SUMMER SCHOOL 2018
Piano Lauree Scientifiche - Unina

Scuola Politecnica e delle Scienze di Base
Università degli Studi di Napoli Federico II

Dipartimento di Biologia
Dipartimento di Medicina molecolare e Biotecnologie mediche
Dipartimento di Matematica e Applicazioni "Renato Caccioppoli"
Fisica "Ettore Pancini"
Scienze Chimiche
DiSTAR Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse
Osservatorio Astronomico di Capodimonte INAF

La didattica integrata delle Grandi Idee della Scienza nella Scuola Secondaria

Perché c'è vita sulla Terra: flusso di energia e riciclo della materia nei cicli bio-geochimici

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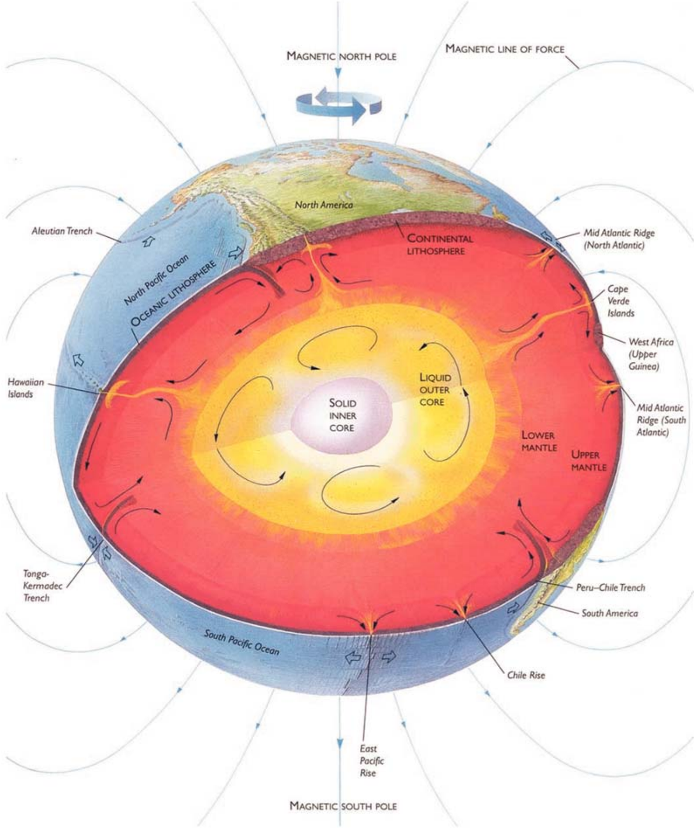
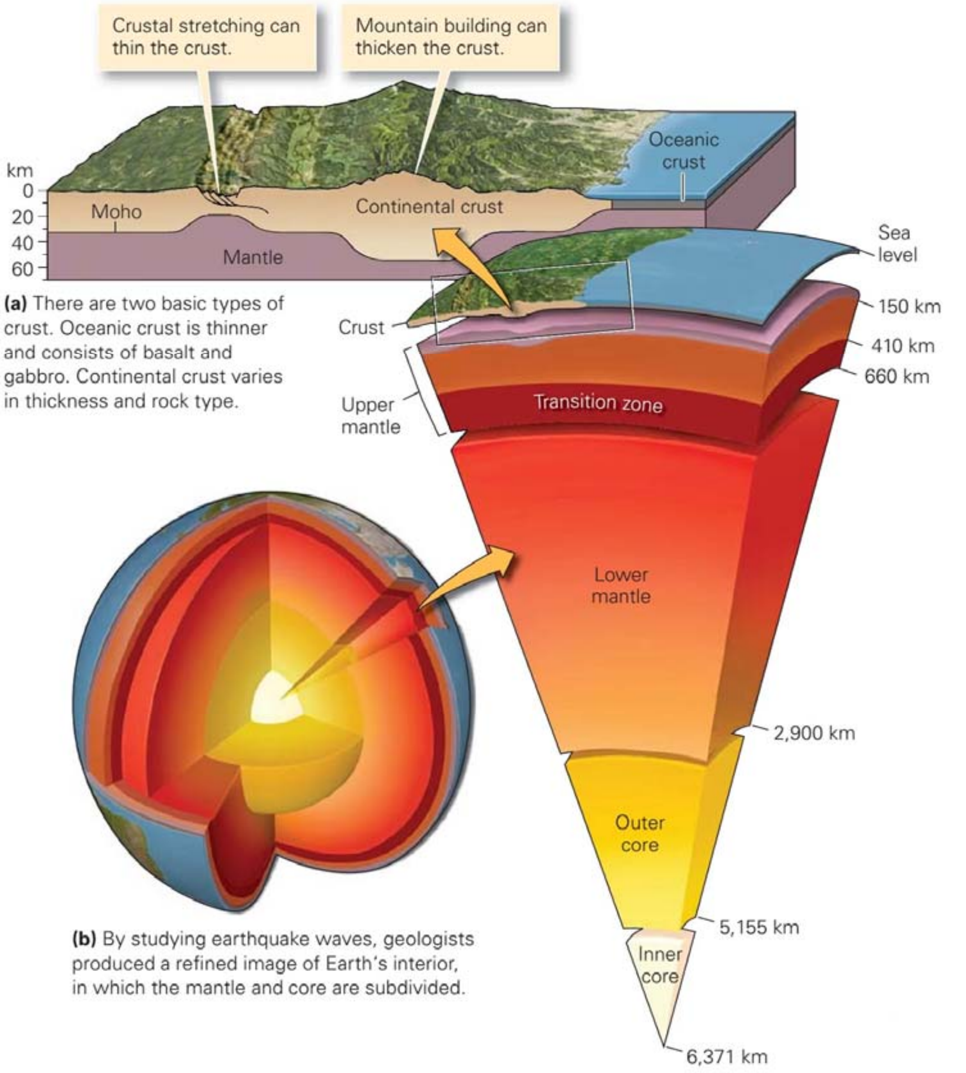
Le complicazioni delle Scienze della Terra: gran parte della Terra è fuori dal nostro raggio di osservazione (spazio)

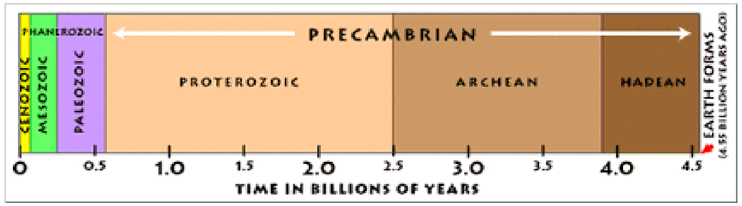


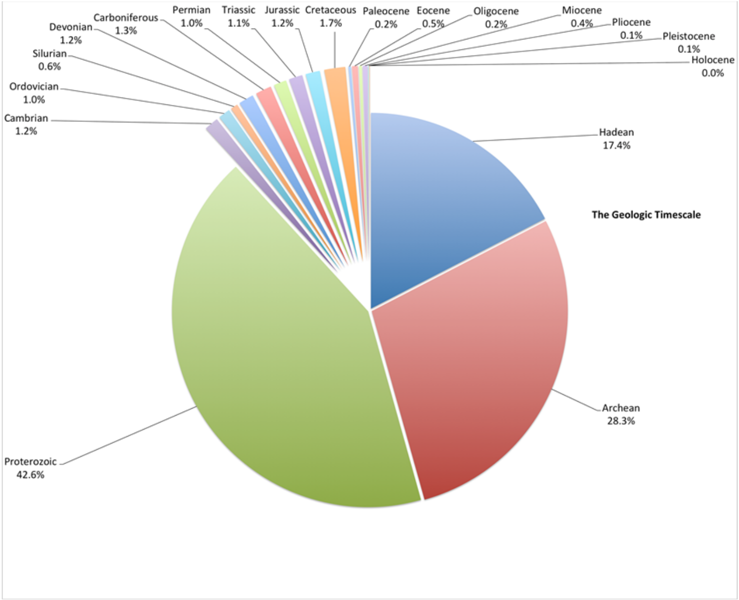


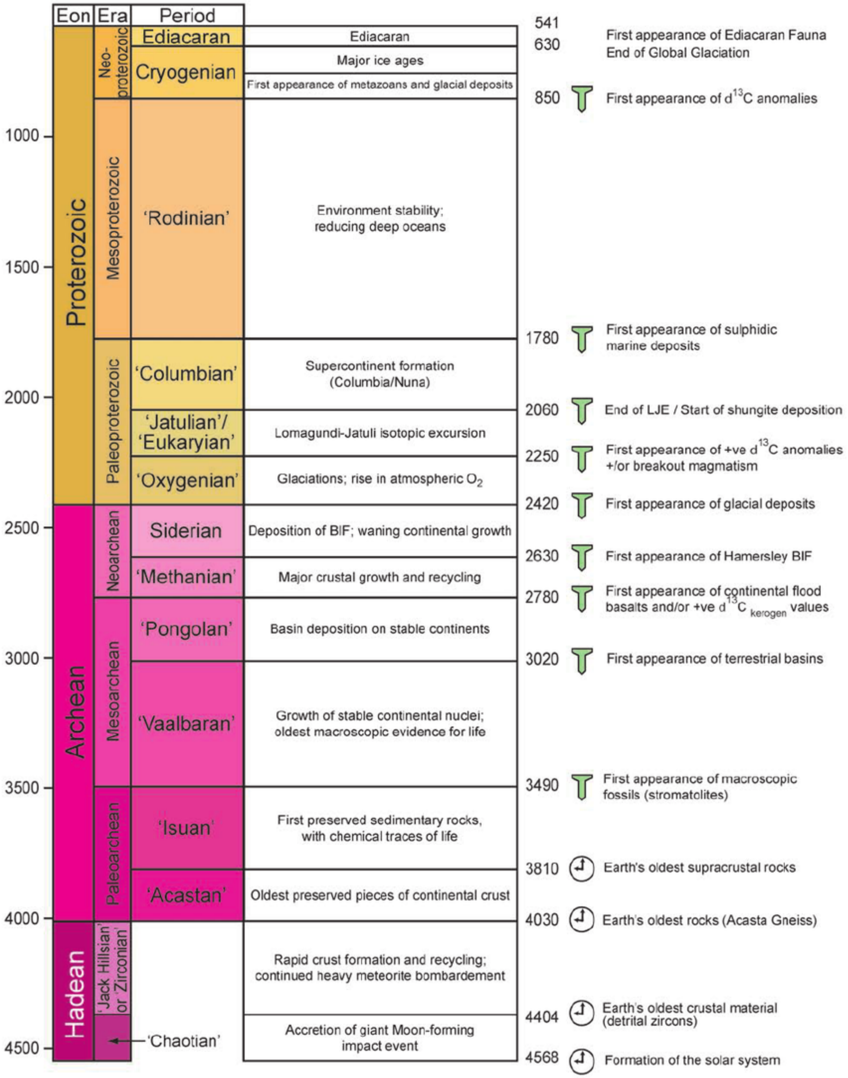
(a) There are two basic types of crust. Oceanic crust is thinner and consists of basalt and gabbro. Continental crust varies in thickness and rock type.

(b) By studying earthquake waves, geologists produced a refined image of Earth's interior, in which the mantle and core are subdivided.

Le complicazioni delle Scienze della Terra: gran parte della Terra è fuori dal nostro raggio di osservazione (tempo)







Abitabilità del Pianeta Terra

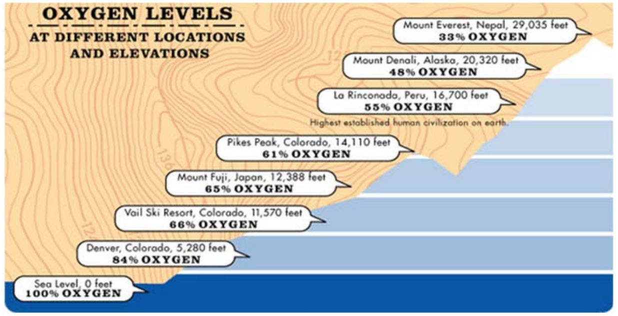
Table 5. A Non-Exhaustive Table of Examples of Factors That Influence Continuous Planetary Habitability on the Surface of a Planetary Body (or Interior Liquid Water Worlds)

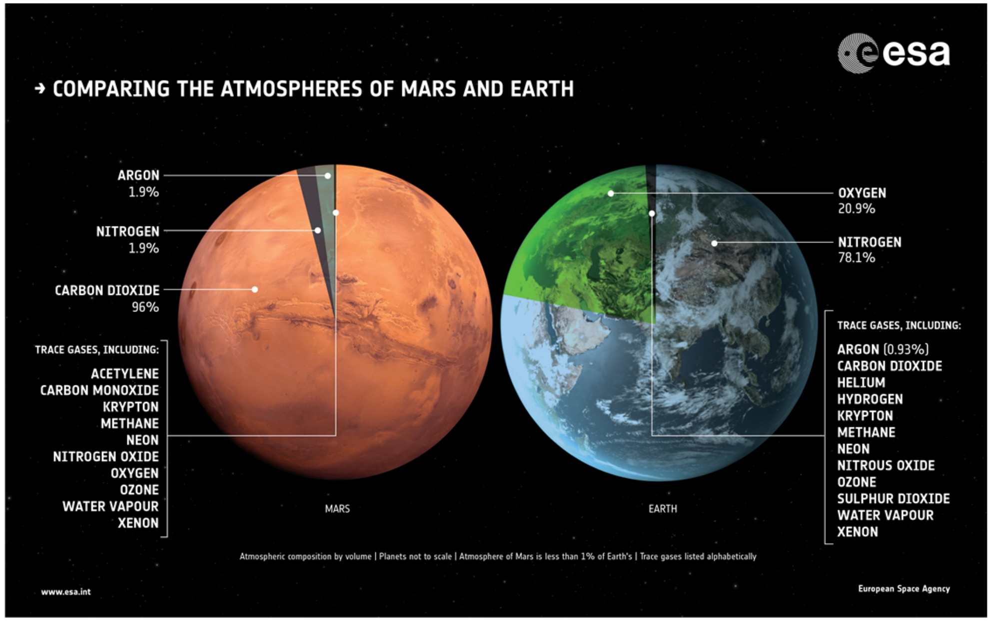
Habitability factor	*Example of influence on habitability*
Planetary factors	
Mass	Insufficient mass to retain gases required for greenhouse warming and liquid water. *Insufficient mass to generate heating for subsurface ocean. Influence on size of internal ocean and thus potential biomass.*
Atmospheric composition	Insufficient greenhouse gases for surface liquid water. High concentrations of greenhouse gases lead to runaway greenhouse effect. Presence of oxygen for multicellular life. *Production of reactants for energy and nutrients cycled into deep ocean (even in tenuous atmosphere).*
Plate tectonics	Lack of plate tectonics shuts down carbonate-silicate cycle influencing surface temperature and presence of liquid water. *Plate tectonics may enhance movement of surface material into a deep ocean.*
Magnetic field	Insufficient field can result in early loss of atmosphere (*e.g.*, planets close to M stars). Strong magnetic field can enhance longevity of atmosphere and hence habitable conditions. *May generate radicals and other species on the surface of an icy world with implications for energy/nutrients.*
Astronomical factors	
Orbital characteristics	Obliquity may not critically determine habitability. Some combinations of orbital characteristics, such as high eccentricity and tidal locking can circularize orbit outside habitable zone. Extremity of climatic excursions caused by high eccentricity. *Lack of tidal heating caused by tidal locking could prevent formation of habitable subsurface water bodies.* *Influences extent of tidal heating*
Star type	Can influence early sputtering away of atmosphere. Influences longevity of habitable zone.
Presence of a moon	Lack or presence of a moon probably not critical for presence of habitable conditions on a planet but may influence extremity of climatic excursions caused by obliquity variations.
Impact events	Frequent large impacts that sterilize oceans could prevent life emerging. Frequent impacts create selection pressure for high-temperature tolerant/loving organisms or prevent atmospheric oxygen buildup from photosynthesis. *Impacts may deliver material into subsurface ocean or enhance surface-subsurface exchange of material.*

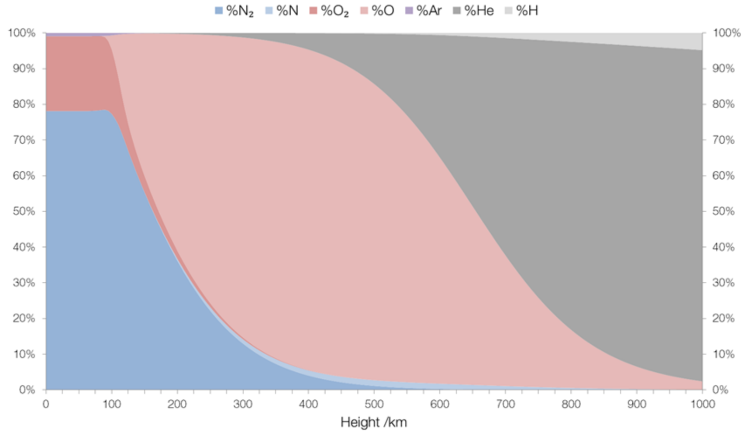
Statements in italics, where appropriate, show factors that apply to habitability in interior liquid water worlds.

