Milestones in the evolution of the atmosphere with reference to climate change and mass extinctions

Andrew Glikson
Research School of Earth Science and Planetary Science Institute
Australian National University
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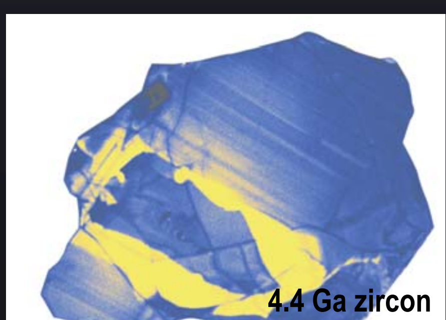
- Climate forcing factors and atmospheric states
- Atmospheric states with time, emergence and the evolution of life
- Long term climate trends
- Episodic mass extinctions

MARS (D 6796 km)
-113^{o}C to 0^{o}C ;
thin atmosphere
0.01 Bar at surface;
CO_2 95.3%;
O_2 0.13% of O_2 on Earth

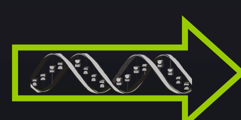
VENUS (D 12 100 km)
>450^{o}C
90 Bar at surface;
CO_2 & sulphuric acid

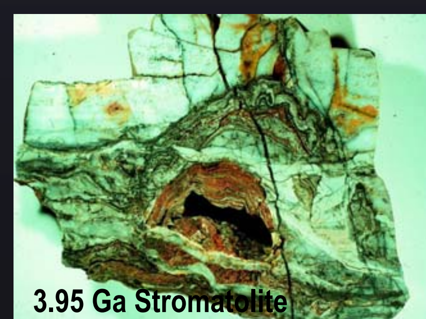
EARTH (D 12,756 km)
mean T +18^{o}C (-50 to+55^{o}C)
(without the greenhouse
effect mean T -14^{o}C);
1 bar; N 79%, O_2 20%
CO2 ~250-300 ppm
2006:~381 ppm CO2

6CO2 + 6H2O→C6H12O6 + 6O2



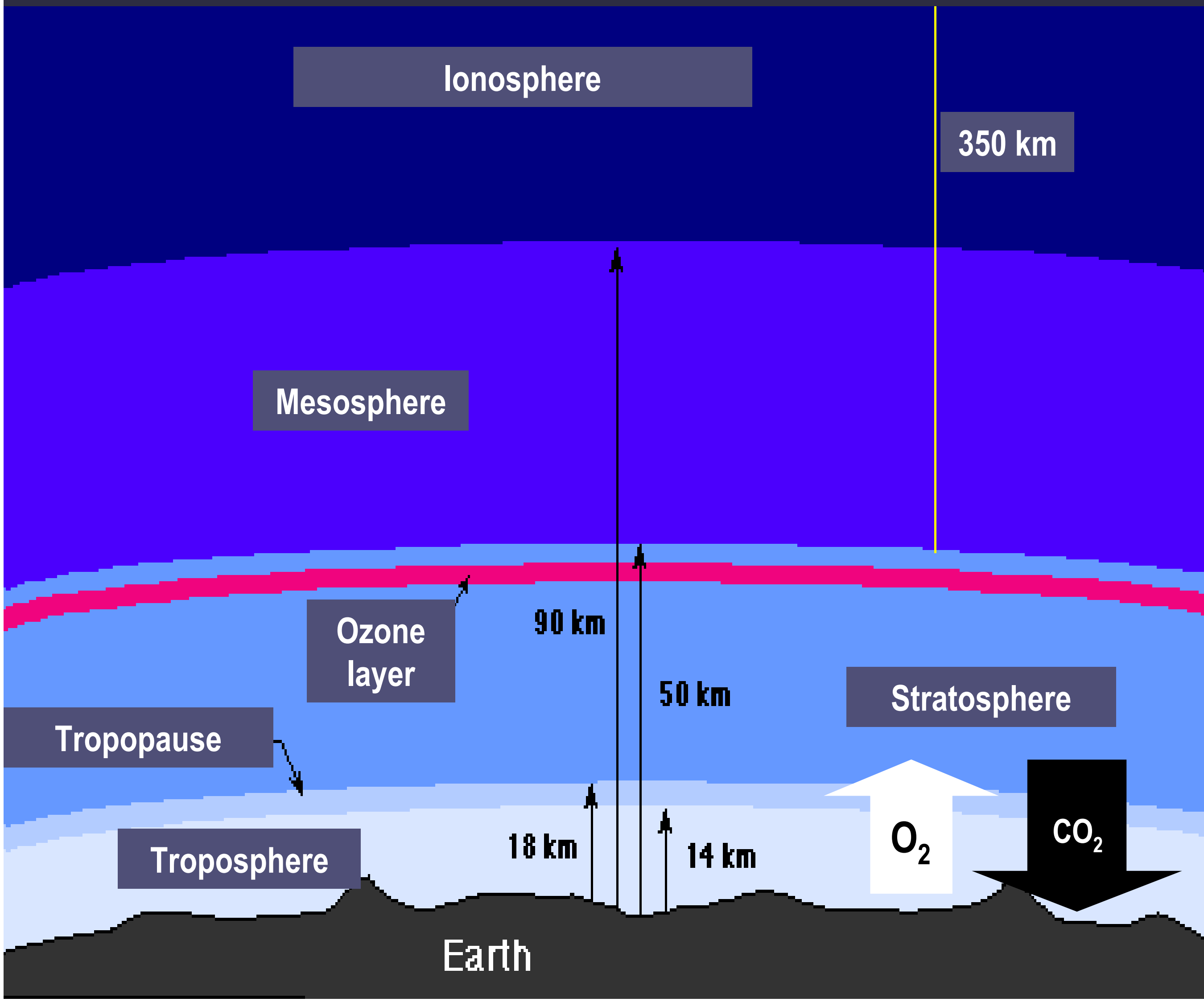
H_2O

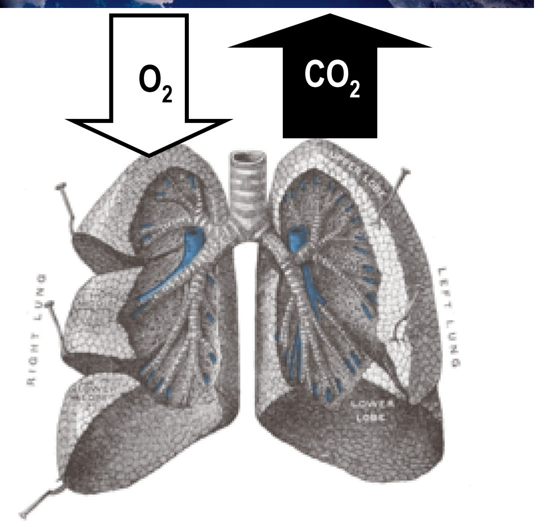




Nanobes Courtesy: P.J.R. Uwins

LUNGS OF THE EARTH



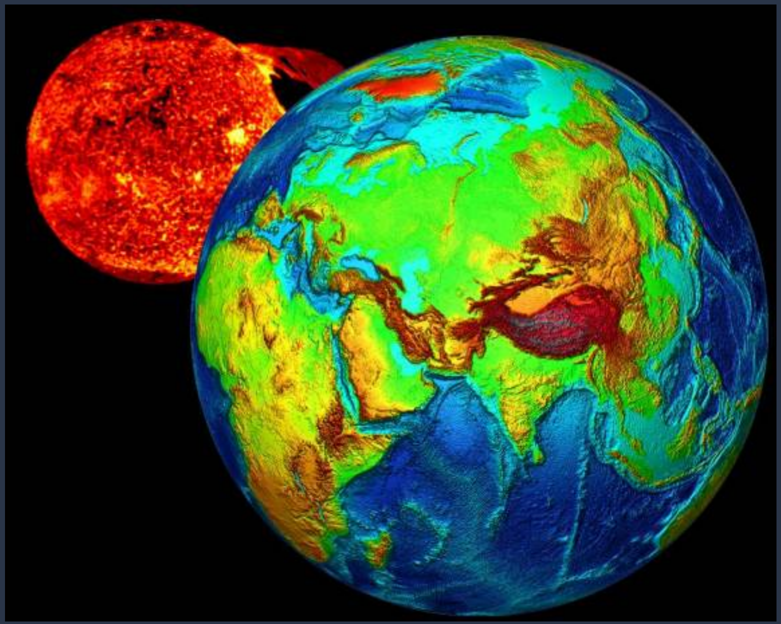


CLIMATE FORCING FACTORS

"Paleoclimate data show that the Earth's climate is remarkably sensitive to global forcing. Positive feedbacks predominate. This allows the entire planet to be whipsawed between climate states. A climate forcing that 'flips' the albedo of a sufficient portion of an ice sheet can spark a cataclysm."

Hansen et al., 2007 (J. Royal Society)

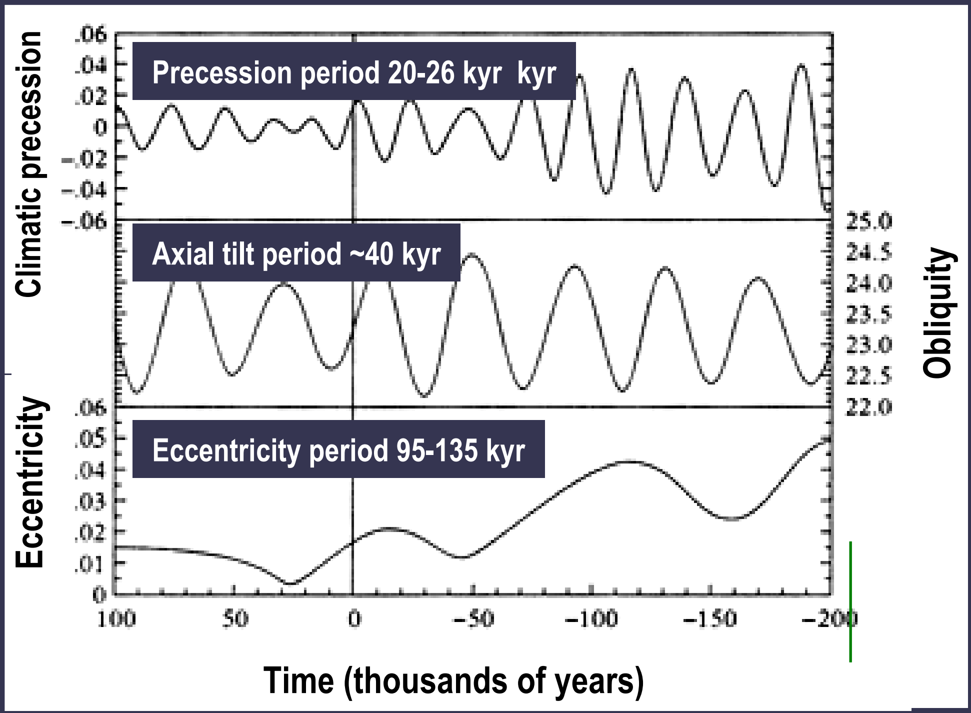
GREENHOUSE GASES AND AEROSOLS

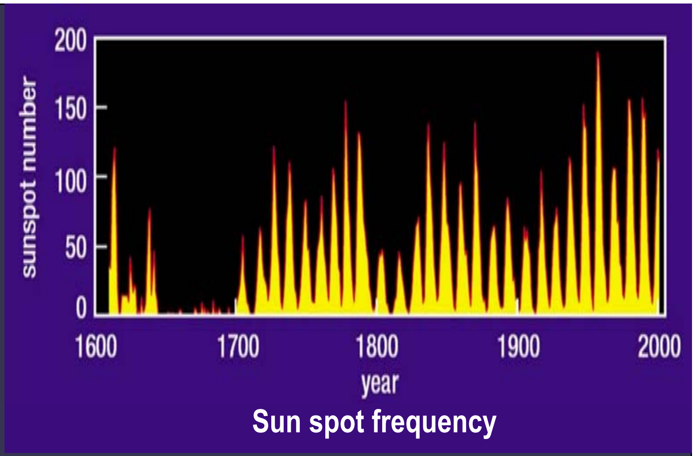


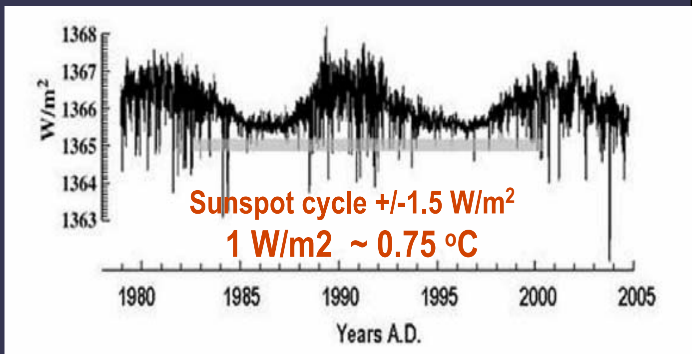
ORBITAL FORCING

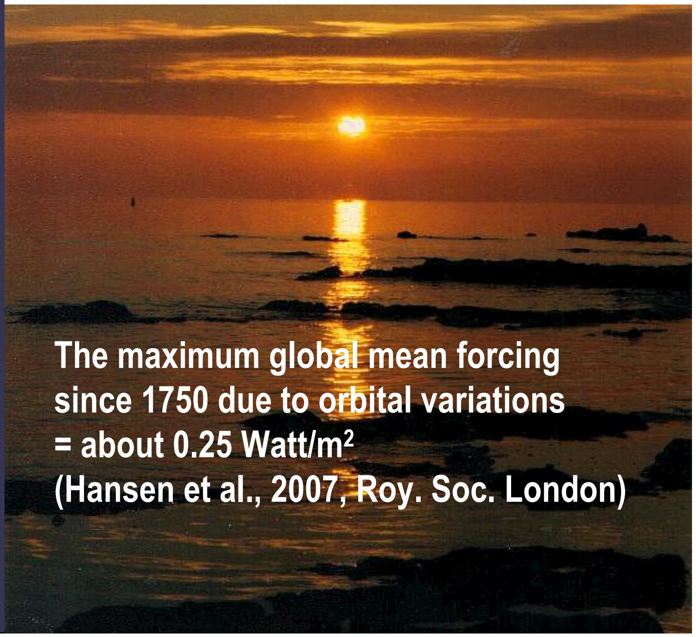
THE ICE ALBEDO FLIP

ORBITAL FORCING







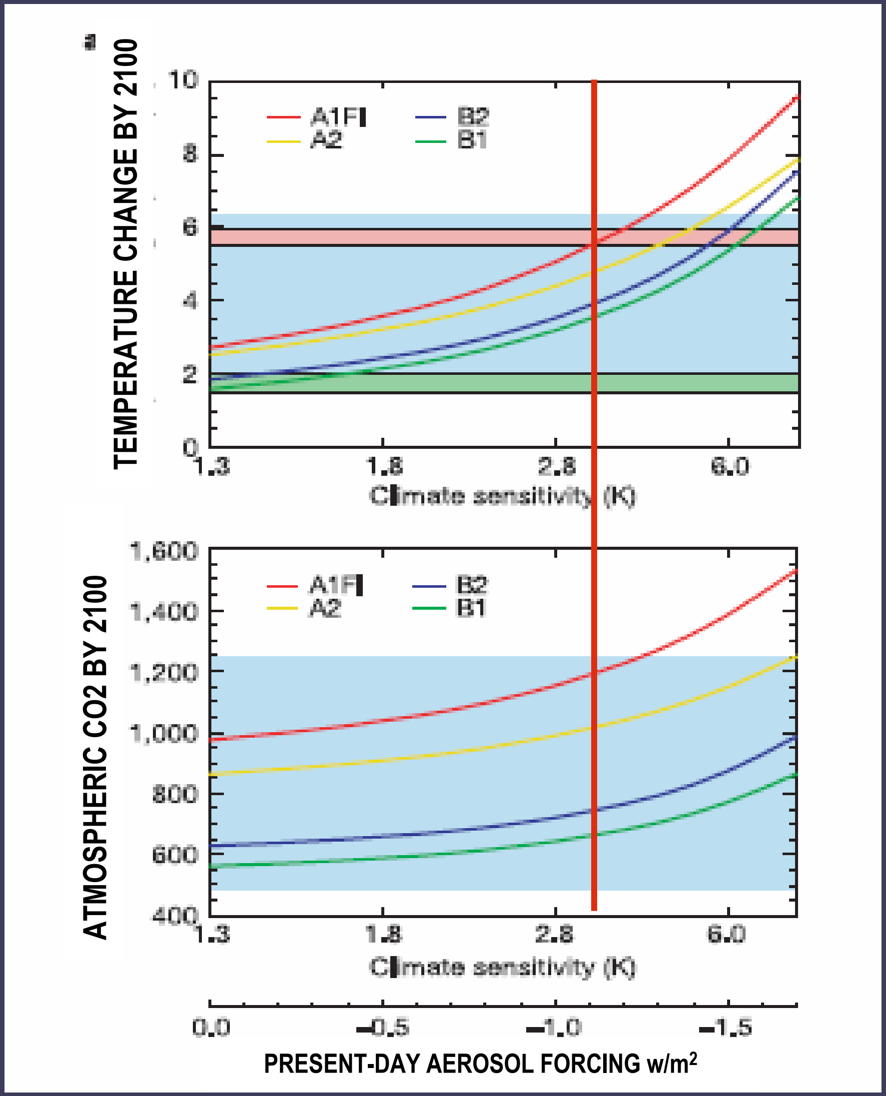


Eccentricity: Circular, elliptic, parabolic or hyperbolic trajectories.

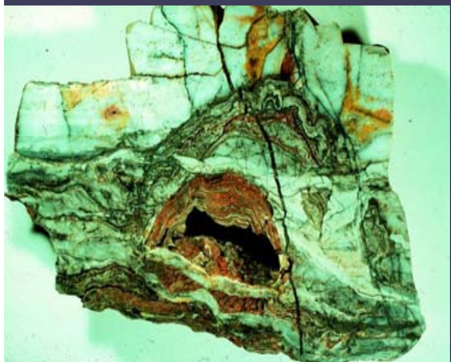
Precession: Change in the direction of the Earth's axis of rotation relative to the Sun at the time of perihelion and aphelion.

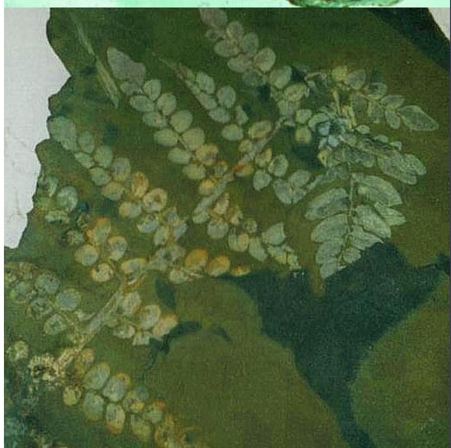
Obliquity: Earth axial tilt relative to the ecliptic plane

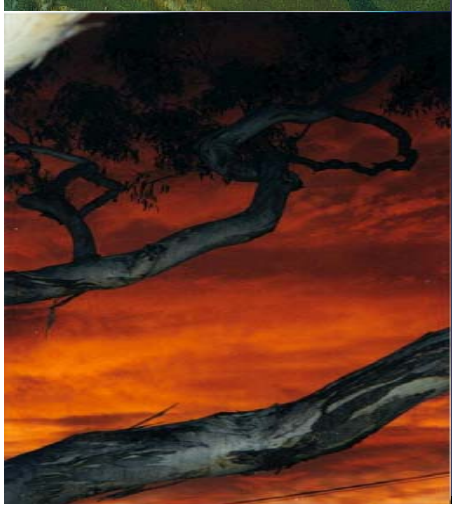
CLIMATE SENSITIVITY AND AEROSOL EFFECTS



BIOLOGICAL FORCING: THE ATMOSPHERIC RESPIRATION SYSTEM







PLANTS

Production of oxygen

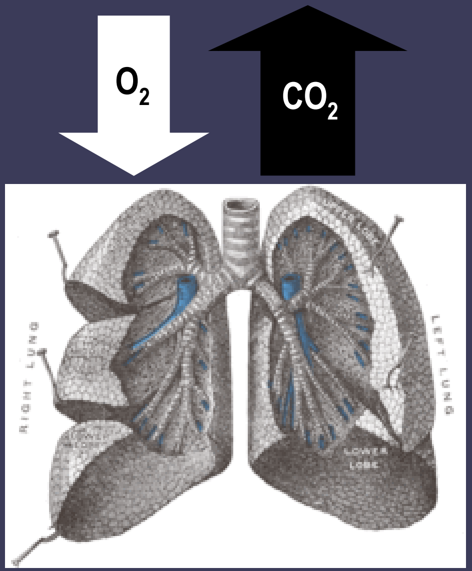
- Regulation of carbon dioxide
- Accumulation of methane, pit and coal
- Regulation of ground water level
- Regulation of local temperatures and rainfall
- Extensive fires — tinderbox Earth

ANIMALS

- Absorption of oxygen
- Emission of CO2 and CH4

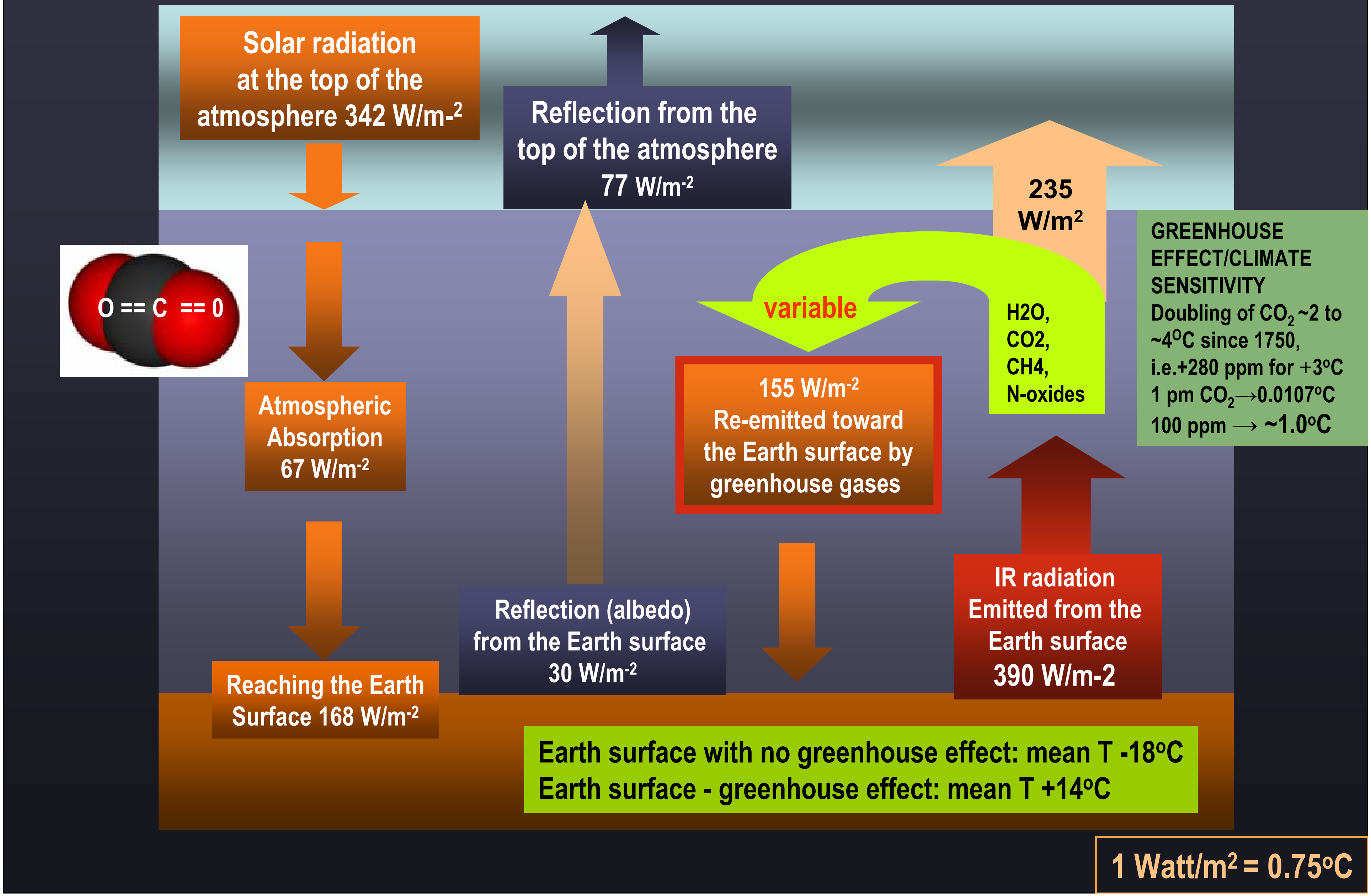
ANTHROPOGENIC

- Absorption of oxygen
- Emission of CO_2
- Extra-emission of CO_2



THE GREENHOUSE EFFECT (natural balance)

