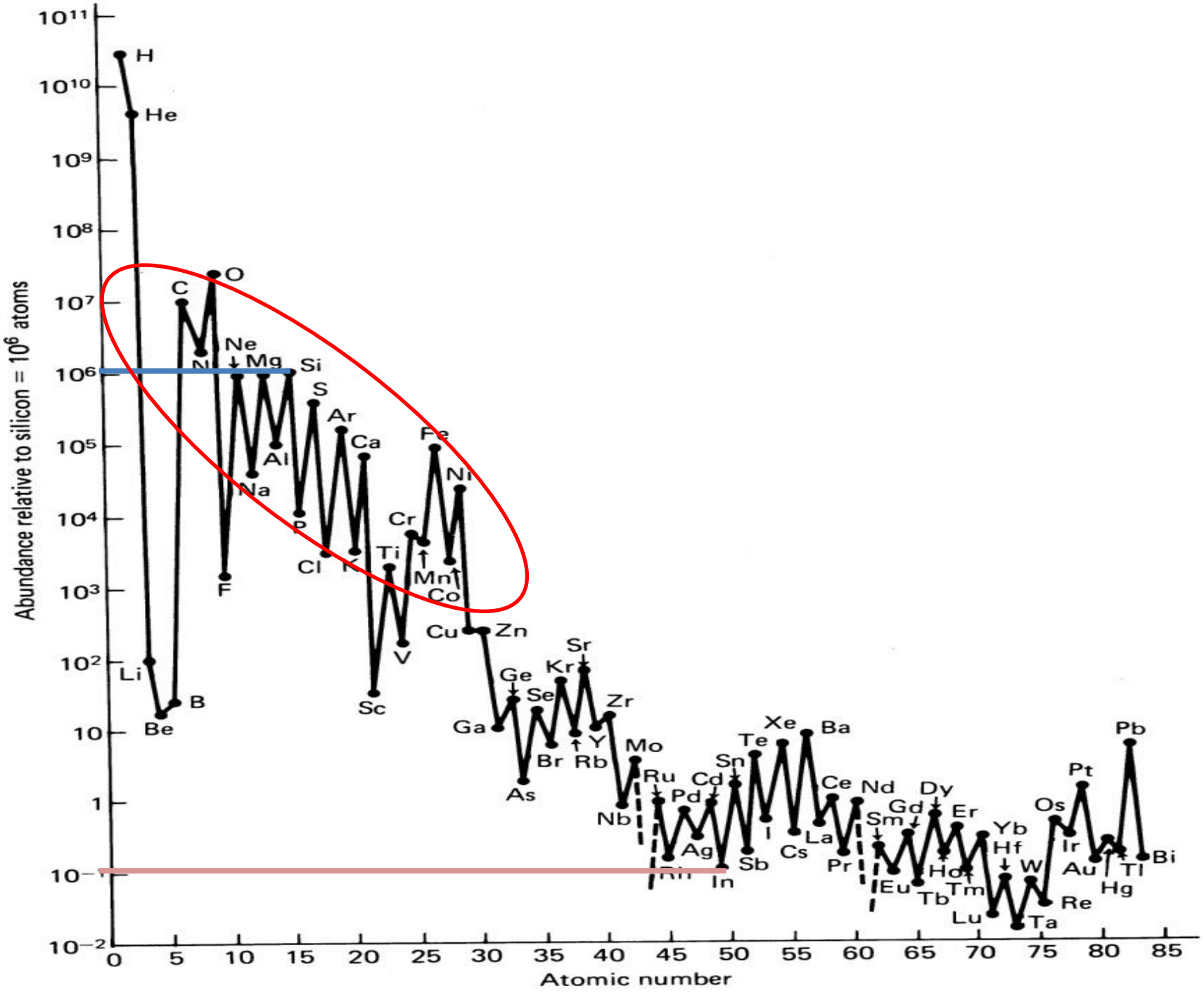


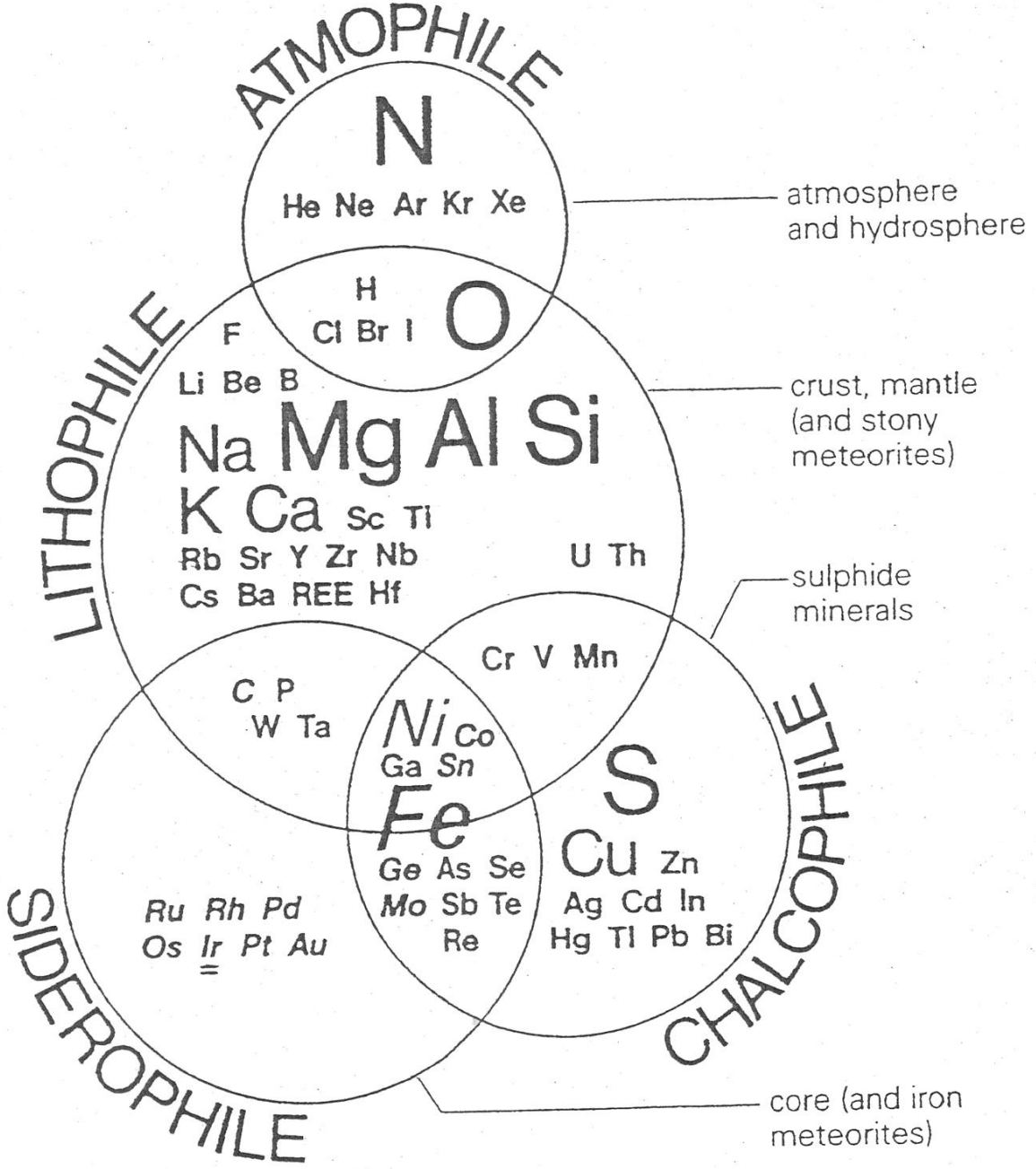


The chemical composition of cosmos



- Most H and He, formed at Big Bang (12,7 Ga)
- A lot of C, N, O (the bricks for life and the atmosphere)
- A lot of elements forming our most common minerals
- Very few heavy elements
- Same distribution in our solar system


Abundance relative to silicon = 10^6 atoms
10^{11}
10^{10}
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
H
He
Li
Be
B
C
O
F
Ne
Na
Mg
Al
Si
P
S
Cl
Ar
K
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ga
Ge
As
Se
Br
Kr
Rb
Sr
Y
Zr
Nb
Mo
Ru
Rh
Pd
Ag
Cd
In
Sn
Sb
Te
I
Xe
Cs
Ba
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
Hf
Ta
W
Re
Os
Ir
Pt
Au
Hg
Tl
Pb
Bi
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
Atomic number


ATMOPHILE
N
He Ne Ar Kr Xe
atmosphere
and hydrosphere
H
F
Cl Br I
O
LITHOPHILE
Li Be B
Na Mg Al Si
K Ca Sc Ti
Rb Sr Y Zr Nb
U Th
Cs Ba REE Hf
crust, mantle
(and stony
meteorites)
sulphide
minerals
Cr V Mn
C P
W Ta
Ni Co
Ga Sn
Fe
S
Cu Zn
Ag Cd In
Hg Tl Pb Bi
Ge As Se
Mo Sb Te
Re
Ru Rh Pd
Os Ir Pt Au
CHALCOPHILE
SIDEROPHILE
core (and iron
meteorites)

The 9 most common elements in the Earths crust (wt %)

The Earths composition is a mirror to the composition of cosmos!

- O 45.5
- Si 26.8
- Al 8.40
- Fe 7.06
- Ca 5.3
- Mg 3.2
- Na 2.3
- K 0.9
- Ti 0.5
- 99.96%

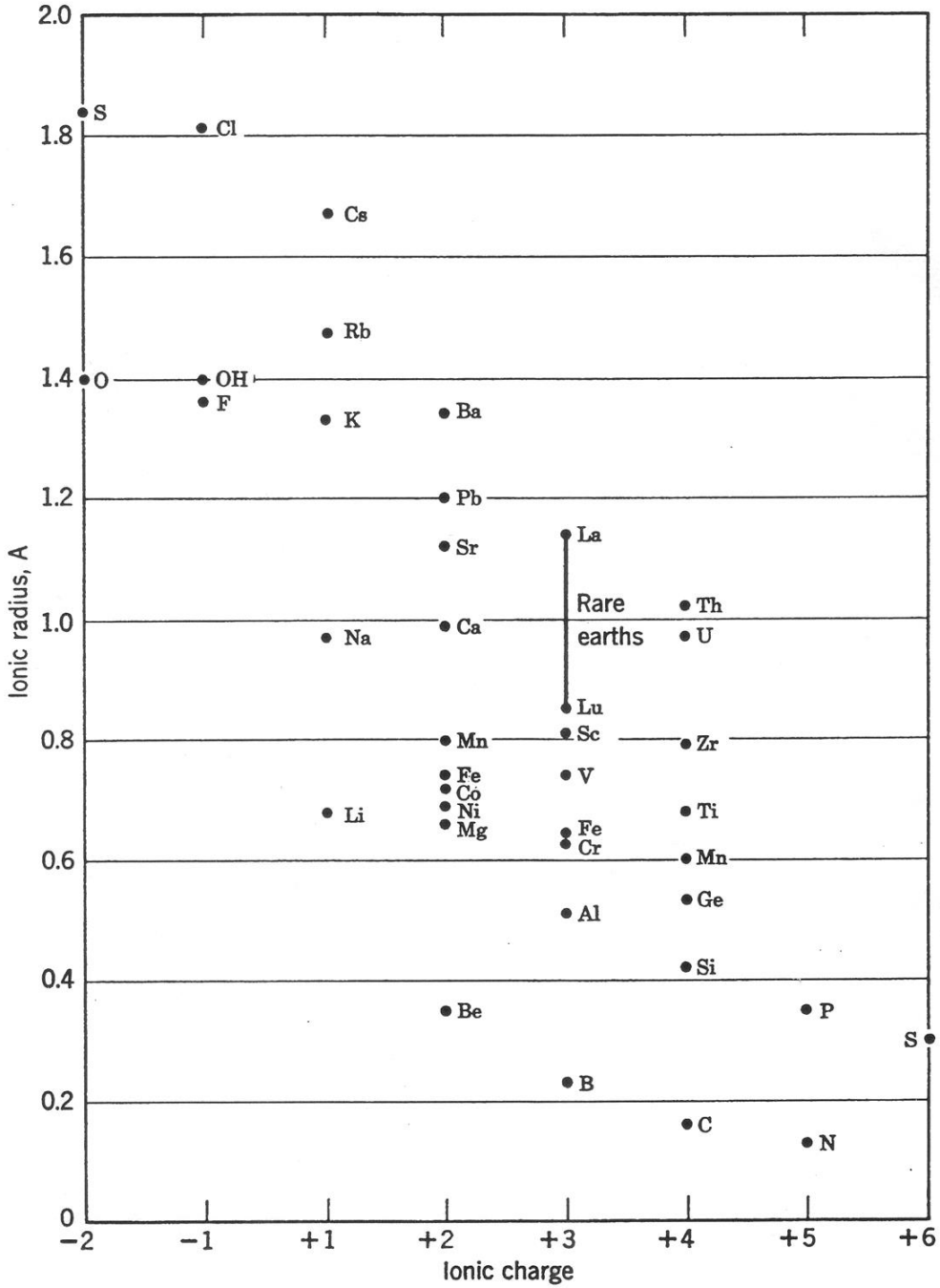
- **The rest, 0.04% , where are they hidden?**

- quartz SiO_2
- alkaline feldspar $(K,Na)AlSi_3O_8$
- plagioclase $Na[AlSi_3O_8]$-$Ca[Al_2Si_2O_8]$
- albite $NaAlSi_3O_8$
- anortite $CaAl_2Si_2O_8$

- olivine $(Mg,Fe)_2SiO_4$
- clinopyroxene $Ca(Mg,Fe)Si_2O_6$
- orthopyroxene $(Mg,Fe)SiO_3$
- amphibole $Ca_3(Mg,Fe)_5Si_8O_{22}(OH)_2$
- biotite $K(Mg,Fe)_3(AlSi_3O_{10})(OH,F)_2$

- apatite $Ca_5(PO_4)_3(OH,F,Cl)$

	Major elements	*Co-ordination*	*Trace elements*
Feldspars	Ca, Na, K	6–9	Ba, Eu, Pb, Rb, Sr
	Al, Si	4	Ge
Olivine	Mg, Fe	6	Co, Cr, Mn, Ni
	Si	4	Ge
Clinopyroxenes	Ca, Na	8	Ce, La, Mn
	Mg, Fe	6	Co, Cr, Ni, Sc, V
	Si	4	Ge
Micas	K	12	Ba, Cs, Rb
	Al, Mg, Fe	6	Co, Cr, In, Li, Mn, Sc, V, Zn
	Si, Al	4	Ge
Apatite	Ca	7–9	Ce, La, Mn, Sr, Th, U, Y
	P	4	As, S, V
Zircon	Zr	8	Ce, Hf, La, Lu, Th, Y, Yb
	Si	4	P


2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
Ionic radius, A
−2
−1
+1
+2
+3
+4
+5
+6
Ionic charge
S
Cl
Cs
Rb
O
OH
F
K
Ba
Pb
Sr
La
Rare
earths
Lu
Th
U
Na
Ca
Mn
Sc
Zr
Fe
Co
Ni
Mg
V
Li
Fe
Cr
Ti
Mn
Ge
Al
Si
Be
P
S
B
C
N

Partition coefficient (the ability for minerals to take in trace elements)

$Kd = C_{(mineral)}/C_{(melt)}$

Kd = Partition coefficient

C = concentration of a trace element

ex. A melt contains 600 ppm Ni. Olivine crystals with 3000 ppm Ni precipitate from the melt. Kd = 3000/600 = 5