L'atmosfera e gli oceani attuali contengono ossigeno

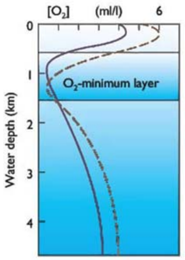
- ✓ Quanto ce n'è?
- ✓ Per la Terra attuale possiamo misurarlo
- ✓ ma dopo averlo misurato comunque dobbiamo spiegarlo!
- ✓ La vera conoscenza non è nei dati ma nella comprensione delle leggi/processi
- ✓ La vera conoscenza è predittiva !!!



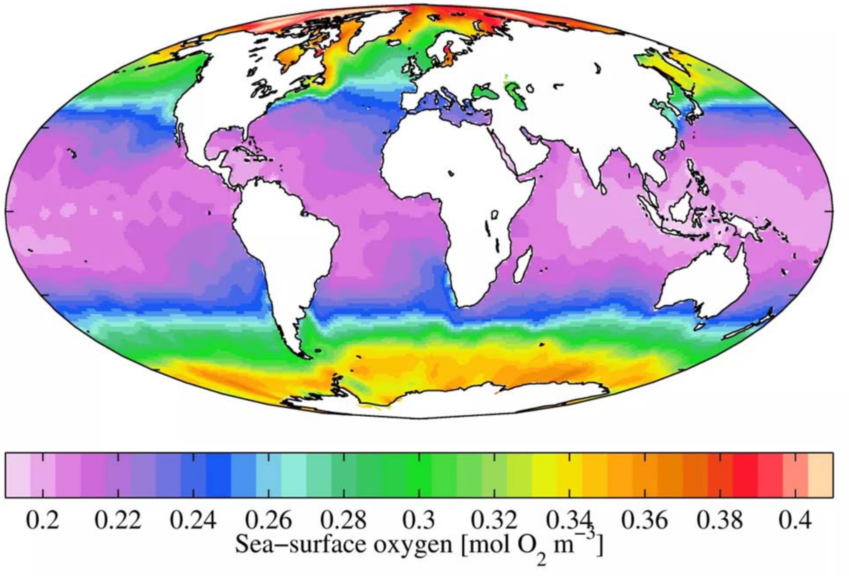


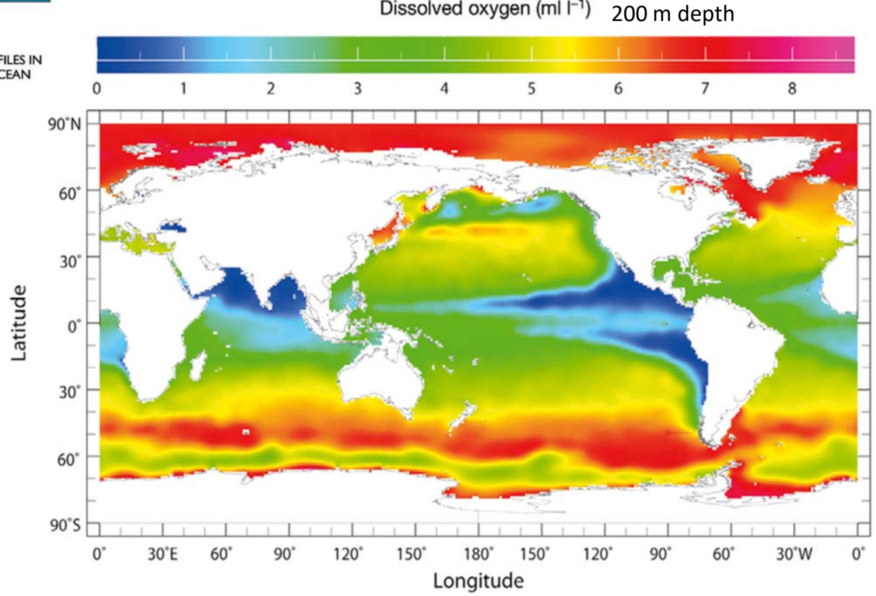


L’ossigeno negli oceani



(a) VERTICAL O_2 PROFILES IN THE ATLANTIC OCEAN





200 m depth

$$H_2O+CO_2 \underset{\text{respirazione}}{\overset{\text{fotosintesi}}{\rightleftharpoons}} CH_2O+O_2$$

Q: qual è la conseguenza geologica di questa reazione?

A: l'accumulo di materia organica nei sedimenti consente l'accumulo di ossigeno nell'atmosfera

$$16H^+ + 16HCO^{3-} \rightarrow 16CH_2O + 16O_2$$

$$8SO^{2-} + 16CH_2O \rightarrow 16HCO^- + 8H_2S$$

$$8H_2S + 2Fe_2O_3 + O_2 \rightarrow 8H_2O + 4FeS_2$$

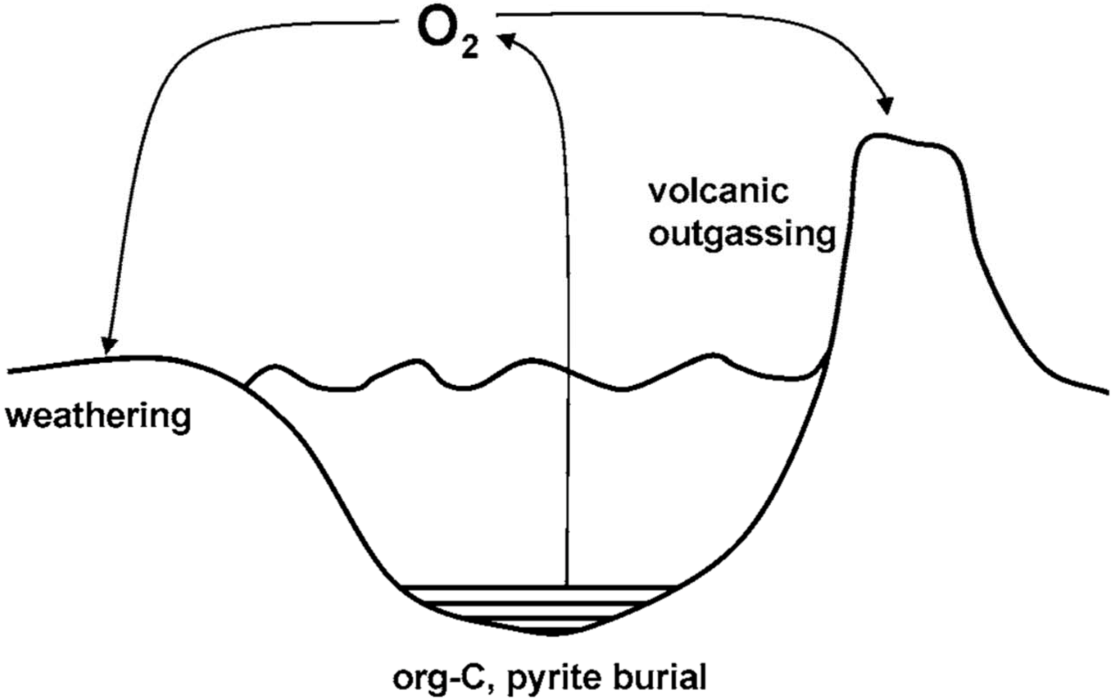
$$16H^+ + 8SO_4^{2-} + 2Fe_2O_3 \rightleftharpoons 8H_2O + 4FeS_2 + 15O_2$$

Q: qual è la conseguenza geologica di queste reazioni?

A: l'accumulo di pirite nei sedimenti consente l'accumulo di ossigeno nell'atmosfera

Il ciclo geologico dell'Ossigeno:

un equilibrio dinamico fra le velocità dei processi che producono ossigeno e le velocità dei processi che lo consumano



Il ciclo geologico dell'Ossigeno:

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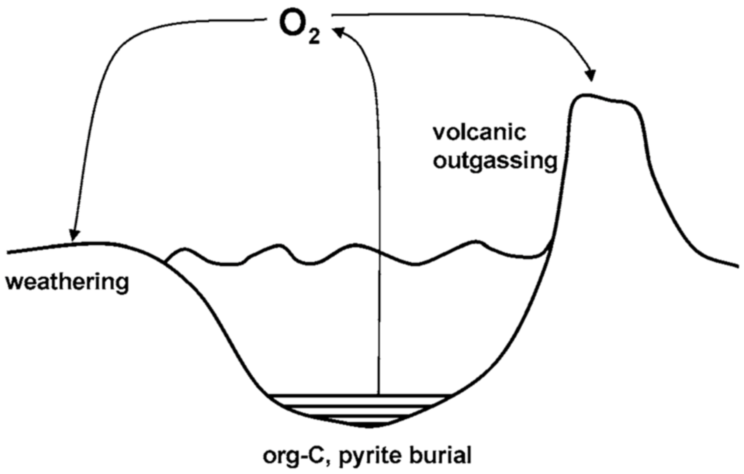


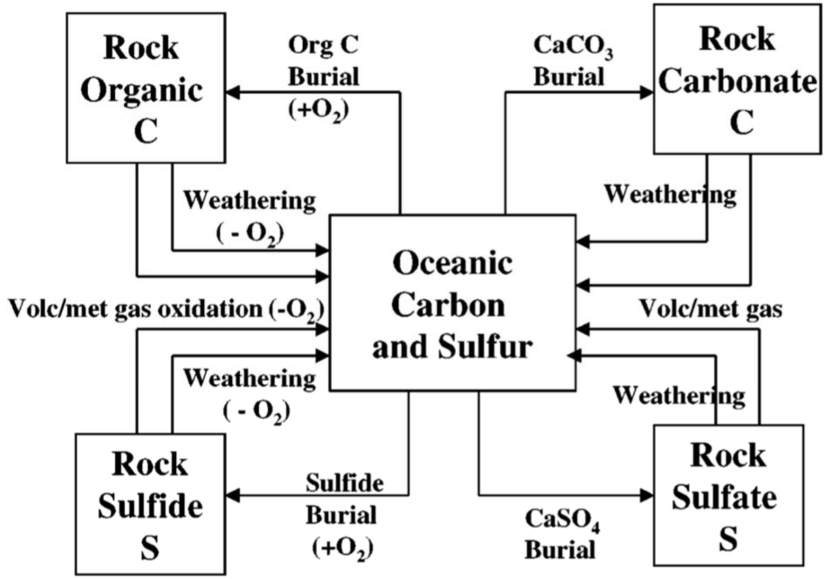


Figure 2 Box model for calculating variations with time in the fluxes affecting atmospheric oxygen. Each box and flux represents both total carbon or sulfur and ^{13}C or ^{34}S. The fluxes for weathering and degassing are often combined under the generalized term "weathering." The symbols ($+O_2$) and ($-O_2$) represent the addition or subtraction of oxygen from the atmosphere.

Il ciclo geologico dell'Ossigeno:

un equilibrio dinamico fra le velocità dei processi che producono ossigeno e le velocità dei processi che lo consumano

$$F_{bg} = (1/\alpha_c)\left[-\delta_g F_{wg} - \delta_c F_{wc} + \delta_{csw}(F_{wg} + F_{wc})\right]$$

$$F_{bc} = F_{wg} + F_{wc} - F_{bg}$$

F_{bg} = tasso di seppellimento di carbonio organico nei sedimenti

F_{bc} = tasso di seppellimento di carbonio inorganico (carbonati) nei sedimenti

F_{wg} = tasso di weathering di materia organica + degassing da metamorfismo e vulcanismo

F_{wc} = tasso di weathering di carbonio inorganico + decarbonatazione termica (metamorfismo)

α_c = frazionamento isotopico di ^{13}C fra carbonati e materia organica

δ_{csw} = $\delta^{13}C$ oceano

δ_g = $\delta^{13}C$ del carbonio organico che subisce weathering e decomposizione termica

δ_c = $\delta^{13}C$ carbonio inorganico (carbonati) che subisce weathering e decarbonatazione

Geocarbsulf

I flussi di carbonio e zolfo vengono calcolati a partire dal record isotopico usando i bilanci di massa

Una volta calcolati i flussi di carbonio e zolfo è possibile calcolare i flussi di ossigeno

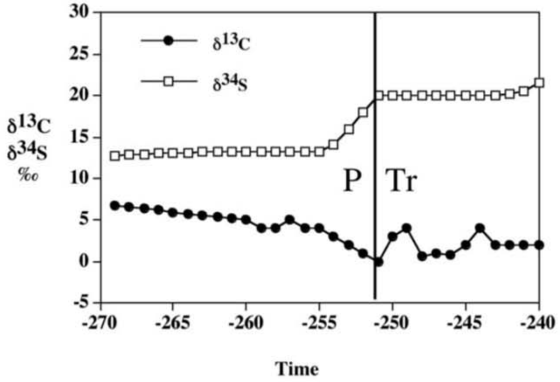


Fig. 1. Isotopic data for the oceans used in the carbon and sulfur cycle modeling. Values are smoothed one million year averages. (For sources of the data see text.)

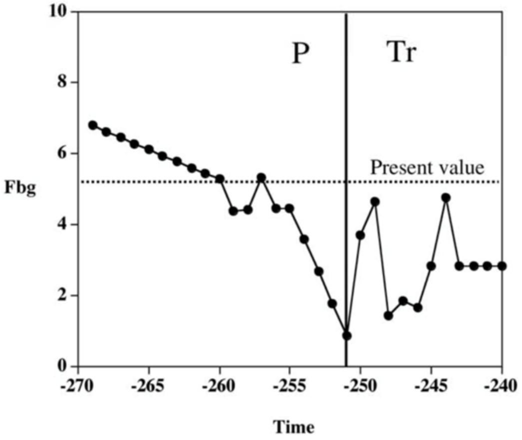


Fig. 2. Organic carbon burial rate (F_{bg}) vs. time. Units are 10^{18} mol/my.

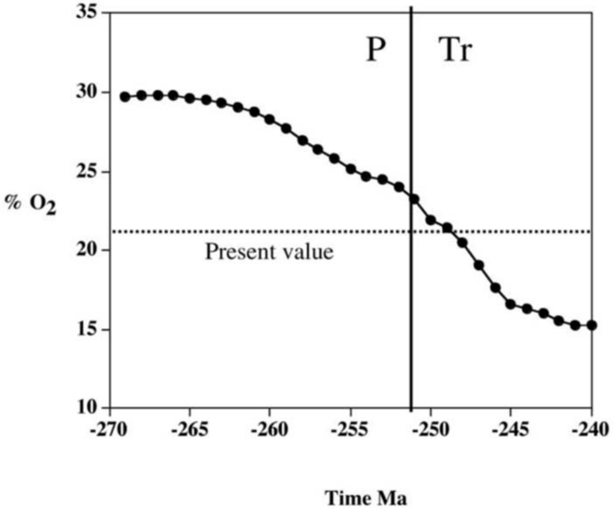
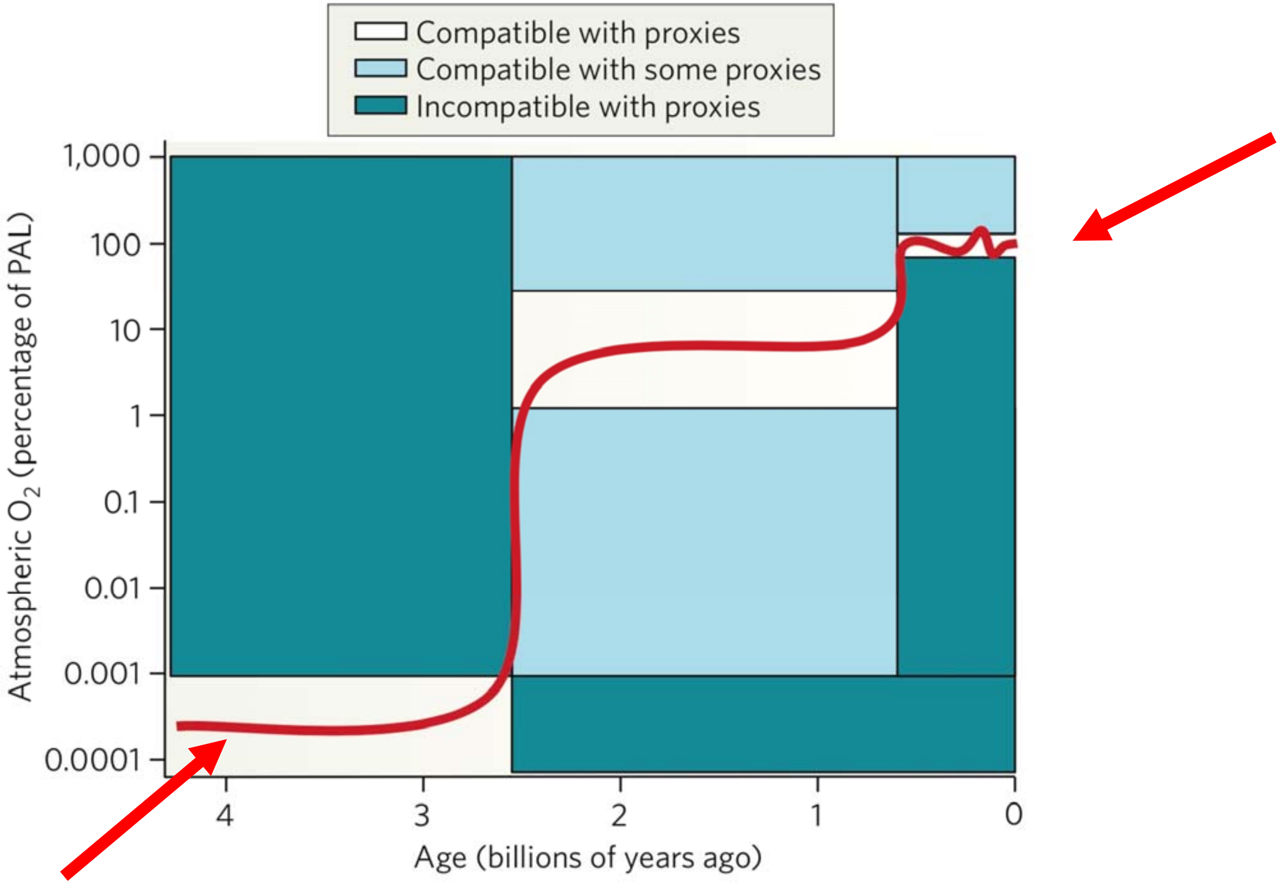


Fig. 6. Atmospheric oxygen concentration vs. time for 270 to 240 Ma. The concentration is calculated assuming constant masses of atmospheric nitrogen and argon.