(Radiative forcing units Watt/m^{-2})



EXTREME ATMOSPHERIC STATES: GREENHOUSE WORLD

LOWER CRETACEOUS

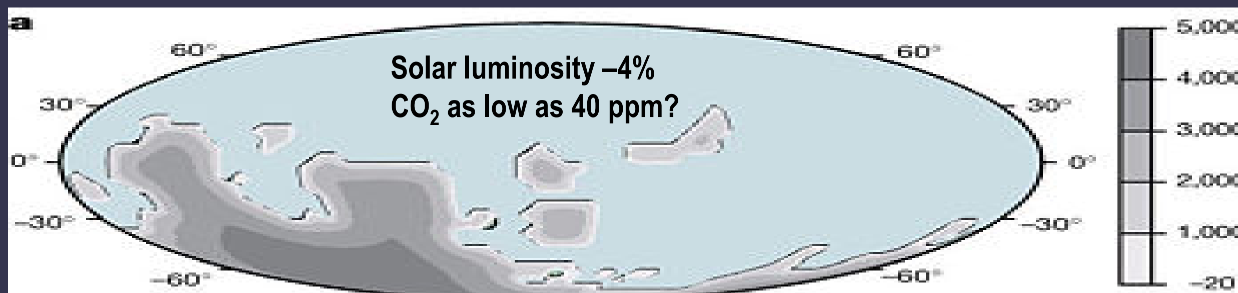
110 – 90 Ma >1000 ppm CO_2; ~7°C warmer that at present

Global Climate Change and the Cretaceous Greenhouse World by Greg A. Ludvigson

Deep ocean basins (dark blue) and shallow inland seas (light blue) are shown in this view of the Earth 110 million years ago (Cretaceous Period). Note the opening of the central Atlantic Ocean caused by rifting between North America (upper left) and Africa (lower right). *Image by Ron Blakey, Northern Arizona University.*

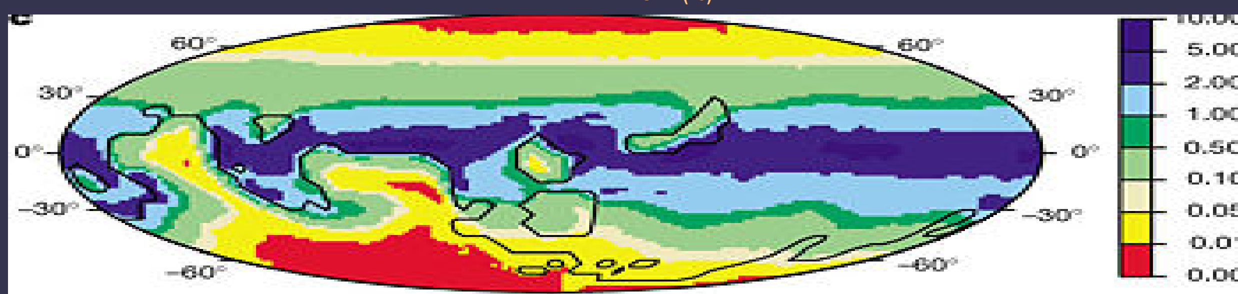
EXTREME ATMOSPHERIC STATES: SNOWBALL EARTH

(Cryogenian 850-630 Ma)



ICE THICKNESS (METRES)

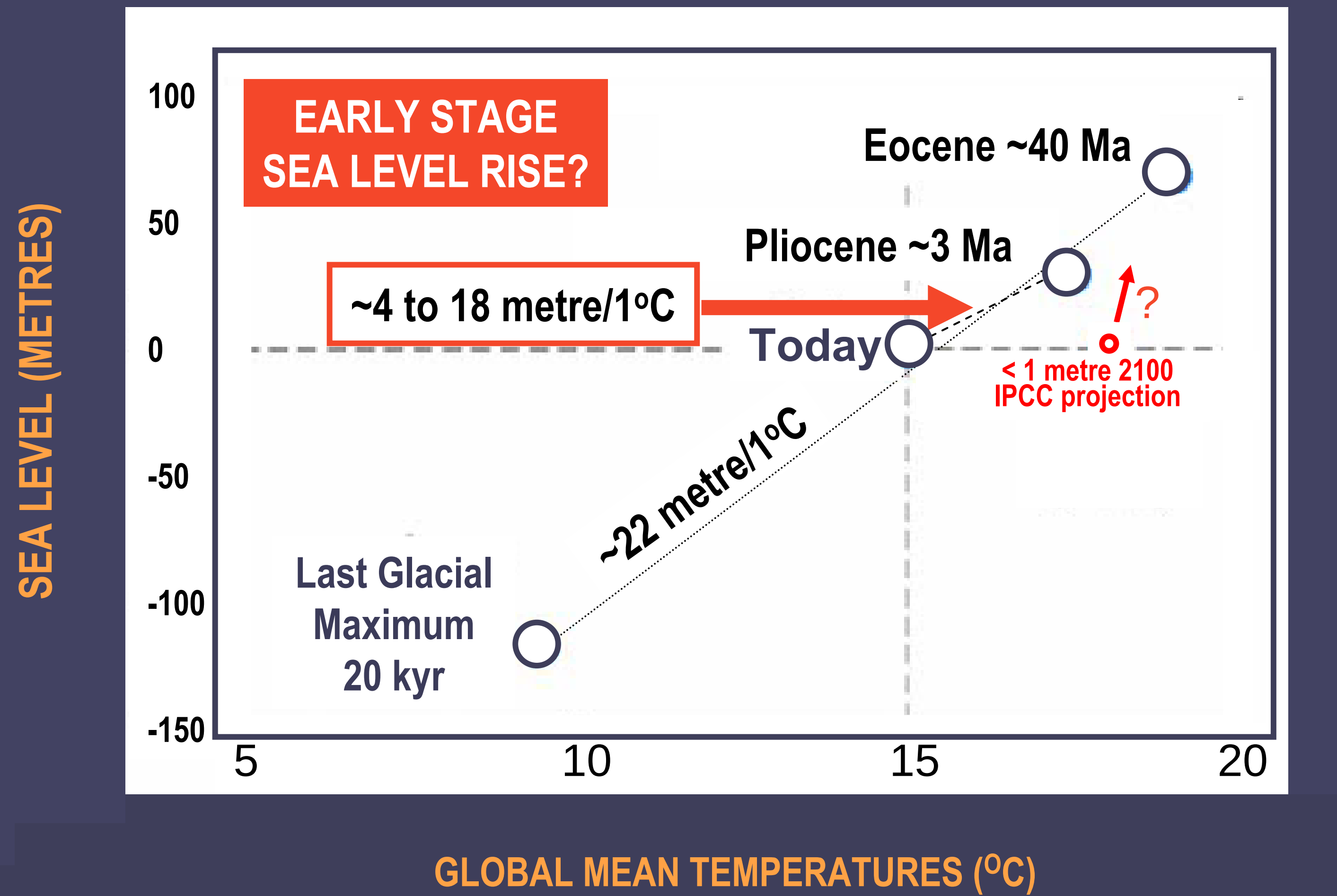
TEMPERATURE (°c)



PRECIPITATION (MM D-1)

Computer simulation of conditions during the Snowball Earth period Hyde *et al* (2000) Nature 405:425-429

SEA LEVEL CHANGES BETWEEN EXTREME CLIMATE STATES
SEA LEVEL AMPLITUDE >200 METRES



Climate Change Fact Sheet *Compiled by Prof. Stefan Rahmstorf Potsdam Institute for Climate Impact Research (www.pik-potsdam.de/~stefan)*

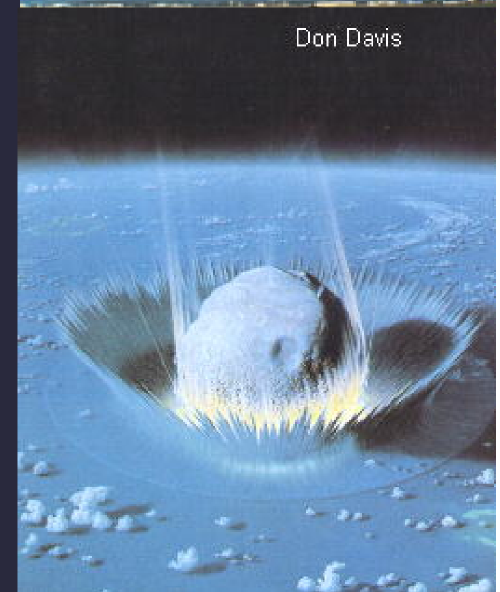

EXTRATERRESTRIAL FORCING AND ENDOGENIC RESPONSES

EPISODIC EXTRATERRESTRIALO IMPACT AND ENDOGENIC VOLCANIC FORCING

"Late Cretaceous/Early Tertiary background CO2 levels of 350-500 ppm by volume, With a marked increase to at least 2,300 ppm by volume within 10,000 years of the KTB impact, due to instantaneous transfer of approximately **4,600 GtC** to the atmospheric reservoir by a large extraterrestrial bolide impact. A resultant climatic forcing of +12 W/m^2 would have been sufficient to warm the Earth's Surface by approximately 7.5 degrees C, in the absence of counter forcing by sulfate aerosols. Beerling et al., 2002, PNAS, 99, 7836-7840

305 GtC EMITTED SINCE 1750

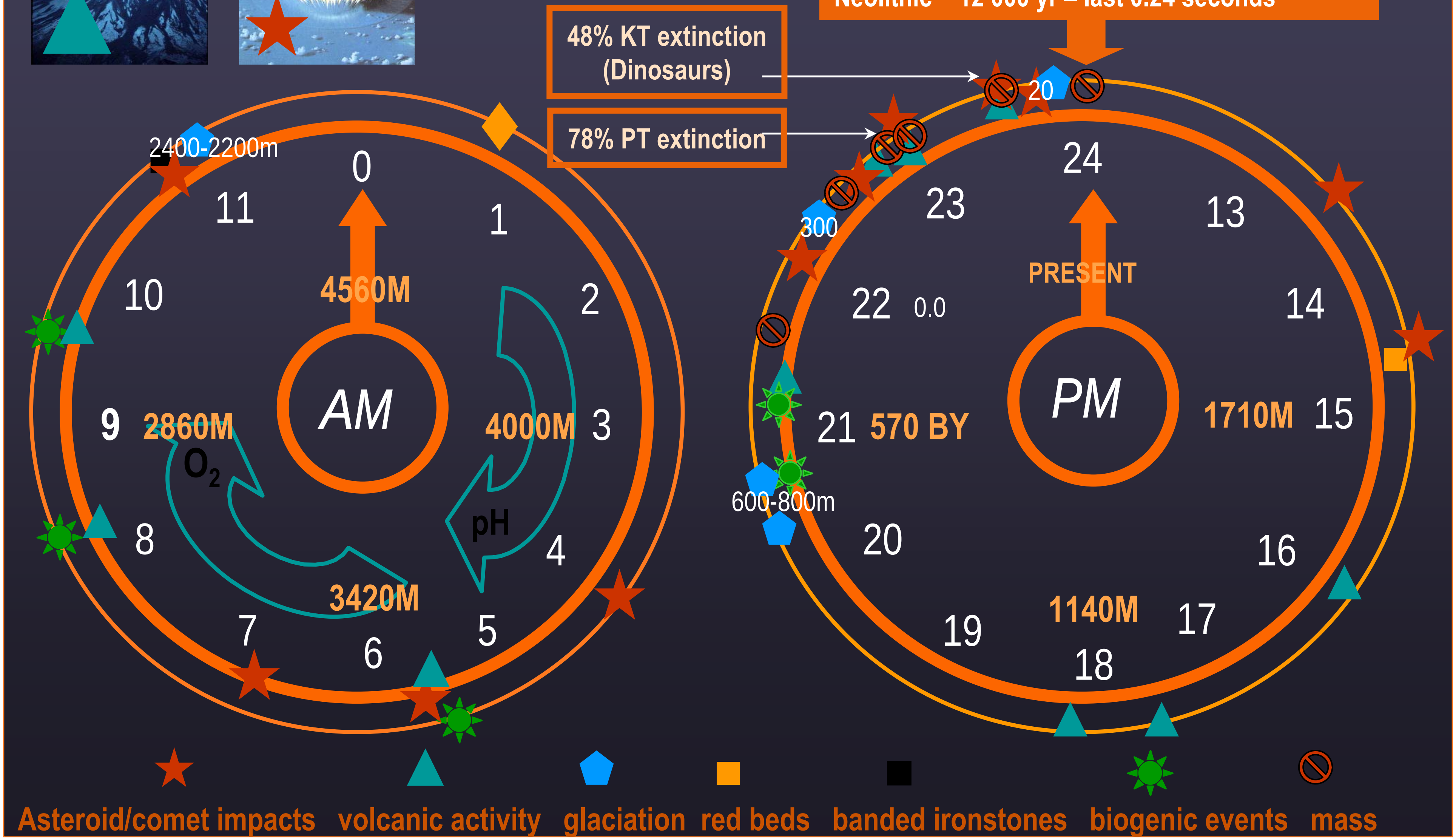
TOTAL ESTIMATED FOSSIL CARBON RESERVES ~ 4000 GtC



Atmospheric states with time, emergence and the evolution of life

Milestones in terrestrial evolution

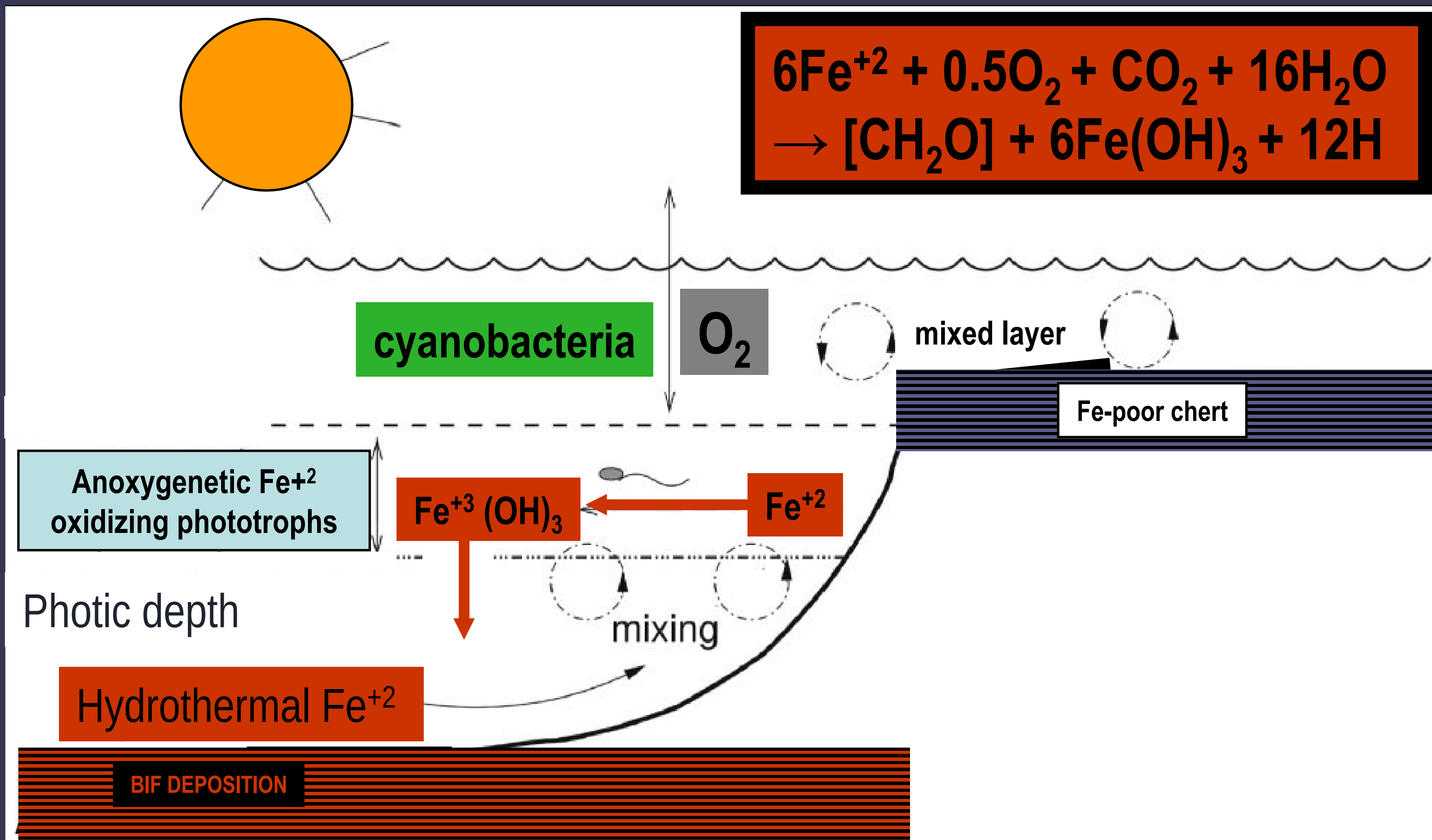
Bipedalism ~5 my – last 1 minute 35 seconds
Stone tools ~ 3 my – last minute
Fire ~700 000 yr – last 13 seconds
Burial ~ 100 000 yr – last 2 seconds
Neolithic ~ 12 000 yr – last 0.24 seconds



THE EARLY ATMOSPHERE

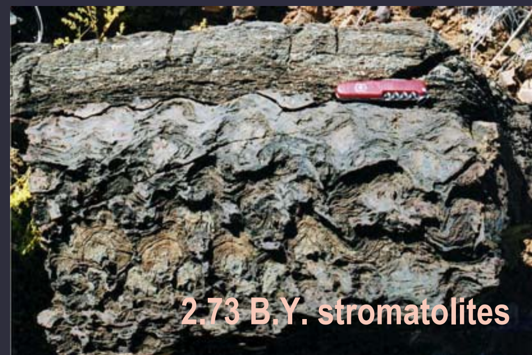
- Low solar luminosity (-70-80%), compensated by super-greenhouse effect (due to high CH_4, H_2O, CO_2, CO, H_2S, polymerized hydrocarbons)
- Evidence of low O_2 from unoxidized pyrite & uraninite in sediments and abundance of ferrous iron – forming banded iron formations.
- Some oxygen available (according to S isotope studies).
- High temperatures of the hydrosphere, due to high geothermal gradients and greenhouse effects.
- CO_2 supplied by volcanic activity, but low sequestration due to high water temperatures (evidenced by scarcity of carbonates pre-2.7 Ga) and limited erosion due to low continent/ocean ratio.
- Anoxic, reducing, sulphur-rich oceans constrained biological evolution of all but the most primitive single-cell prokaryotes lacking in nucleus, including methanogenic bacteria and cyanobacteria (forming stromatolites).