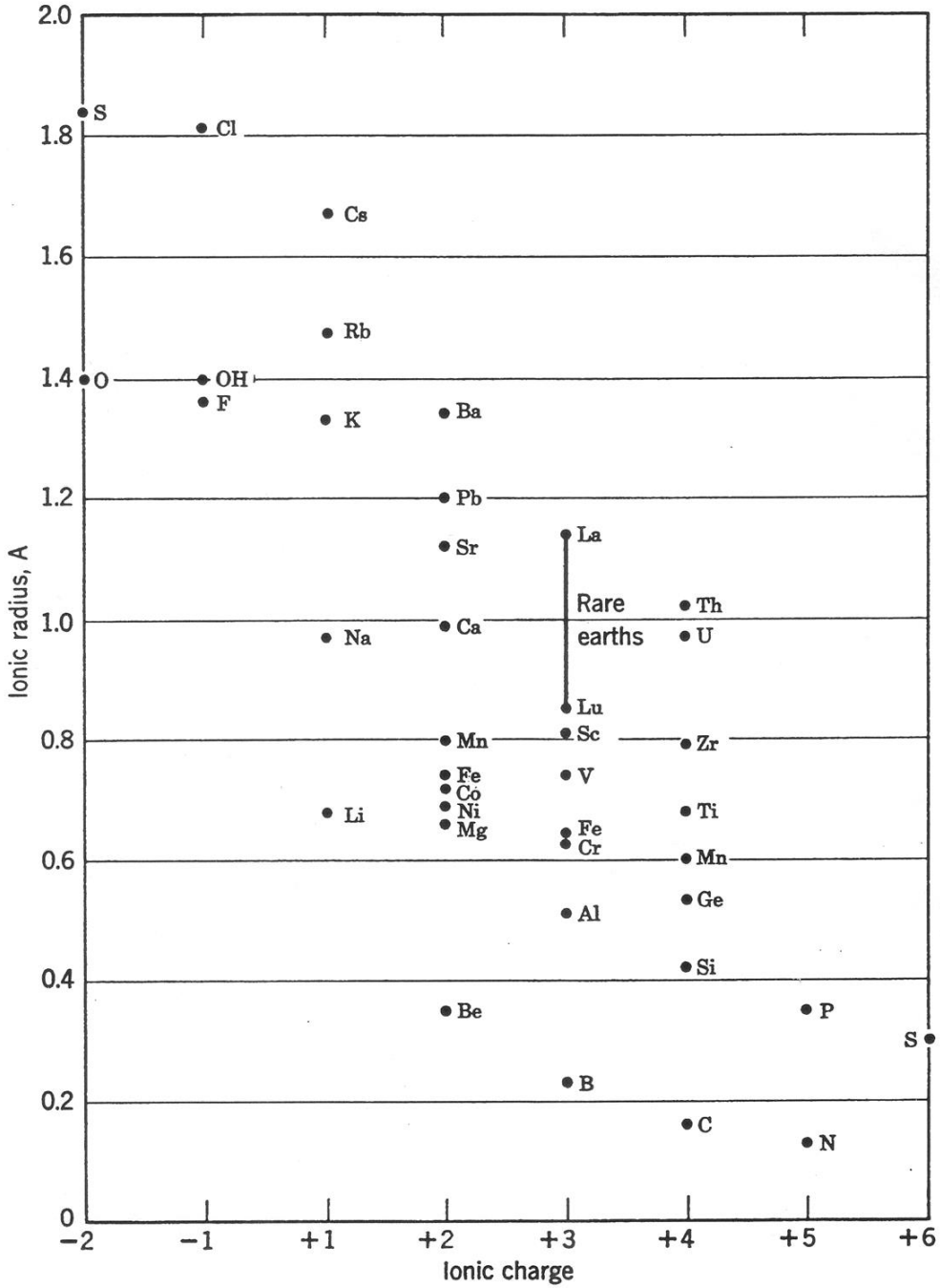
Kd > 1, the element is compatible with the mineral.

Kd < 1, the element is compatible with the melt

i.e. Ni is compatible with olivine

The same melt contains 50 ppm Rb. The olivines contain 5 ppm Rb

Kd = 5/50 = 0.1


2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
Ionic radius, A
−2
−1
+1
+2
+3
+4
+5
+6
Ionic charge
S
Cl
Cs
Rb
O
OH
F
K
Ba
Pb
Sr
La
Rare
earths
Lu
Th
U
Na
Ca
Mn
Sc
Zr
Fe
Co
Ni
Mg
V
Li
Fe
Cr
Ti
Mn
Ge
Al
Si
Be
P
S
B
C
N

ZV14

Major elements oxides (Wt %)

SiO_2	48.91
TiO_2	0.45
Al_2O_3	9.24
Fe_2O_3	2.62
FeO	8.90
MnO	0.18
MgO	15.32
CaO	9.01
Na_2O	1.15
K_2O	0.08
P_2O_5	0.03
S	0.04
H_2O^+	3.27
H_2O^-	0.72
CO_2	0.46
Total	100.38

Volatiles: H_2O^+ = kidevettä
H_2O^- = höyryy 110ºC
S
CO_2

1%	= 10000 ppm
0.1%	= 1000 ppm
0.01%	= 100 ppm
0.001%	= 10 ppm
0.0001%	= 1 ppm

ZV14

Selected trace elements (ppm)

Ni	470
Cr	2080
V	187
Y	10
Zr	21
Rb	3.38
Sr	53.3
Ba	32
Nd	2.62
Sm	0.96

Radiogenic isotope ratios

εNd	+2.4
$^{87}Sr/^{86}Sr$	0.7056

Stable isotope ratios ($^o/_{oo}$)

$\delta^{18}O$	+7.3

Ex. 1000 kg of this rock contain

490 kg	SiO2
90 kg	CaO
33 kg	vatten
900 g	K2O
470 g	Ni
21 g	Zr
0.9 g	Sm

Economic geologists are trying to find new economically profitable ores.
An ore is an area where geological processes have enrished the rock in economically profitable metals or industry minerals

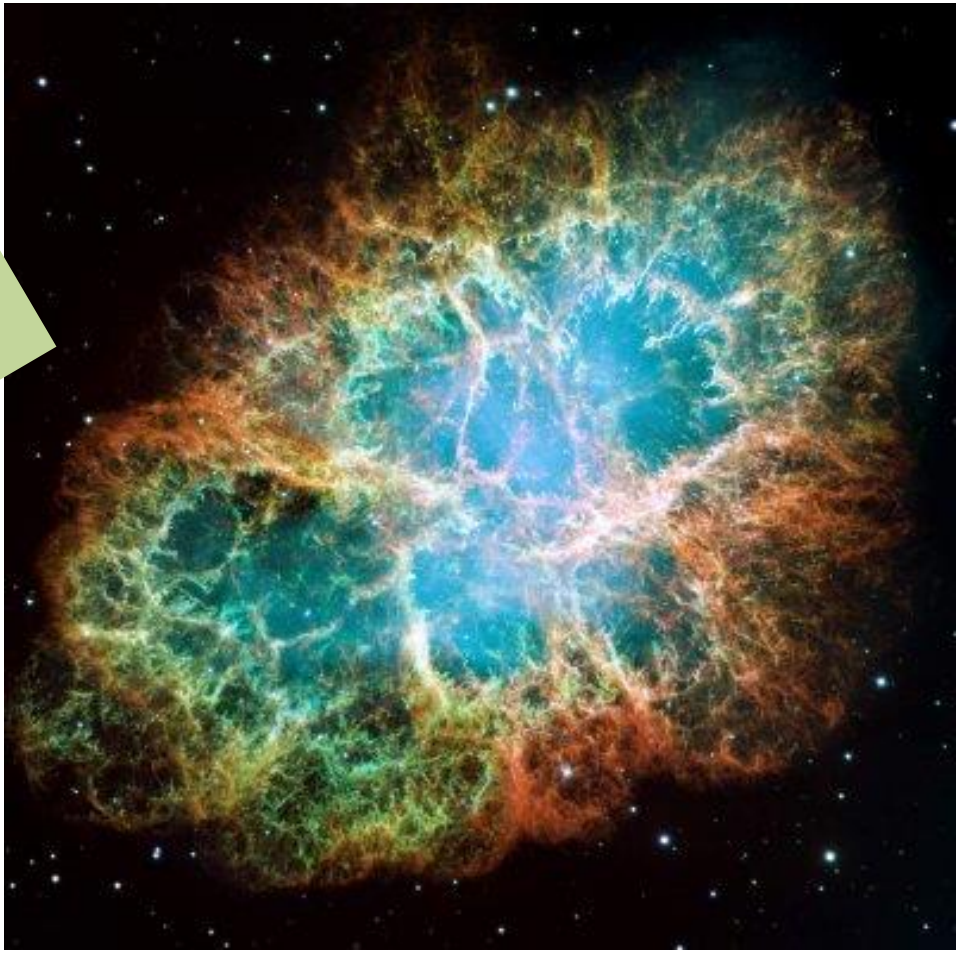
About 100 years ago, mankind needed about 10 metals: iron, cuper, tin, lead, silver, gold

Today mankind need almos all elements found in the periodic table. Our planet will be depleted in these elements within some years, like indium .

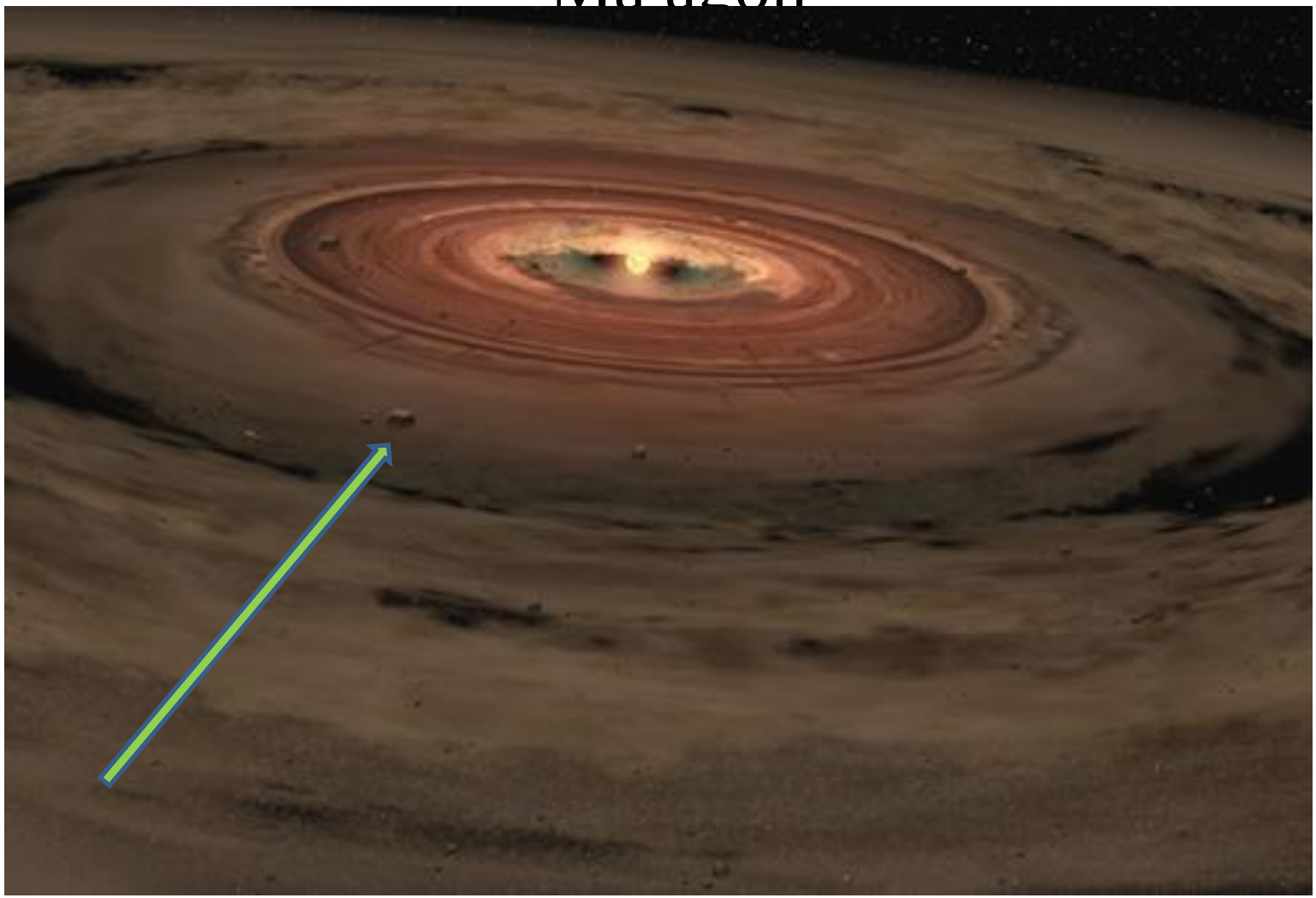
Did you know that your moble phone contains more than 60 elements?

All materia, I mean ALL MATERIA in our solar system were initially gas and matter in a nebula. The nebula was the remnant of a star explosion

You are a Supernova Remnant – Star dust made of Stellar Explosion Debris



The nebula started to rotate and got the shape of a discus, the sun was lighted in the centre 4564 Ma agoh



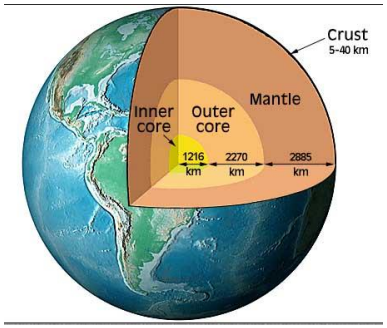
The young Earth was growing due to meteor bombardment

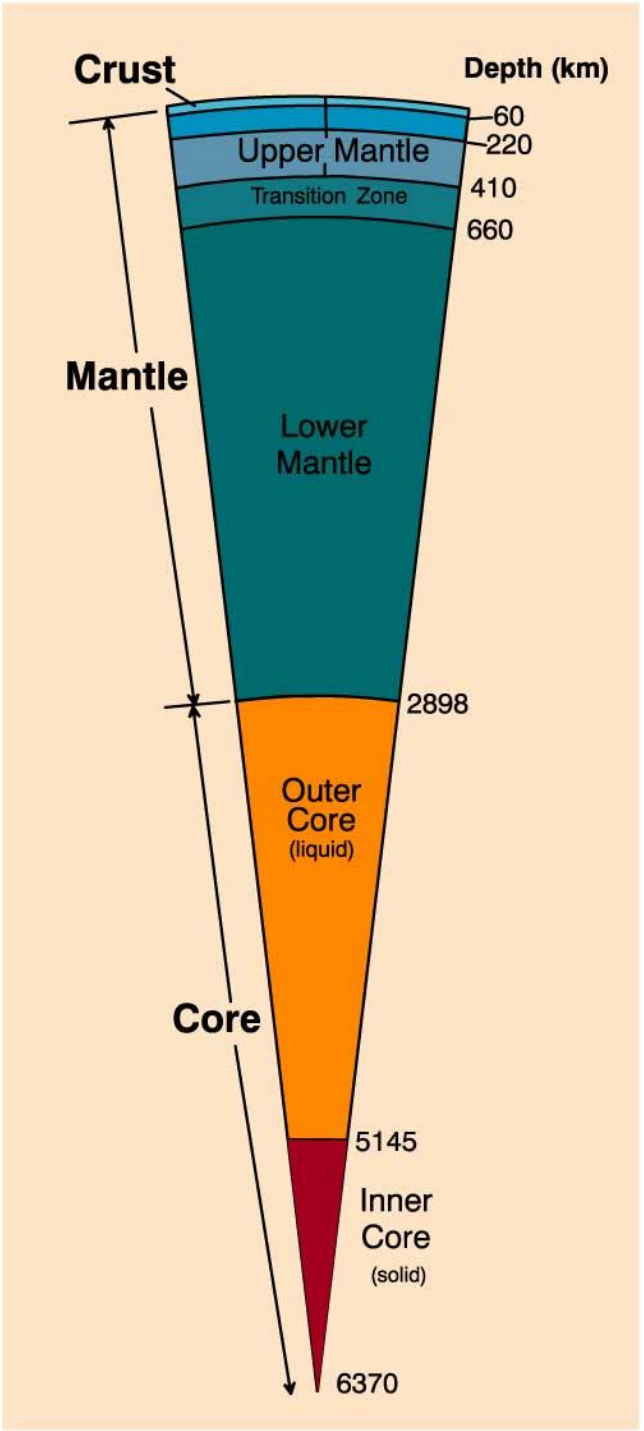
Meteorites and comets

- Chondritic meteorites formed simultaneously as the origin of the solar system.
- The composition of chondrites are quite close to the bulk composition of the Earth. Some of them may contain more than 20% H_2O
- Comets use to be called ”dirty snowballs” (fortunately we have Jupiter)

Hadean time: Energy is released from the planet through volcanism. The kinetic energy of the meteors is converted to heat energy at the impact event. The surface of the Earth was in liguid state (magma). All water were in solution with the magma.