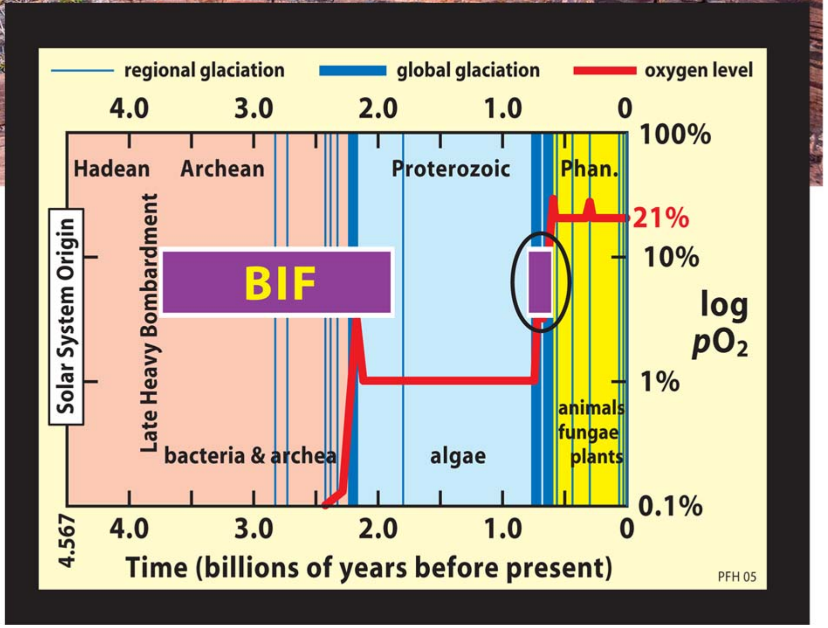
La storia dell'Ossigeno

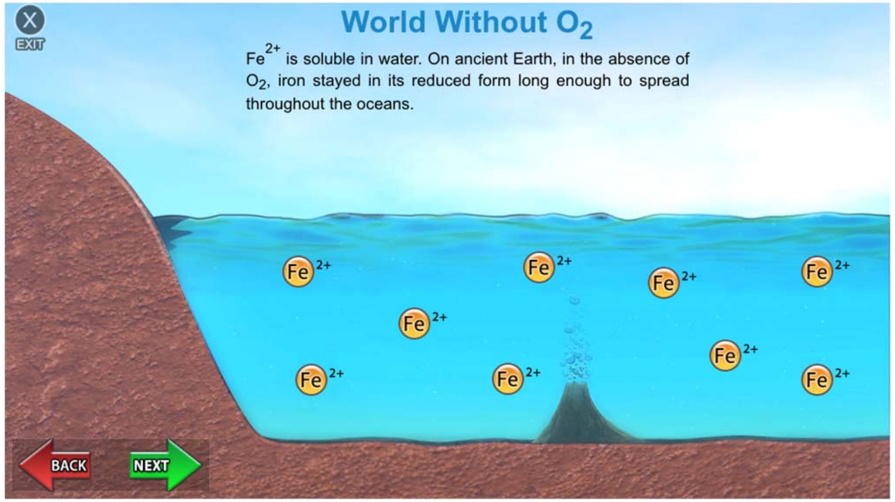


Indicatori geologici del livello di ossigeno atmosferico

(paleo)suoli e rocce sedimentarie rosse =
presenza di ossigeno atmosferico

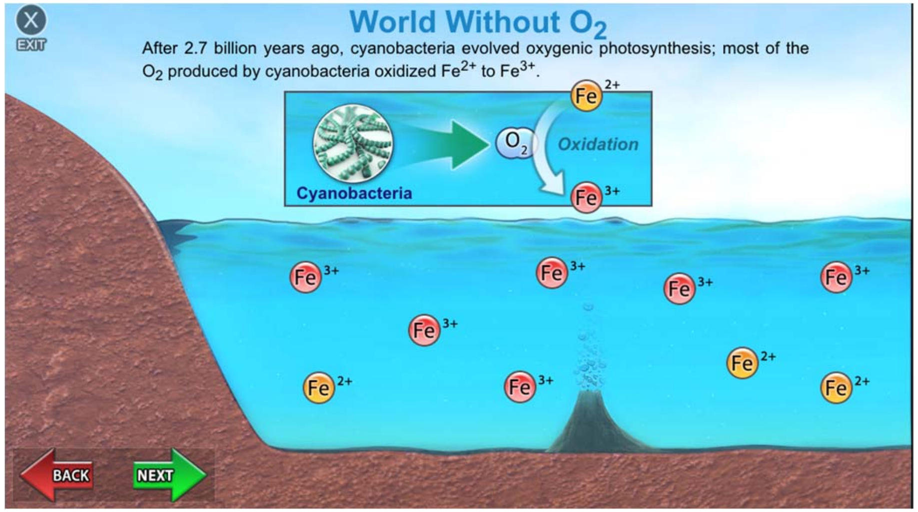
Banded Iron Formations (BIF)





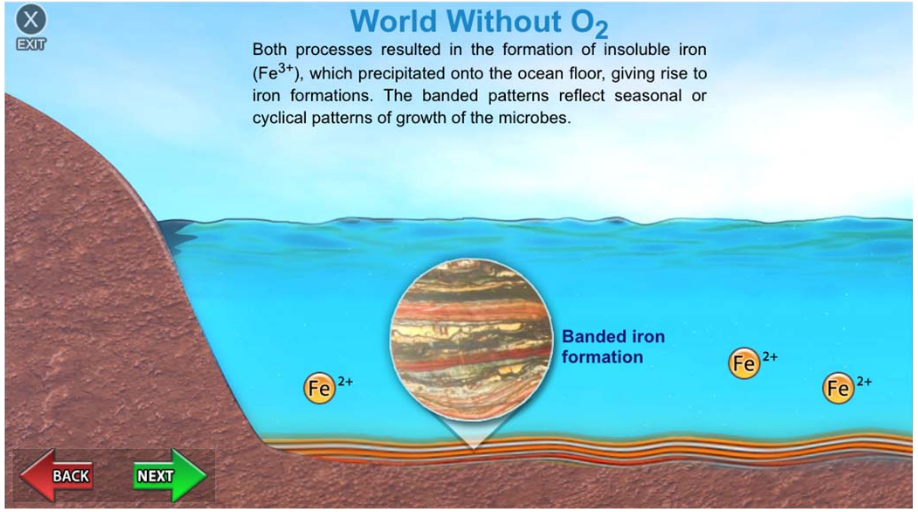
World Without O_2

Fe^{2+} is soluble in water. On ancient Earth, in the absence of O_2, iron stayed in its reduced form long enough to spread throughout the oceans.



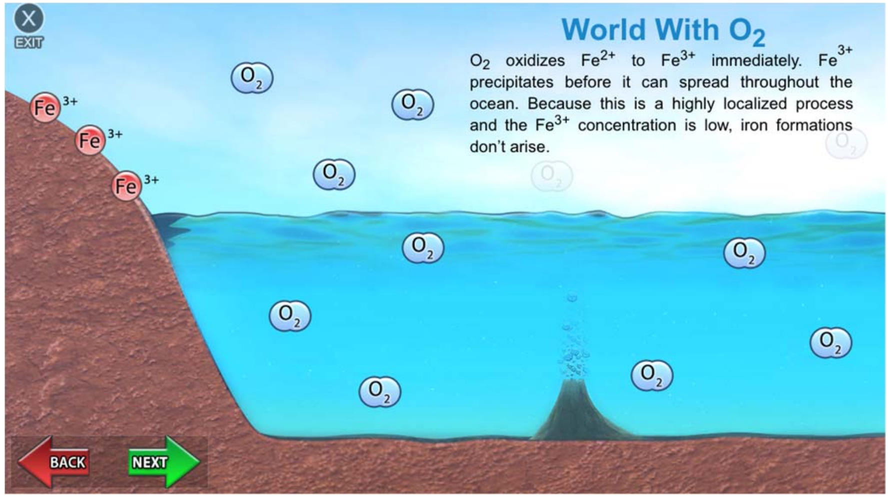
World Without O_2

After 2.7 billion years ago, cyanobacteria evolved oxygenic photosynthesis; most of the O_2 produced by cyanobacteria oxidized Fe^{2+} to Fe^{3+}.



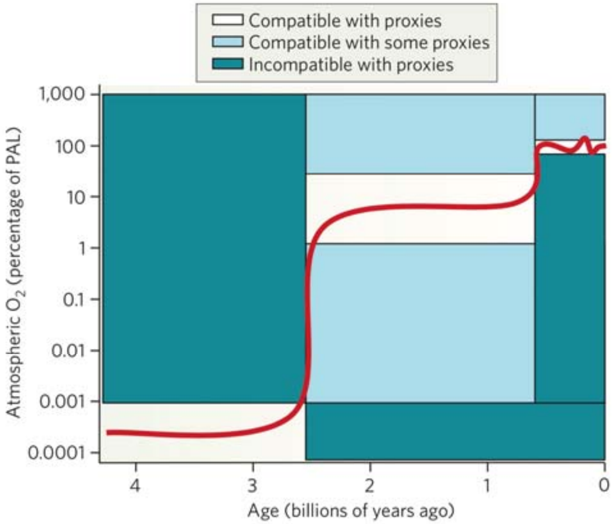
World Without O_2

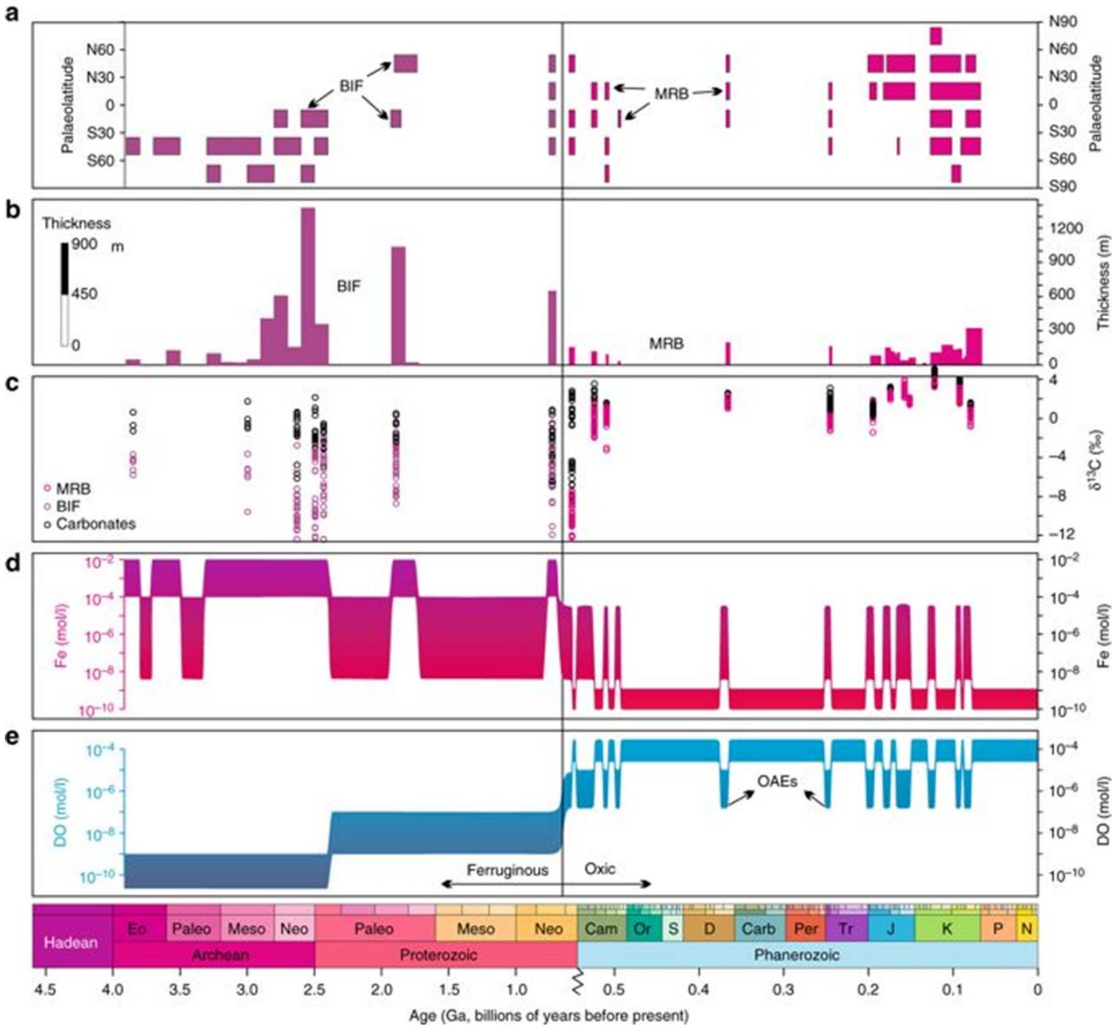
Both processes resulted in the formation of insoluble iron (Fe^{3+}), which precipitated onto the ocean floor, giving rise to iron formations. The banded patterns reflect seasonal or cyclical patterns of growth of the microbes.



World With O_2

O_2 oxidizes Fe^{2+} to Fe^{3+} immediately. Fe^{3+} precipitates before it can spread throughout the ocean. Because this is a highly localized process and the Fe^{3+} concentration is low, iron formations don't arise.