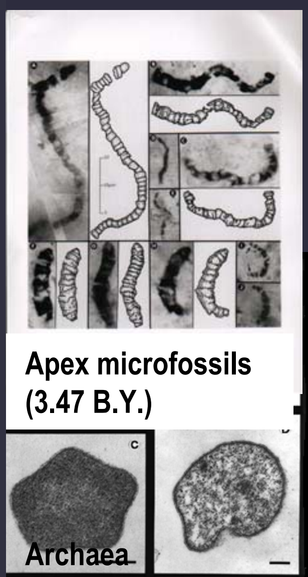
BIOGENIC ORIGIN OF BANDED IRON FORMATION

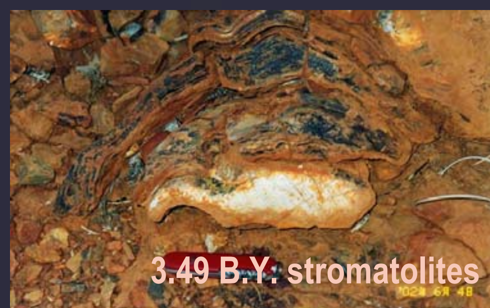


Model of ancient stratified ocean with cyanobacteria colonizing surface mixed layer, above layer of anoxygenic photoautotrophic Fe(II)-oxidizing bacteria, with a hydrothermal source of Fe(II) underneath (Holland, 1973; Morris, 1993). Question mark and double arrow point to thickness of layer of anoxygenic phototrophs supported by Fe(II) input. After Kappler et all., Geology, 2005

MILESTONES IN THE EVOLUTION OF LIFE FORMS







Sulphur-rich oceans
CO2-rich reducing
Atmosphere (detrital
Sulphide, uranitite, sulphur isotopes)
Soluble ferrous oxide

2..1 Ga

OXYGEN ENRICHMENT

1.5 Ga Mitosis

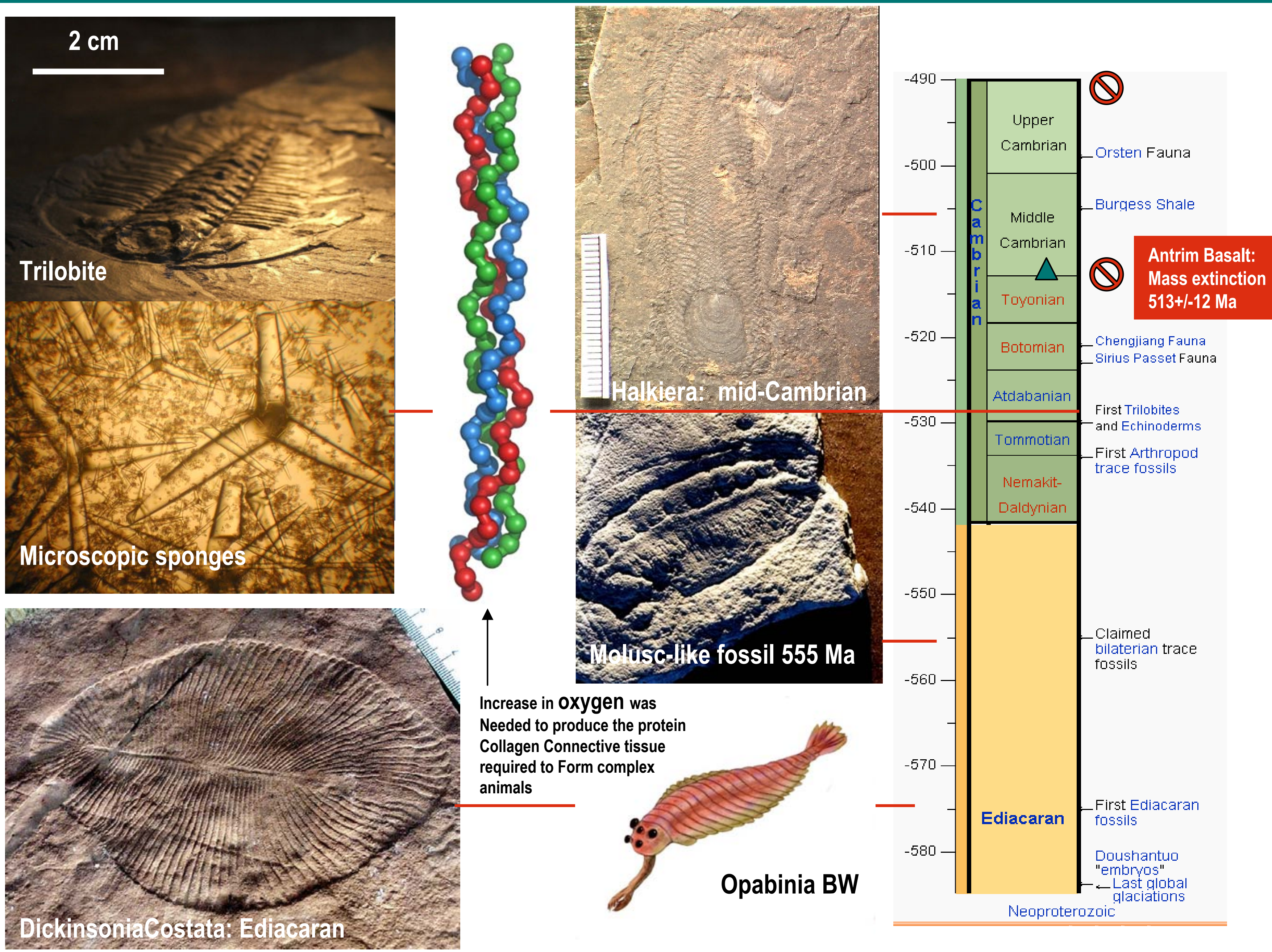
0.54 Ga
Multicelular
Animals;
calcareous shells

Stromatolites: past and present

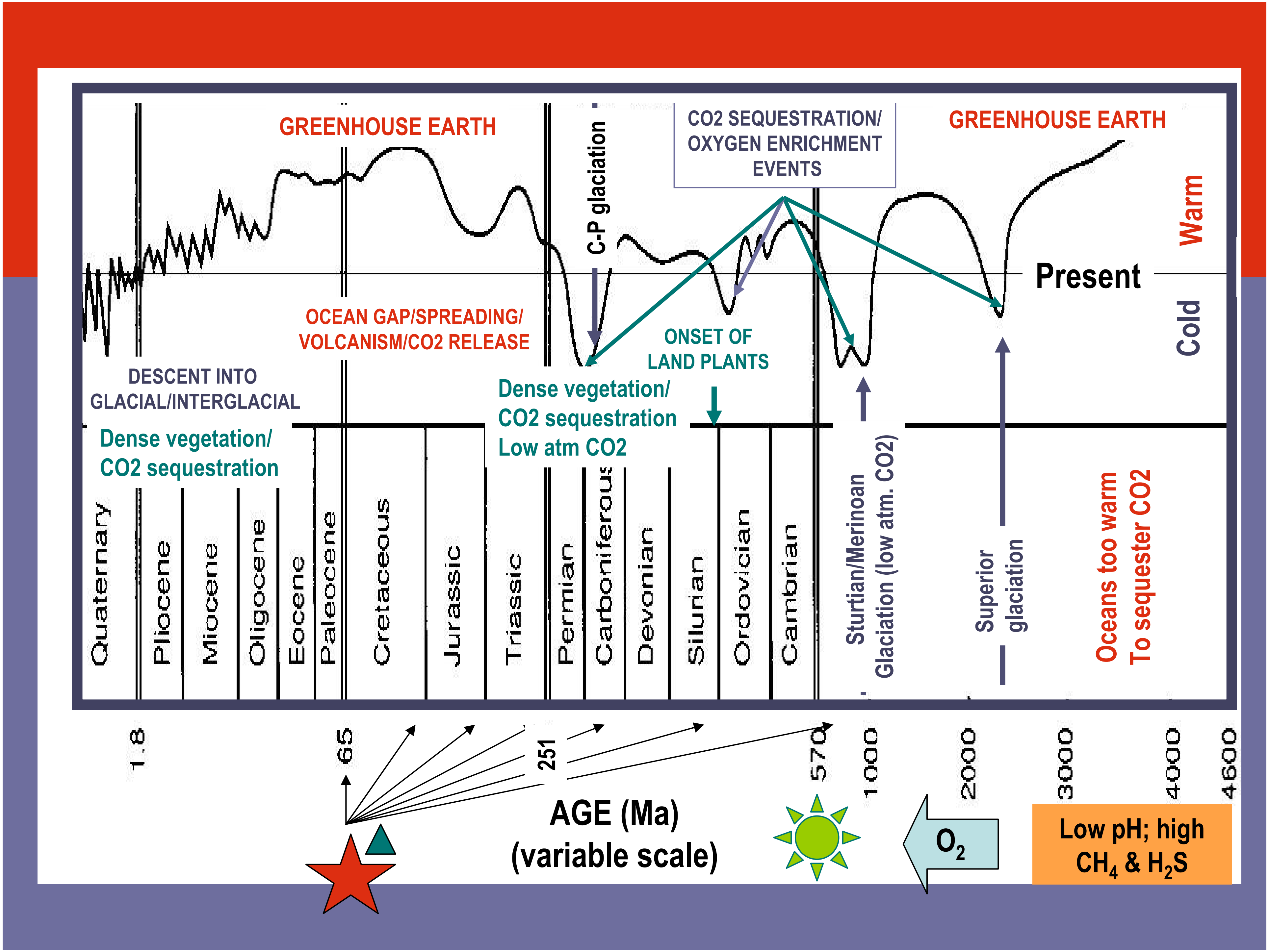
A. 2.63 Ga giant stromatolite, Carawine Dolomite Pilbara, Western Australia.

B. Shark Bay stromatolites.

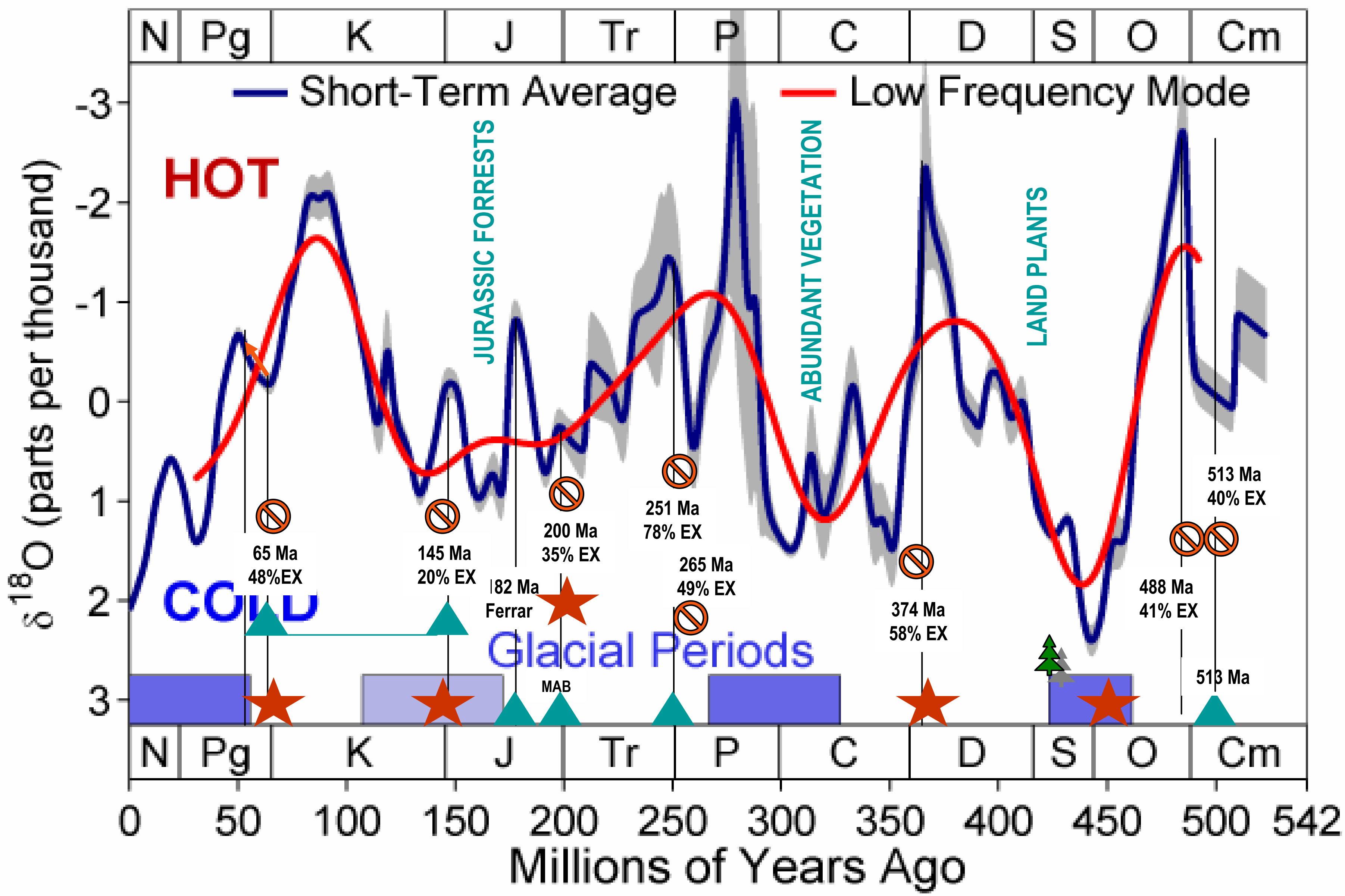
THE "CAMBRIAN EXPLOSION"



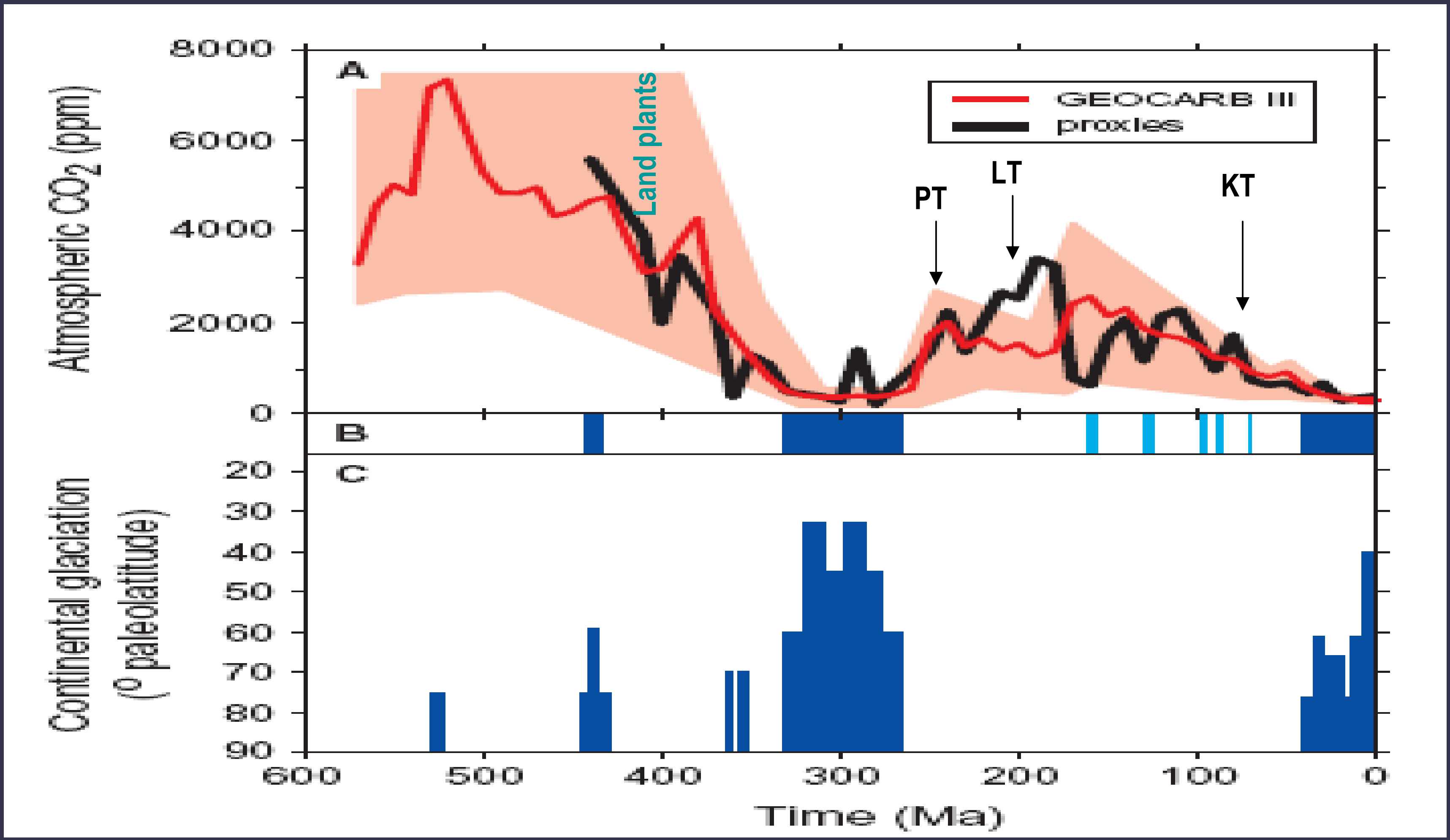
Long term climate trends


GREENHOUSE EARTH
C-P glaciation
CO2 SEQUESTRATION/ OXYGEN ENRICHMENT EVENTS
GREENHOUSE EARTH
Warm
Present
Cold
OCEAN GAP/SPREADING/ VOLCANISM/CO2 RELEASE
ONSET OF LAND PLANTS
DESCENT INTO GLACIAL/INTERGLACIAL
Dense vegetation/ CO2 sequestration Low atm CO2
Dense vegetation/ CO2 sequestration
Quaternary
Pliocene
Miocene
Oligocene
Eocene
Paleocene
Cretaceous
Jurassic
Triassic
Permian
Carboniferous
Devonian
Silurian
Ordovician
Cambrian
Sturtian/Merinoan Glaciation (low atm. CO2)
Superior glaciation
Oceans too warm To sequester CO2
1.8
65
251
570
1000
2000
3000
4000
4600
AGE (Ma) (variable scale)
O2
Low pH; high CH4 & H2S

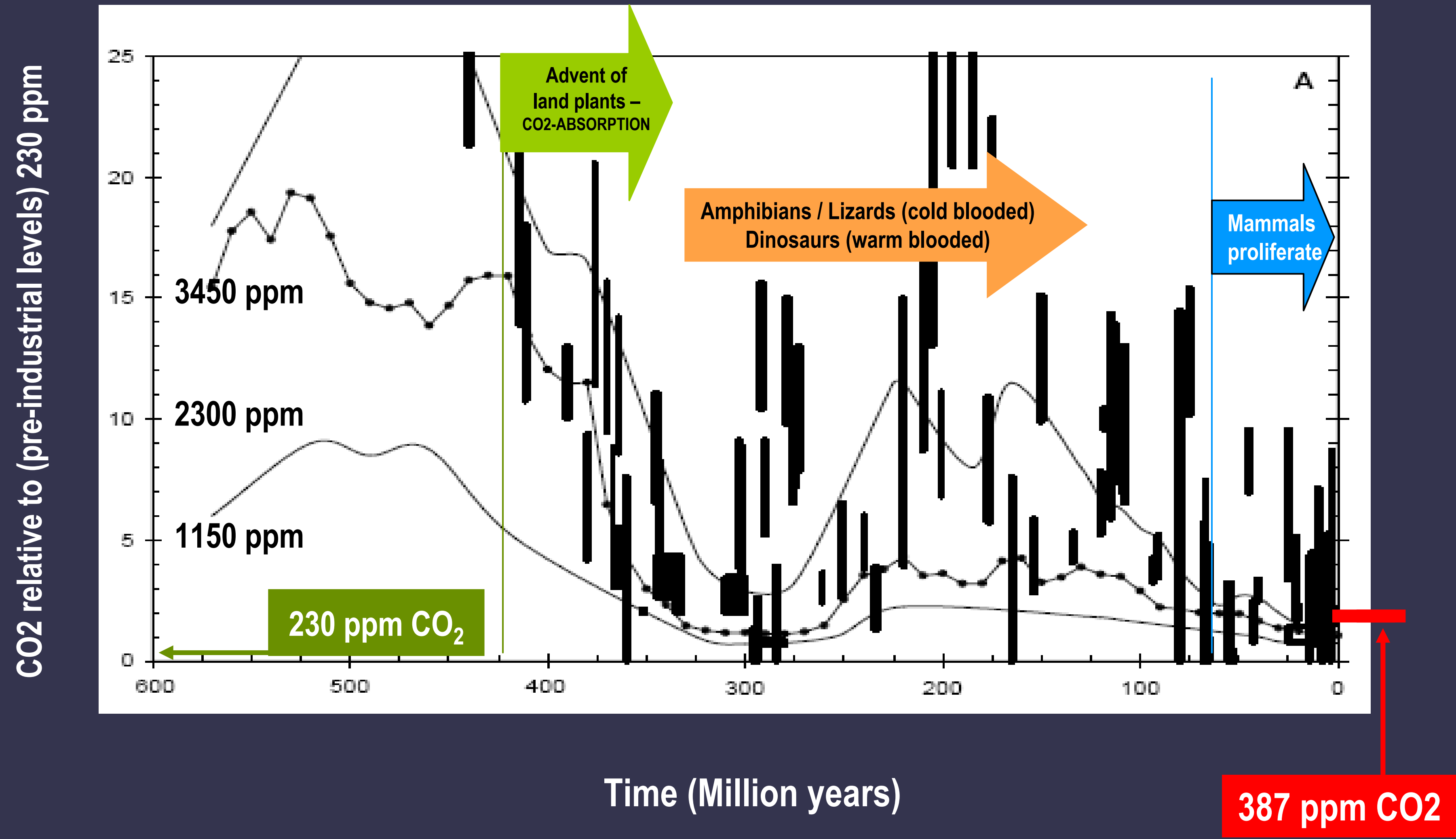
Phanerozoic Climate Change



CO2 FORCING OF ATMOSPHERIC TEMPERATURES

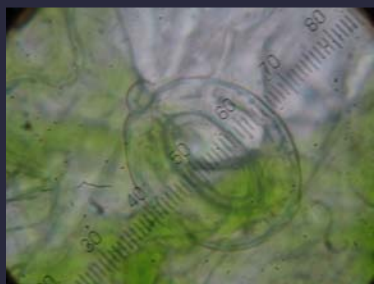


CO2 LEVELS THROUGH TIME RELATIVE TO PRE-INDUSTRIAL AGE LEVELS



Dana L. Royer, 2002

OXYGEN LEVELS AND BIOLOGICAL EVOLUTION



STOMATA
(CO_2 capture perforation)

END-CAMBRIAN EXTINCTIONS

APPEARANCE OF LAND PLANTS AND ANTHROPODS

LATE DEVONIAN EXTINCTIONS

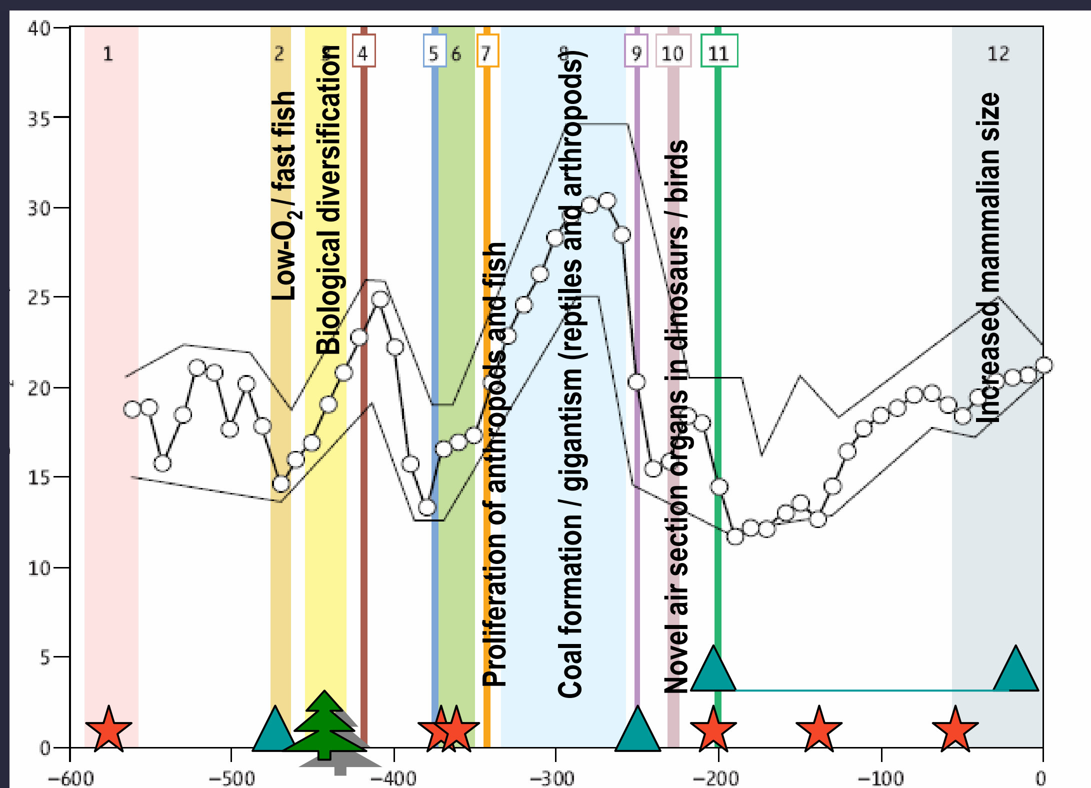
CARBONIFEROUS-PERMIAN GLACIATION (caused in part by plant absorption of CO2)