The differentiation of the Earth



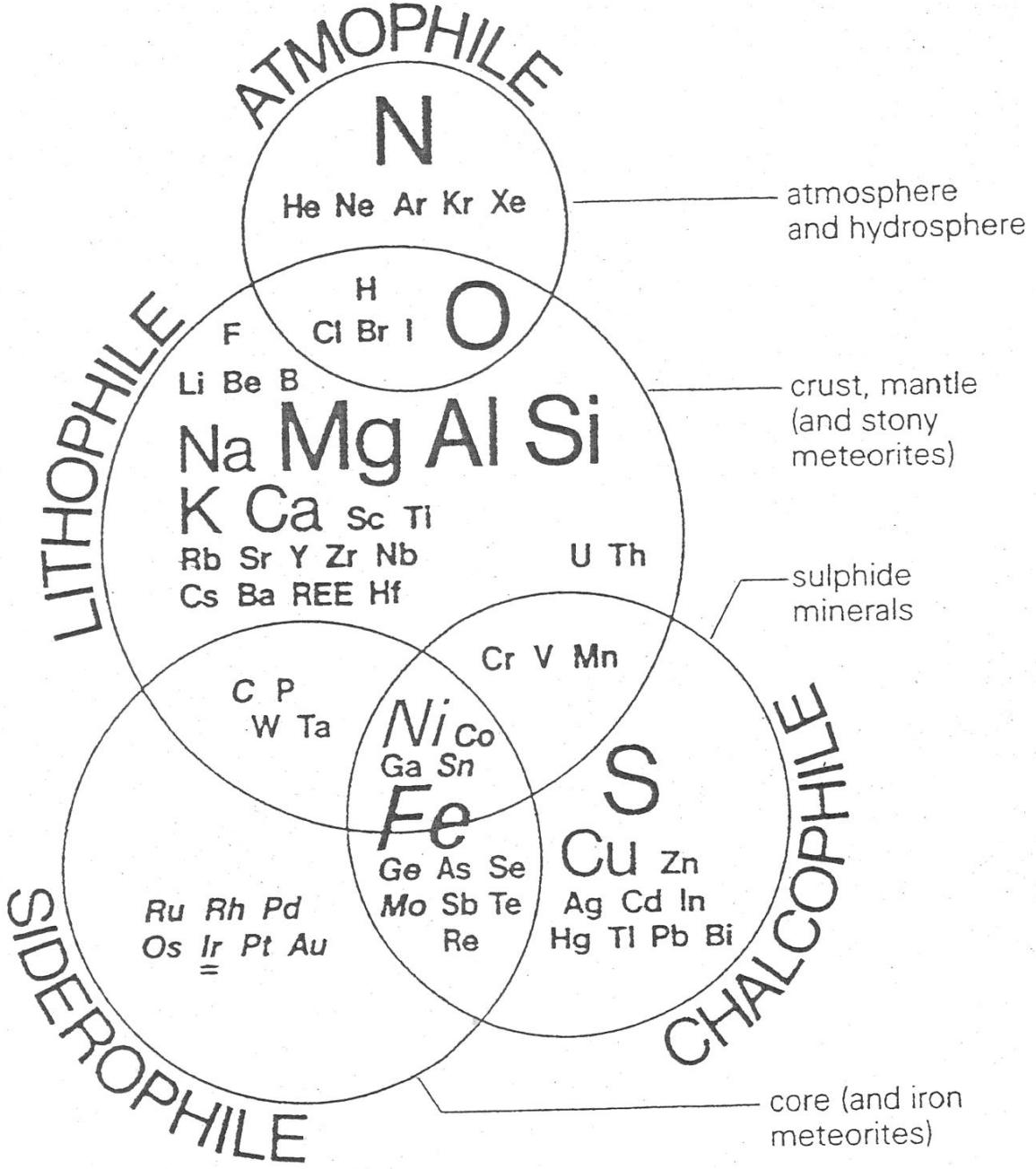


atmosphere, N, O

Earths crust, Si, Al, Na, K, Ca

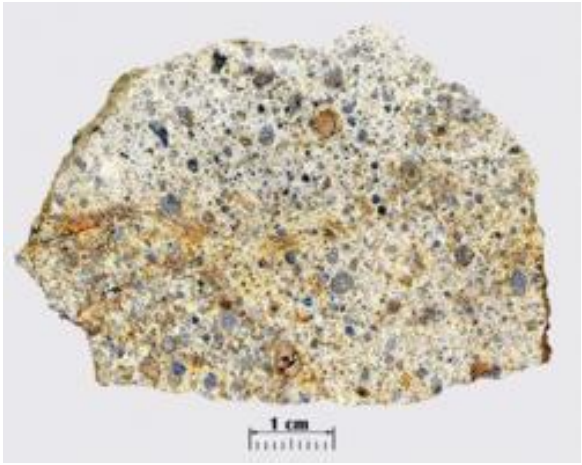
The mantle, Fe, Ni, Si, Al, Ca

The core, Fe, Ni

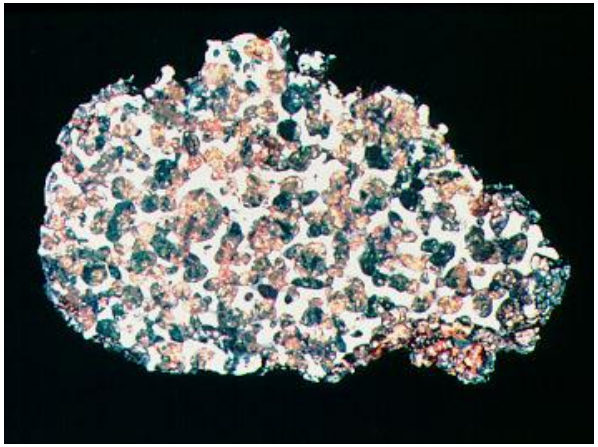

ATMOPHILE
N
He Ne Ar Kr Xe
atmosphere
and hydrosphere
H
F
Cl Br I
O
LITHOPHILE
Li Be B
Na Mg Al Si
K Ca Sc Ti
Rb Sr Y Zr Nb
U Th
Cs Ba REE Hf
crust, mantle
(and stony
meteorites)
sulphide
minerals
Cr V Mn
C P
W Ta
Ni Co
Ga Sn
Fe
S
Cu Zn
Ag Cd In
Hg Tl Pb Bi
Ge As Se
Mo Sb Te
Re
Ru Rh Pd
Os Ir Pt Au
CHALCOPHILE
SIDEROPHILE
core (and iron
meteorites)

chondrite

achondrite

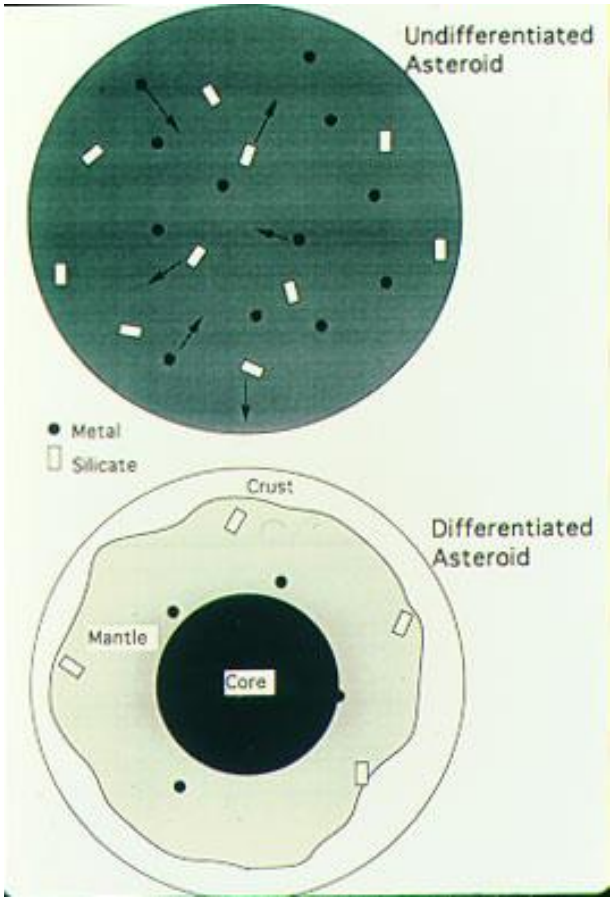


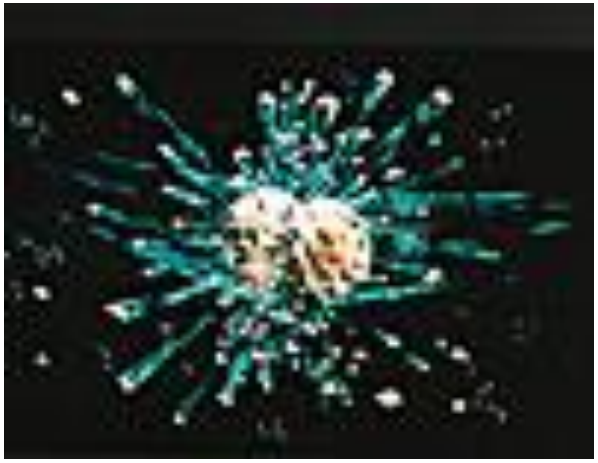
stony-iron



iron

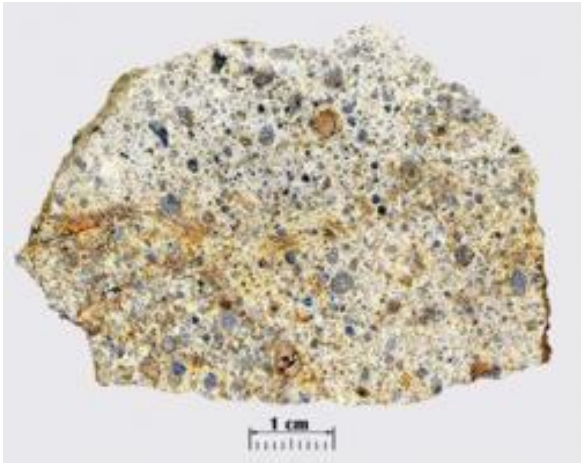
Differentiation of an asteroid (big meteor)



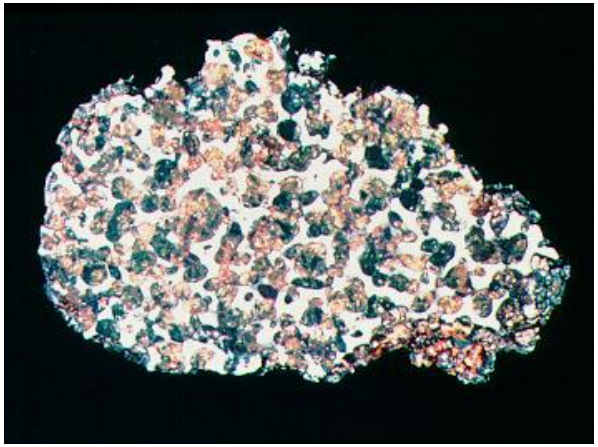


chondrite

achondrite



stony-iron

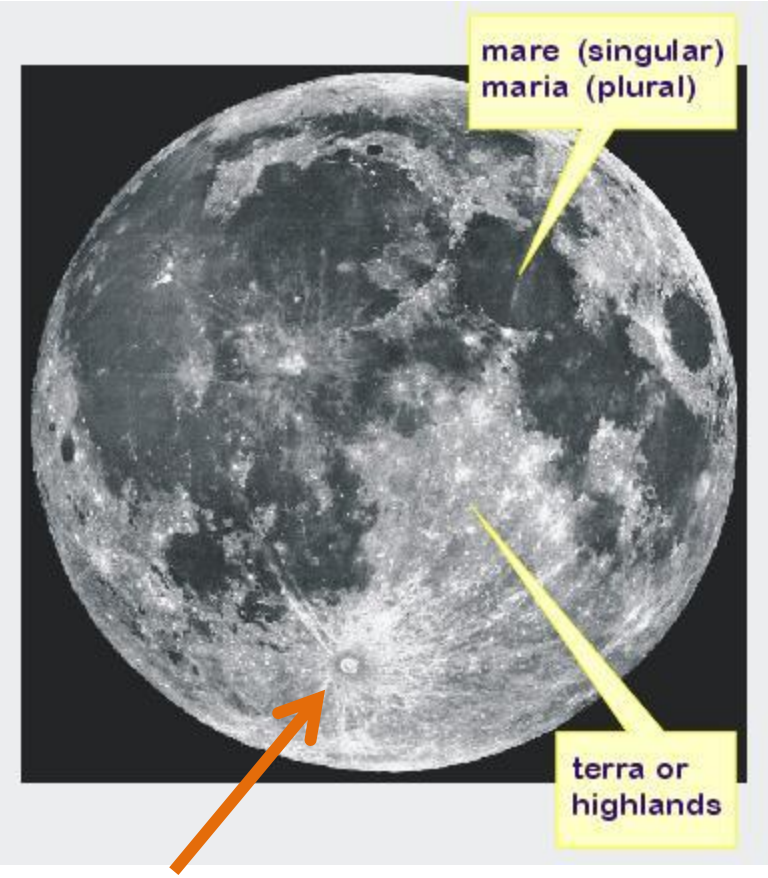


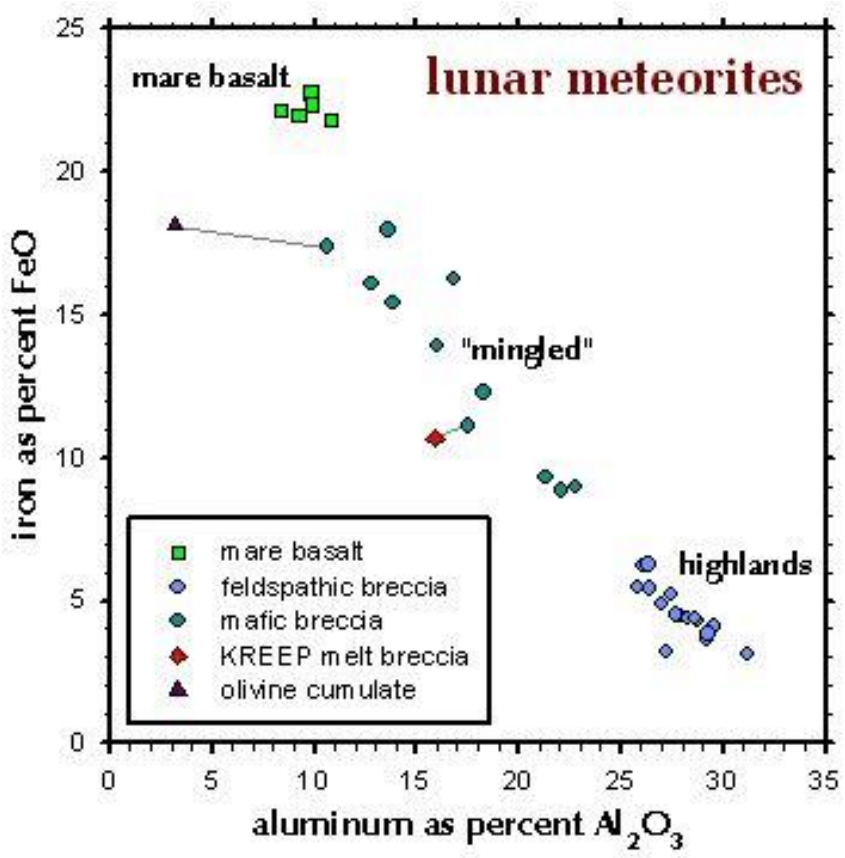
iron

The magma ocean solidified, H_2O and CO_2 were released from the magma to the atmosphere, the greenhouse effect was so strong, that the crust was partly molten