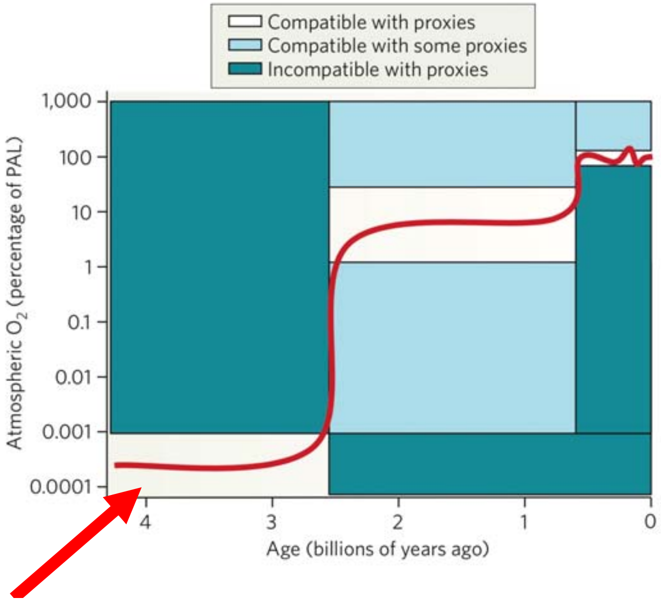




a
Palaeolatitude
N90
N60
N30
0
S30
S60
S90
BIF
MRB
b
Thickness
900 m
450
0
BIF
MRB
1200
900
600
300
0
Thickness (m)
c
MRB
BIF
Carbonates
4
0
−4
−8
−12
δ13C (‰)
d
Fe (mol/l)
10−2
10−4
10−6
10−8
10−10
e
DO (mol/l)
10−4
10−6
10−8
10−10
OAEs
Ferruginous
Oxic
Hadean
Eo
Paleo
Meso
Neo
Archean
Paleo
Meso
Neo
Proterozoic
Cam
Or
S
D
Carb
Per
Tr
J
K
P
N
Phanerozoic
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.4
0.3
0.2
0.1
0
Age (Ga, billions of years before present)

Indicatori del livello di ossigeno nell'atmosfera e negli oceani:

Sulfur MIF = contenuto in ossigeno
< 0.001 PAL, sufficiente contenuto di zolfo
nell'atmosfera, atmosfera riducente
(contenuto sostanziale di CH_4)



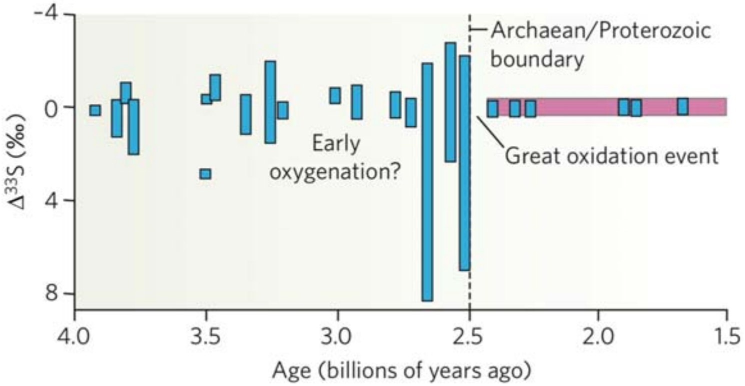
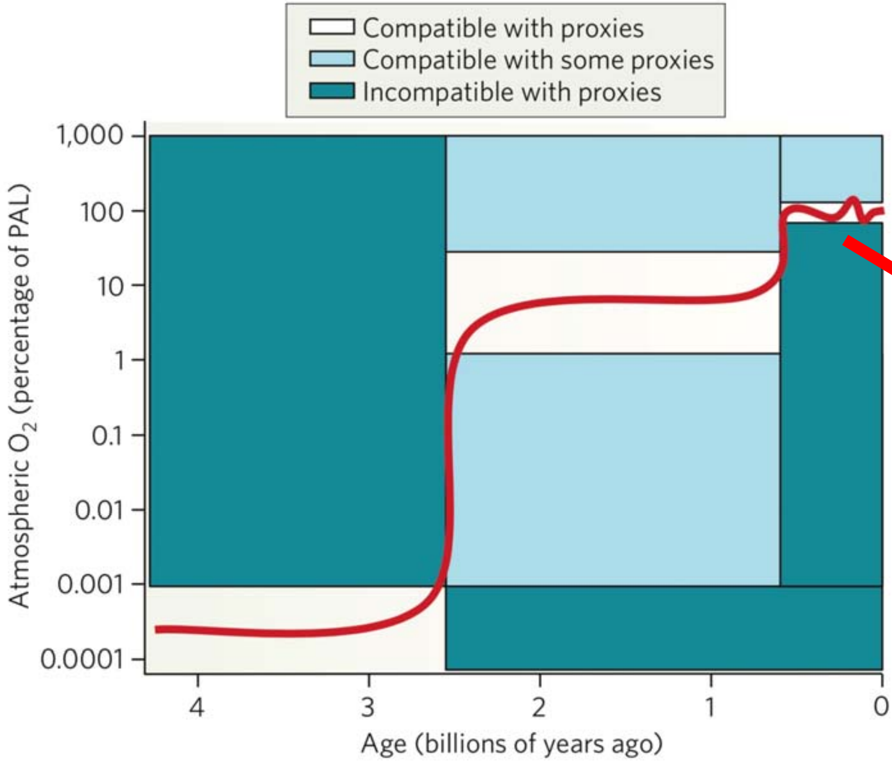
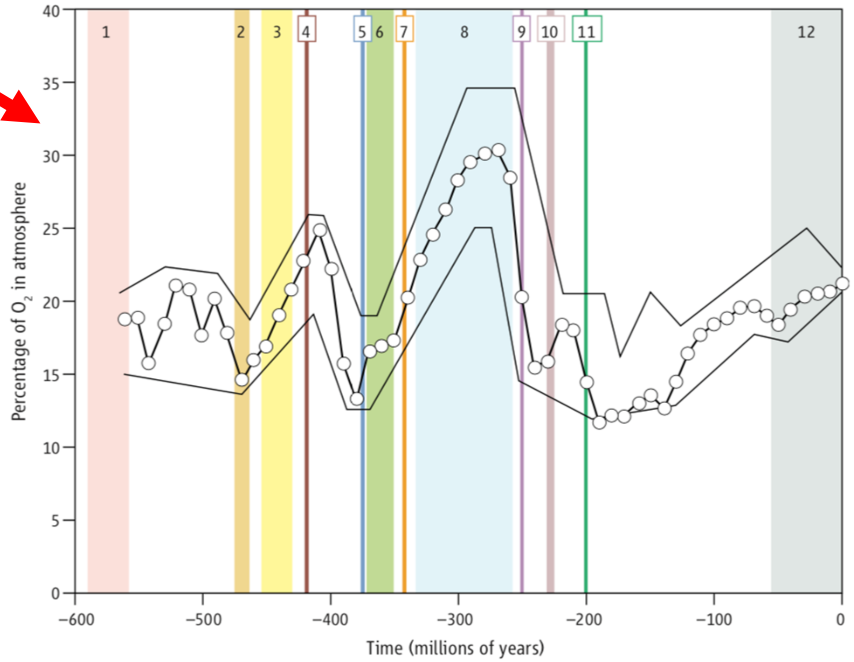


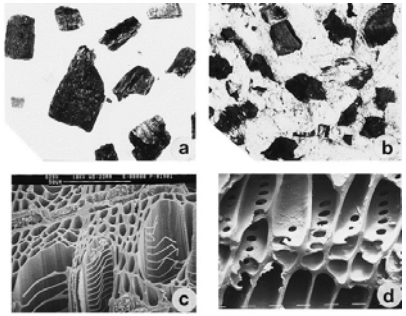
Figure 1 | Range of MIF of sulphur over time. The great oxidation event occurred ~2.45 billion years ago, and an early, failed, oxygenation event might have occurred around 3.2 billion years ago (but this is hotly debated). The degree of MIF (blue) is indicated by $\Delta^{33}S$, which is the parts per thousand (‰) deviation of the standardized $^{33}S/^{32}S$ ratio from the value predicted from the $^{34}S/^{32}S$ ratio and mass-dependent fractionation. The range of values from samples of a given age is shown by vertical bars. The pink bar shows the range of variability in $\Delta^{33}S$ that is due to mass-dependent effects, indicating only small variations during the past 2.32 billion years.



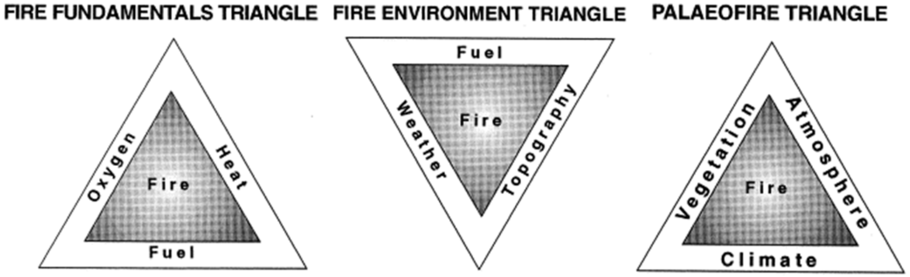
calcolato a partire dal ciclo del carbonio e dello zolfo (Geocarbsulf, Berner)

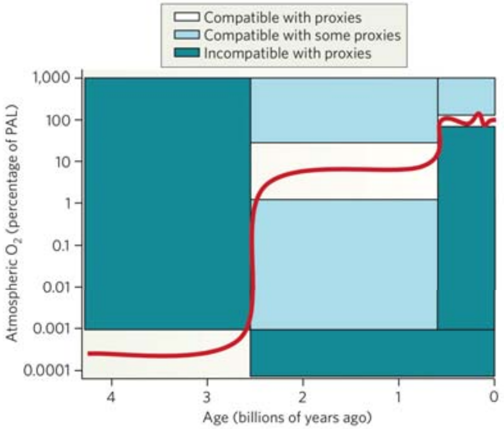


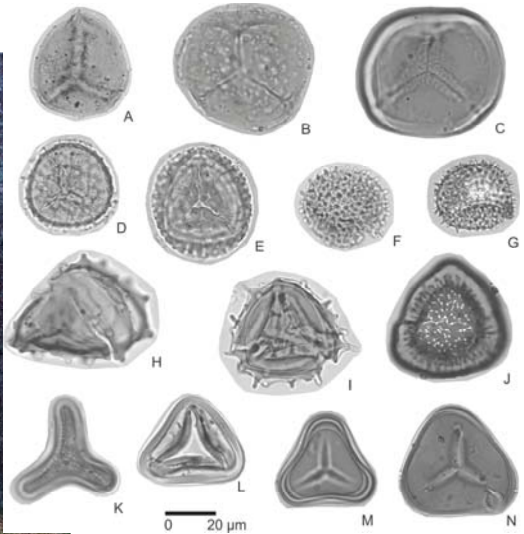
Indicatori geologici del livello di Ossigeno nell'Atmosfera durante il Fanerozoico: la chimica e la fisica del fuoco!

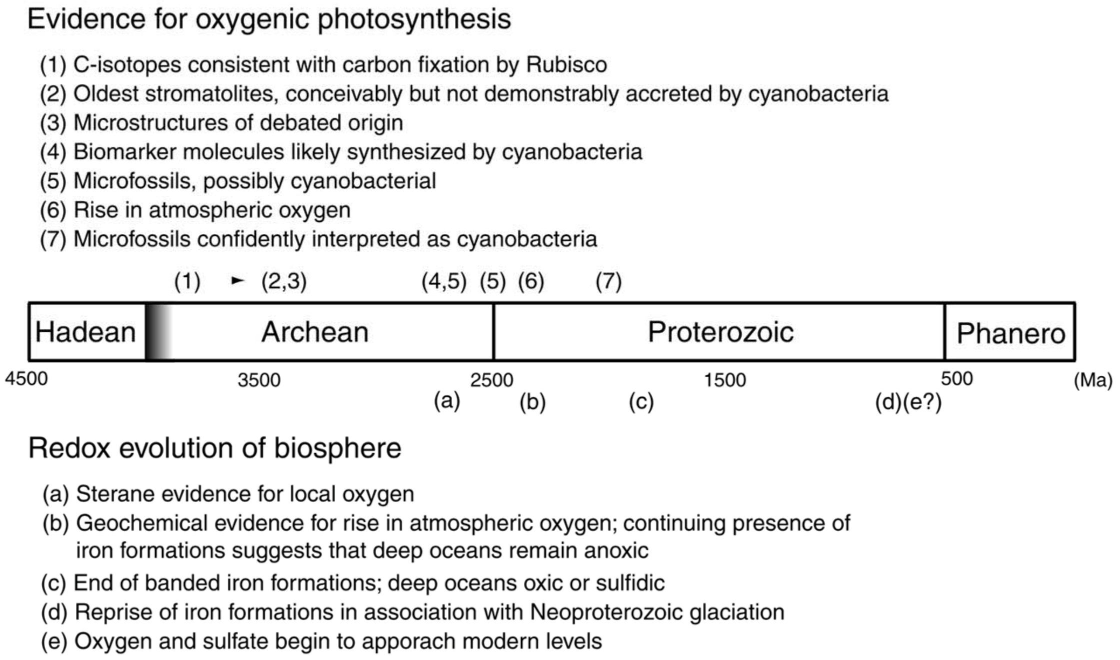


- ✓ Charcoal nei sedimenti da 420 Ma ad oggi
- ✓ no incendi per $O_2 < 60\%$ PAL
- ✓ troppi incendi (no foreste) per $O_2 > 160\%$ PAL









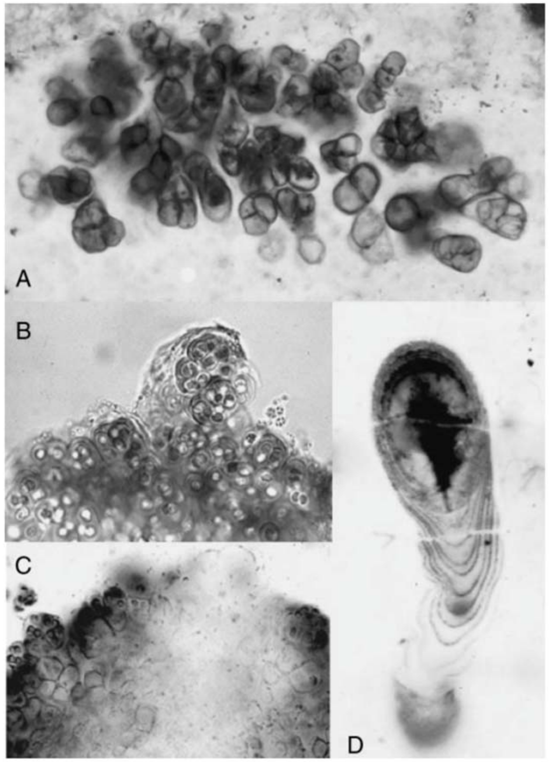
Evidence for oxygenic photosynthesis

(1) C-isotopes consistent with carbon fixation by Rubisco
(2) Oldest stromatolites, conceivably but not demonstrably accreted by cyanobacteria
(3) Microstructures of debated origin
(4) Biomarker molecules likely synthesized by cyanobacteria
(5) Microfossils, possibly cyanobacterial
(6) Rise in atmospheric oxygen
(7) Microfossils confidently interpreted as cyanobacteria

Redox evolution of biosphere

(a) Sterane evidence for local oxygen
(b) Geochemical evidence for rise in atmospheric oxygen; continuing presence of iron formations suggests that deep oceans remain anoxic
(c) End of banded iron formations; deep oceans oxic or sulfidic
(d) Reprise of iron formations in association with Neoproterozoic glaciation
(e) Oxygen and sulfate begin to apporach modern levels

Fig. 2 Geological time-scale showing palaeontological and geochemical constraints on the antiquity of oxygenic photosynthesis (cyanobacteria), as well as the inferred redox history of the oceans and atmosphere. Phanero = Phanerozoic Era. See text for discussion and references.



Proterozoic microfossils reliably interpreted as cyanobacteria.

I cianobatteri (fotosintesi oxygenica) ci sono almeno da 2.7 Ga e forse da molto prima
I livelli bassissimi di O_2 nell'Archeano inferiore sono limitati dall'accumulo non dalla produzione

L’effetto serra (fisica)
CO_2 e clima (fisica + geologia + ecologia)
il feedback del weathering dei silicati (geologia)