PERMIAN-TRIASSIC EXTINCTION

TRIASSIC-JURASSIC EXTINCTION

QUARTRNARY GLACIATION

% of O_2 in the atmosphere

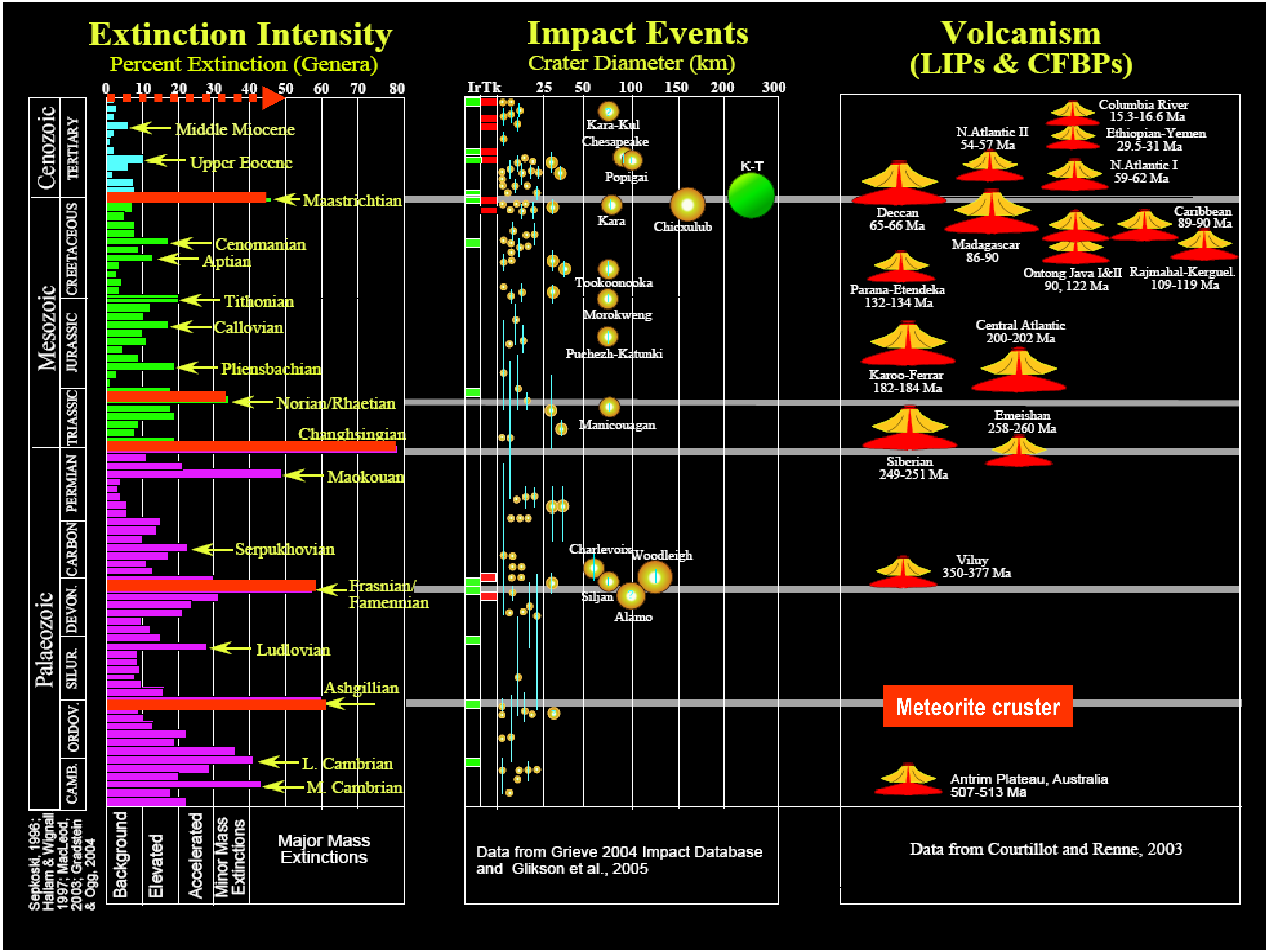


ASTEROID IMPACT

VOLCANISM

Time (million years)

Episodic mass extinctions



Extinction Intensity
Percent Extinction (Genera)
0 10 20 30 40 50 60 70 80
Cenozoic
TERTIARY
Mesozoic
CREETACEOUS
JURASSIC
TRIASSIC
Palaeozoic
PERMIAN
CARBON
DEVON.
SILUR.
ORDOV.
CAMB.
Middle Miocene
Upper Eocene
Maastrichtian
Cenomanian
Aptian
Tithonian
Callovian
Pliensbachian
Norian/Rhaetian
Changhsingian
Maokouan
Serpukhovian
Frasnian/
Famennian
Ludlovian
Ashgillian
L. Cambrian
M. Cambrian
Sepkoski, 1996; Hallam & Wignall 1997; MacLeod, 2003; Gradstein & Ogg, 2004
Background
Elevated
Accelerated
Minor Mass Extinctions
Major Mass Extinctions
Impact Events
Crater Diameter (km)
IrTk 25 50 100 150 200 300
Kara-Kul
Chesapeake
Popigai
K-T
Kara
Chicxulub
Tookoonooka
Morokweng
Puchezh-Katunki
Manicouagan
Charlevoix
Woodleigh
Siljan
Alamo
Data from Grieve 2004 Impact Database and Glikson et al., 2005
Volcanism
(LIPs & CFBPs)
Columbia River
15.3-16.6 Ma
Ethiopian-Yemen
29.5-31 Ma
N.Atlantic II
54-57 Ma
N.Atlantic I
59-62 Ma
Deccan
65-66 Ma
Madagascar
86-90
Caribbean
89-90 Ma
Ontong Java I&II
90, 122 Ma
Rajmahal-Kerguel.
109-119 Ma
Parana-Etendeka
132-134 Ma
Central Atlantic
200-202 Ma
Karoo-Ferrar
182-184 Ma
Emeishan
258-260 Ma
Siberian
249-251 Ma
Viluy
350-377 Ma
Meteorite cruster
Antrim Plateau, Australia
507-513 Ma
Data from Courtillot and Renne, 2003

CORRELATIONS BETWEEN IMPACTS, VOLCANISM AND MASS EXTINCTIONS

	Time	Impact/geological episodes	Extinctions/radiations
■	Paleocene-Eocene boundary (55 Ma);	Eruption of methane associated with volcanic effects on C-rich sediments).	Extinction of Plesiapidae, Champsosaurus Appearance of primates
★ ▲	Cretaceous-Tertiary boundary (65.5±0.3 Ma)	Chicxulub and Boltysh impacts, affecting C-rich and carbonate-rich sediments; Decan Plateau basalts):	Extinction 47% of Genera, including plankton, marine invertebrates (including reef builders), marine reptiles, dinosaurs.
			Flowering plants become dominant on land.
★ ▲	Jurassic-Cretaceous boundary (145.5±4 Ma)	Morokweng, Gosses Bluff, Mjolnir impacts; dyke systems; ocean spreading):	Extinction of 20% of Genera, including marine invertebrates, dinosaurs.
			Appearance of early birds.
	End-Pliensbachian (183±1.5 Ma)	peak Karoo volcanism):	Extinction of marine invertebrates.
★ ▲	End Triassic (~201 Ma) Late Triassic (Norian-Rhaetian (216.5 Ma)	opening of the Atlantic Ocean; Manicouagan [214±1 Ma], Saint Martin [220±32 Ma], Rochechouart [213±8 Ma])	Extinction of 33% of Genera, including marine invertebrates and reptiles.
			Earliest mammals evolve.
★	Permian-Triassic boundary (251.7±0.4 to 251.1±0.3 Ma)	Siberian Norlisk plateau basalts; Araguainha impact 252.7±3.8 Ma, affecting C and carbonate-rich sediments).	Extinction of 78% of Genera, including sea floor protozoans, marine invertebrates, reef builders, reptiles.
			Vertebrates invade land
★ ▲	End-Devonian (374-359 Ma)	Woodleigh [359±4 Ma], Siljan [361.1 Ma], Alamo [360 Ma] impacts).	Extinction of 30% of Genera.
★ ▲	Late Devonian (Frasnian-Fammenian (383 Ma)		Extinction 58% of Genera.
★	Late Ordovician (443.7±1.5 Ma).	Impact cluster (K–Ar gas retention or shock ages of about 450–500 Myr)	Extinction of 60% of Genera, including trilobites. Cause unknown (supernovae?)
			Earliest fish evolve
	End-Cambrian (488 Ma).		Extinction of 41% of Genera.
	End-lower Cambrian (513±2 Ma)	Kalkarinji volcanism, 507±4 Ma).	Extinction of 42% of Genera.
★	580 Ma	Acraman impact.	Extinction and radiation of acrytarchs species.

Crutzen P.J. and Stoermer, E.F., 2000. The "Anthropocene". *Global Change Newsletter* 41, 12-13
Glikson, A.Y., 2008. Milestones in the evolution of the atmosphere with reference to climate change. *Aust. J. Earth Science*, 55, 123-127.
Keller, G., 2005. Impacts, volcanism and mass extinction: random coincidence or cause and effect? *Australian Journal of Earth Sciences* 52, 725 – 757.
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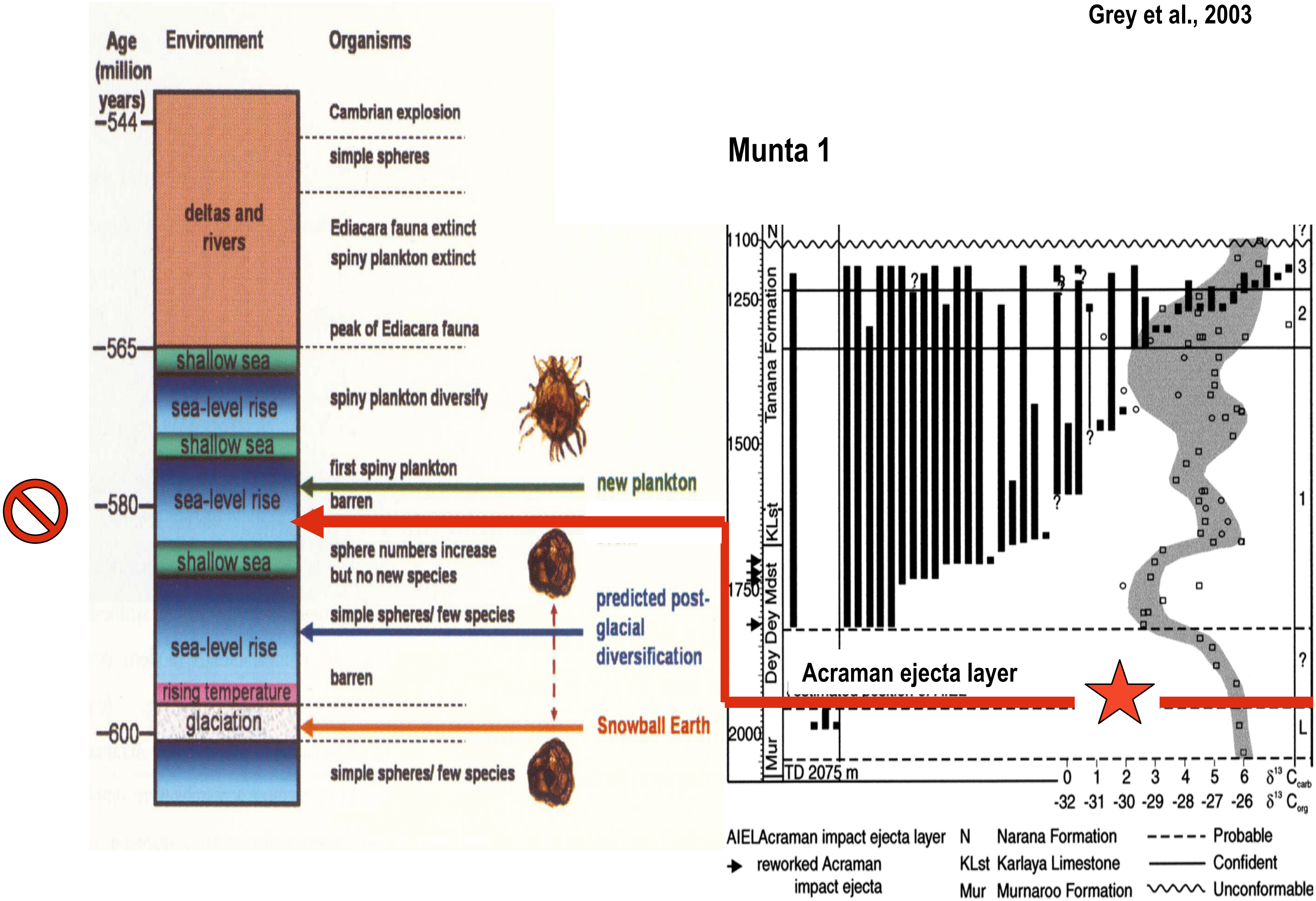
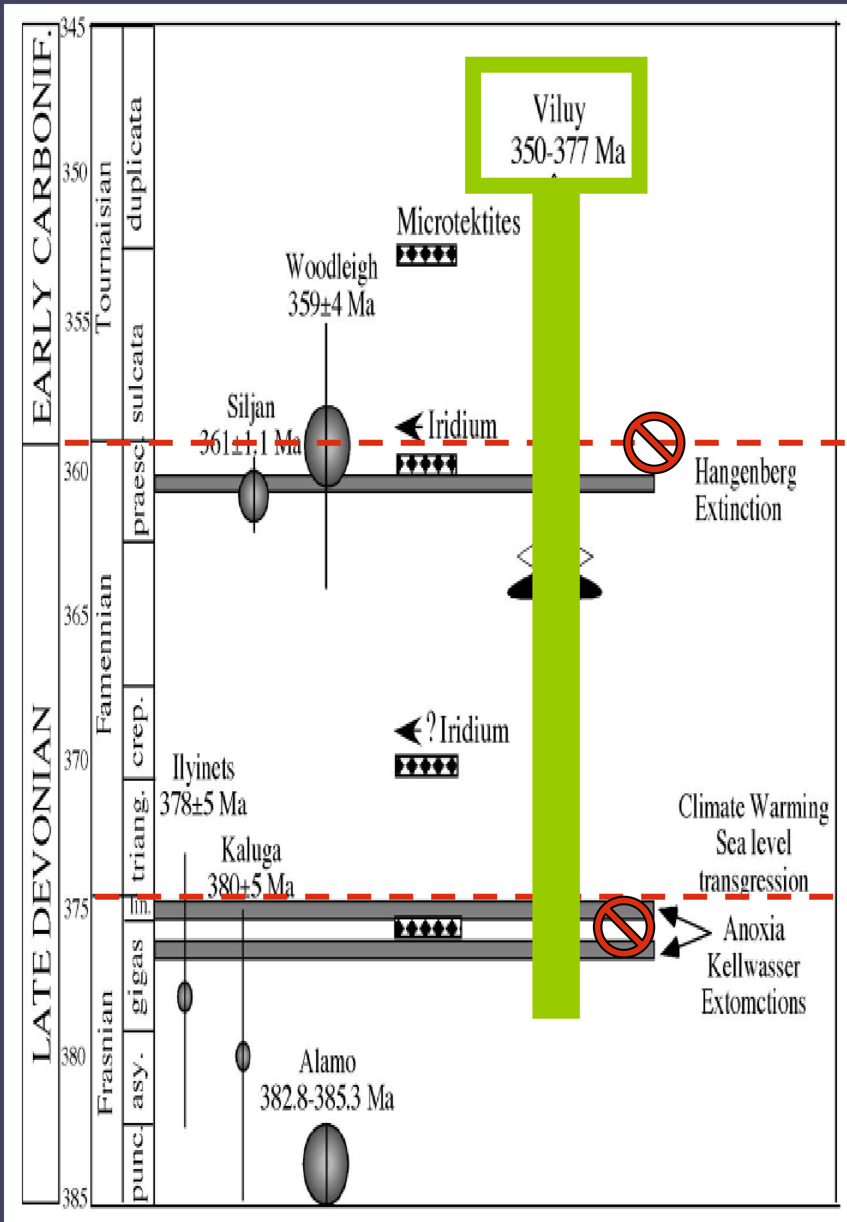
Ruddimann, W.F., Varvus, S.J., Kutzbach, J.E., 2003. Test of the overdue-glaciation hypothesis, *Quaternary Science Reviews* 24.
Schmitz, B. et al., 2008. Asteroid breakup linked to the great Ordovican biodiversification event. *Nature Geoscience* 1, 49-53
Sepkosky, J. J. JR 1996. Patterns of Phanerozoic extinction: a perspective from global data bases. In: Walliser O. H. ed. *Global Events and Event Stratigraphy*, 35 – 52, Springer, Berlin.
Stanley, S.M., 1977. Extinction. *Scientific American Library*, W.H. Freeman and Co., New York

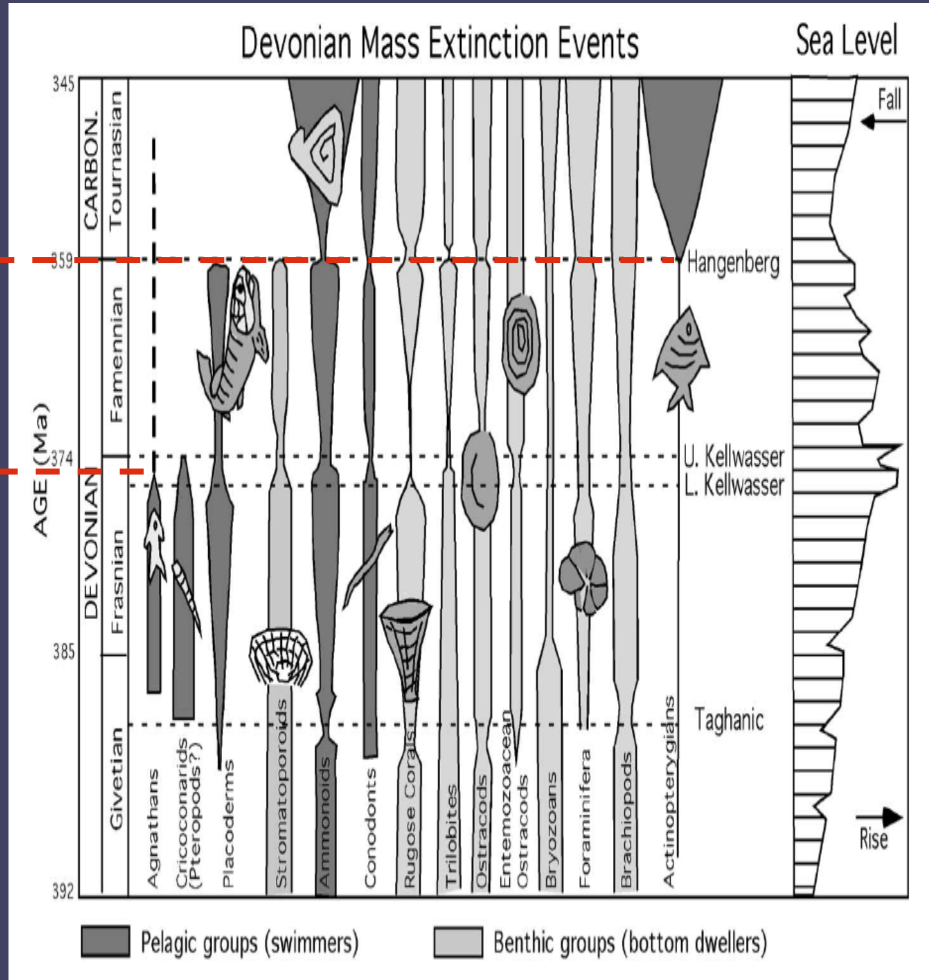
★ Asteroid impact
▲ Volcanism
■ Methane eruption