A meteor (Thea, the mother of the Moon) with the size of Mars collided with the young Earth at 4450 Ma and whiped away the protoatmosphere. Parts of the meteor and parts of the Earth formed the moon

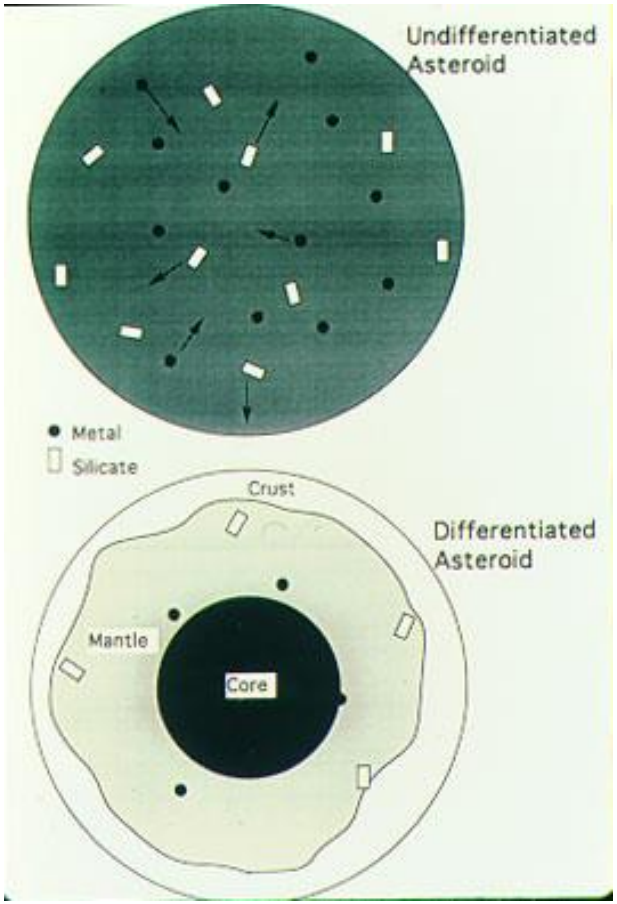
The geochemistry of the Moons crust
highlands (terra): ”light” Si,Al-rich minerals like anortite $Ca[Al_2Si_2O_8]$
oceans (mare) ”heavy” Fe-rich minerals like olivine $(Mg,Fe)_2SiO_4$





The craters of the moon are remnants of the wild days from the earliest time of the solar system

Differentiation of the moon



When the moons early anortite crust was bombarded, the pressure decreased in the mantle and basaltic magmas were formed due to partial melting of the mantle

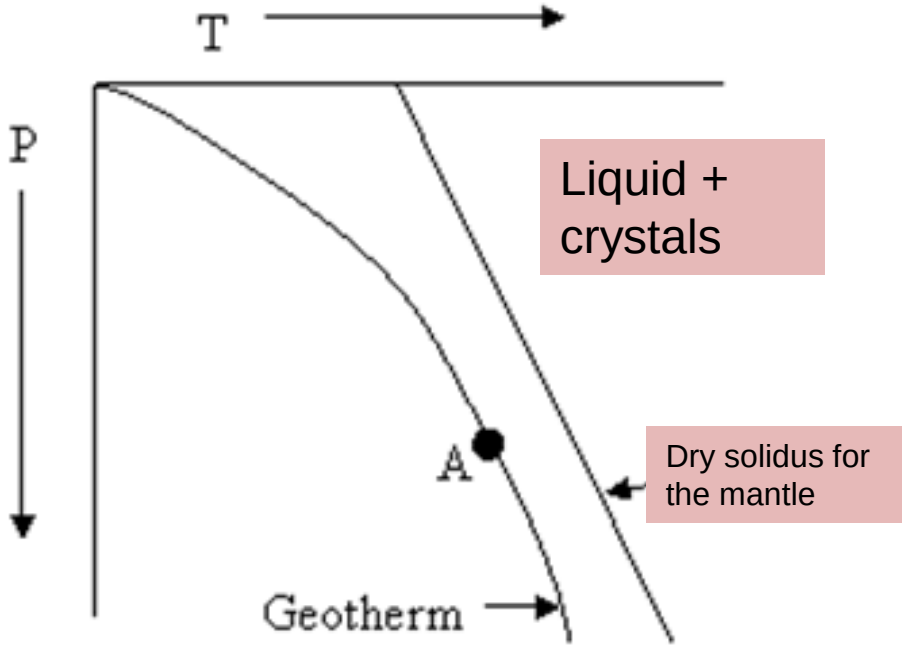
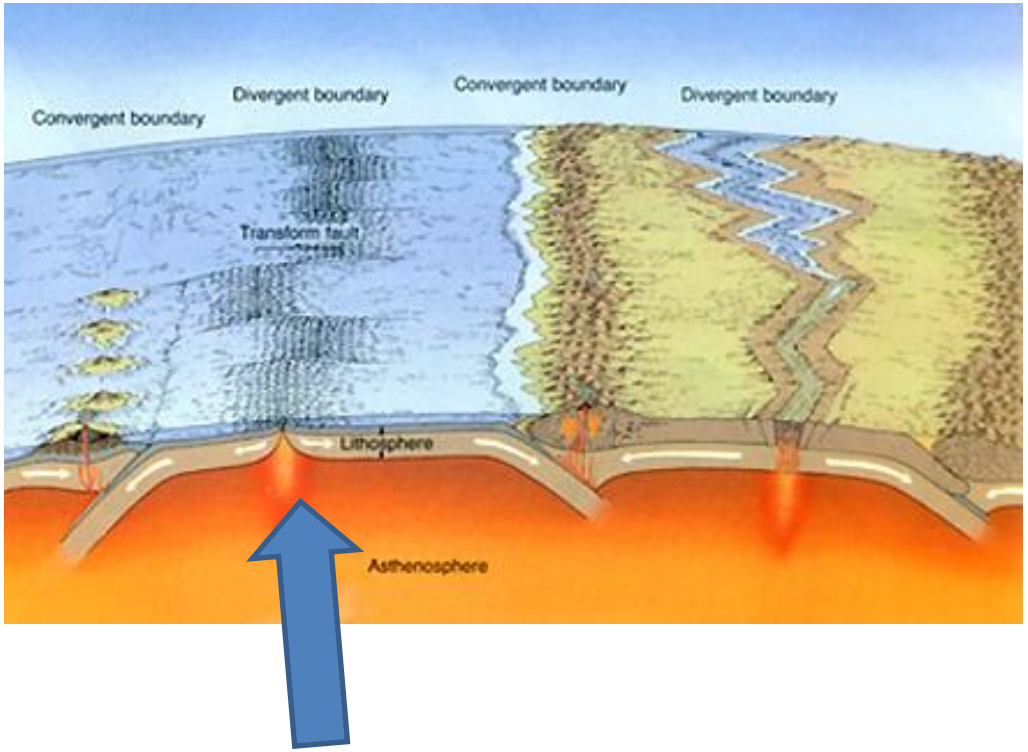
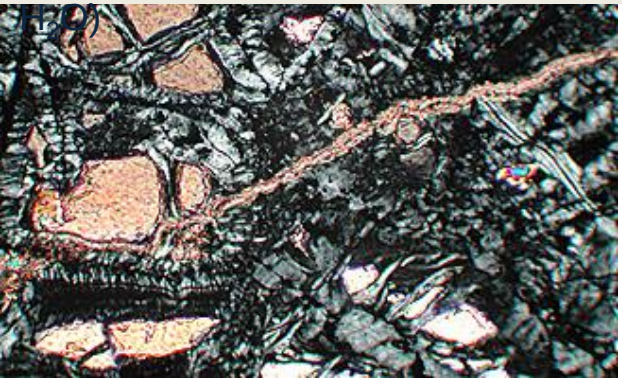


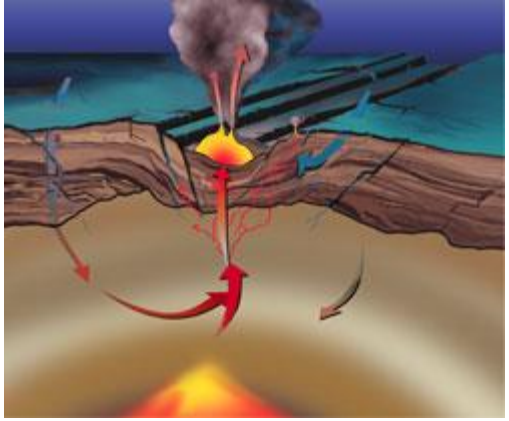
Plate tectonics is the motor that keep up the balance between the atmosphere, hydrosphere and the lithosphere. A motor that is missing in our neighbours

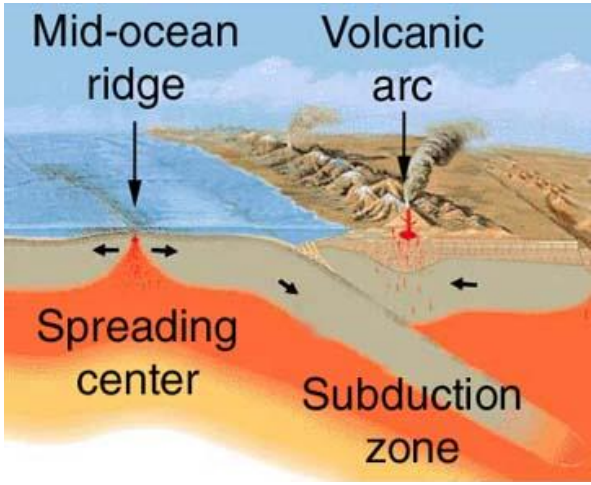


What happends when 1200°C magma gets in contact with 2°C water?

Dry olivine => serpentine (13% H2O)







When hot magma from the mantle gets in contact with the cool ocean water, reactions like this takes place:

Olivine + $H_2O \rightarrow$ serpentin + magnetit + brucit + H_2

$Mg_2SiO_4 + 2H_2O \Rightarrow Mg_3Si_2O_5(OH)_4 + Mg(OH)_2 + H_2$

Consequently, enormous contents of water is bounded to minerals in the ocean floors.

It has been calculated that the sea level would rise 375 meters if all crystal waters should be released from the ocean floor

This crystal water is transportated to destructive plate margins (subduction zones). Here the water is released again and extrudes through volcanoes.

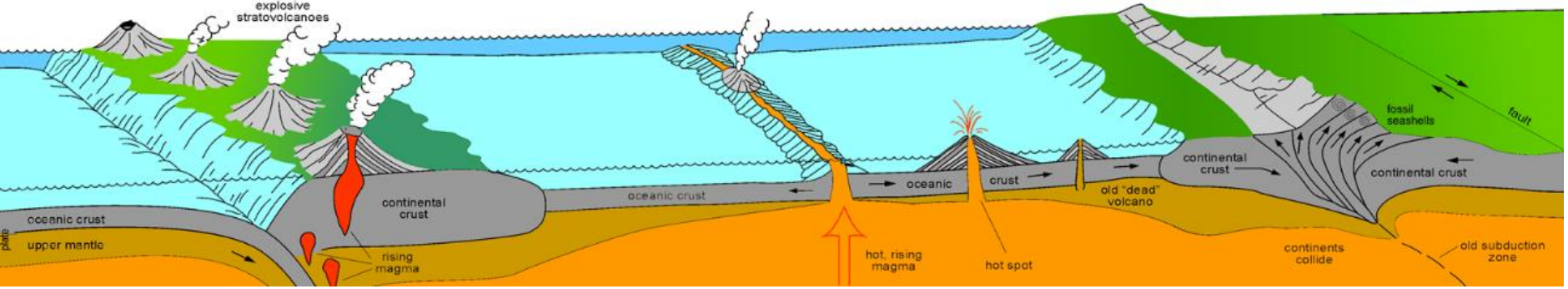
Serpentin

$Mg_3Si_2O_5(OH)_4$

43.36 % SiO_2

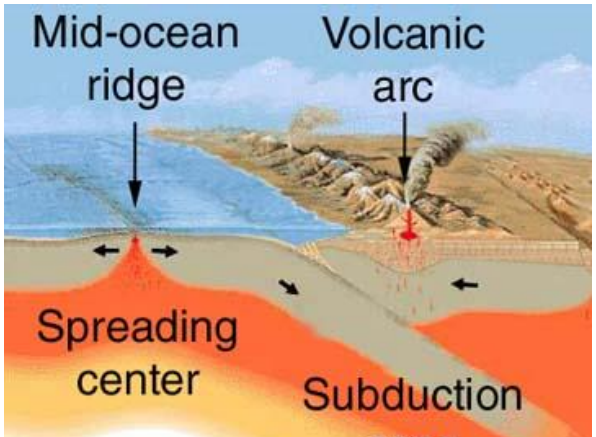
43.63 % MgO

13.00 % H_2O



Oceanplattorna som glider fram på astenosfären innehåller en massa vatten bundet till mineral som hornblände och serpentin. Då kontinenter eroderar sedimenteras det vattenrika leror t,ex, kaolinit på havsbottnet

Man har räknat med att vattennivån på jordklotet skulle höjas med 375 meter om allt vatten som är bundet i oceanskorpan skulle frigöras till oceanerna



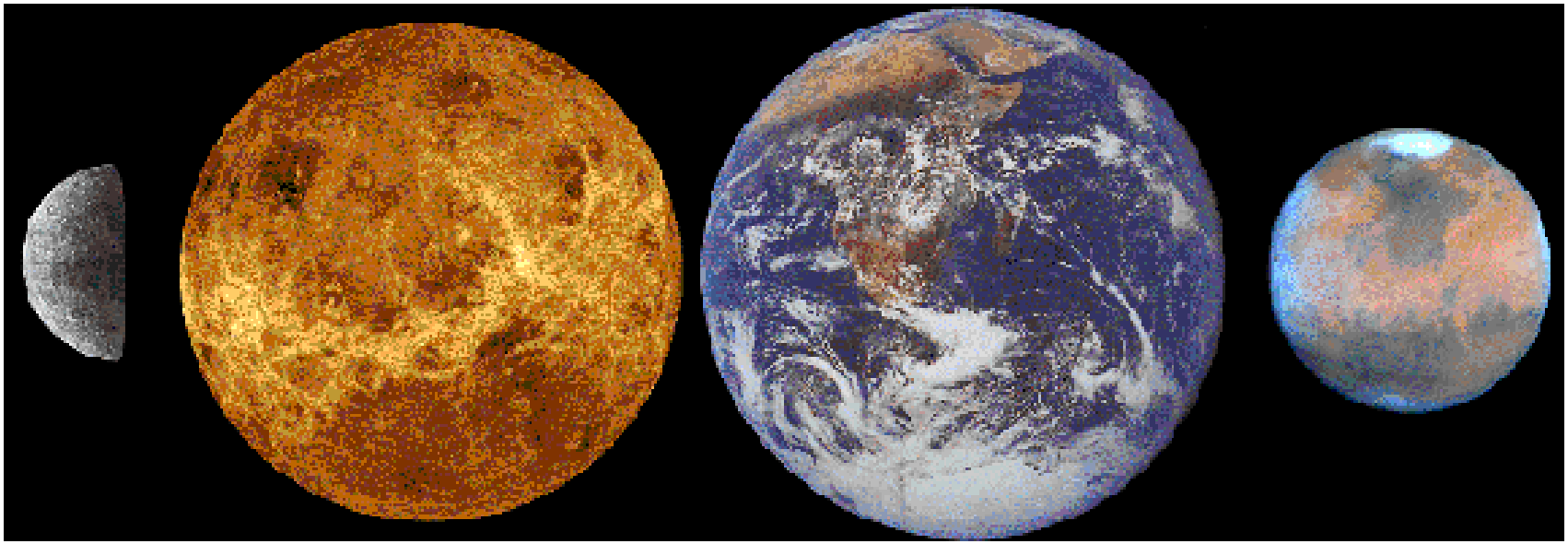
Hornblende
$Ca_2[Fe^{2+}4(Al,Fe^{3+})]Si_7AlO_{22}(OH)_2$
44.40 % SiO_2
9.42 % Al_2O_3
11.84 % CaO
30.34 % FeO
1.90 % H_2O
100.00 %