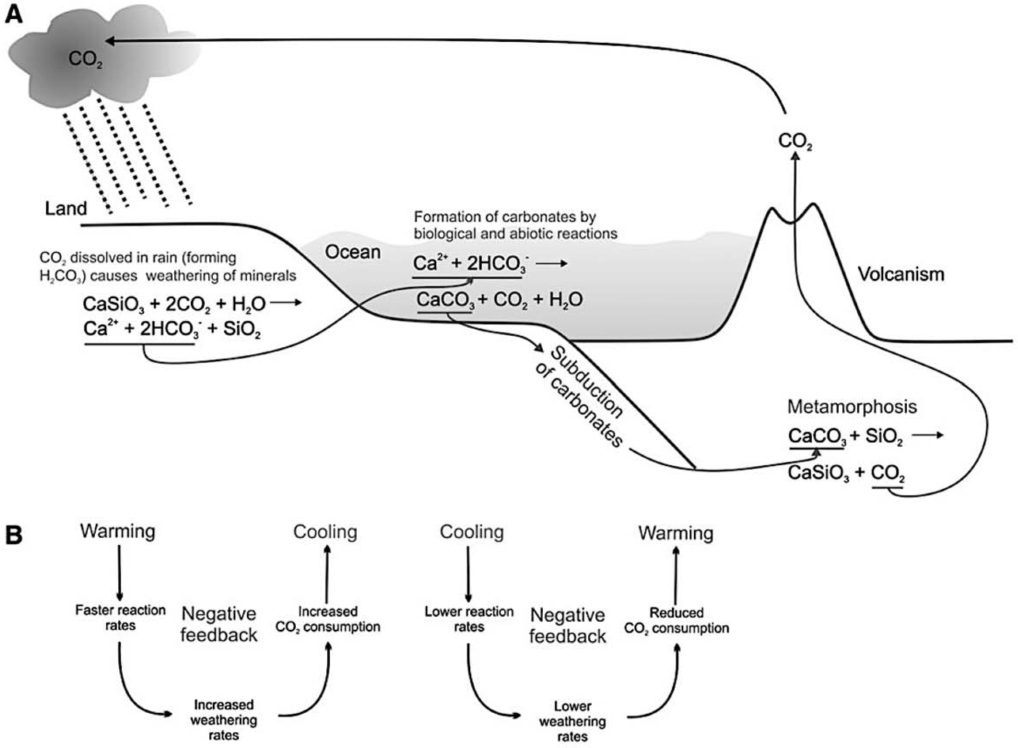
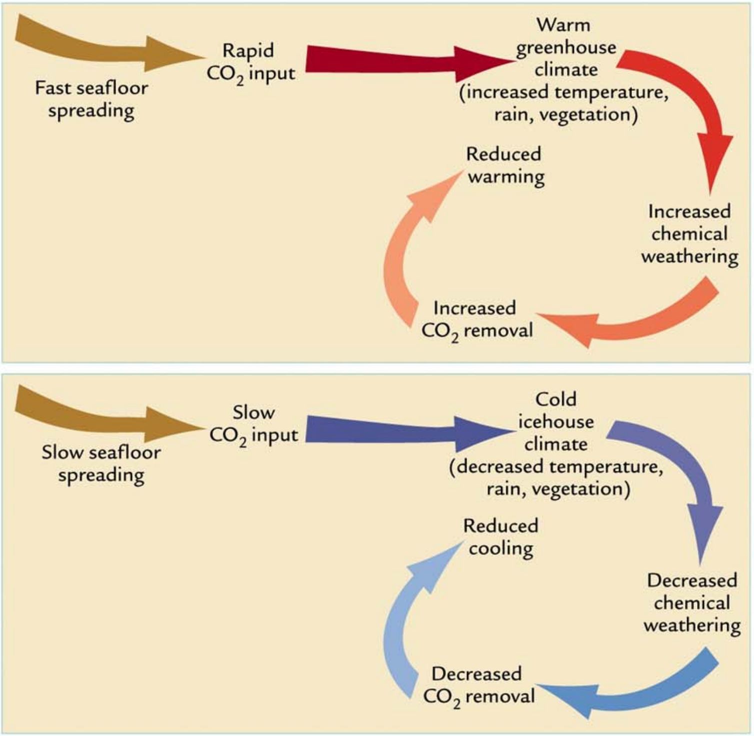
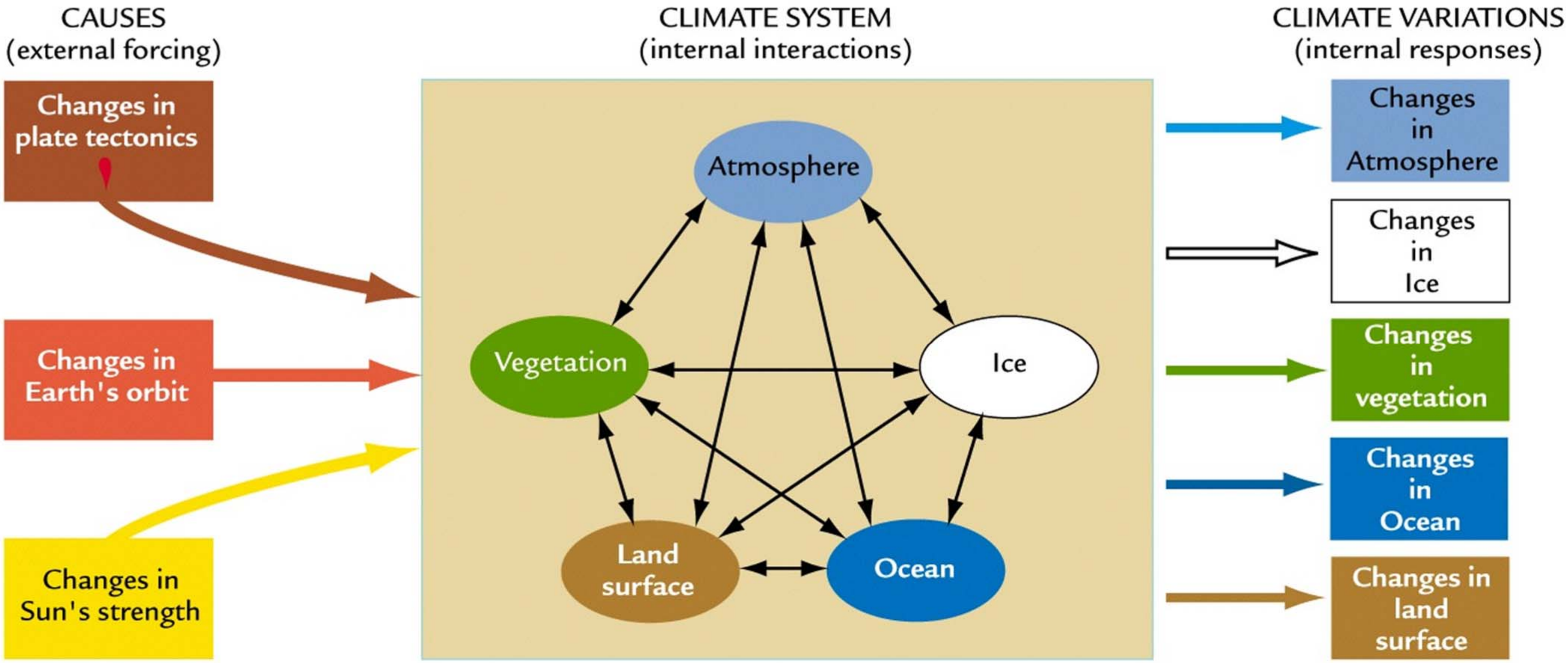


FIG. 6. The carbonate-silicate cycle. (**A**) One principal mechanism by which temperatures on the surface of Earth are regulated through the feedback control of the greenhouse gas, CO_2. The cycle also illustrates the link between plate tectonics (subduction of carbonates) and habitability. (**B**) The carbonate-silicate cycle works by a negative feedback process.





CAUSES
(external forcing)

Changes in plate tectonics

Changes in Earth's orbit

Changes in Sun's strength

CLIMATE SYSTEM
(internal interactions)

Atmosphere

Vegetation

Ice

Land surface

Ocean

CLIMATE VARIATIONS
(internal responses)

Changes in Atmosphere

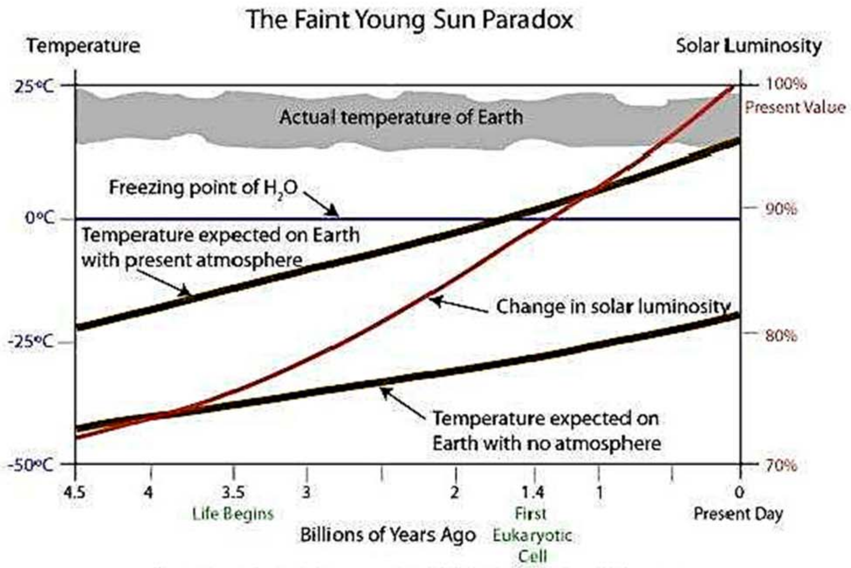
Changes in Ice

Changes in vegetation

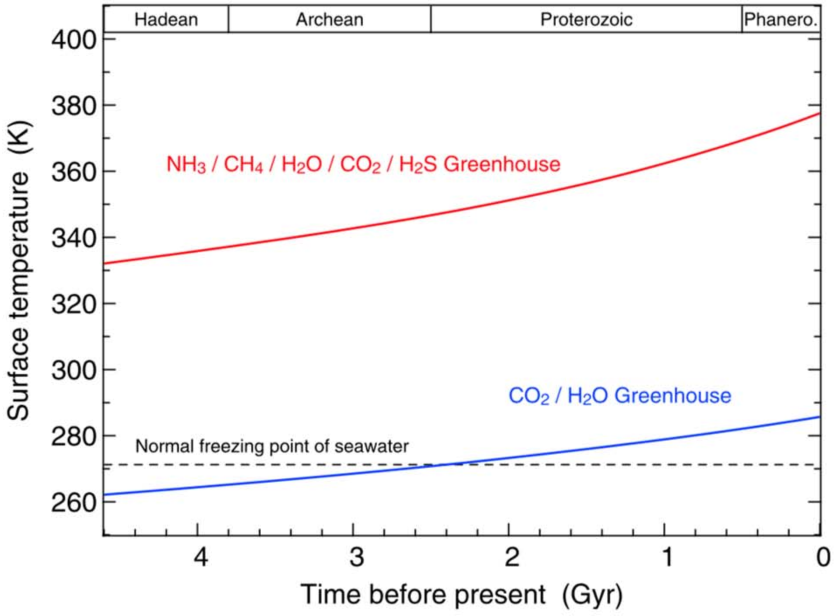
Changes in Ocean

Changes in land surface

The faint young sun paradox

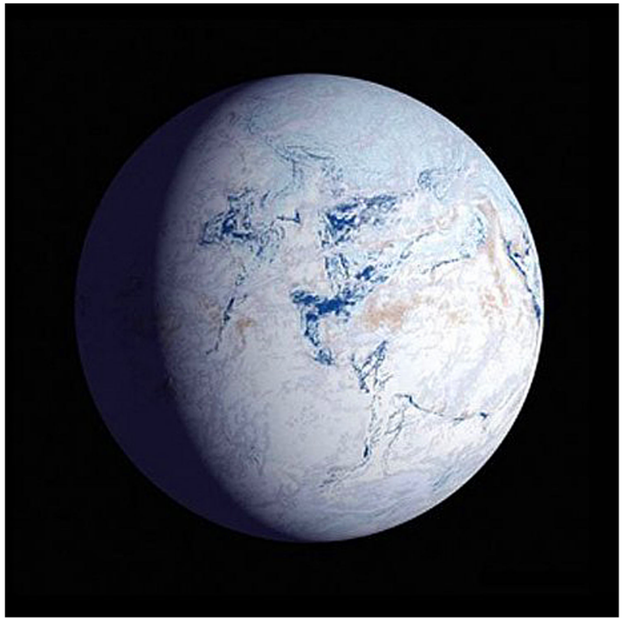


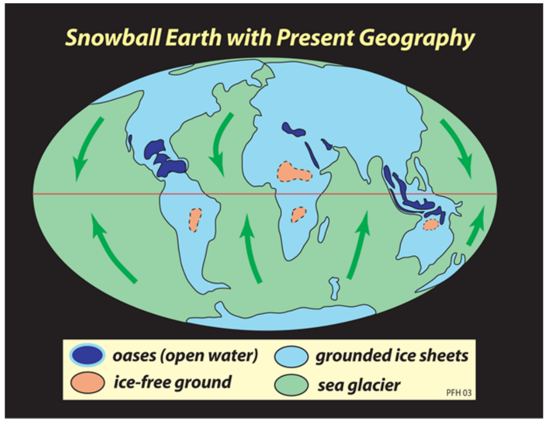
Even though the Sun was about 30% dimmer than it is now, the temperature on Earth has been more or less stable.