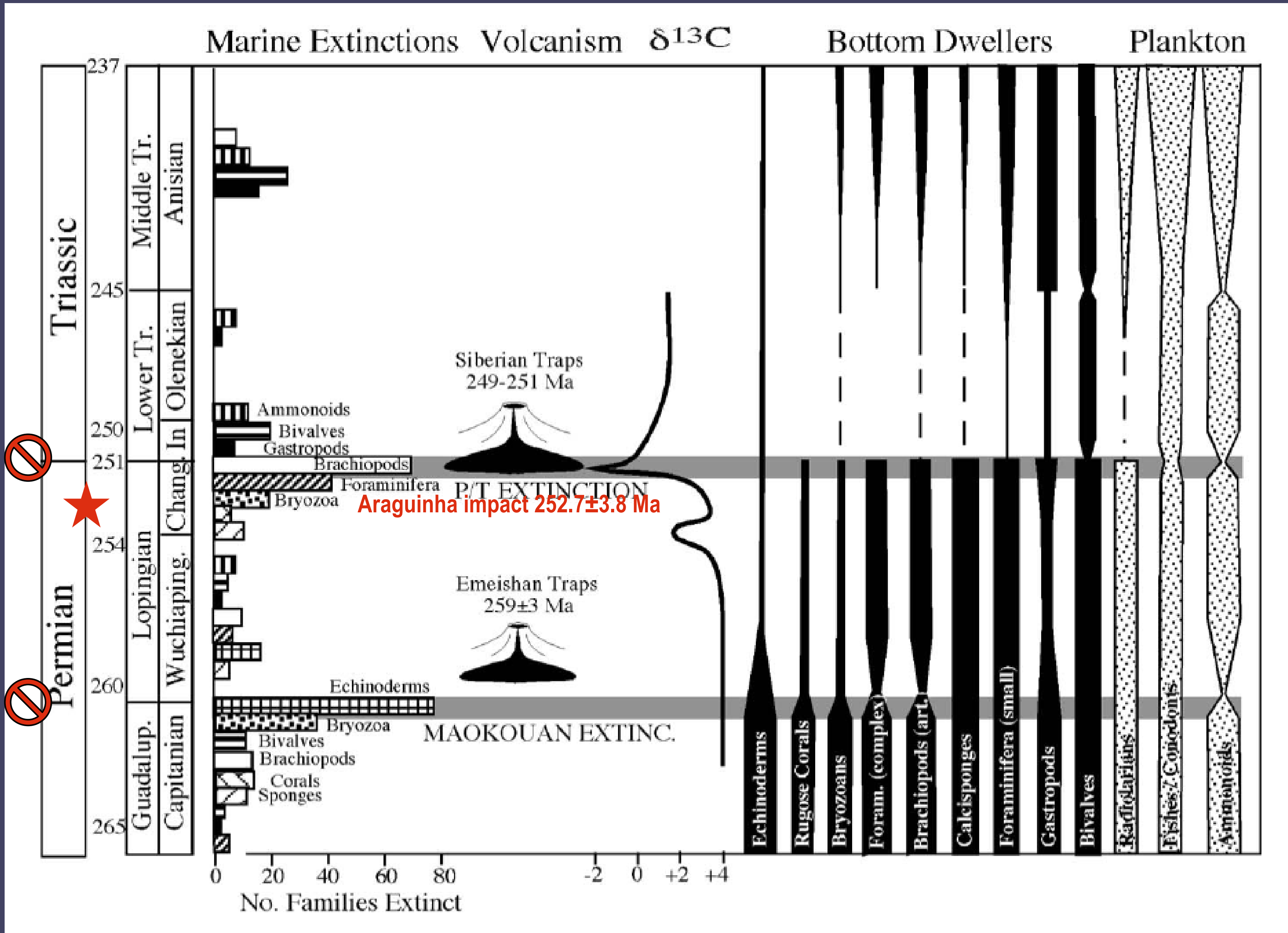
ACRAMAN IMPACT ACRYTARCHS EXTINCTION - RADIATION

Grey et al., 2003



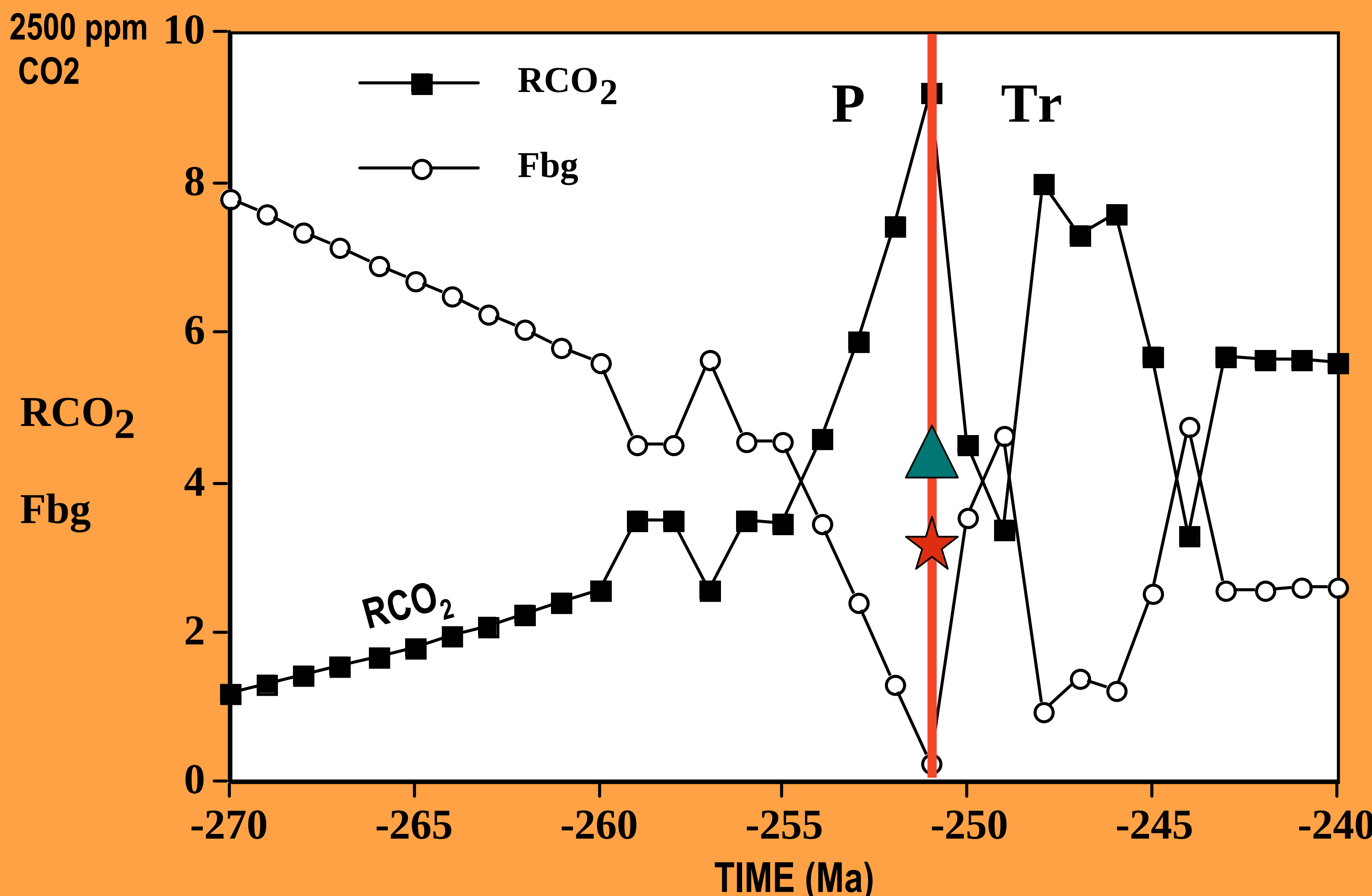

EARLY CARBONIF.
LATE DEVONIAN
Tournaisian
Famennian
Frasnian
duplicata
sulcata
praesc.
crep.
triang.
lin.
gigas
asy.
punc.
Viluy
350-377 Ma
Microtektites
Woodleigh
359±4 Ma
Siljan
361±1.1 Ma
Iridium
Hangenberg
Extinction
?Iridium
Ilyinets
378±5 Ma
Kaluga
380±5 Ma
Climate Warming
Sea level
transgression
Anoxia
Kellwasser
Extomctions
Alamo
382.8-385.3 Ma


Devonian Mass Extinction Events
Sea Level
AGE (Ma)
CARBON.
Tournaisian
DEVONIAN
Famennian
Frasnian
Givetian
Hangenberg
U. Kellwasser
L. Kellwasser
Taghanic
Fall
Rise
Agnathans
Cricoconarids (Pteropods?)
Placoderms
Stromatoporoids
Ammonoids
Conodonts
Rugose Corals
Trilobites
Ostracods
Entemozoacean Ostracods
Bryozoans
Foraminifera
Brachiopods
Actinopterygians
Pelagic groups (swimmers)
Benthic groups (bottom dwellers)

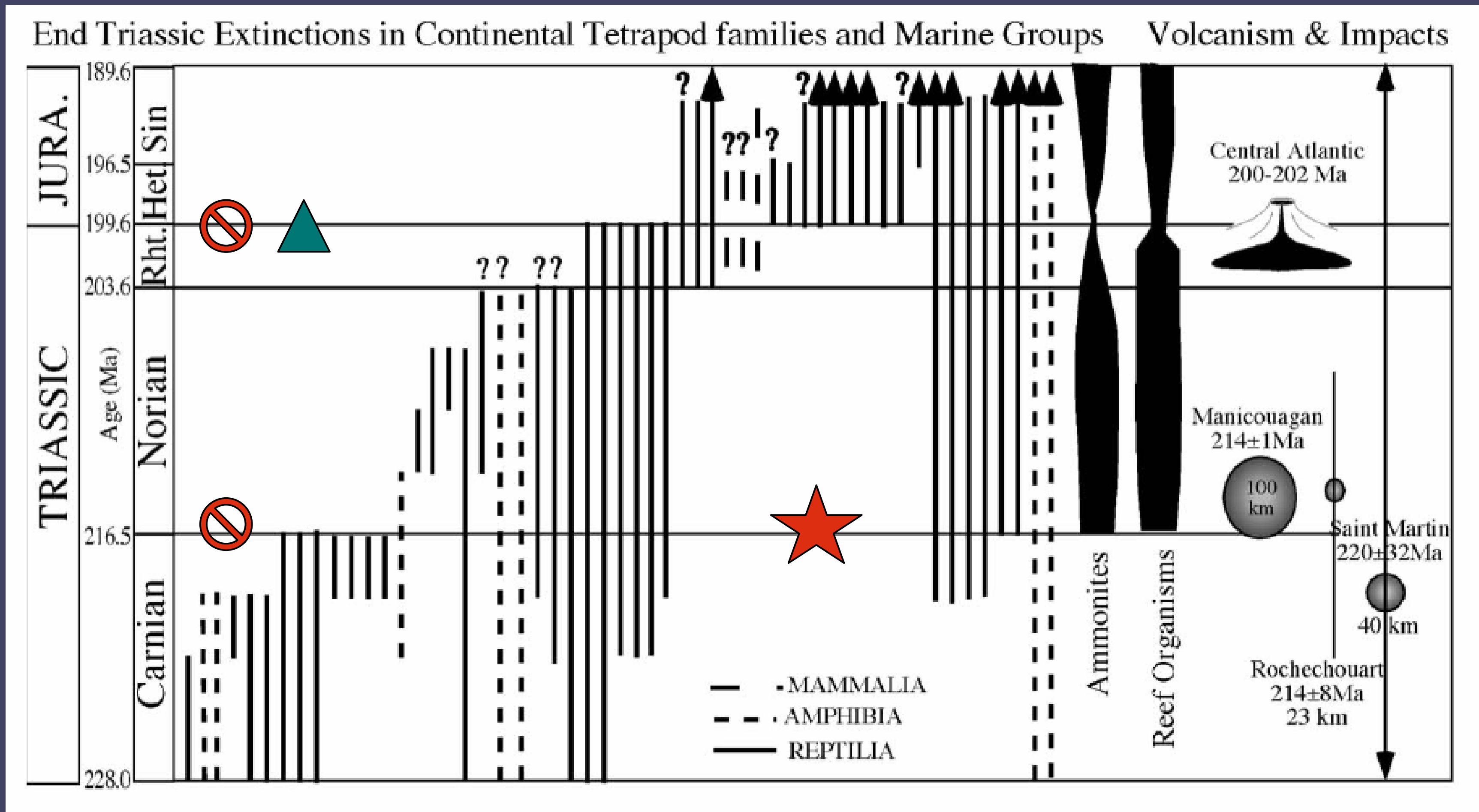


Marine Extinctions
Volcanism
δ13C
Bottom Dwellers
Plankton
Triassic
Permian
Middle Tr.
Lower Tr.
Lopingian
Guadalup.
Anisian
Olenekian
In
Chang.
Wuchiaping.
Capitanian
237
245
250
251
254
260
265
Ammonoids
Bivalves
Gastropods
Brachiopods
Foraminifera
Bryozoa
P/T EXTINCTION
Araguinha impact 252.7±3.8 Ma
Siberian Traps
249-251 Ma
Emeishan Traps
259±3 Ma
Echinoderms
Bryozoa
Bivalves
Brachiopods
Corals
Sponges
MAOKOUAN EXTINC.
0
20
40
60
80
No. Families Extinct
-2
0
+2
+4
Echinoderms
Rugose Corals
Bryozoans
Foram. (complex)
Brachiopods (art.)
Calcisponges
Foraminifera (small)
Gastropods
Bivalves
Radiolarians
Fishes, Conodonts
Ammonoids

CO2 RISE AND REDUCED BURIAL OF ORGANIC MATTER AT THE PERMIAN-TRIASSIC BOUNDARY

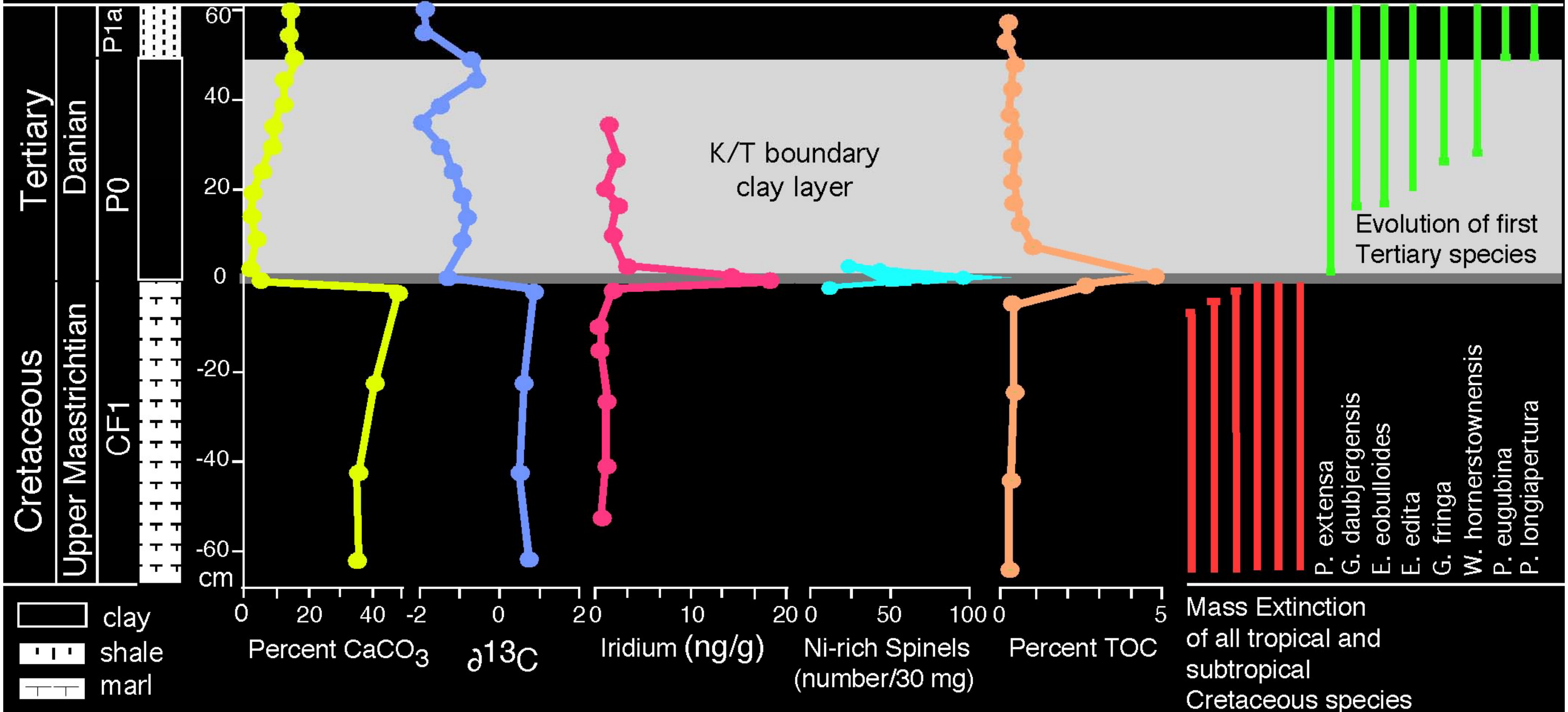


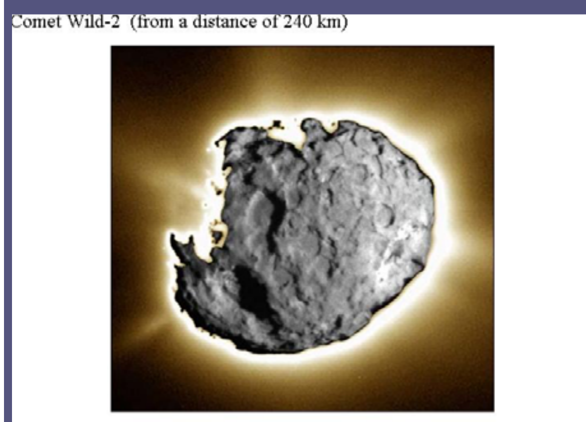
RCO2 - ratio of CO2 mass in the atmosphere to that at present (Pleistocene mean 250 ppm).
Fbg - burial rate of organic matter in 10^18 moles/ million years.



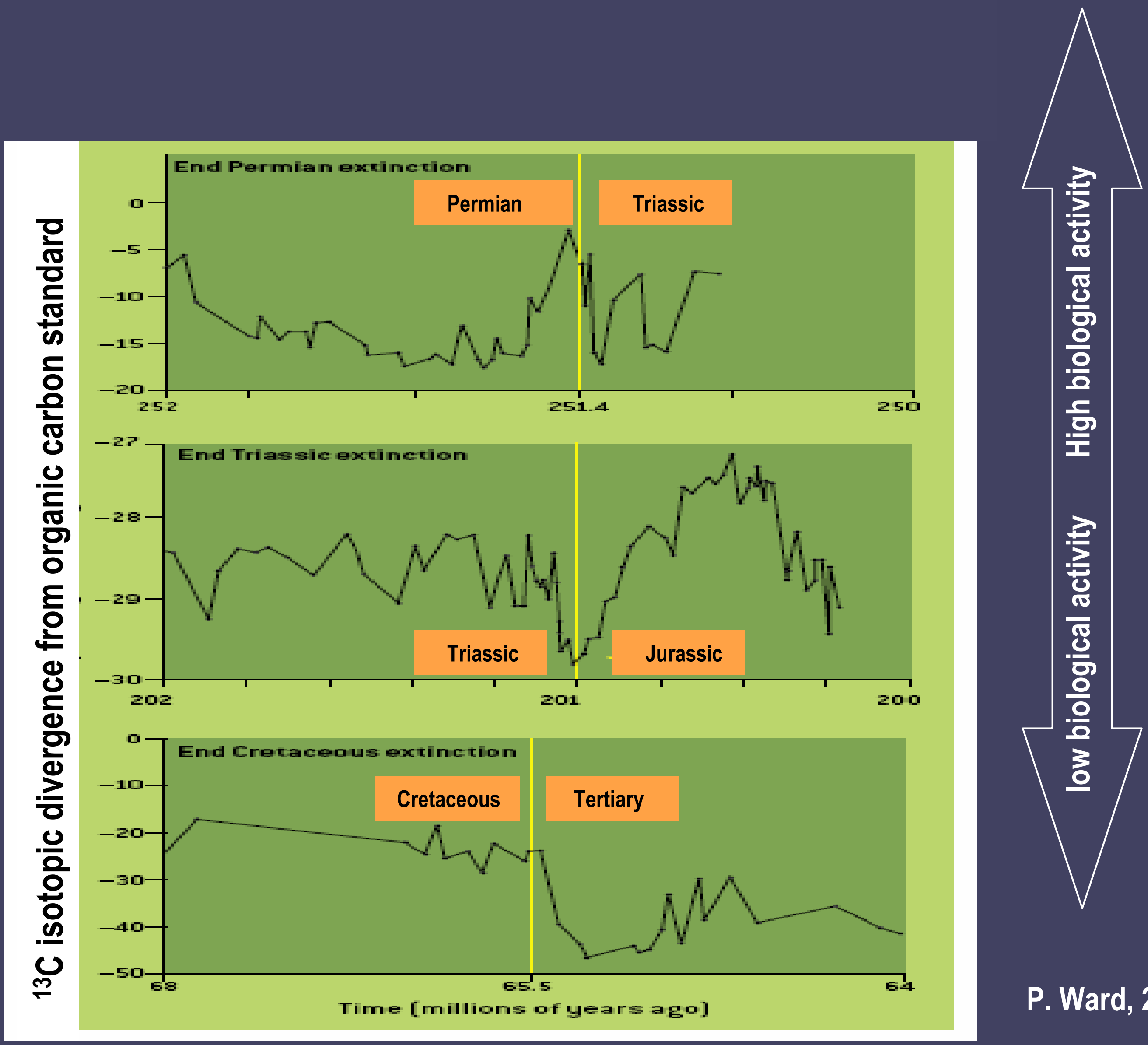
End Triassic Extinctions in Continental Tetrapod families and Marine Groups
Volcanism & Impacts
JURA.
TRIASSIC
Age (Ma)
189.6
196.5
199.6
203.6
216.5
228.0
Sin
Het
Rht.
Norian
Carnian
Central Atlantic
200-202 Ma
Manicouagan
214±1Ma
100 km
Saint Martin
220±32Ma
40 km
Rochechouart
214±8Ma
23 km
Ammonites
Reef Organisms
MAMMALIA
AMPHIBIA
REPTILIA

EL KEF STRATOTYPE: K/T Boundary Criteria





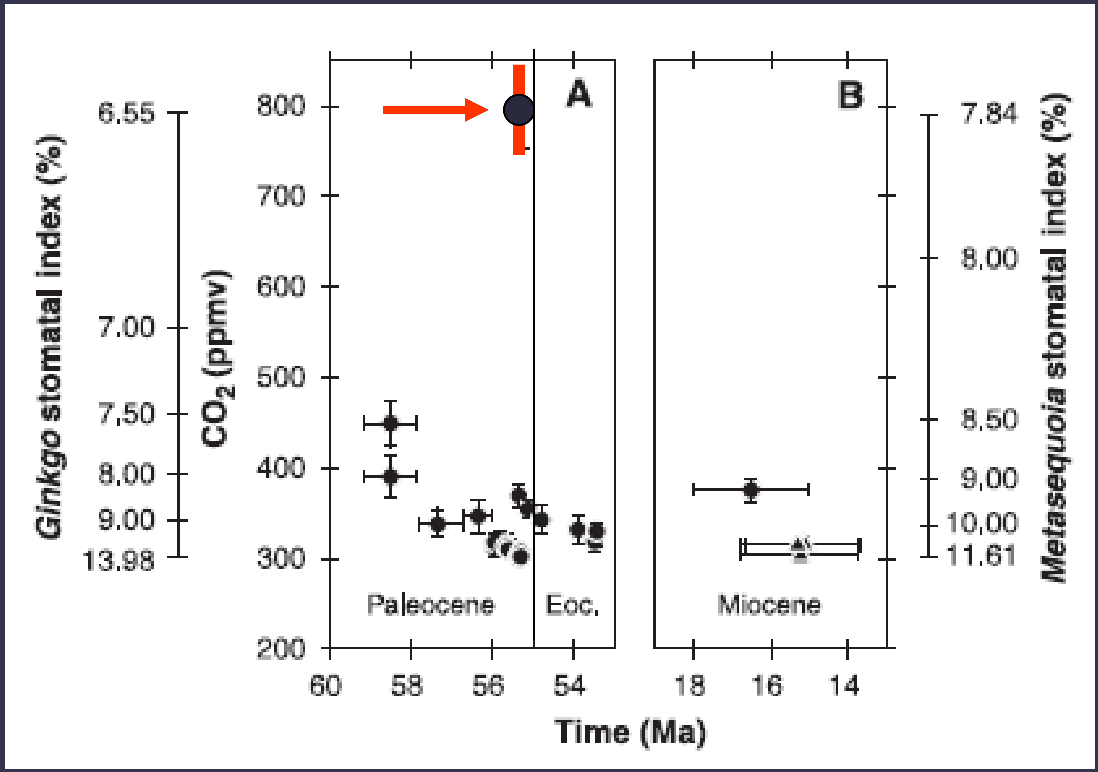
Carbon isotopic evidence of mass extinctions across geological boundaries