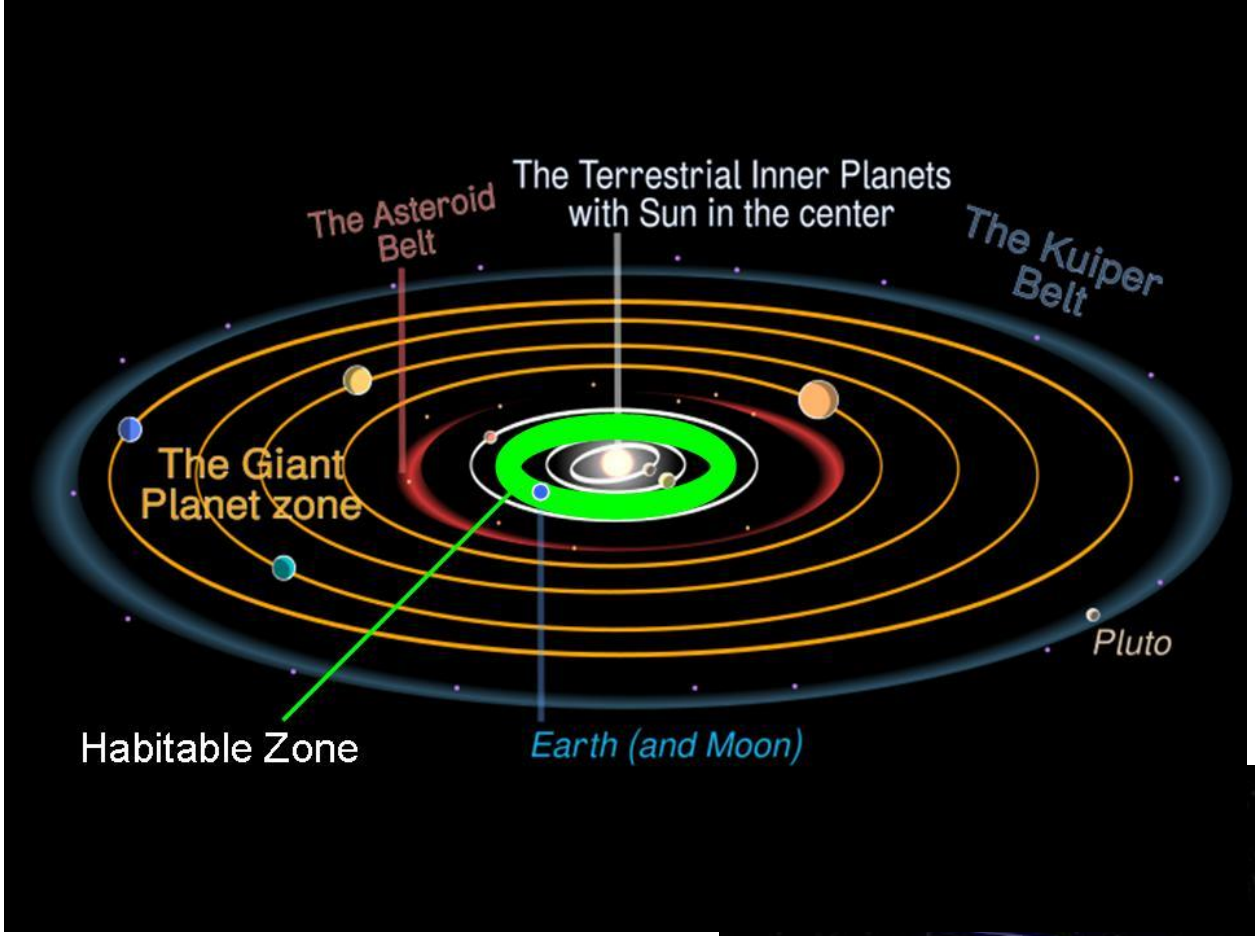
Serpentin $Mg_3Si_2O_5(OH)_4$
43.36 % SiO_2
43.63 % MgO
13.00 % H_2O
100.00 %

Kaolinit $Al_2Si_2O_5(OH)_4$
46.55 % SiO_2
39.50 % Al_2O_3
13.96 % H_2O
100.0%

The terrestric or stony planets have the same origin, why appear life only here? What happend to our neighbours? Can it happend to us?

- Merkurius, Venus, Jorden, Mars



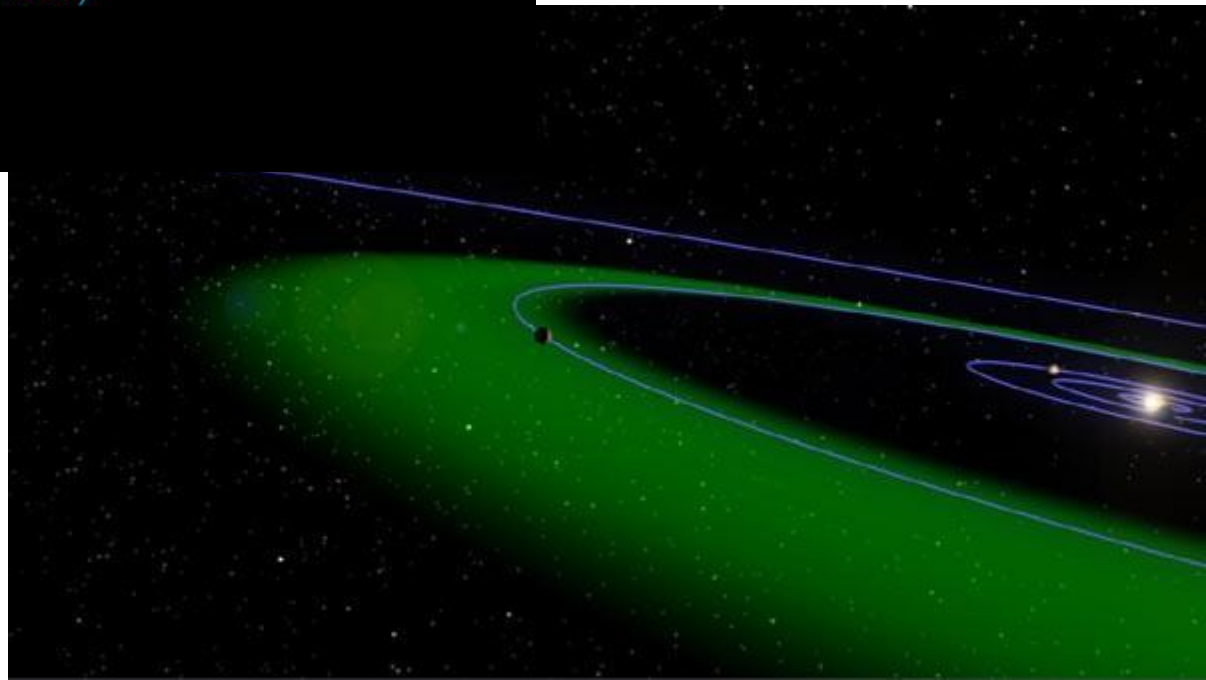


The habitable zone is the distance from a star where H_2O on a planet is principally in liquid form, i.e. water

- more close to the star, H_2O = gas
- more distant from a star, H_2O=ice

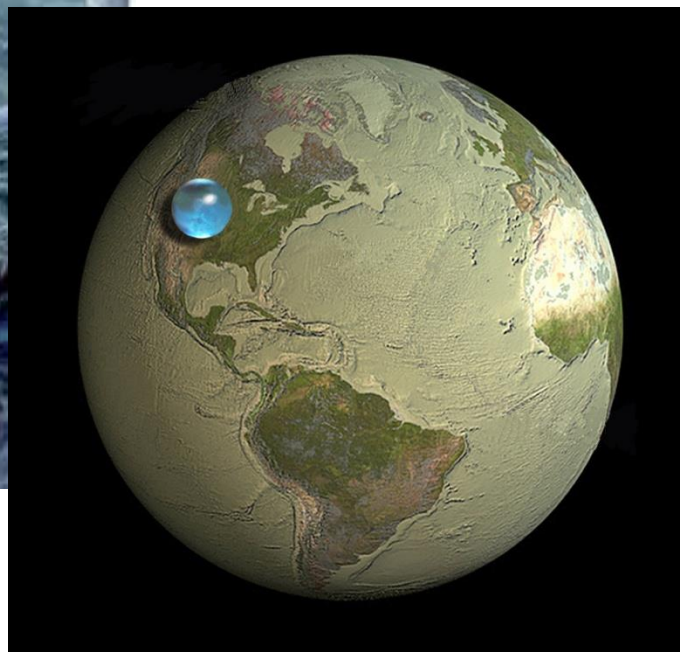
(dependent on the surface pressure of the planet)

Why do we have life only on our planet ?



When the Earth started to cool, water was released from the magma ocean and more water came to the surface with meteorites and comets (based on oxygen isotopes)

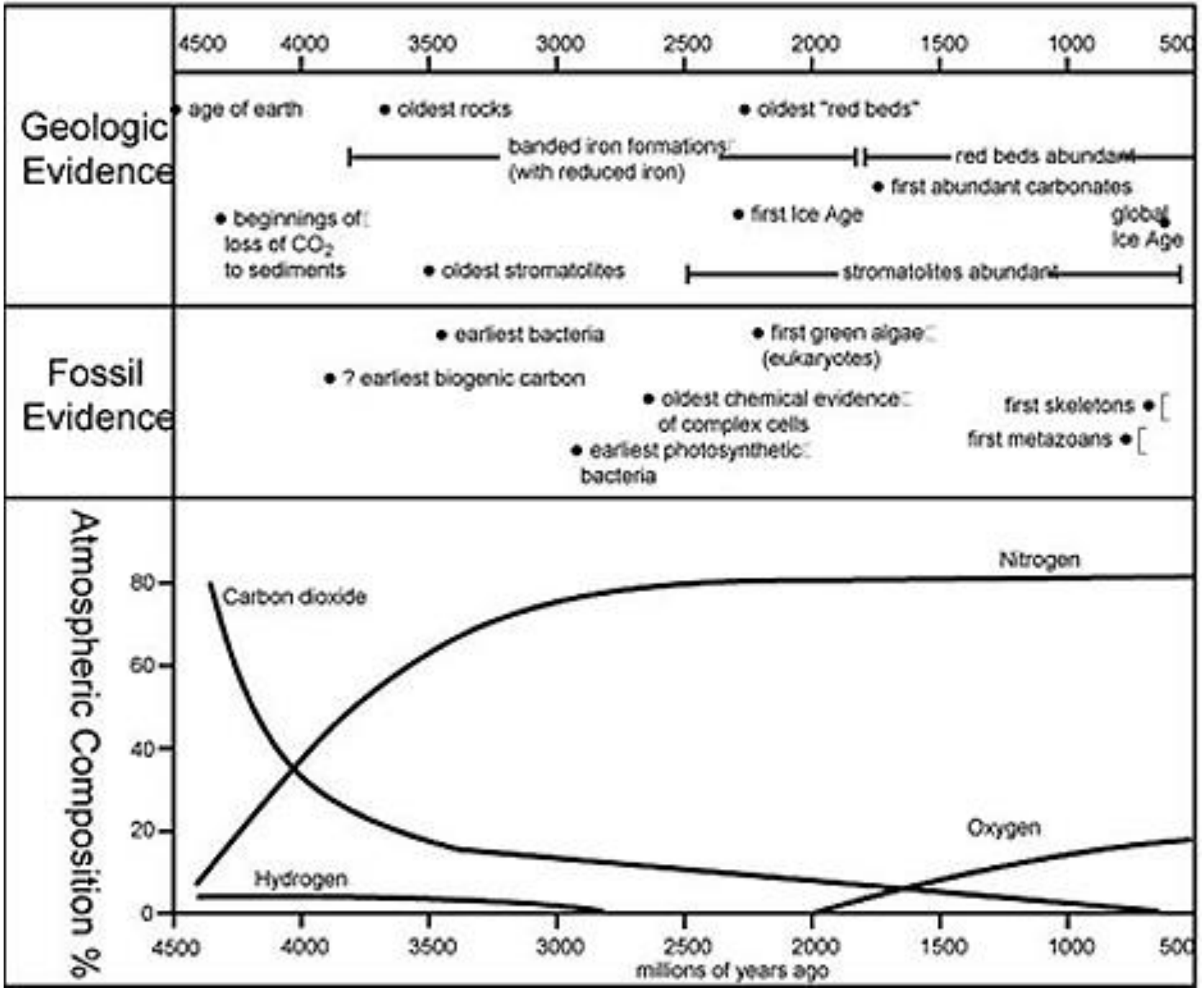
Öh...this is the amount of water we have on the surface



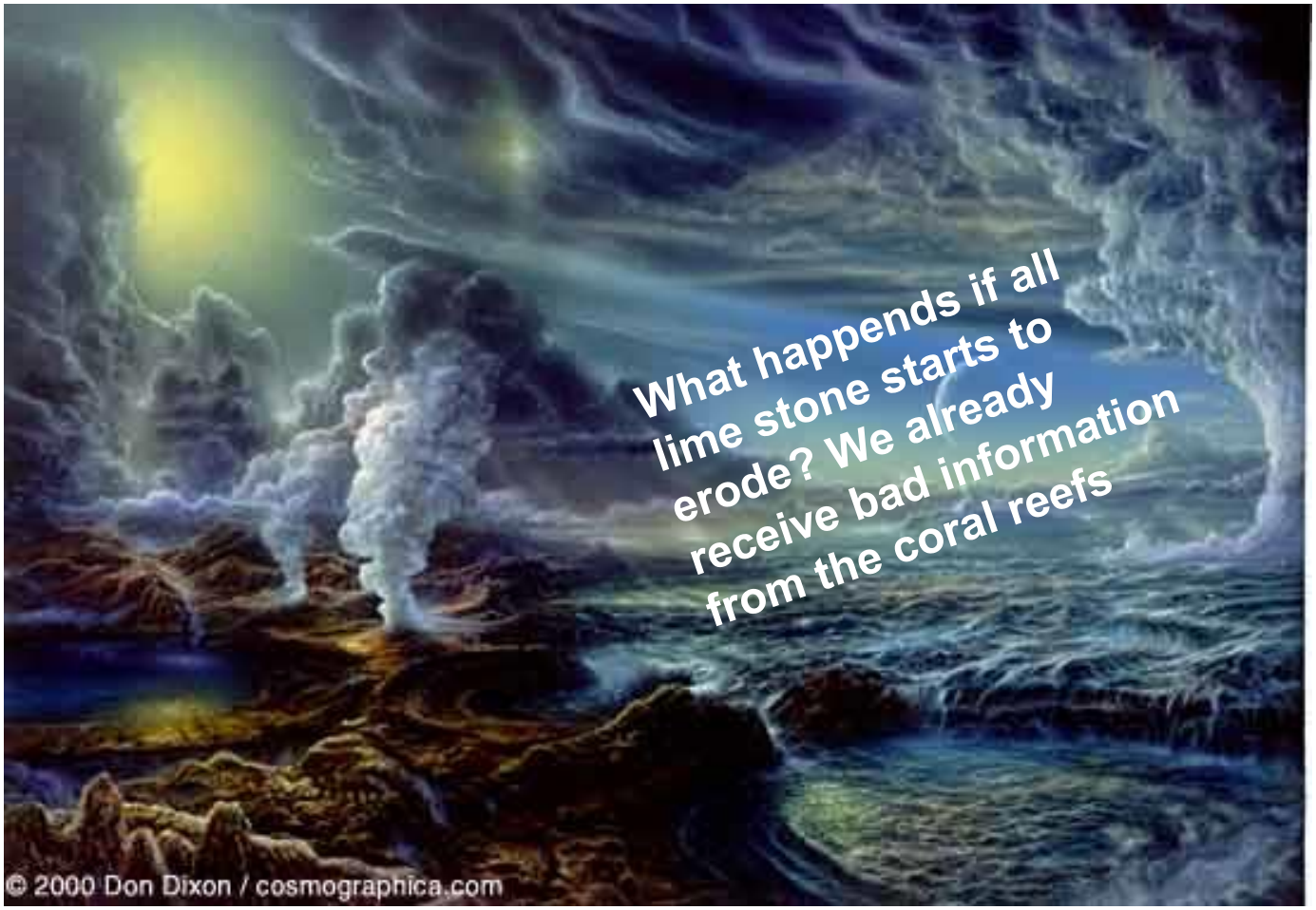
The composition of some atmospheres

		Mars	Earth	Venus
Carbon dioxide	CO_2	95.32	0.031	96.5
nitrogen	N_2	2.7	78.08	3.5
oxygen	O_2	0.13	20.95	
water	H_2O	0.03	0-4	

WHERE IS THE EARTHS CO_2 AND FROM WHERE COMES THE OXYGEN?