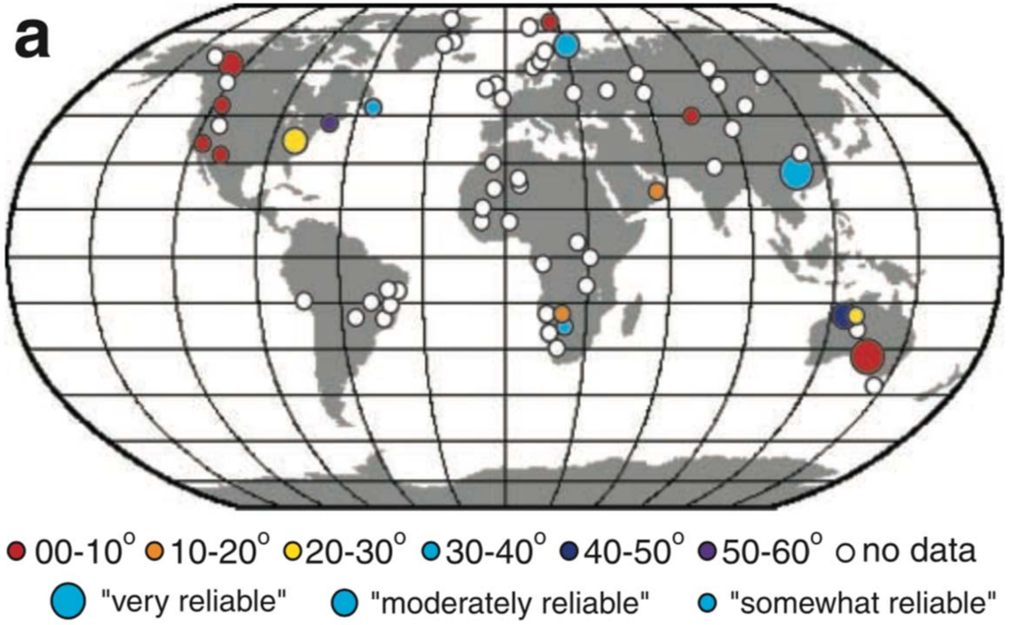


Sagan and Muller (1972) solution to faint young sun paradox

Snowball earth

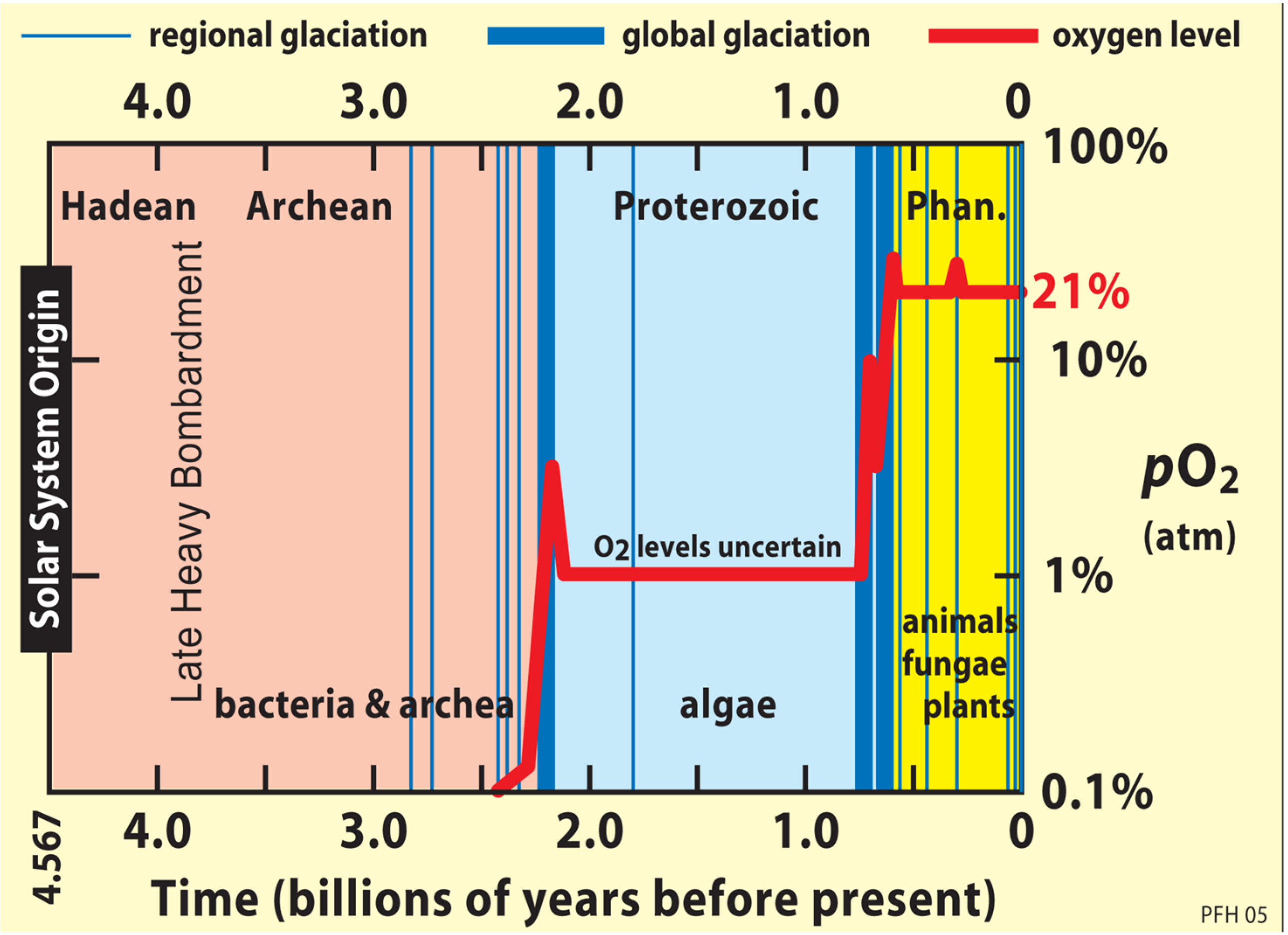




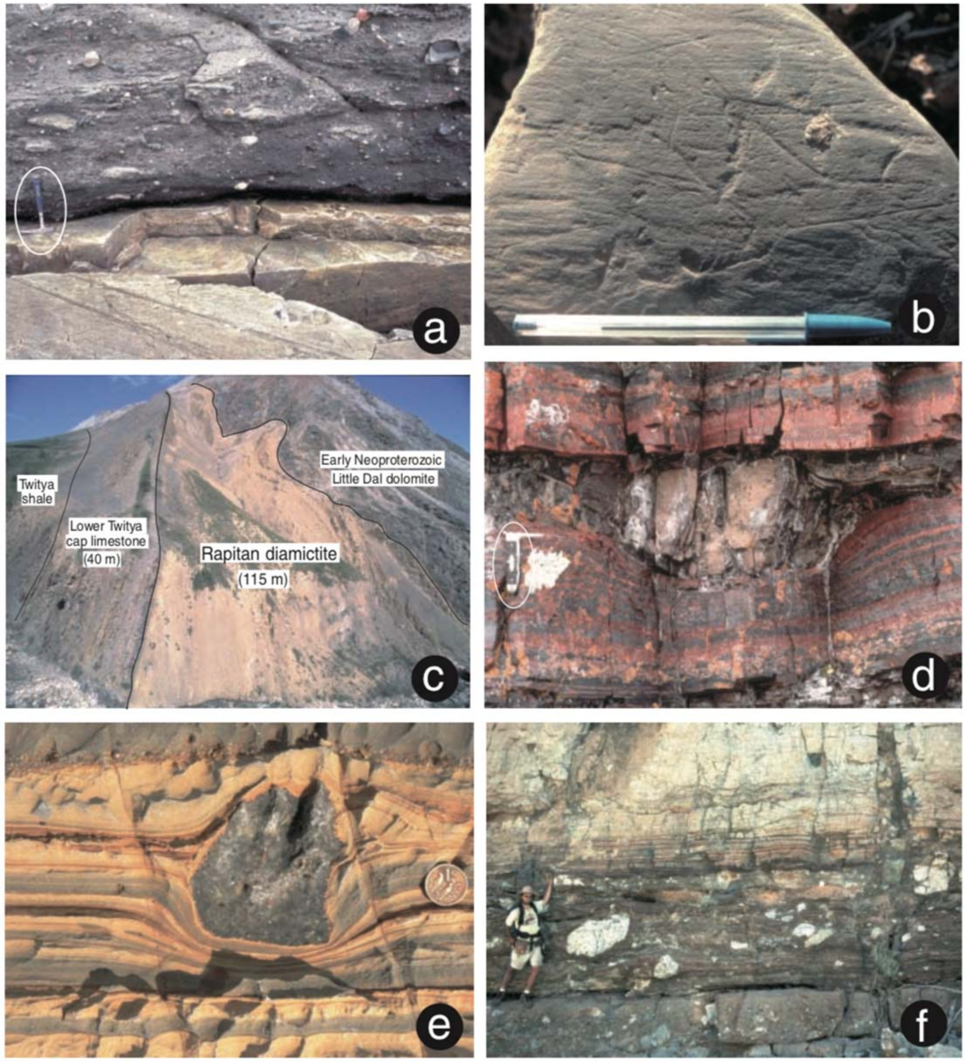


Global distribution (a) of Neoproterozoic glaciogenic deposits with estimated palaeolatitudes based on palaeomagnetic data (modified from Evans, 2000).

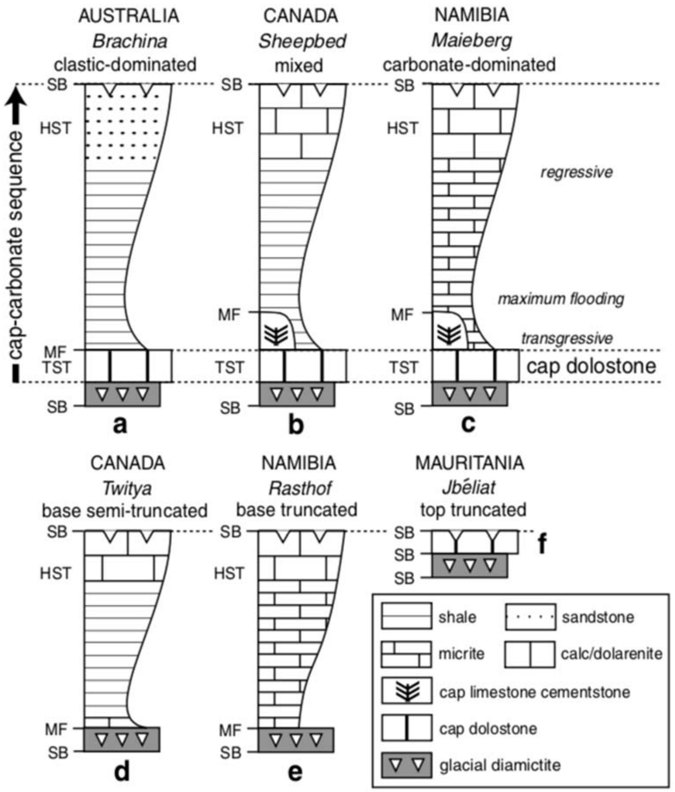
Snowball earth

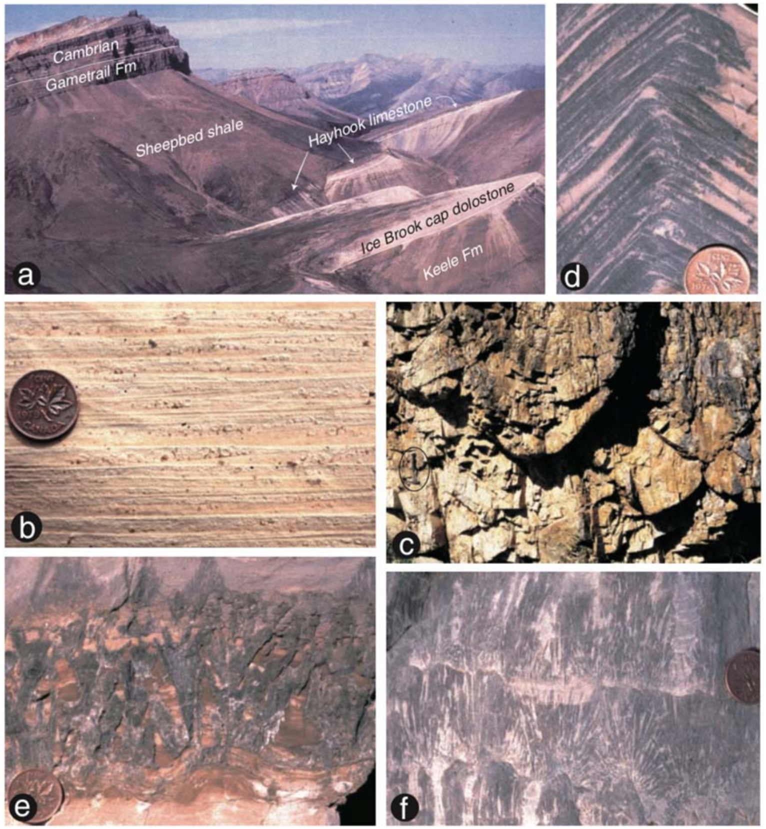


Snowball earth



Snowball earth

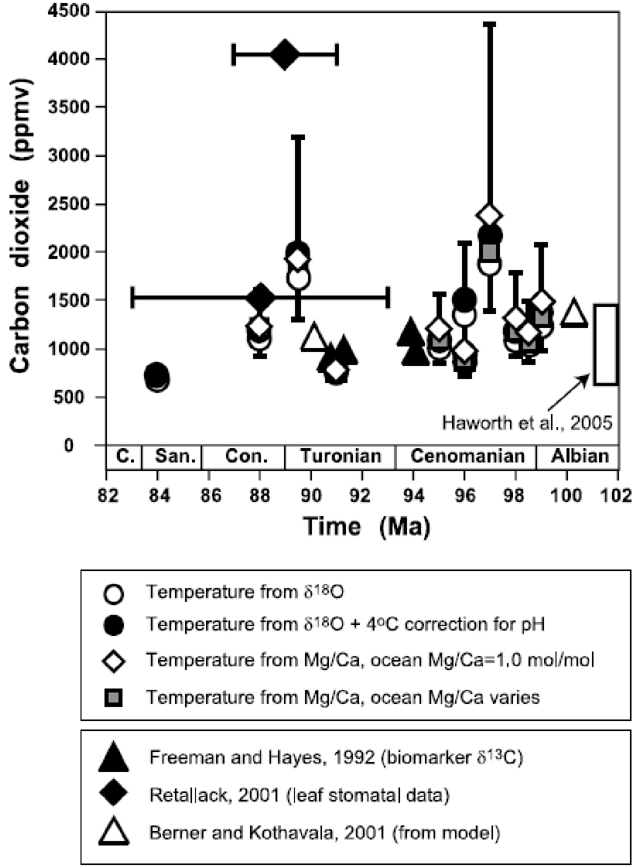


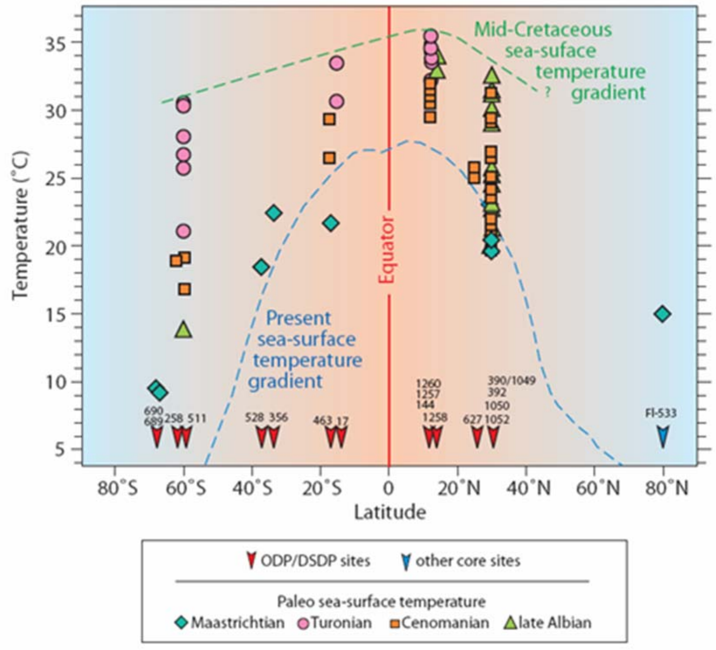


Snowball earth

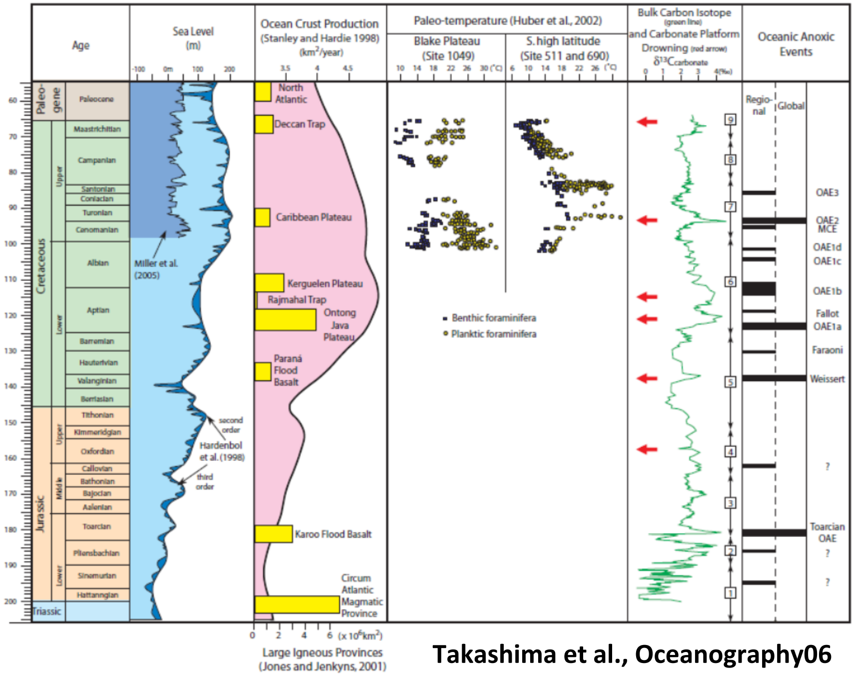
Contact between glacial marine Ghaub Fm (DF, debris flows; IRD, ice-rafted debris) & Keilberg Mb (CD, post-glacial cap dolostone) on Otavi foreslope, northern Namibia.

The middle Cretaceous super-greenhouse: warm and equable

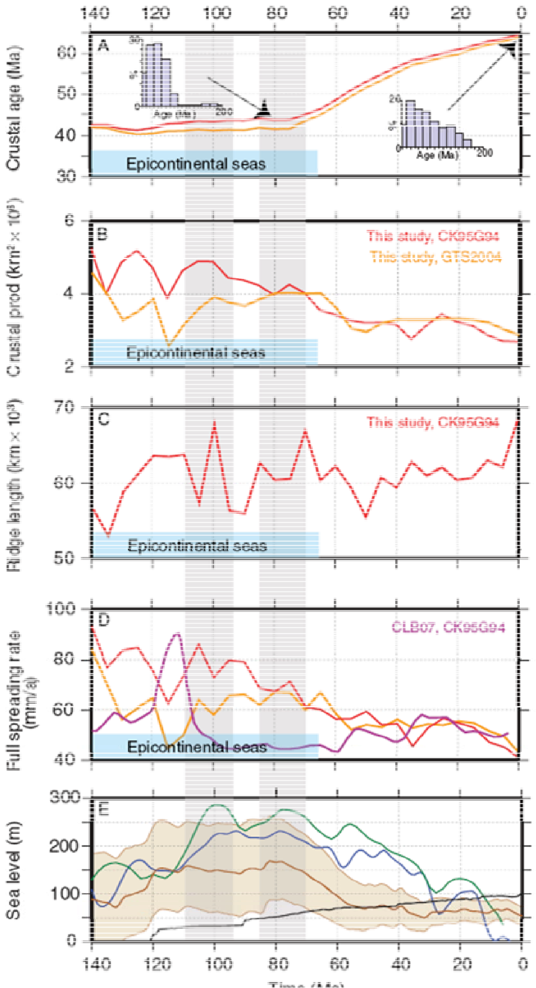




- high pCO_2
- warm at high latitudes
- reduced latitudinal gradient



Takashima et al., Oceanography06

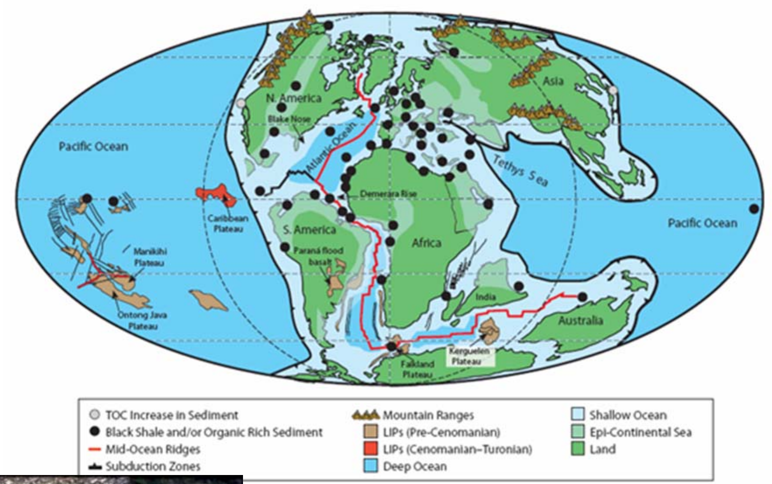


Seton et al., Geology09

Mid Cretaceous

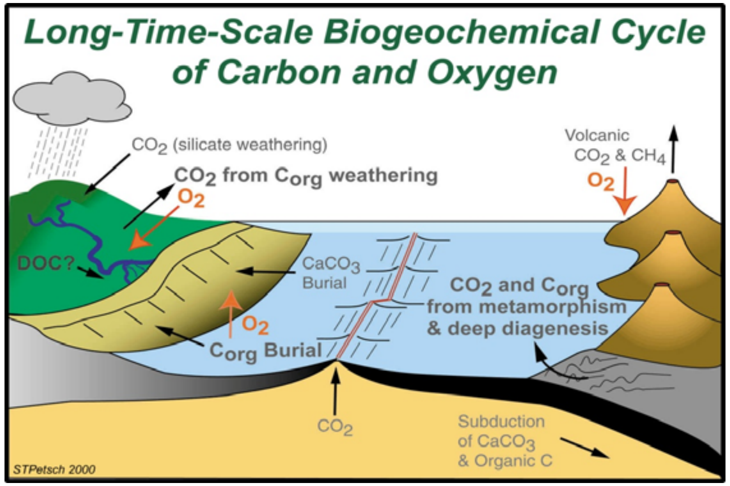
sea floor spreading pulse, LIPS, high sea level, wide epicontinental seas, OAEs

OAEs & black shales



_ca_ 30% of world oil generated by middle Cretaceous source rocks

extreme perturbations of the global carbon cycle (10^5 - 10^6 ky timescale)