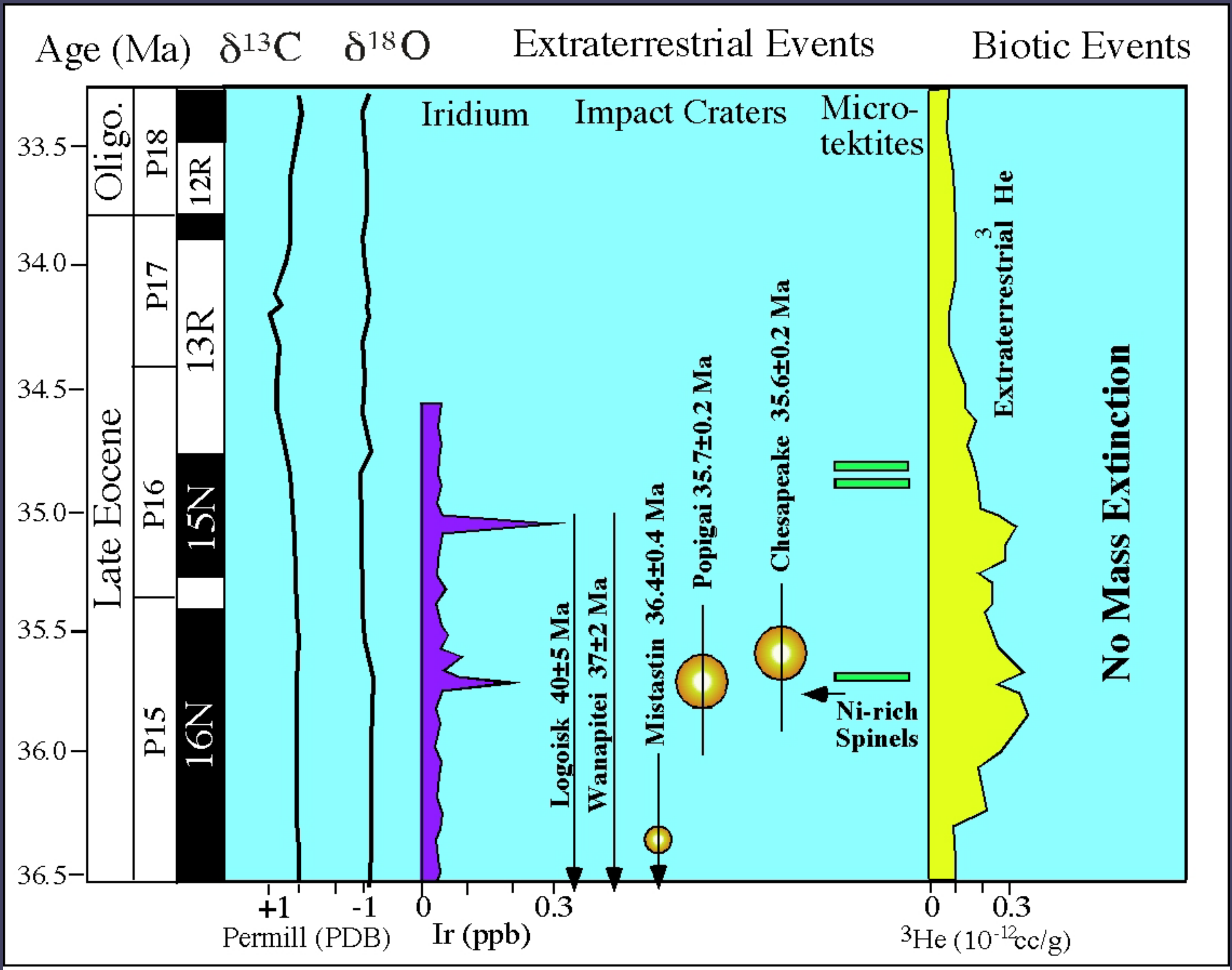
P. Ward, 2007

METHANE ERUPTION:

Paleocene-Eocene thermal maximum (PETM) 55 Ma

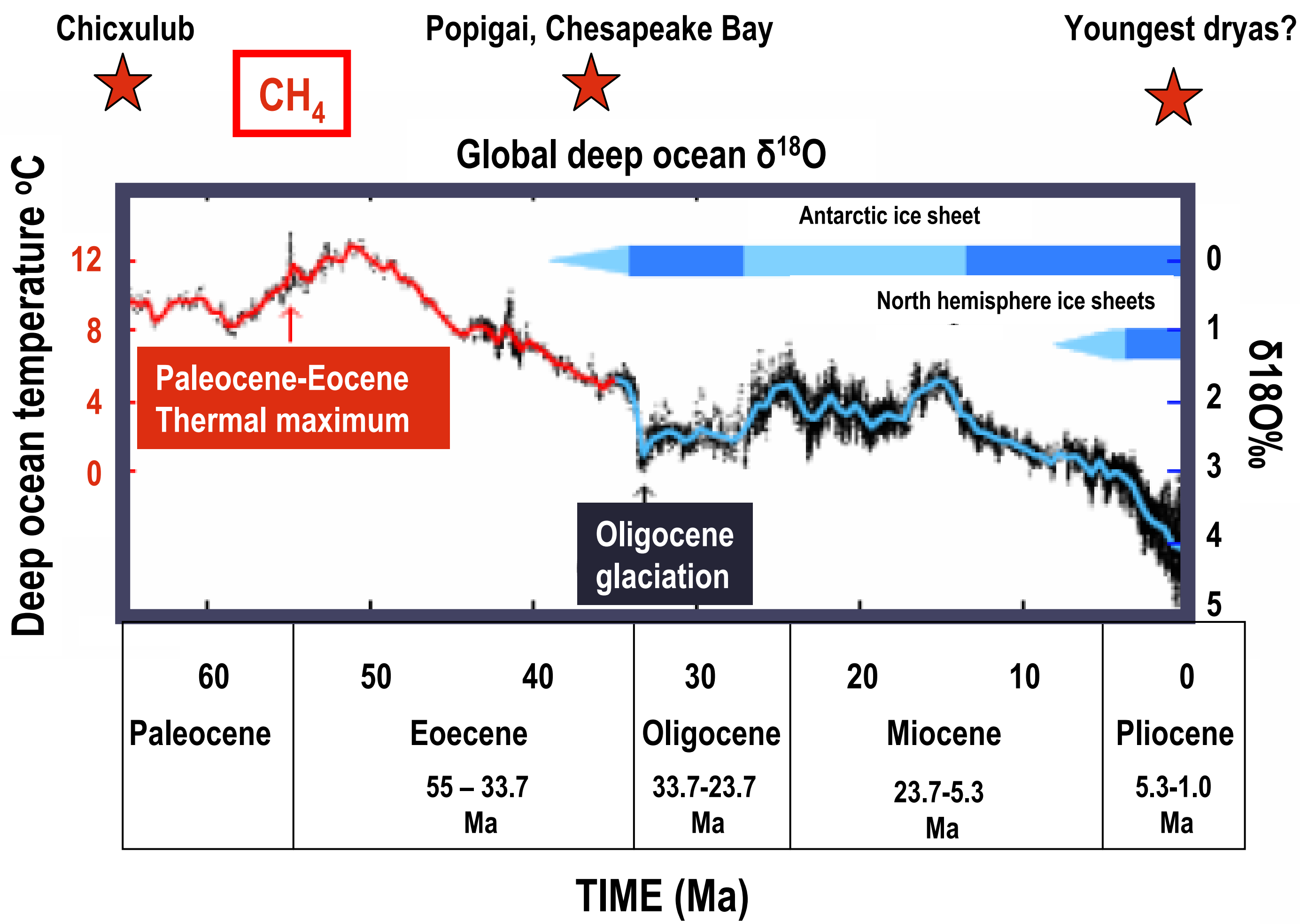


Royer, D.L., Wing, S.L., Beerling, D.J. et al. (2001) Palaeobotanical evidence for near present-day levels of atmospheric CO2 during part of the Tertiary. ***Science,*** **292, 2310-2313**



Keller, Fig. 5a

The descent into Quaternary ice ages



(Hansen et al., 2008)

Pleistocene
1000 – 10 kyr
Holocene
10 kyr – 1750AD
Anthropocene – 1750AD - ?

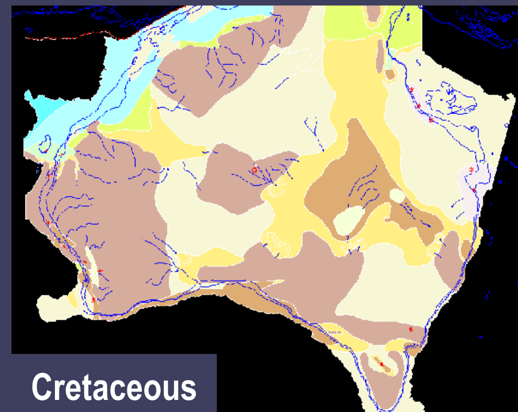
Global deep ocean δ18O‰ values and temperatures with time
Age resolution +/- 0.5 m.y.

HIGH SEA LEVELS

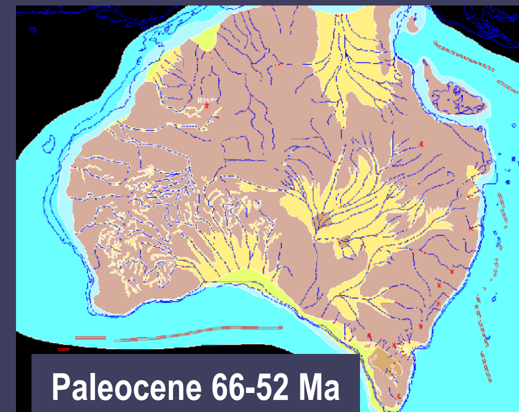
LOW SEA LEVELS

AUSTRALIA PALAEO-MAPS

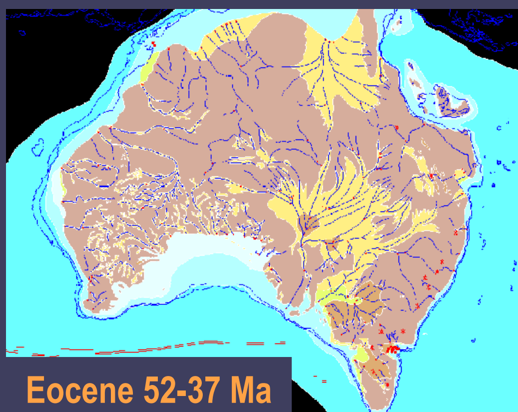
Geoscience Australia Atlas



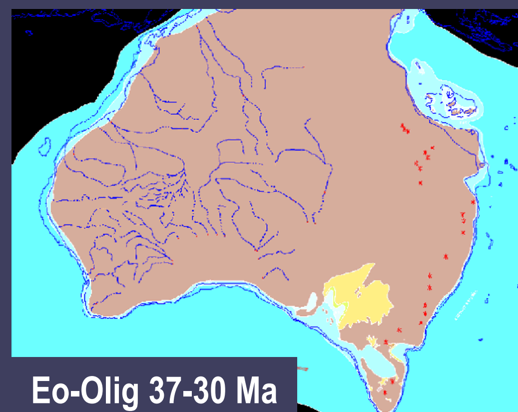
Cretaceous



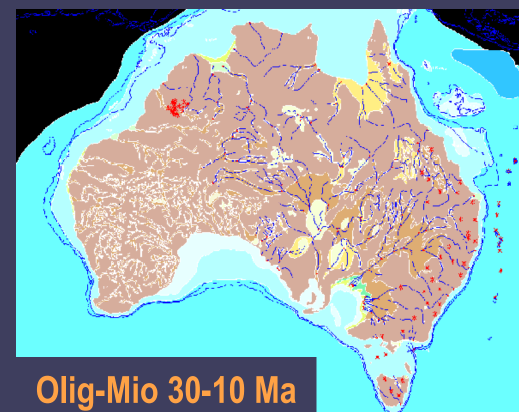
Paleocene 66-52 Ma



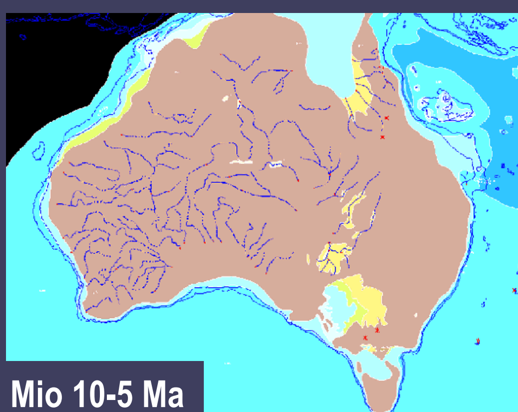
Eocene 52-37 Ma



Eo-Olig 37-30 Ma



Olig-Mio 30-10 Ma

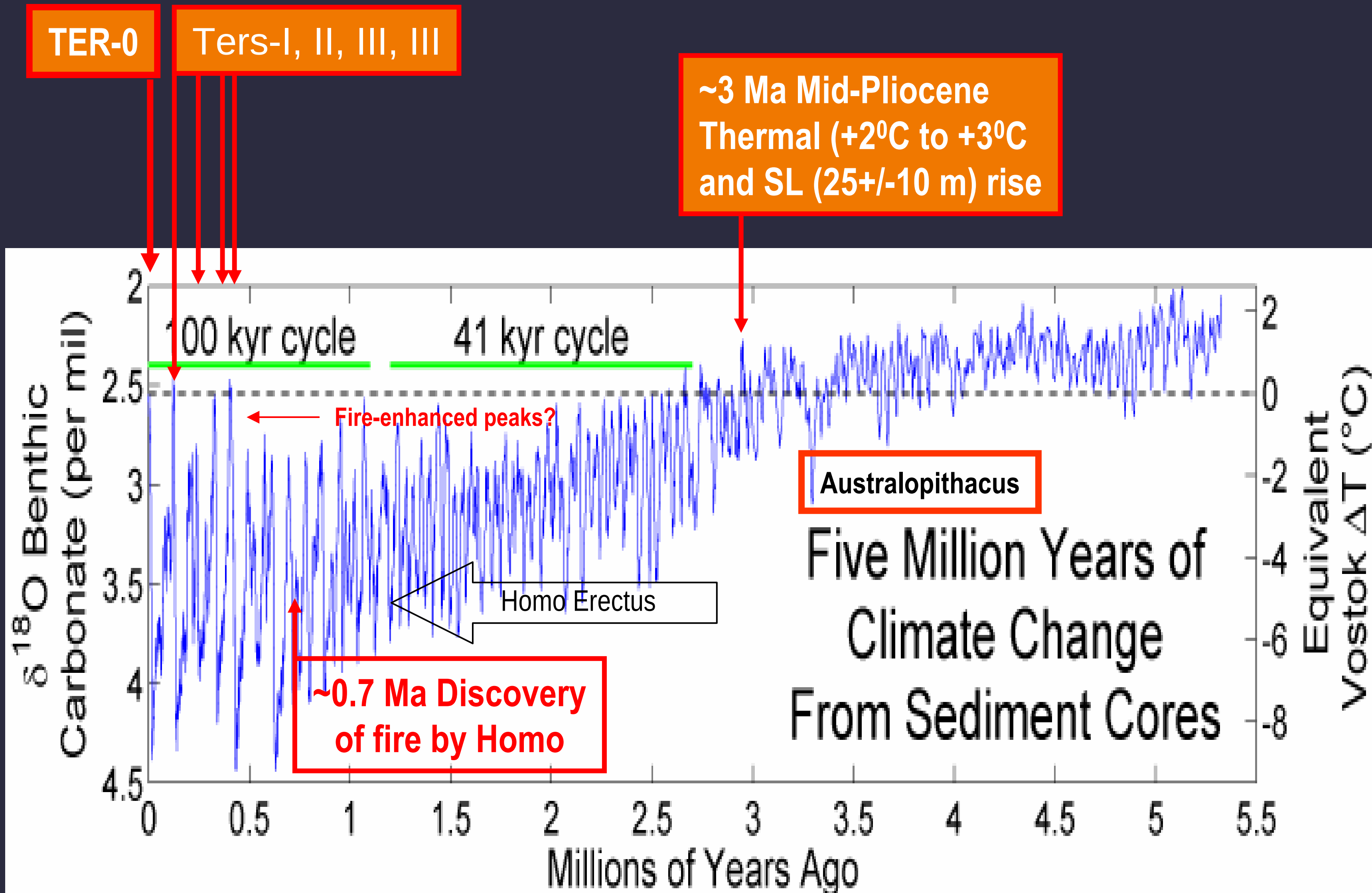


Mio 10-5 Ma

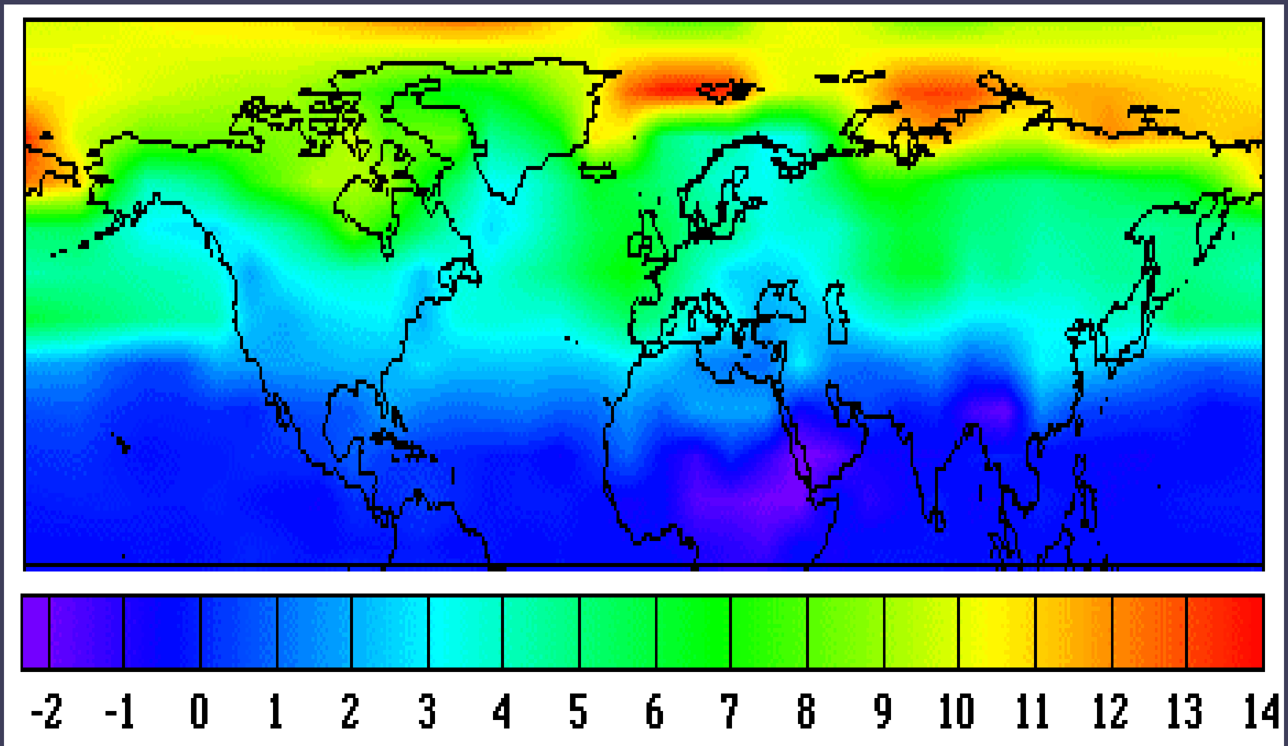
Pliocene 5-2 Ma

2 Ma – 10kyr

QUATERNARY CRISES

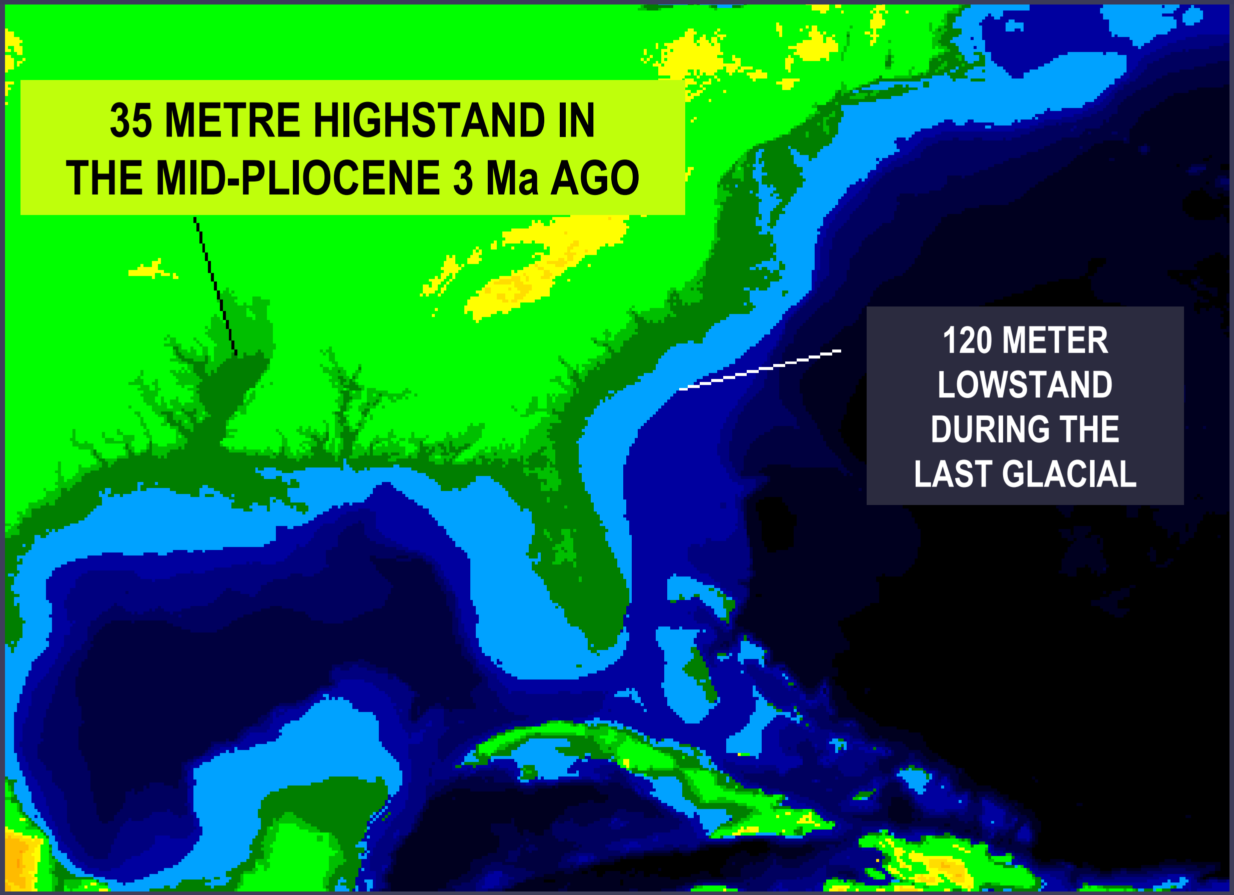


MID-PLIOCOENE ~3 Ma TEMPERATURE ANOMALIES
(R. Chandler, 1997 NASA Goddard Institute of Space Science)