Geologic Evidence
4500
4000
3500
3000
2500
2000
1500
1000
500
age of earth
oldest rocks
oldest "red beds"
banded iron formations (with reduced iron)
red beds abundant
first abundant carbonates
beginnings of loss of CO_2 to sediments
first Ice Age
global Ice Age
oldest stromatolites
stromatolites abundant
Fossil Evidence
earliest bacteria
first green algae (eukaryotes)
? earliest biogenic carbon
oldest chemical evidence of complex cells
first skeletons
first metazoans
earliest photosynthetic bacteria
Atmospheric Composition %
80
60
40
20
0
Carbon dioxide
Nitrogen
Oxygen
Hydrogen
4500
4000
3500
3000
2500
2000
1500
1000
500
millions of years ago

Voluminous cirkulation of H_2O cause erosion where Ca is extracted from rocks and forms limestone, $CaCO_3$, after reacting with atmospheric CO_2. that is a major reason for our low CO_2 content in our atmosphere

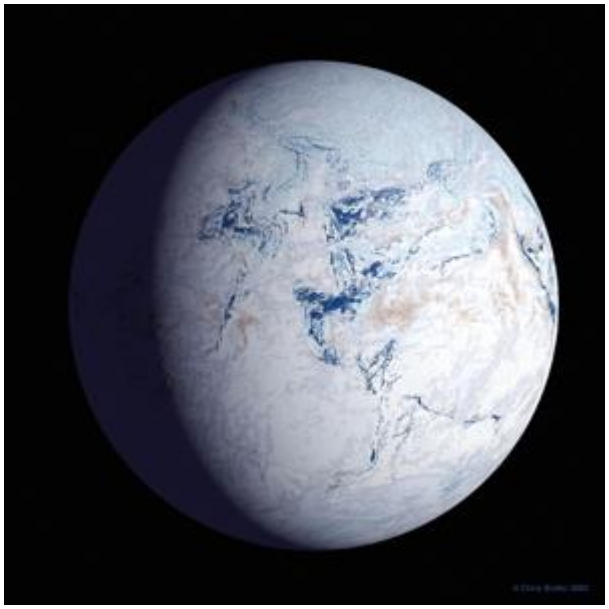


The **Great Oxygenation Event 2400 Ma**

- GOE is the time when free oxygen appeared in the atmosphere. This revolution took place about 2400 Ma ago.
- The photosynthesis produced oxygen also before GOE. The difference was, before GOE, that all oxygen produced was bounded to rocks . GOE was the point when minerals were saturated in oxygen and oxygen could accumulate in the atmosphere.

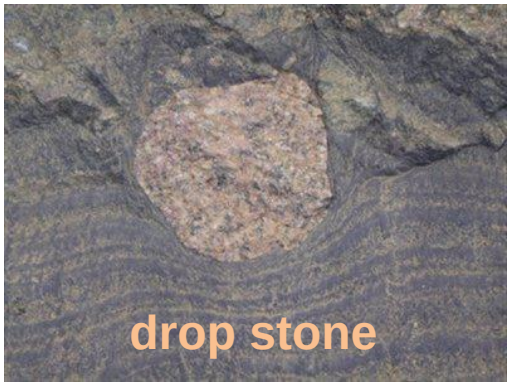
In rock forming minerals, iron appears as Fe^{2+}. By oxidation, a part of the Fe^{2+} bearing minerals form magnetit, Fe_3O_4 ($FeO+Fe_2O_3$) and further to hematite, Fe_2O_3. And rosty rocks we see all over os still today!

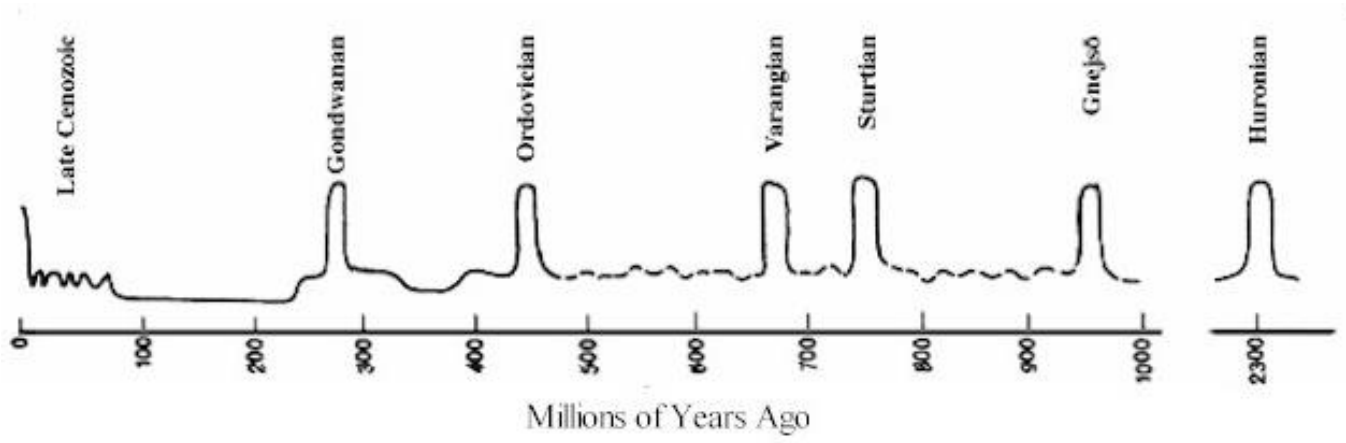
Snowball Earth



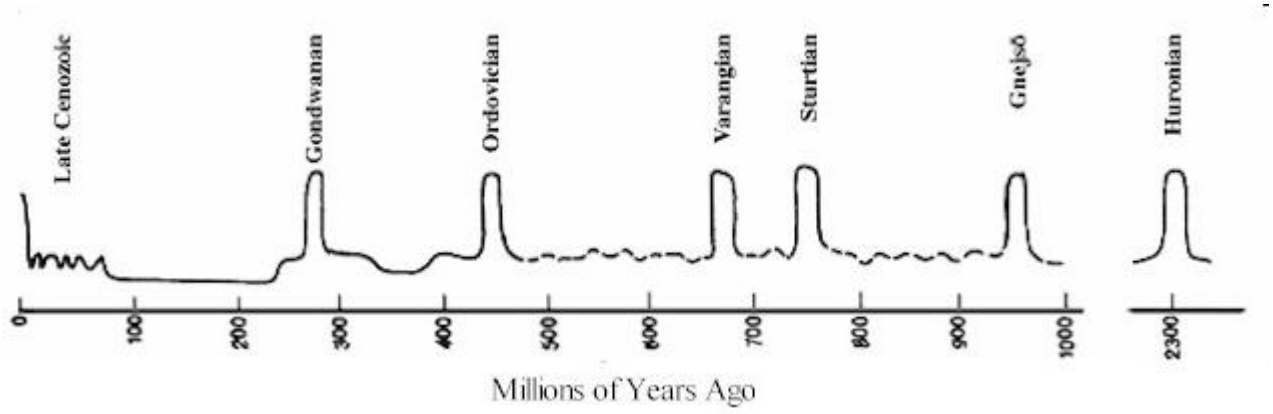
Appear in cycles. Has to do with plate tectonica

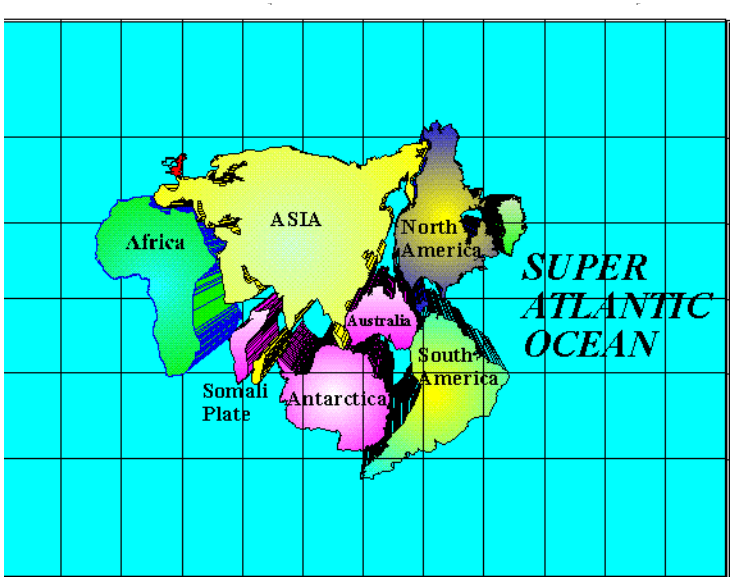
Evideces of ancient ice ages, diamectites and drop stones





Events of snowball Earth can be correlated with super continents



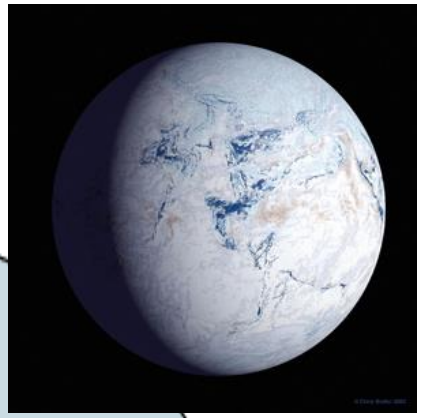


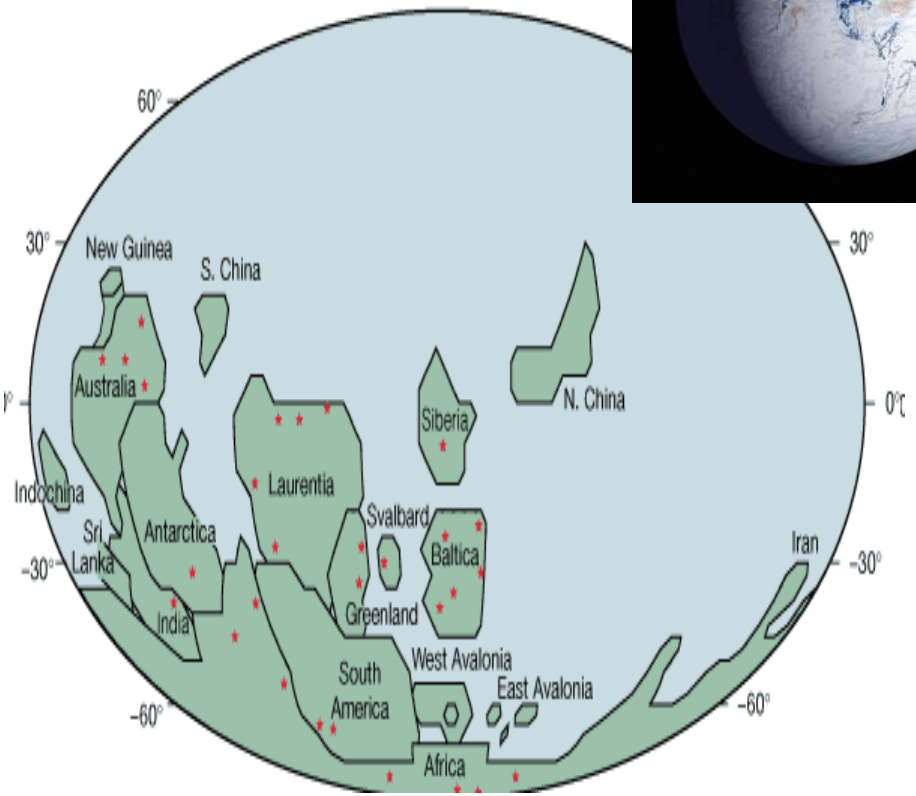
A supercontinent is a situation when all continents are collected to a single continent

When a supercontinent is formed, the plate teconics ends and the CO_2-contet decreases in the atmosphere – it becomes cooler

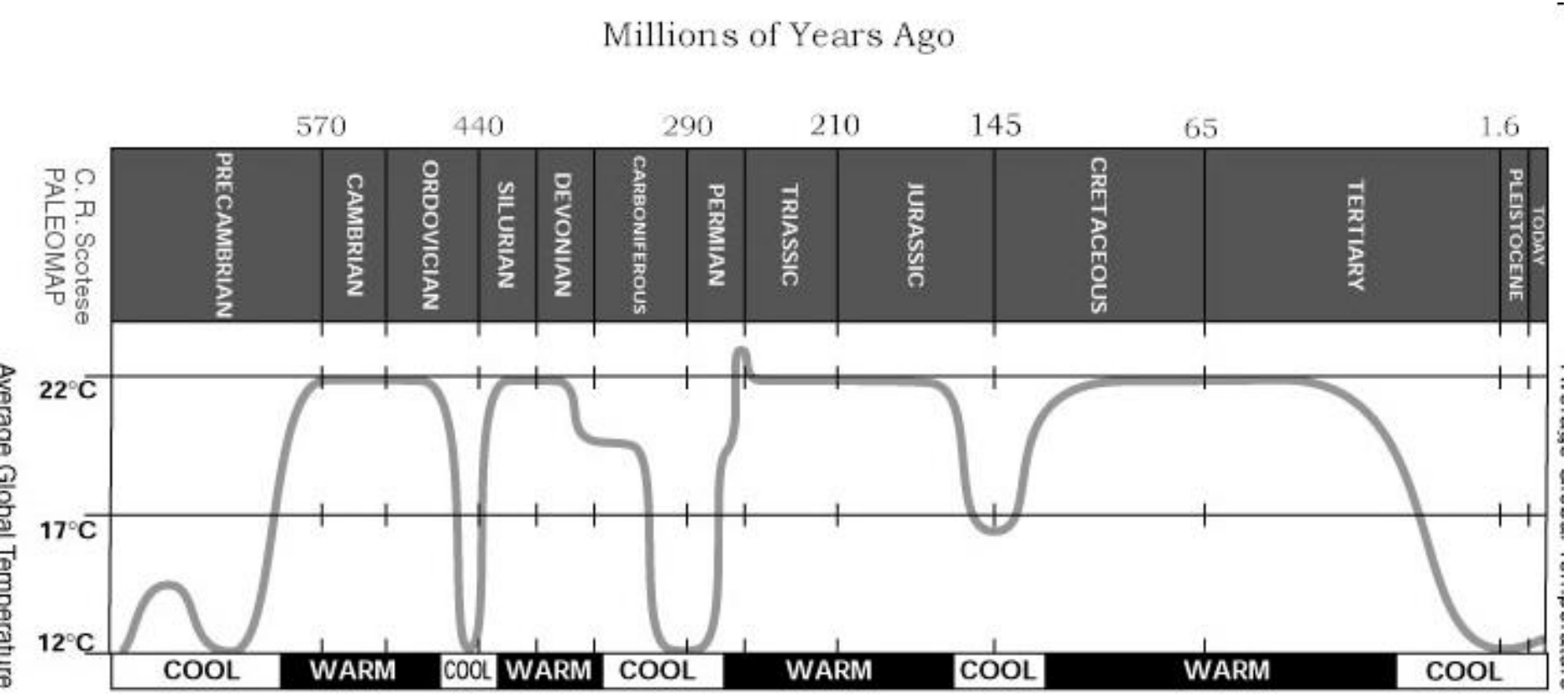
- Supercontinent Rodinia
- 1100 – 750 Ma ago