Sources of CO_2

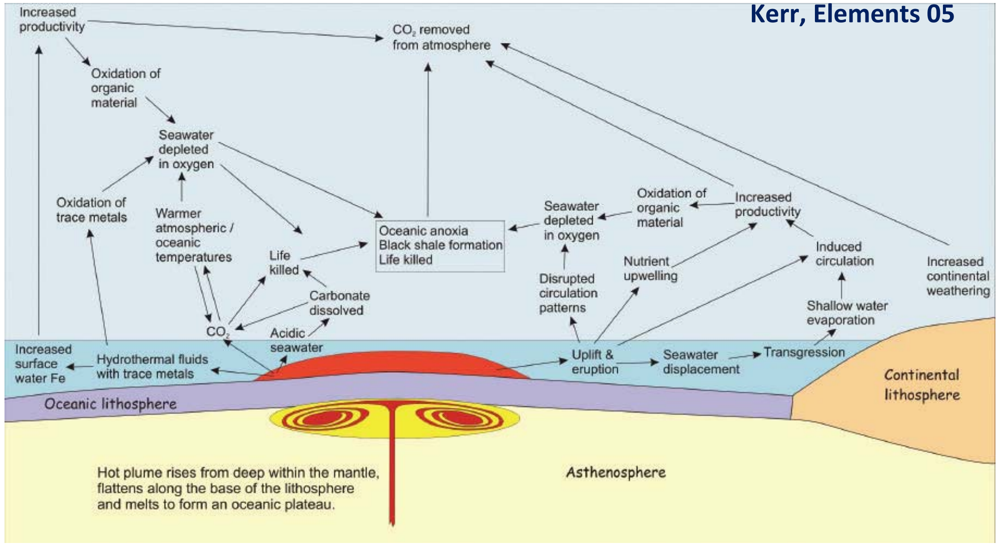
- Volcanism
- Weathering of organic matter

Sinks for CO_2

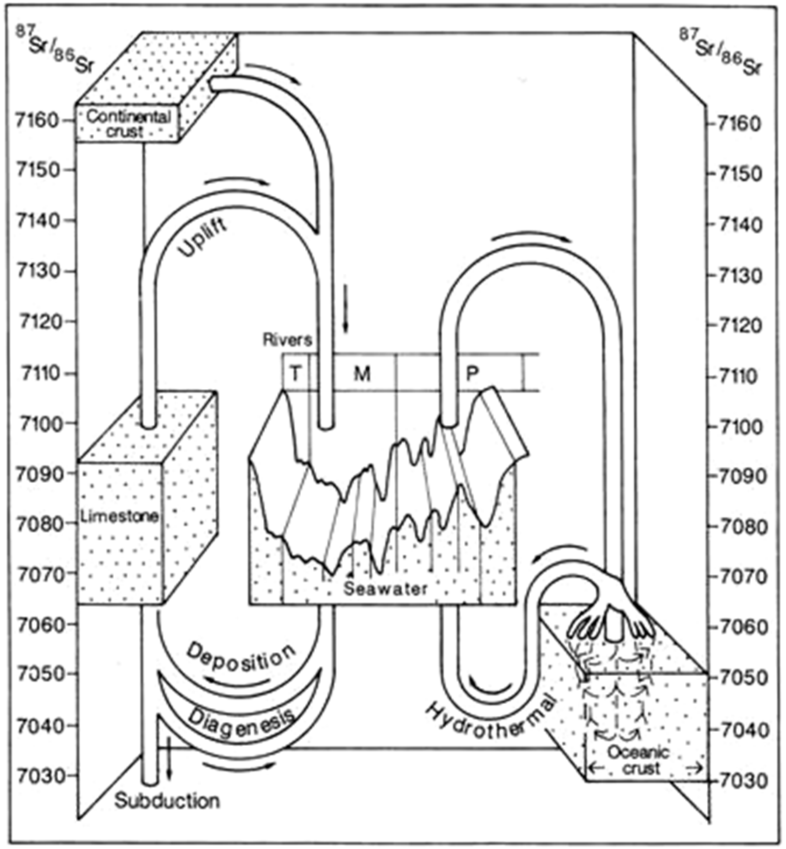
- Organic carbon burial
- silicate weathering } coupled
- carbonate burial

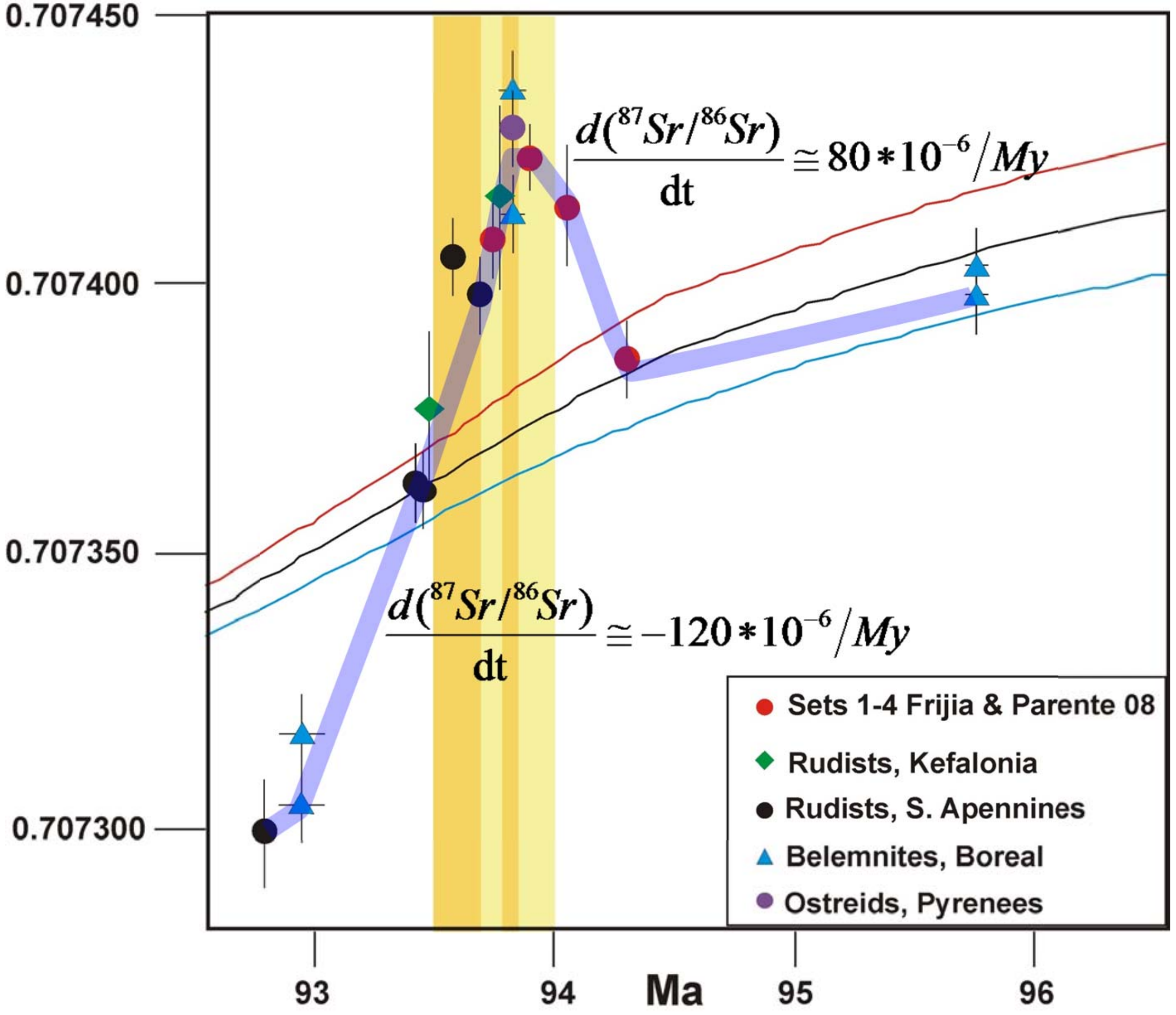
OAEs:

volcanism - CO_2 – warm climate – chemical weathering – nutrients – high productivity – oceanic anoxia – black shales

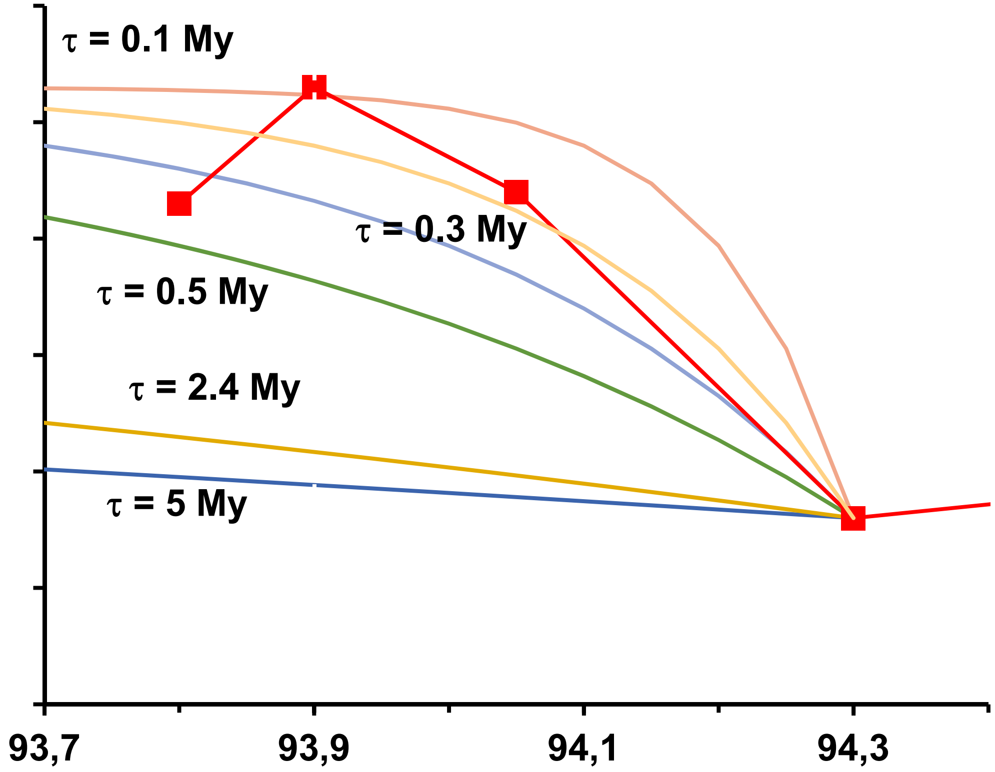

Kerr, Elements 05

The Strontium Isotope Ratio of the ocean: continental weathering and seafloor volcanism



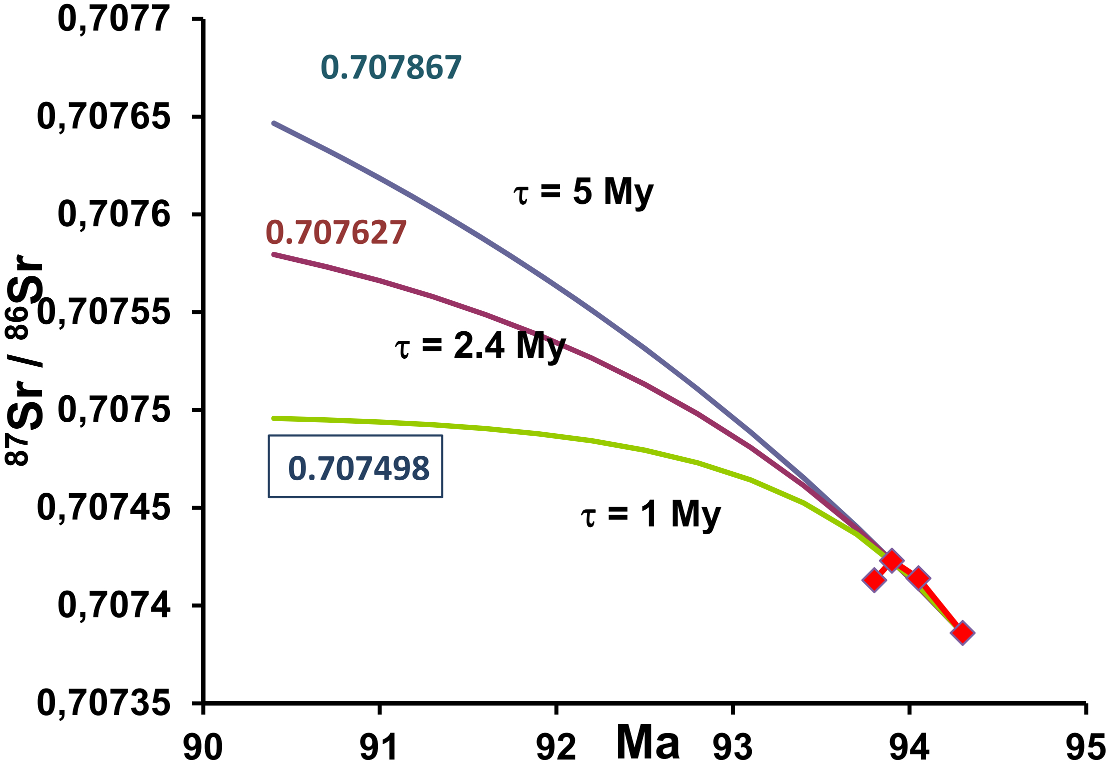

0.707450
0.707400
0.707350
0.707300
93
94
Ma
95
96
$\frac{d(^{87}Sr/^{86}Sr)}{\mathrm{dt}} \cong 80*10^{-6}/My$
$\frac{d(^{87}Sr/^{86}Sr)}{\mathrm{dt}} \cong -120*10^{-6}/My$
● Sets 1-4 Frijia & Parente 08
◆ Rudists, Kefalonia
● Rudists, S. Apennines
▲ Belemnites, Boreal
● Ostreids, Pyrenees

The dynamic response model (Hodell et al., EPSL1989)



$$R(t)= R_{equil}-[R_{equil}-R(t_0)]e^{(t-t_0)/\tau}$$

The dynamic response model (Hodell et al., EPSL1989)

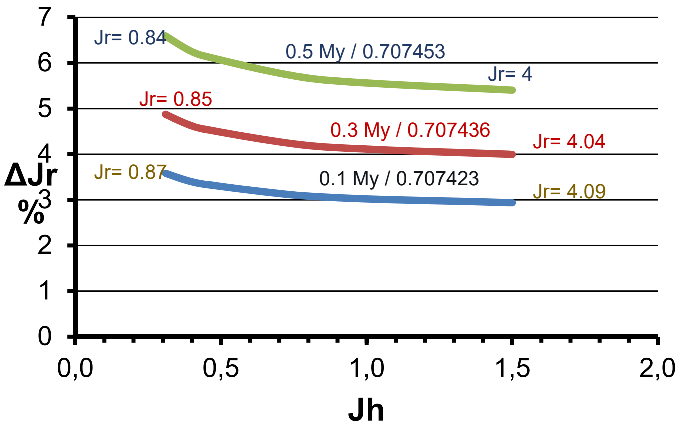


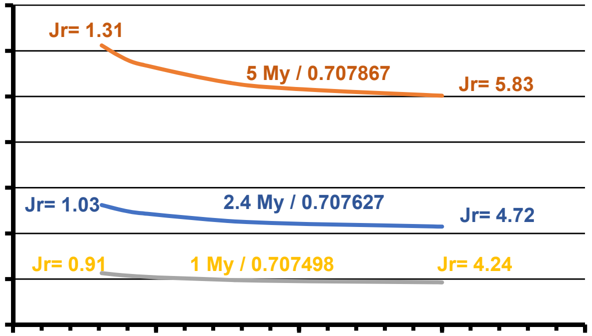
$$R_{equil} = [\ R(t)-R(t_0)\ e^{(t-t_0)/\tau}\ ]\ /\ 1-\ e^{(t-t_0)/\tau}$$

The positive shift: solving for Jr (playing with τ and Jh)

middle Cretaceous pre-OAE2
R = 0.707386
Rr = 0.709280 (Jones & Jenkyns, AmJournSci2001)
Jd = 0.34 x 10^{10} mol / yr
Rd = 0.7084
Jh = 0.31 0.37 0.43 x 10^{10} mol / yr
0.75 1 1.5 x 10^{10} mol / yr
Rh = 0.7025
Jr = 0.82 – 3.89 x 10^{10} mol / yr

a 20-30% Jr pulse is ‘sufficient’ to drive the positive shift (much less if the residence time is shorter…)





Summing up *(more questions than answers...)*

✓ a positive Sr/Sr excursion straddling the onset of OAE2
a short weathering pulse?

✓ a negative excursion steeper than in previous records

✓ problems with high gradients & short response time
non-steady state perturbations?

✓ shorter response time = smaller oceanic Sr inventory?
a two box stagnant ocean at the onset of OAE2?

When you have eliminated the impossible, whatever remains, however improbable, must be the truth (Sir Arthur Conan Doyle)

Q: perchè è così importante la Tettonica delle Placche?