ΔºC

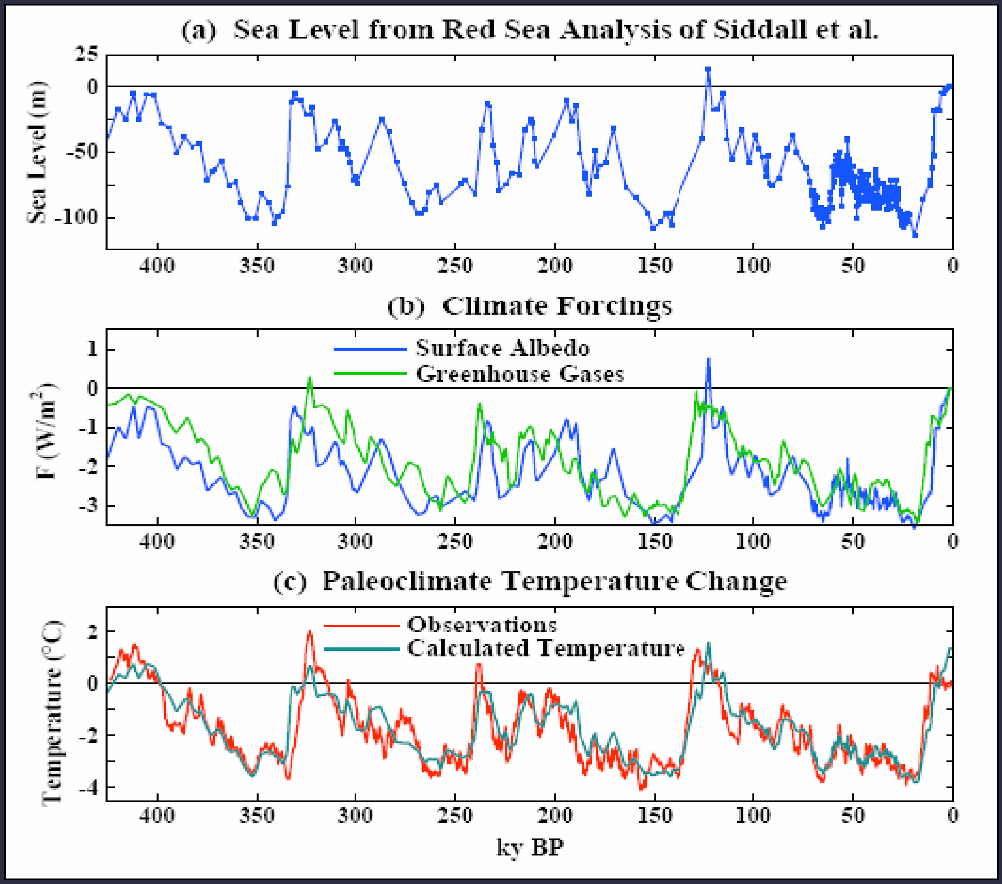
THE MID-PLIOCENE ANALOGY OF CURRENT CLIMATE CHANGE



Images based on Global Gridded Pliocene and Late Quaternary Sea Level,
U.S. Geological Survey Open-File Report 96-000,
Peter N. Schweitzer and Robert S. Thompson.
http://chemistry.beloit.edu/Warming/sealevel/index.html

INTERGLACIAL ONSETS

SOLAR-TRIGGERED GREENHOUSE + ALBEDO-FLIP EVENTS



Orbital forcing (June 65°N) ~ 40-100 W/m^2

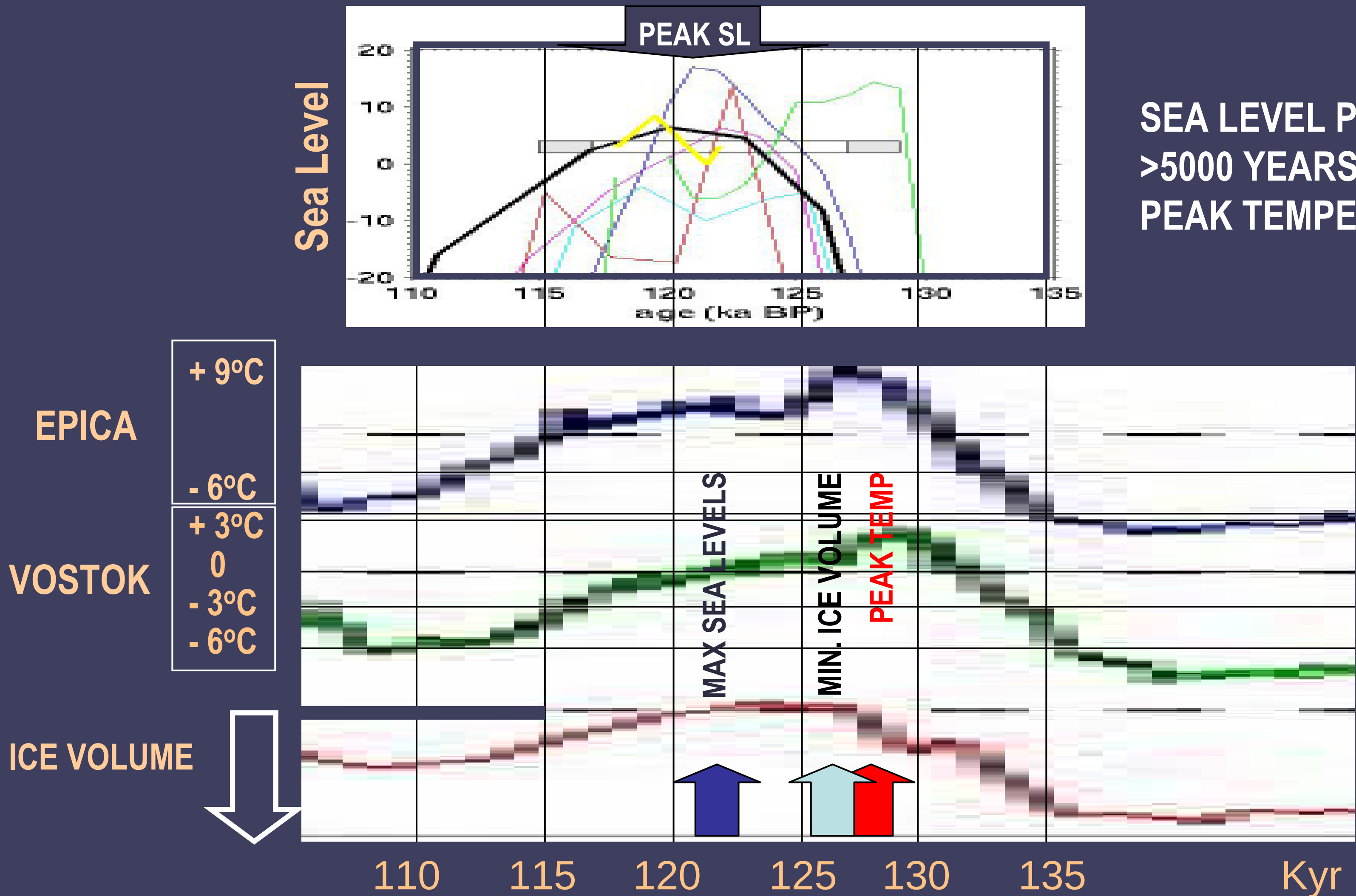
Albedo flip (ice/snow/vegetation) ~3.0-4.0 W/m^2

Greenhouse gas CO_2, CH_4, NOx forcing ~3.0 W/m^2

1 W/m^2 = 0.75 °C

"The salient feature of terrestrial climate change is its asymmetry. Global Warming events are usually rapid, followed by slower descent into colder climate. Given the slow pace of the weak orbital forcings and the magnitude of glacial-to interglacial climate change, the cause of rapid warming at glacial "terminations" must lie in a climate feedback"
(Hansen et al., 2007. Roy. Soc. London)

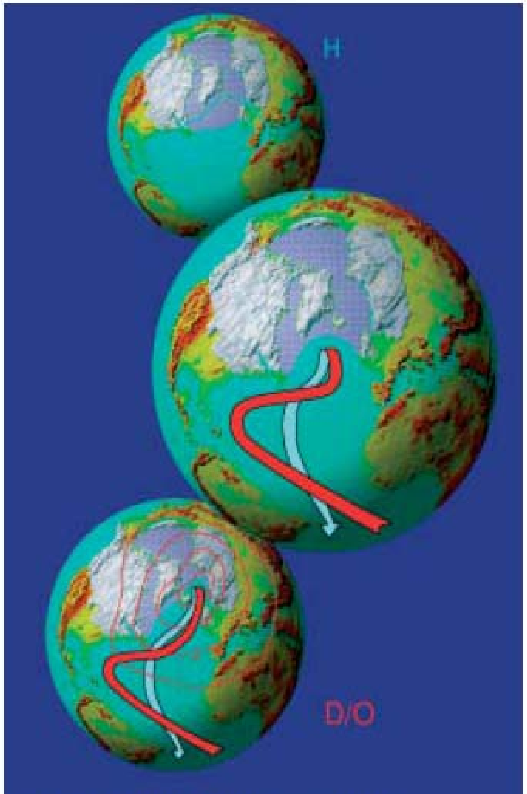
THE TERMINATION-II ANALOGY



SEA LEVEL PEAK LAG >5000 YEARS FROM PEAK TEMPERATURE

Estimates of sea levels during Termination-II 135-110 kyr (Siddall et al., 2006) and termperatures from the Vostok ice core (Petit et al., 1999)

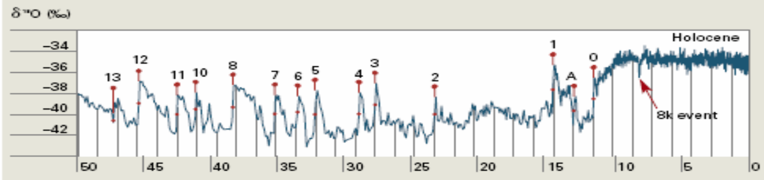
Dansgaard-Oeschenger warming events



Source: Potsdam Institute for Climate Impact Research

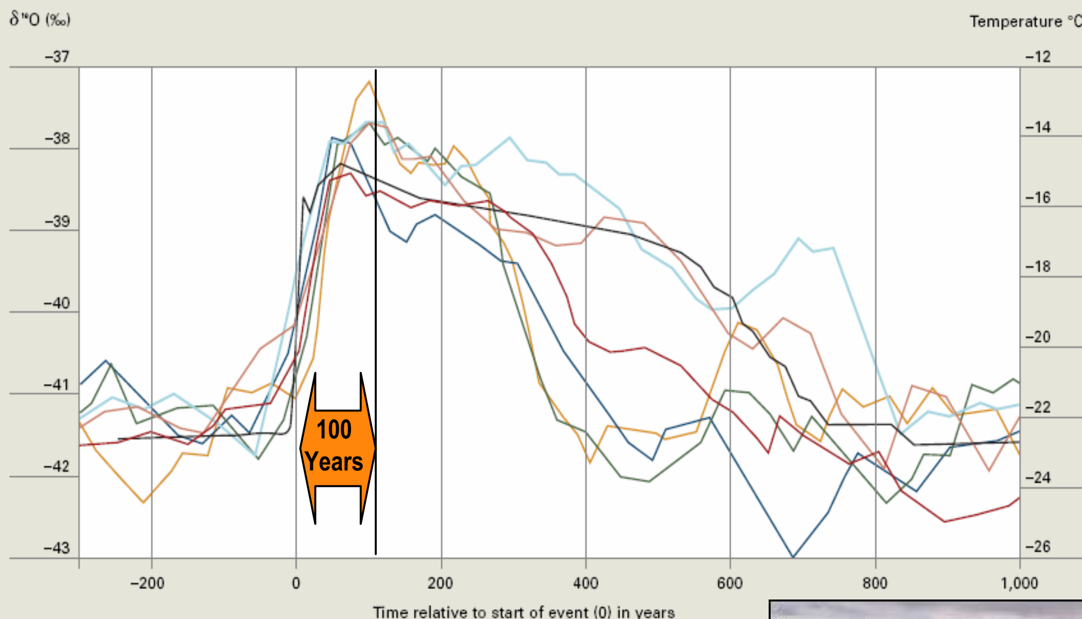
Fig. 2: Schematic illustration of three possible circulation modes in the Atlantic during the last ice age. The middle mode is the stable, cold mode prevailing in the ice age, with warm Atlantic water only flowing as far as the mid-latitudes. The situation during a warm Dansgaard-Oeschger event (D/O) with warm Atlantic water flowing right up to the Nordic Seas is shown below. The red contour lines represent the temperature rise in degrees centigrade during such an event, as calculated in our model. The globe at the top shows the situation following a total cessation of circulation in the Atlantic, as occurred after Heinrich (H) events.

Fig. 1 The climate history of the last great ice age – reconstructed from Greenland ice cores



Source: Rahmstorf, 2003

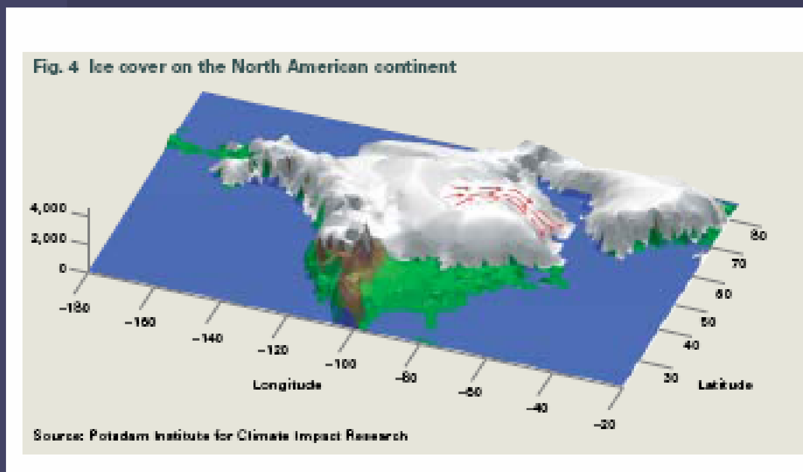
The figure shows a reconstruction of the temperature of the last 50,000 years based on measurements of oxygen isotope 18 in the ice. The stable interglacial period of the last 10,000 years is the Holocene; the unstable cold period preceding it is the second half of the last great ice age. Dansgaard-Oeschger events (refer to the text for an explanation) are marked in red and numbered. The vertical lines are spaced at intervals of 1,470 years; the majority of DO events are located near such lines.

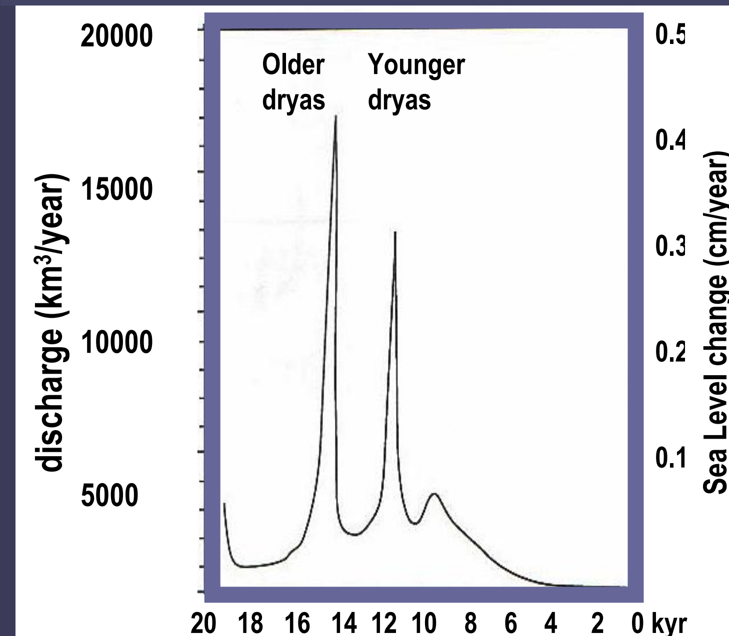


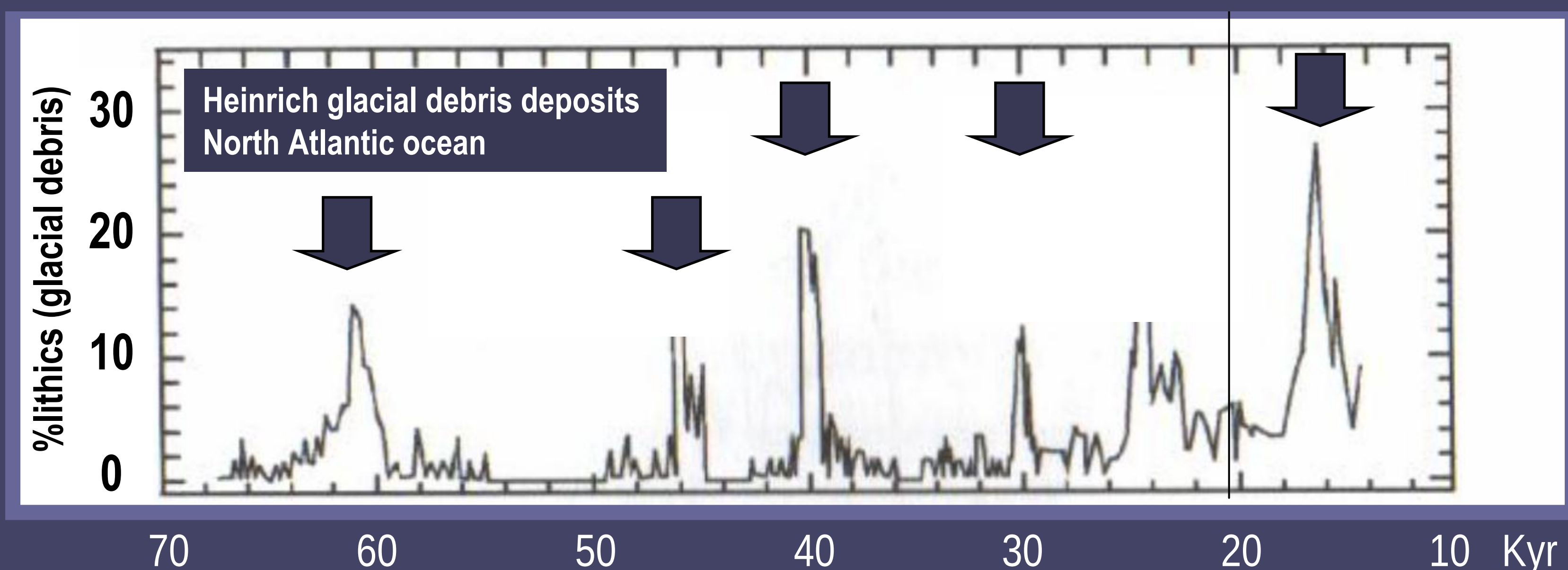
Source: Ganopolski and Rahmstorf, 2001

This graph shows the characteristic temperature evolution of a number of Dansgaard-Oeschger events derived from Greenland ice core data (coloured lines) and a model simulation (black line). An abrupt rise in temperature can clearly be seen at the beginning of each event. It is followed by a plateau phase with a warm temperature and a slight downward trend (in the model, due to the gradual weakening of the warm ocean current). In the third phase, the temperature drops relatively quickly back to the cold original level. In the model, this occurs when the current abruptly ceases to flow into the Nordic Seas.

North Atlantic Heinrich events, ice melt and sea level rises (Salzman, 2002)

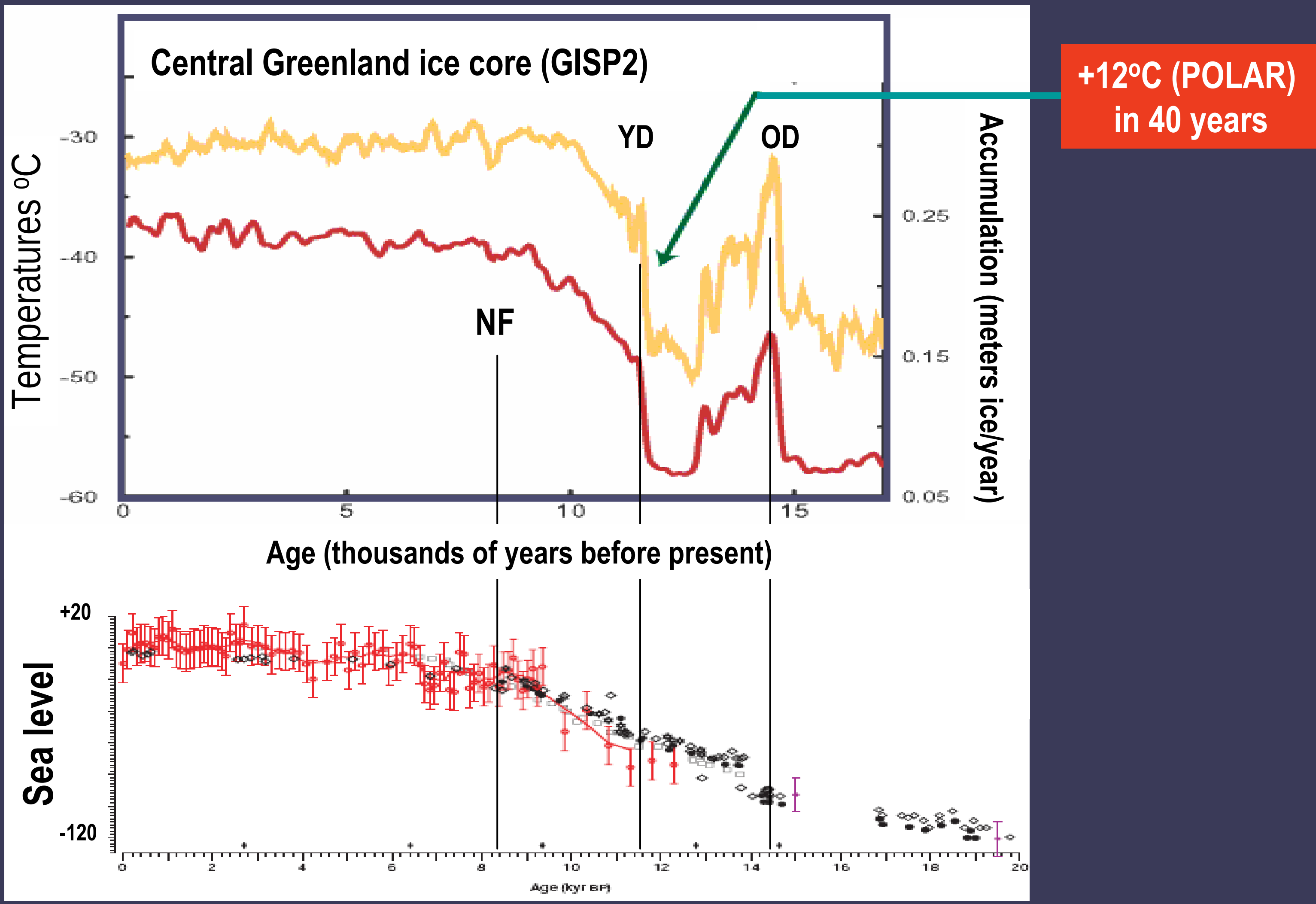




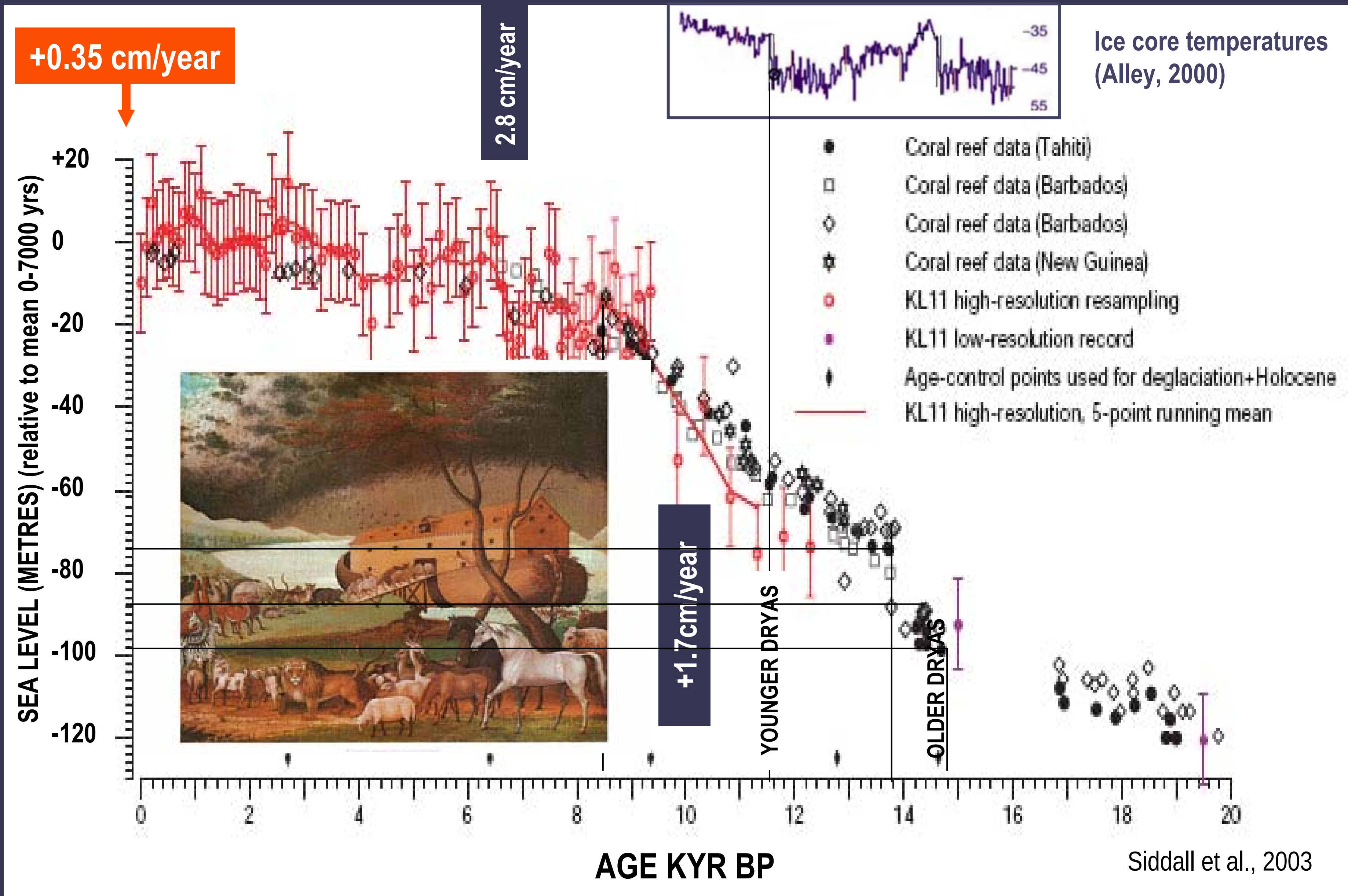


ABRUPT CLIMATE CHANGE

For the best-characterized warming, the end of the Younger Dryas cold interval 11,500 years ago, the transition in many ice-core variables was achieved in three steps, each spanning 5 years and in total covering 40 years. However, most of the change occurred in the middle of these steps. The warming as recorded in gas isotopes occurred in decades or less (Alley, 2000, PNAS, 97, 1331-1334).