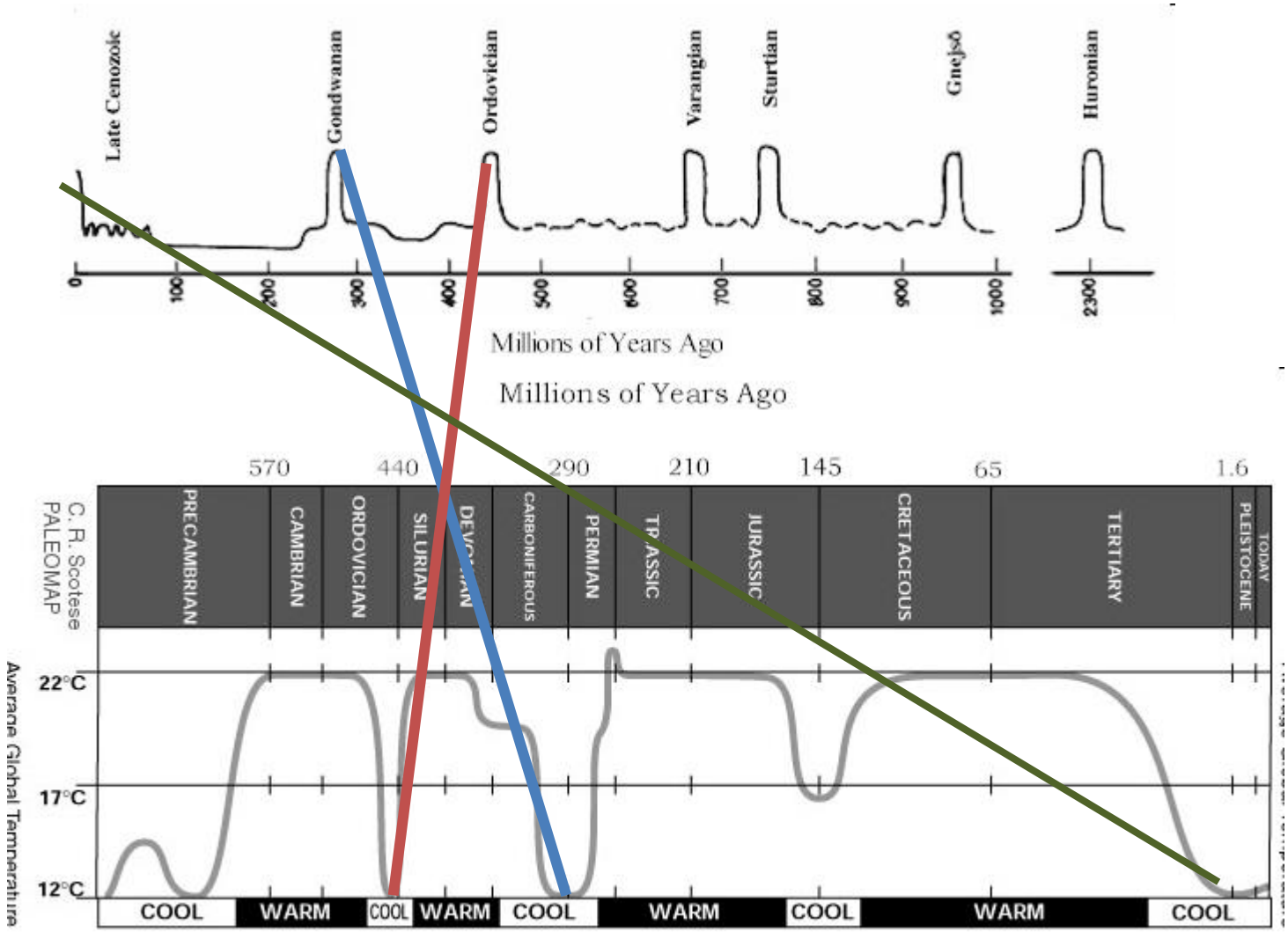
- Simultaneously the Earth was covered with ice and snow. A period we may call **Snowball Earth.**





time-geological processes-CO_2-temperature




Late Cenozoic
Gondwanan
Ordovician
Varangian
Sturtian
Gnejs6
Huronian
0
100
200
300
400
500
600
700
800
900
1000
2300
Millions of Years Ago
Millions of Years Ago
570
440
290
210
145
65
1.6
C. R. Scotese
PALEOMAP
PRECAMBRIAN
CAMBRIAN
ORDOVICIAN
SILURIAN
DEVONIAN
CARBONIFEROUS
PERMIAN
TRIASSIC
JURASSIC
CRETACEOUS
TERTIARY
TODAY
PLEISTOCENE
22°C
17°C
12°C
COOL
WARM
COOL
WARM
COOL
WARM
COOL
WARM
COOL

What is a stable climate?

- The climate history of the Earth evidence great varieties.
- The climate variation is dependent on how geological processes can release CO2 from rocks and sediments
- However, we have a brand new young and stupid actor on the stage – Homo Sapiens – the only species who wants to create an artificial inbalance between all spheres of the Earth by burning fossile fuels

The origin of the ozon shelter

Parts of the oxygene formed due to the photosynthesis were enriched in the form of ozon (O_3) in the stratosphere. The ozonlayer acts as a shelter towards dangerous radiation from the sun.

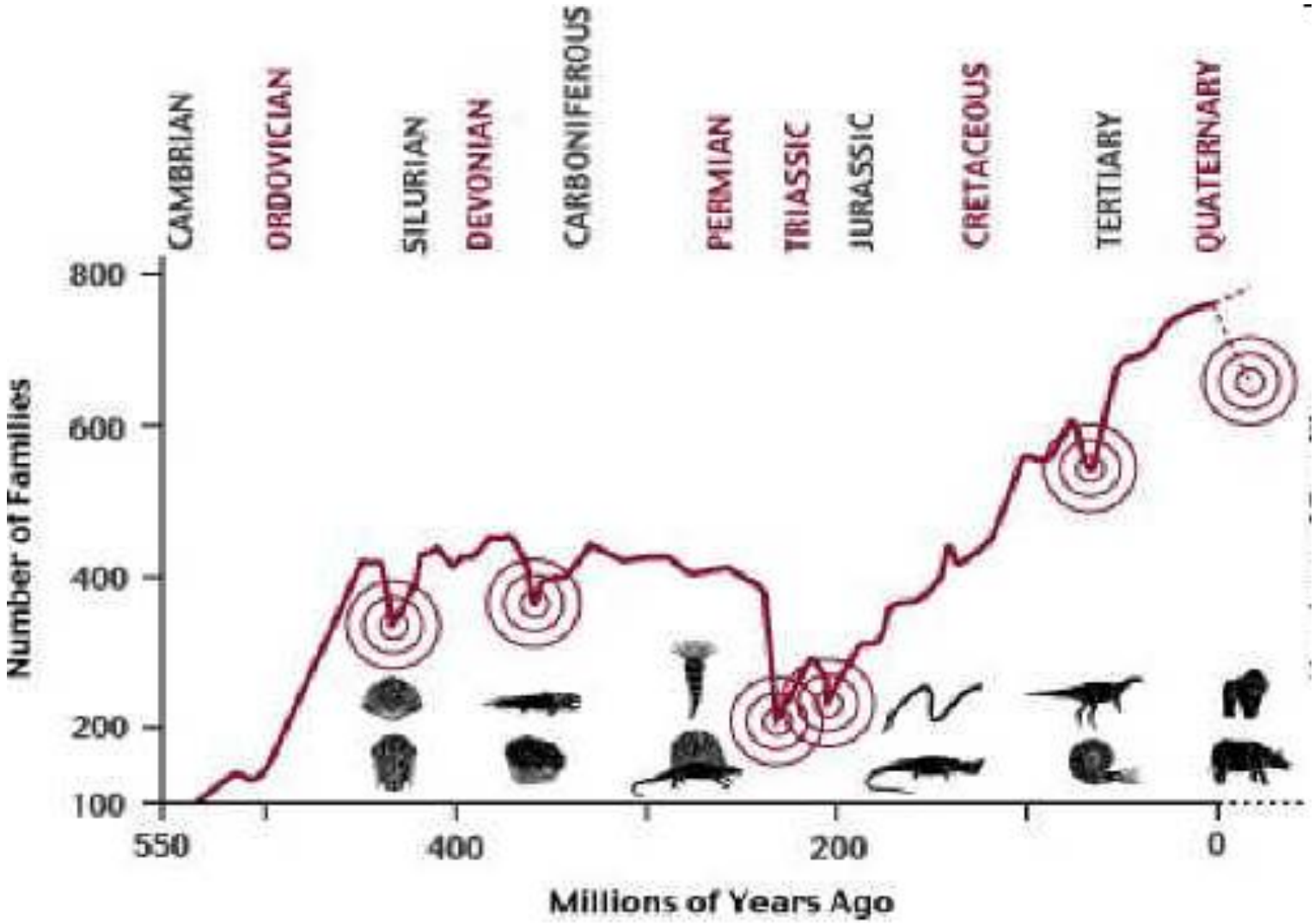
At last, life could expand o dry land! This took place for no more than 400 miljon years ago. (amphibies)

By that time, the Earth had existed in 4100 miljon years!!!

Obs! freongases

Massextintions

disequilibrium in the atmosphere and in the oceans because of volcanic activity, acidification or meteorite impacts



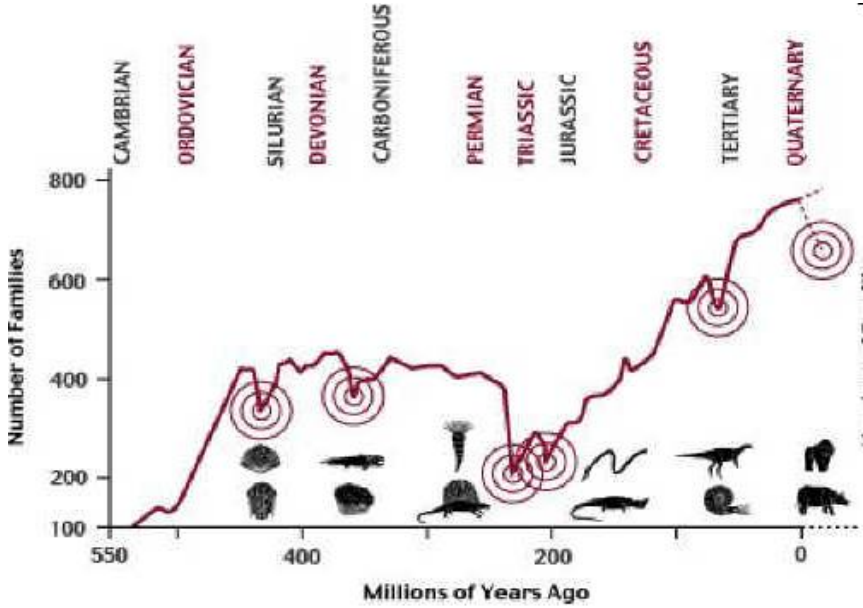
Why massextinctions?

Volcanic activitet has a dubbel effect

- In short perspectives it becames cold ”volcano winters” because of particles in the atmosphere
- In long perspective hot because of CO_2 enrichment in the atmosphere

Meteorite impacts has many consequences: magmatism, heat, new atmosphere

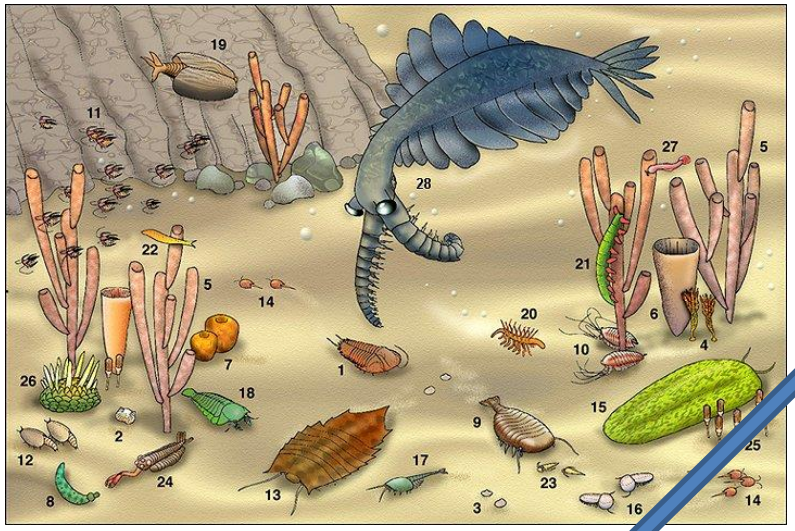
Mass extinction

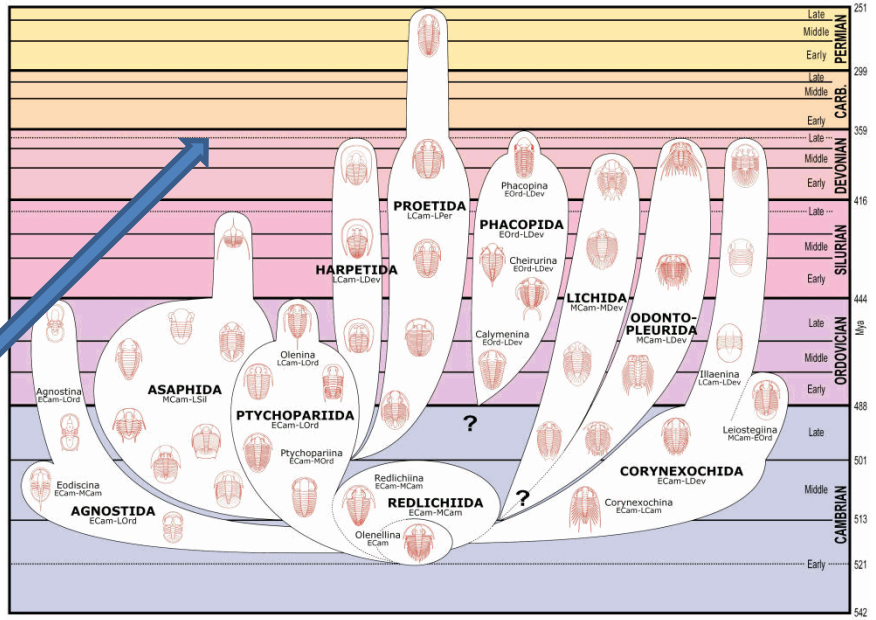


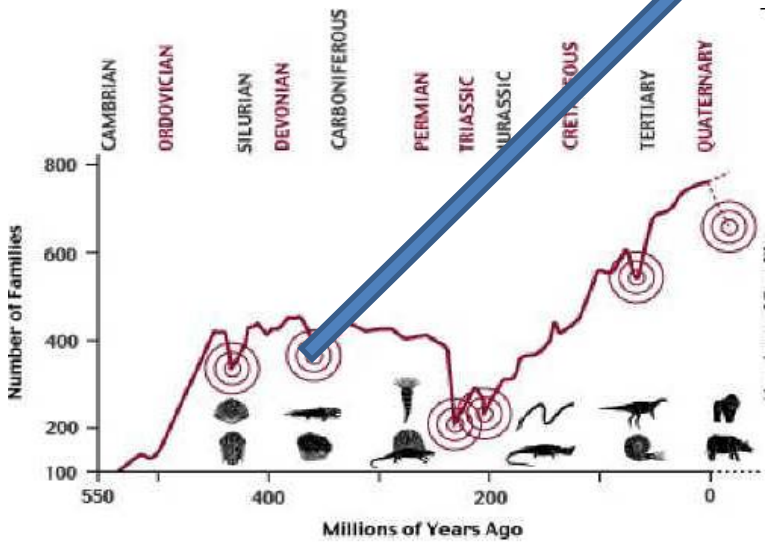
Prehistorics holocoust

- The mass extinction by the end of Perm and in the beginning of Trias has thrilled the scientists in many years.
- More than 95% of all life forms in the seas and 75% of all life forms on the continents disappeared. For example the Trilobites was one species that disappeared at that time.
- The latest data from scientists at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, supports the view that extensive volcanic activity over the course of hundreds of thousands of years released large amounts of carbon dioxide and sulphur dioxide into the air, gradually warming up the planet.