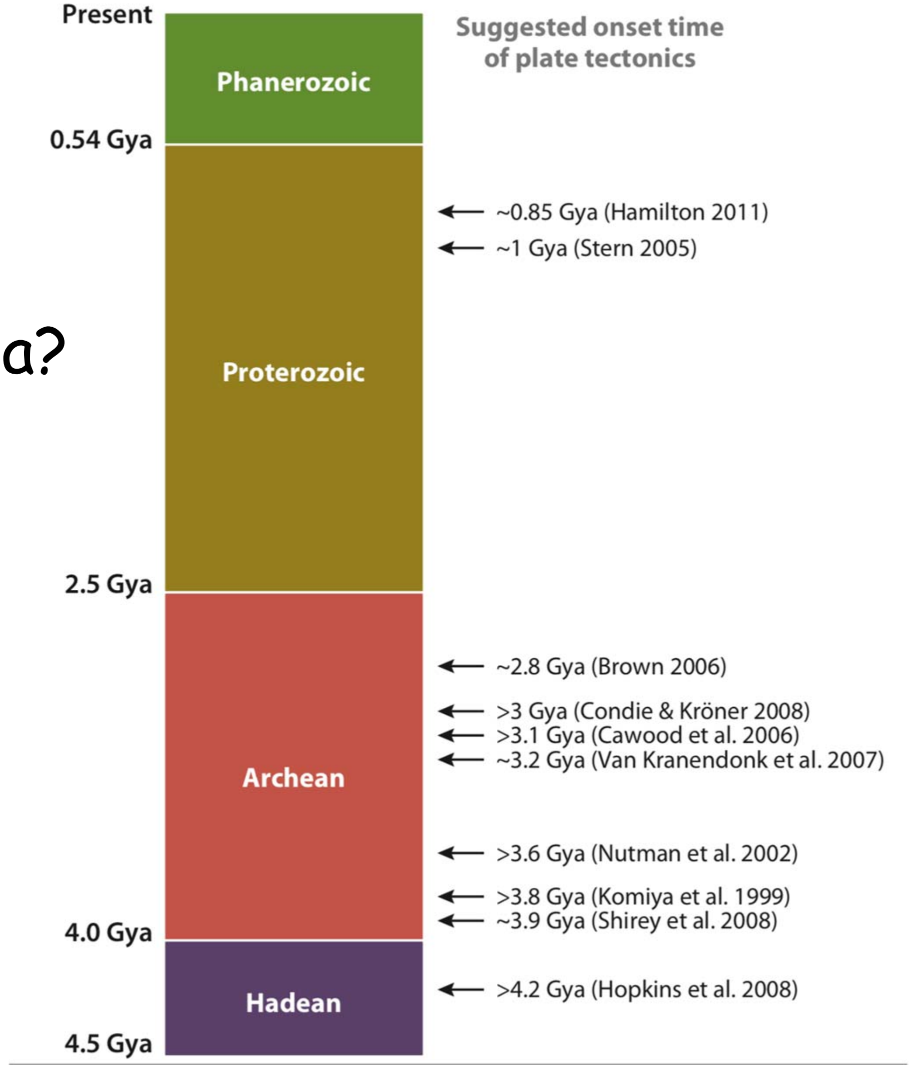
Answers:

- ✓ Cicli biogeochimici e tettonica delle placche
- ✓ CO2, clima e tettonica delle placche
- ✓ Ossigeno e tettonica delle placche
- ✓ Acqua e tettonica delle placche

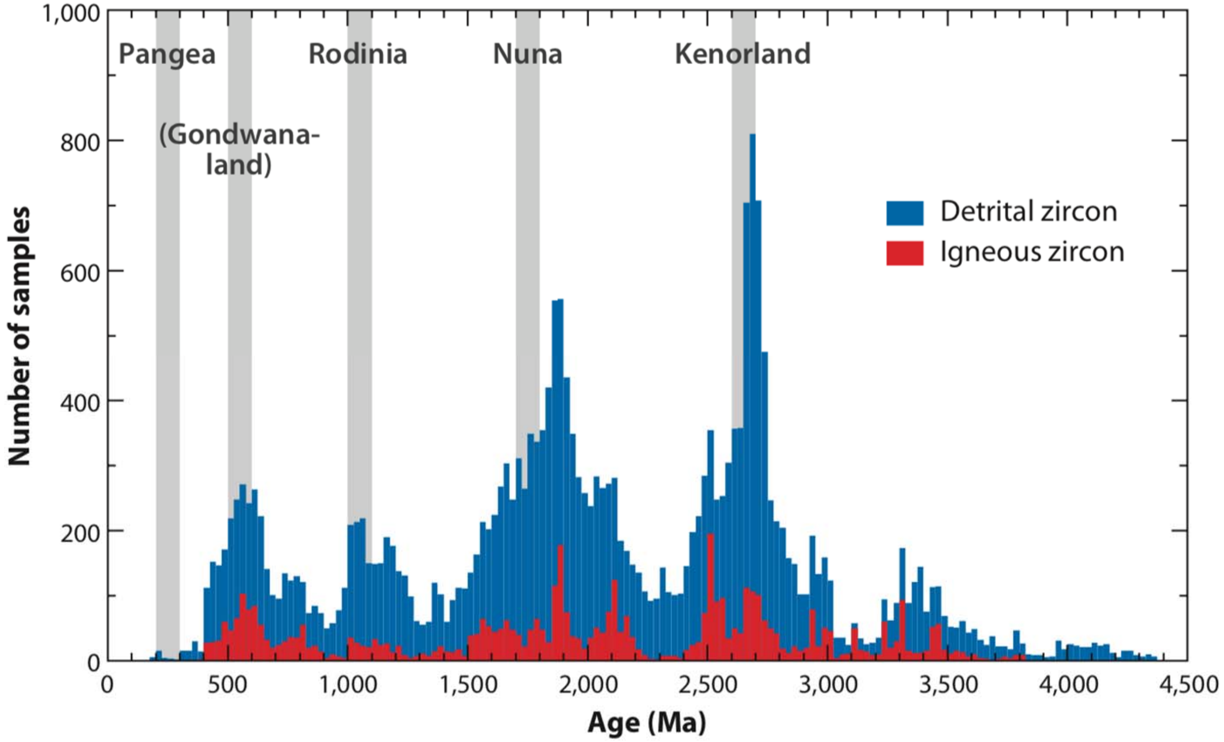
- ✓ La tettonica delle placche attualmente funziona. Se comprendiamo perchè esiste possiamo estrapolare le condizioni del passato partendo dalle condizioni attuali

- ✓ Nel nostro sistema solare la Terra è l'unico pianeta con tettonica delle placche attiva. Altri pianeti come Venere e Marte hanno una convezione di tipo stagnant lid.

E' sempre esistita?
Quando è cominciata?

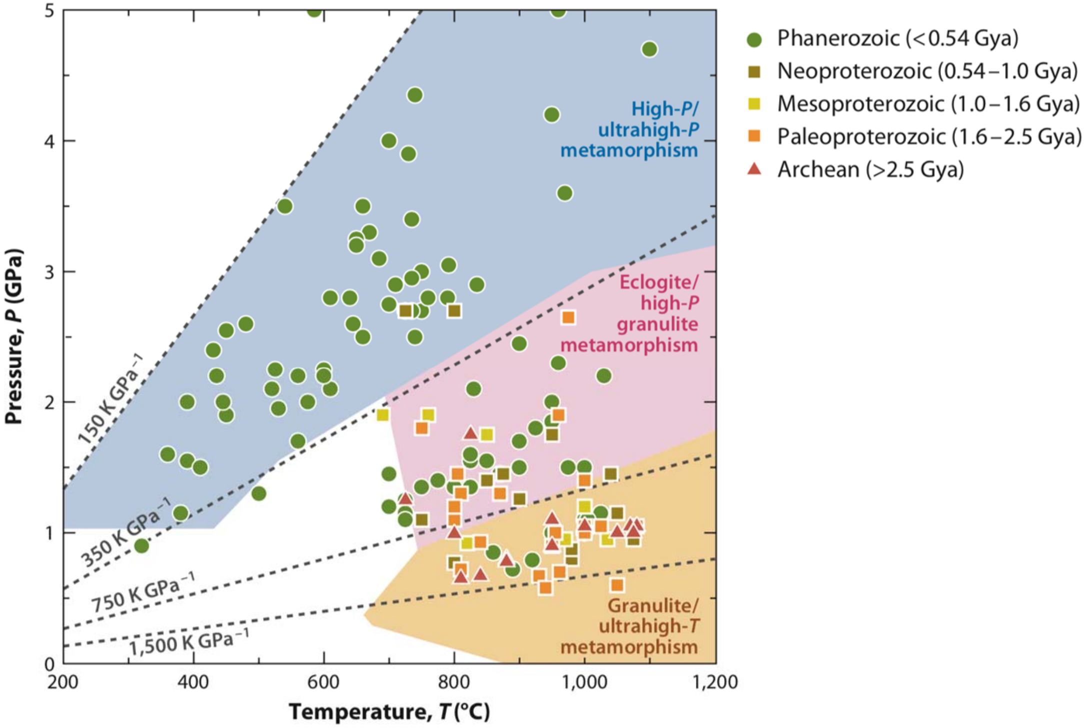


Geological evidences of Plate tectonics



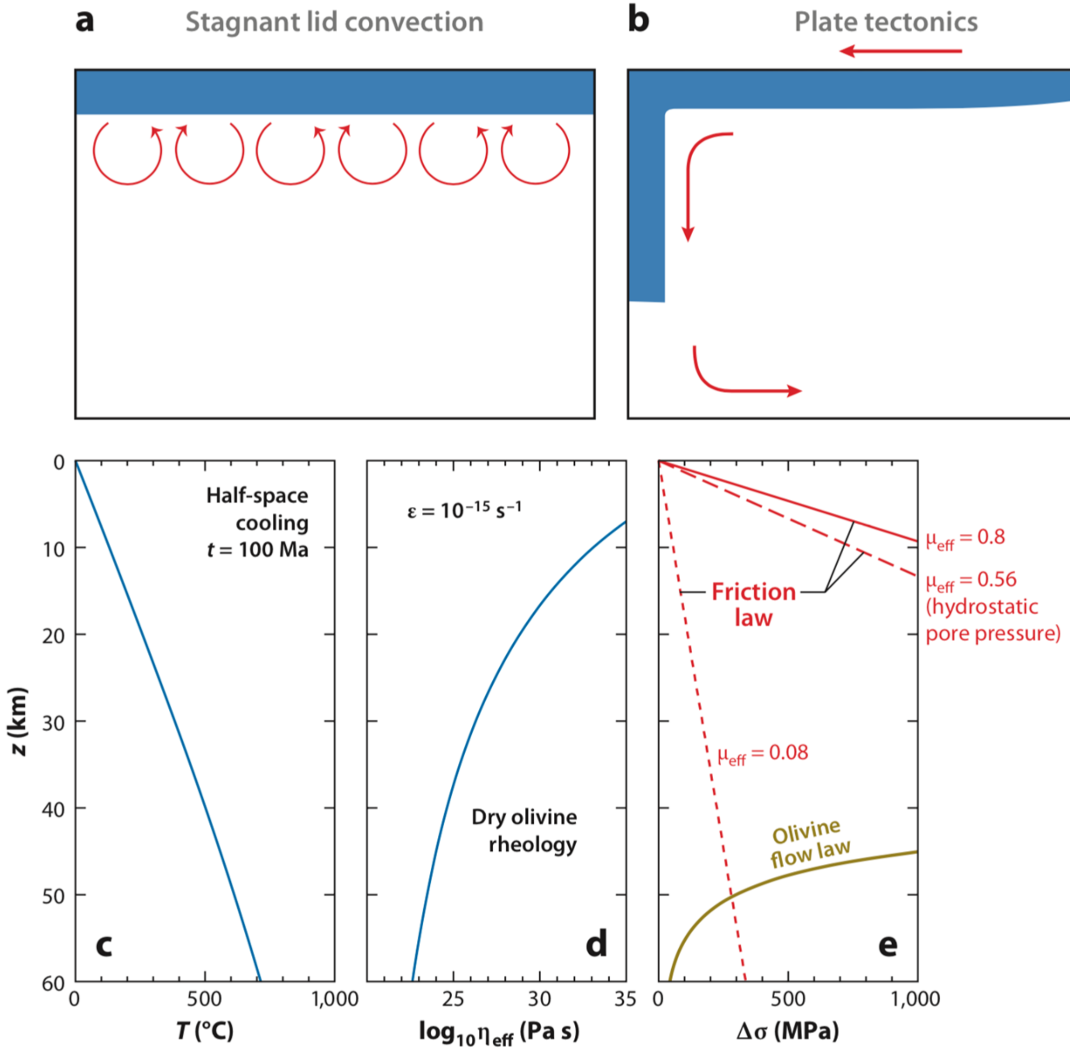
Major peaks of zircon age distribution correlate well with the supercontinental cycle, reflecting high crustal production rates

Geological evidences of Plate tectonics

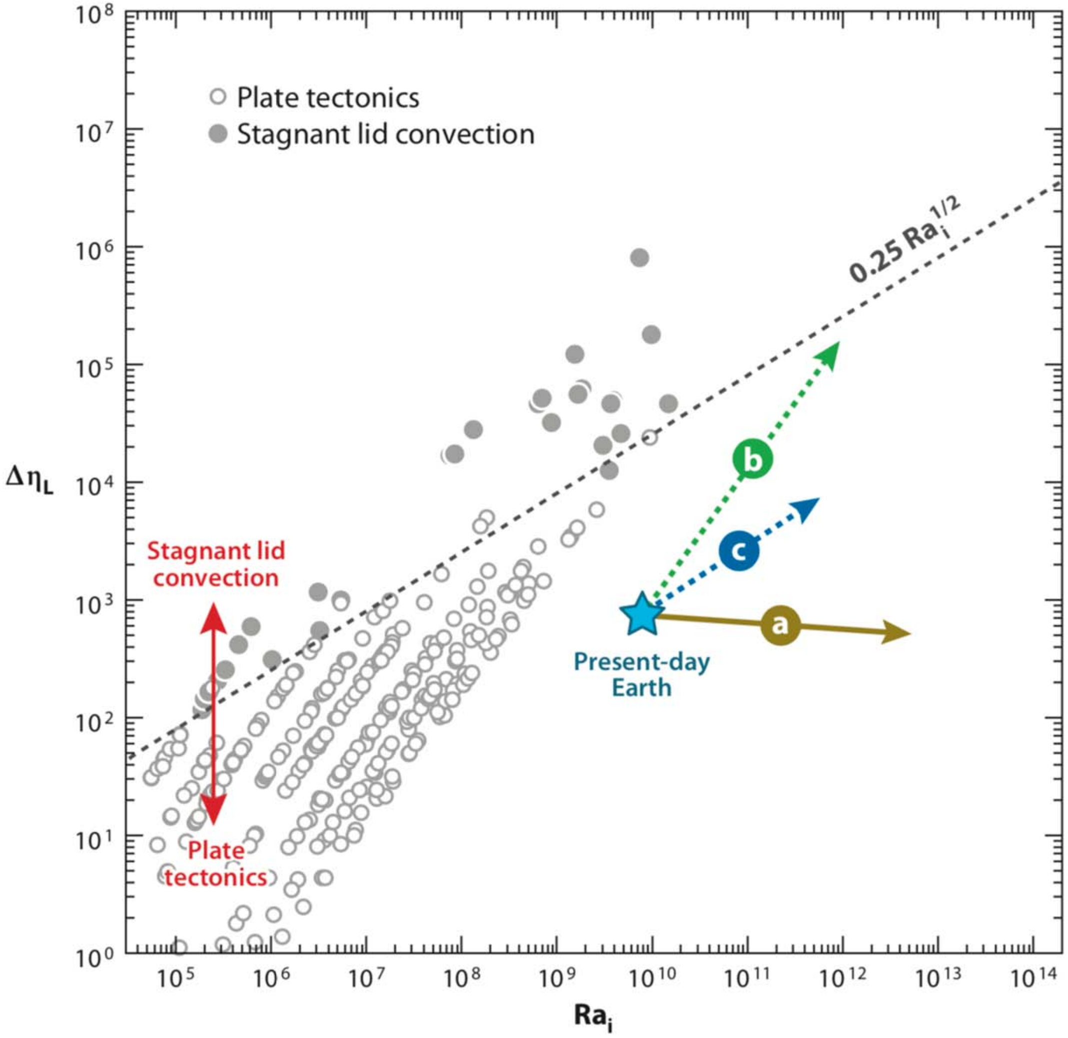


Differenti tipi di metamorfismo implicano diversi gradienti geotermici, cioè diversi contesti geodinamici, che sono possibili solo con la tettonica delle placche

La fisica e la reologia della Tettonica delle Placche



$$\eta(T) \propto \exp\left(\frac{E}{RT}\right)$$



La fisica e la reologia della Tettonica delle Placche:
numero di Raleigh e contrasto di viscosità effettiva

La storia termica della Terra è controllata dal bilancio fra riscaldamento interno (decadimento elementi radioattivi nel mantello e perdita di calore all'esterno guidata dalla convenzione del Mantello

$$C\frac{dT_{\mathrm{i}}}{dt} = H(t) - Q(t).$$

Può essere calcolata a partire dalle condizioni attuali (fisica)

E' vincolata dagli indicatori geologici (geologia)