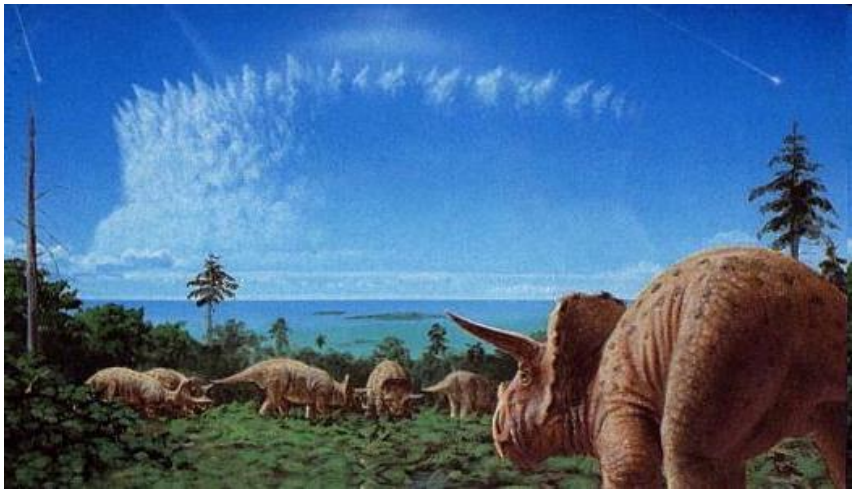
Massdöd, livet under kambrium

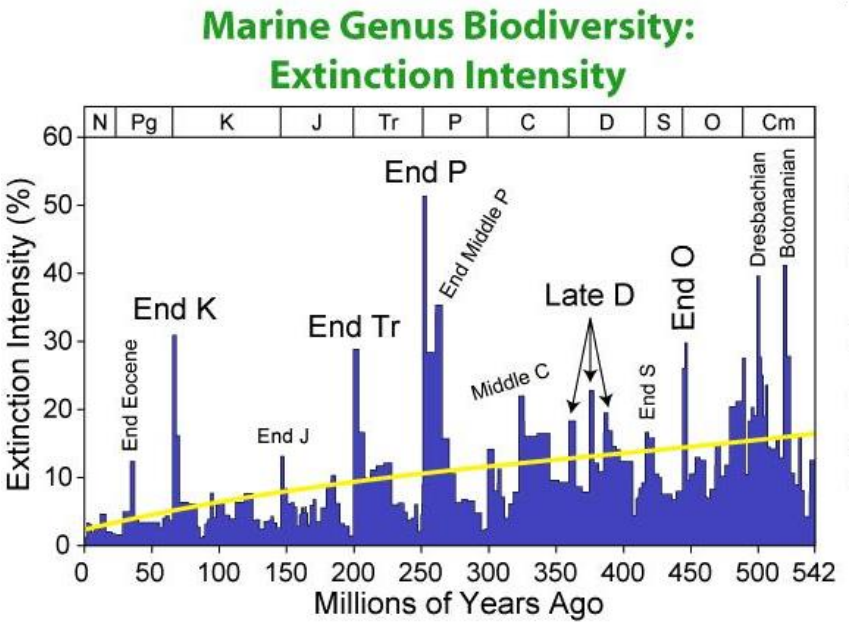






By the end of cretaceous, almost all dinosaurs were extincted as a consequence of the Chichulub meteorite, and mammals started to develop (the irridium anomaly)





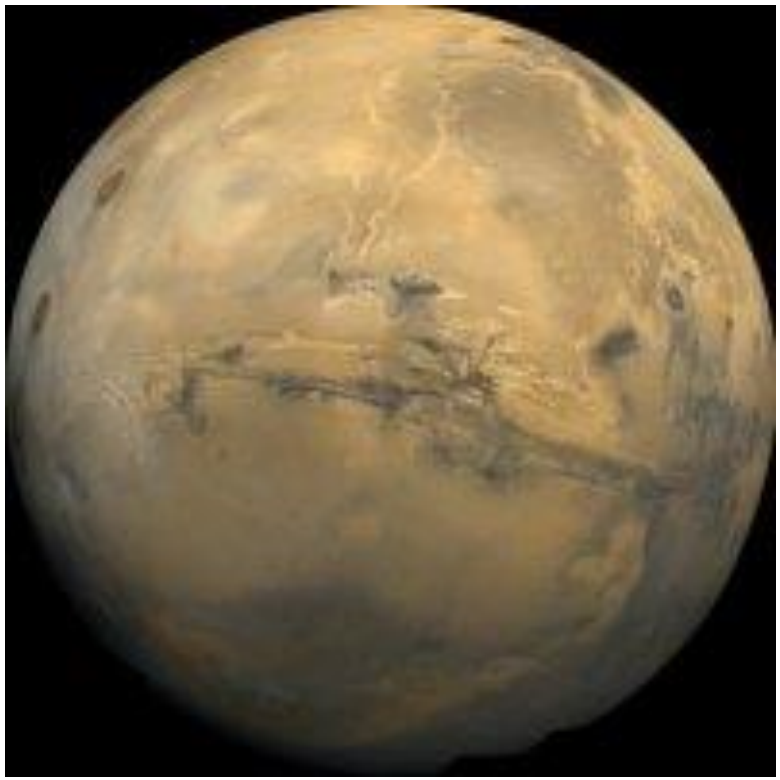
The Toba catastrophy

Between 70,000 and 75,000 years ago, a super volcano eruption took place at the Lake Toba on Sumatra (Indonesia). It was perhaps the biggest explosive eruption within 25 million years.

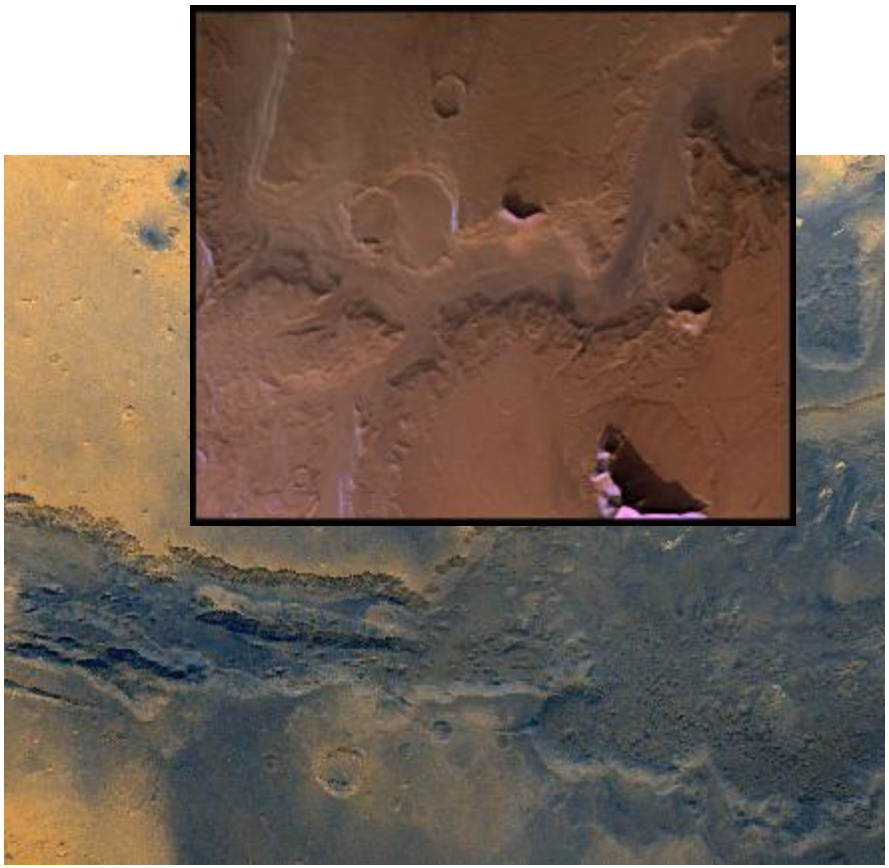
It forced the Earth, that already was in an ice age period to still more cooling. This resultet in that the earth human population decreased to 10000 or perhaps 1000 living human beings.

Mars

- Previously it was tought that there were channels buit by intelligent Martians on the planet.



Water on Mars



- Exampels of dried meandring rivers (above) and dried coastlines (down) evidence that the paleohydrosphere contained floating waters on Mars

Ripple marks on Mars

What happened with the water on Mars?

- The surface temperature ias between -120 and +12
- Has glaciers of ice and frozen CO_2
- The mass of the planet is low, why the atmospheric pressure is too low to keep H_2O in liquid form. A running stream would vaporize or freeze in some hours.
- A meteorite impact may increase the energy flux from the planet, and the ice may melt,

Venus

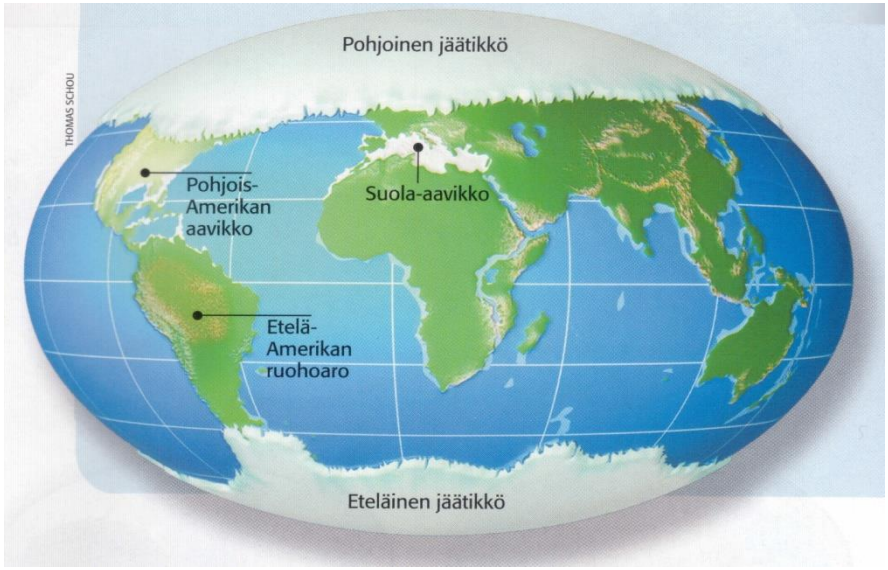
Runaway greenhouse effect

CO_2 in the atmosphere increase the infrared radiation and the surface of the planet heats up. A consequence is that flluid water converts to steam.

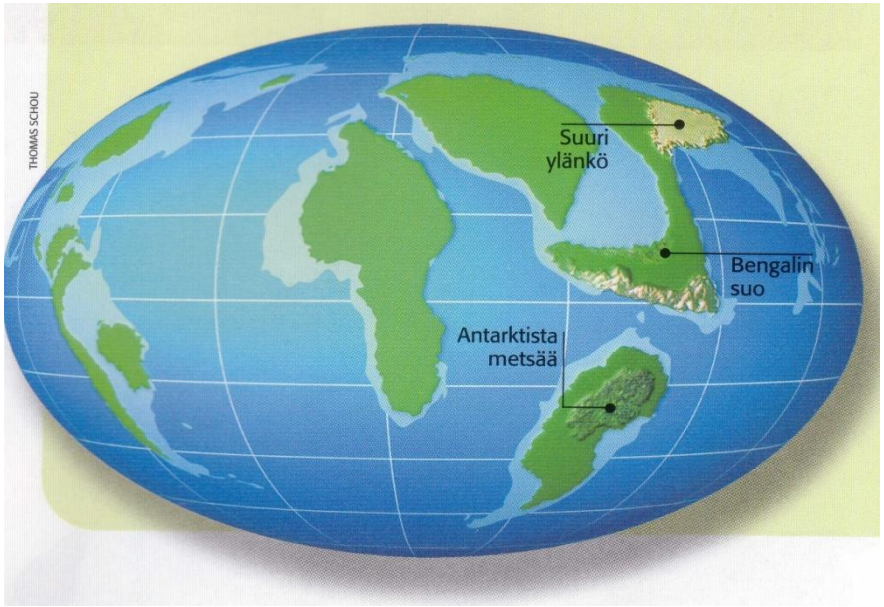
Steam is also a greenhouse gas that can speed up the heating of the planet.

Steam is lighter than carbon dioxide, why water can escape through the CO_2 layer to the outher space.

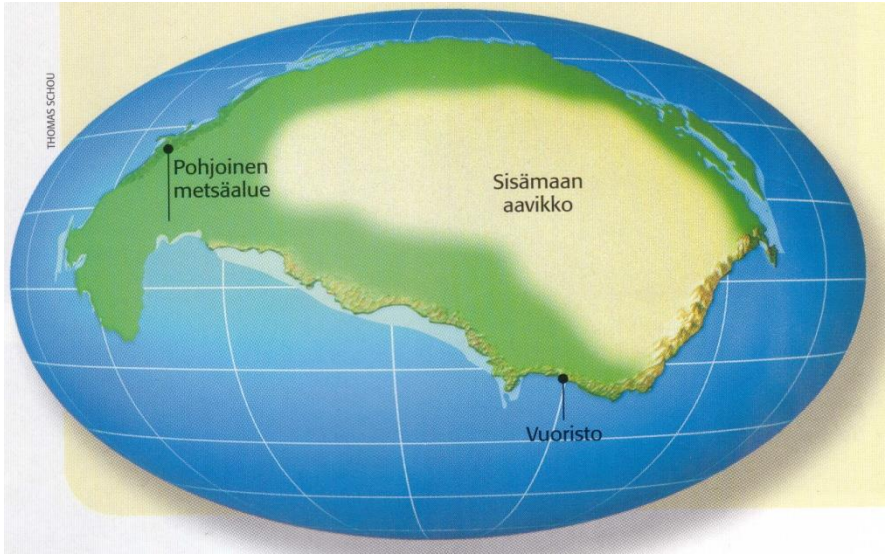
5 milj år framåt, lägre växthuseffekt, kallare



100 milj. framåt, större geologisk aktivitet, högre växthuseffekt



200 milj. framåt, Pangea II, stormiga blöta kuster, torrt i mitten



Dear chemists

- As you see, our planet is a fragile system
- Small changes in the composition of the seas and the atmosphere may have drastic consequences
- Please take this into consideration in your research

Thank you