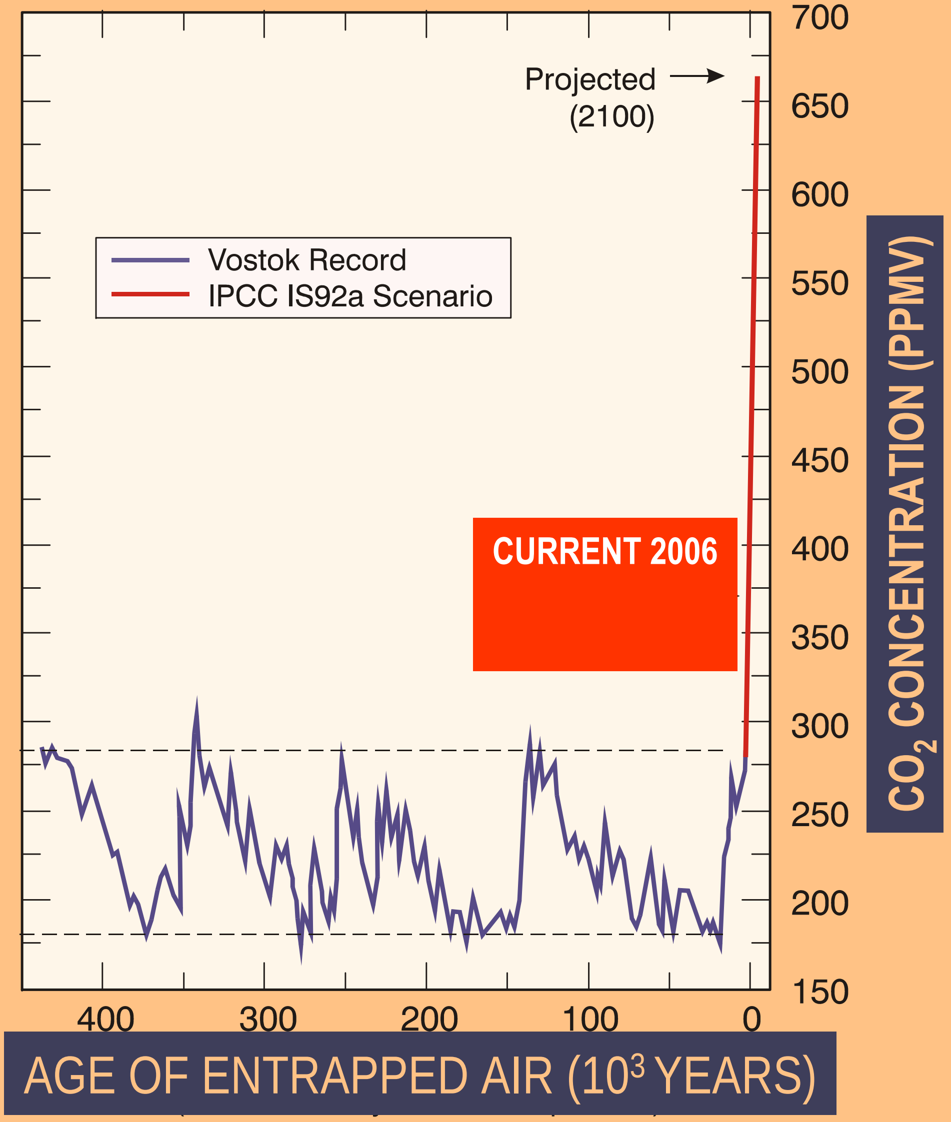


END-GLACIAL (termination-I) SEA LEVEL RISE



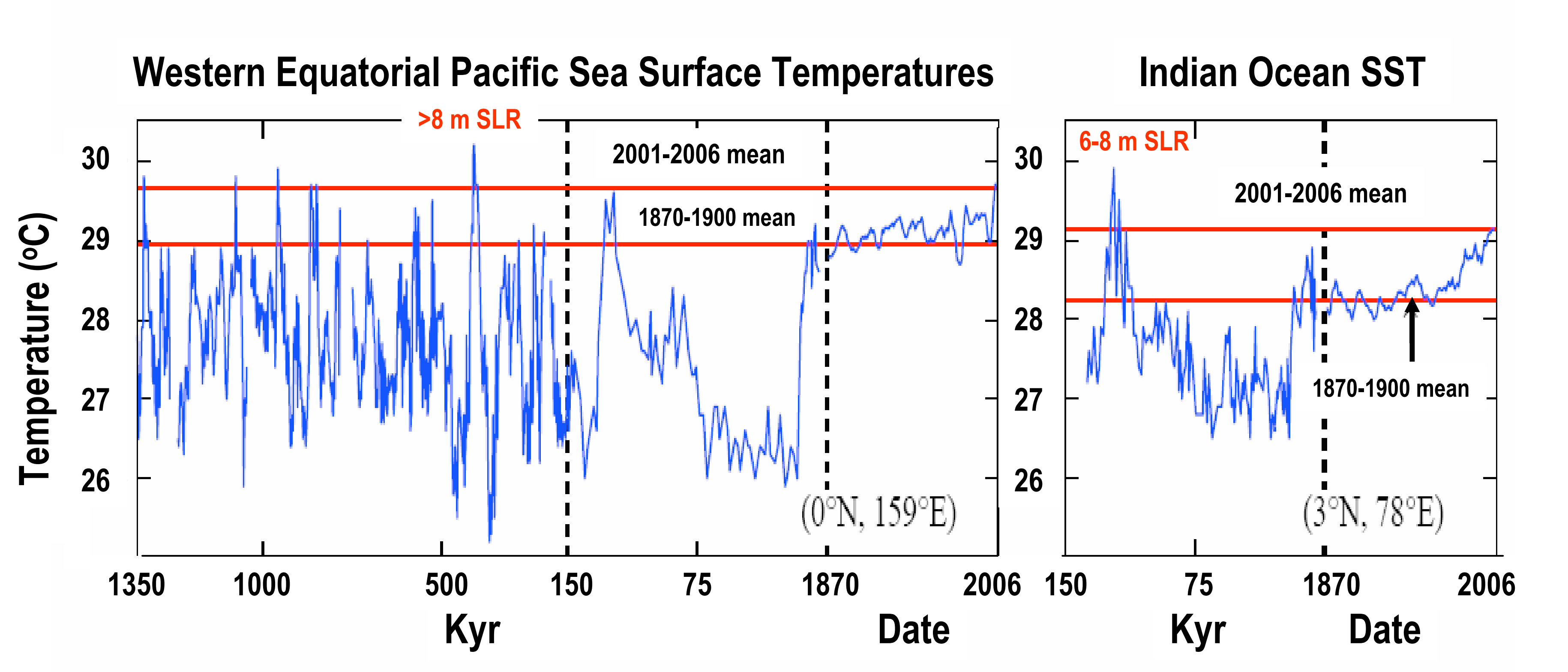
ANTHROPOGENIC FORCING
Atmospheric CO_2 levels last 450,000 years

- Last 450,000 years: Vostok ice core record (blue)
- Last 100 years: Contemporary record (red)
- Next 100 years: IS92A scenario (red)

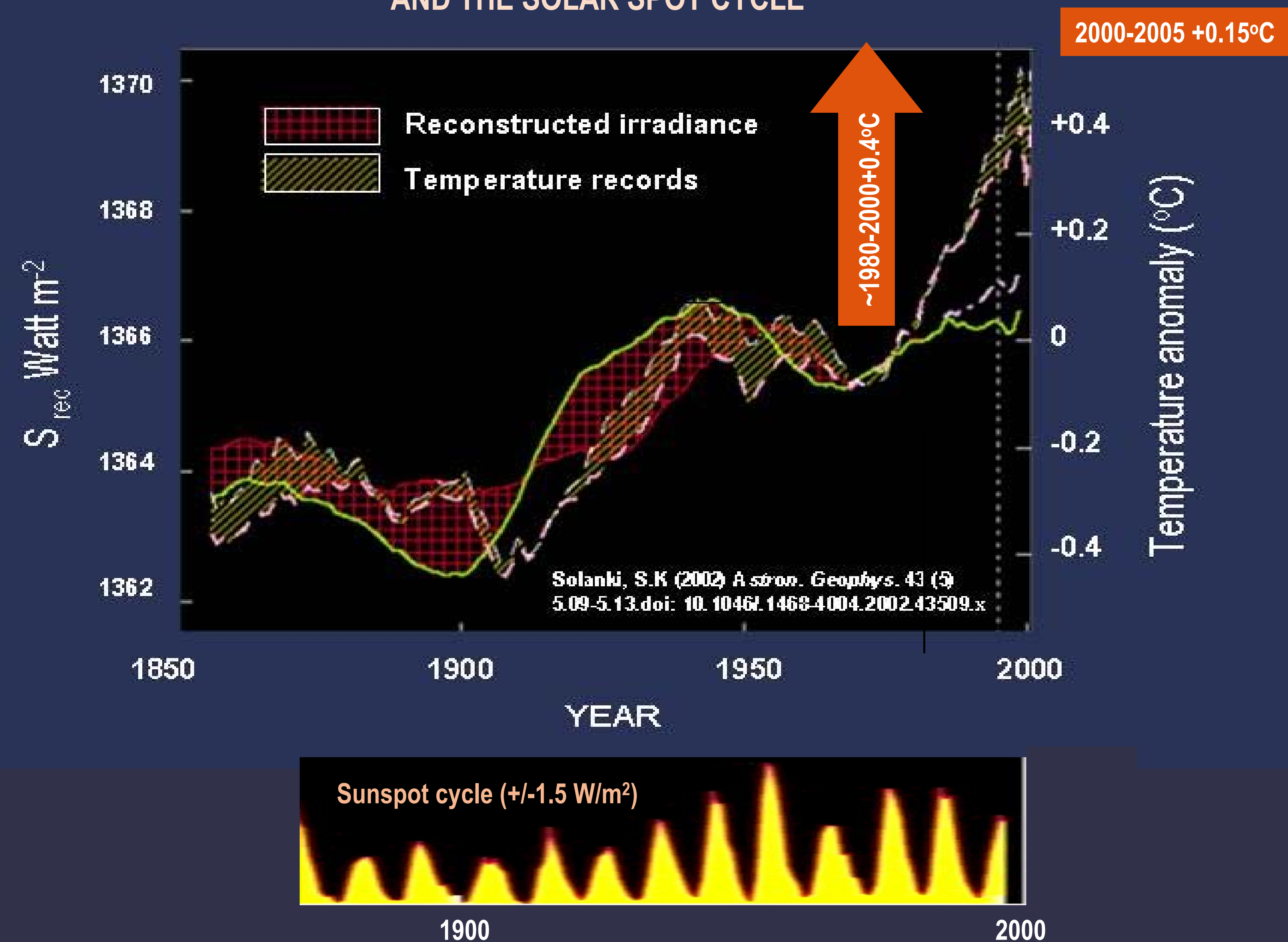


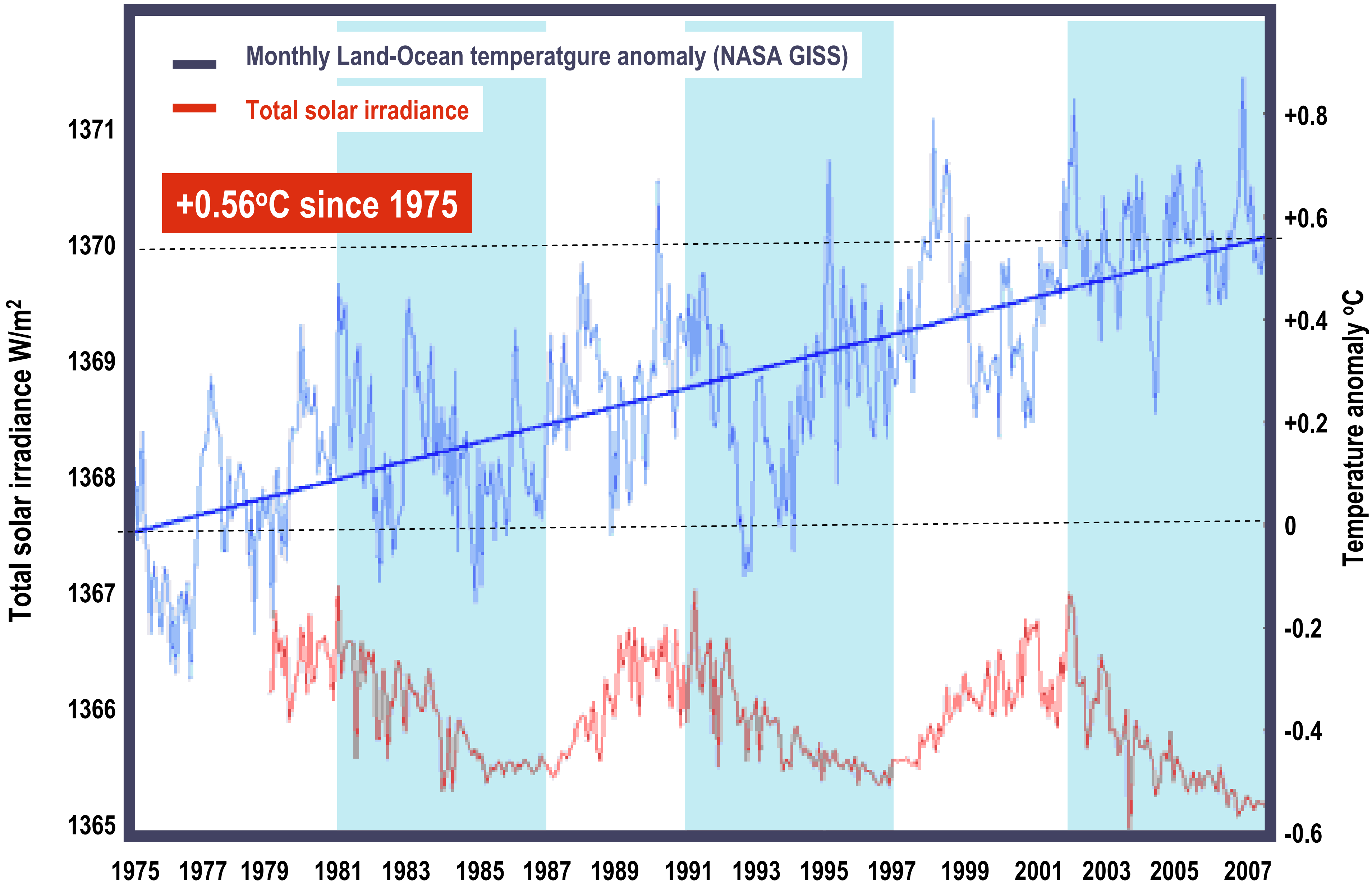
"Sea surface temperatures within 1ºC of the warmest interglacial periods over the past million years."

James Hansen (NASA's chief climate scientist, 2007)



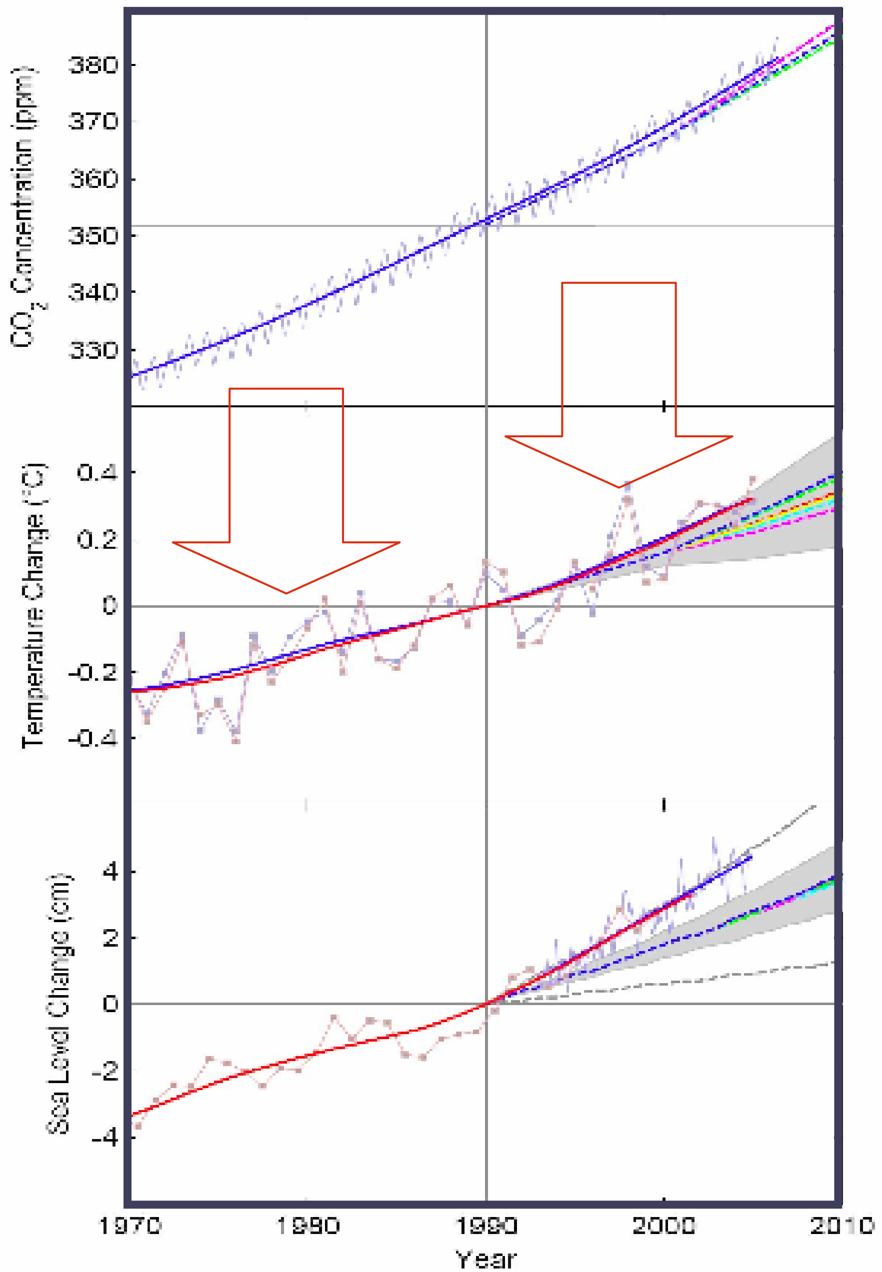
COMBINED TEMPERTATURE EFFECTS OF GREENHOUSE EMISSIONS
AND THE SOLAR SPOT CYCLE

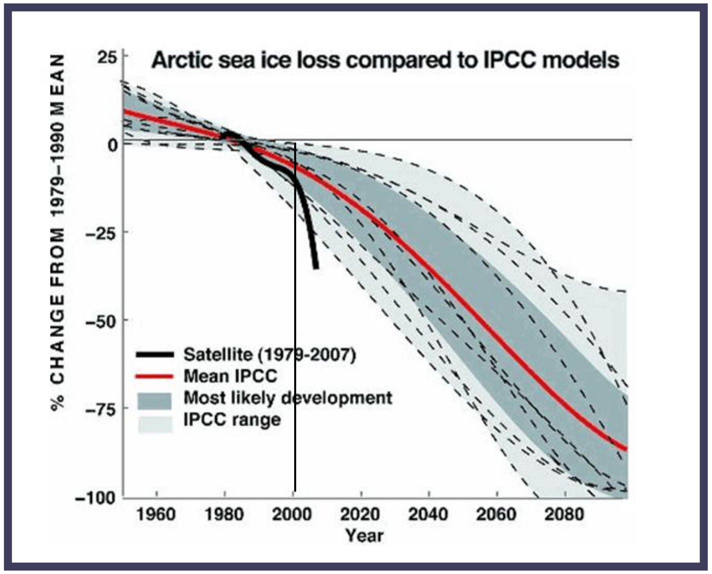




http://www.skepticalscience.com/Global-warming-stopped-in-1981.html

CLIMATE TIPPING POINTS





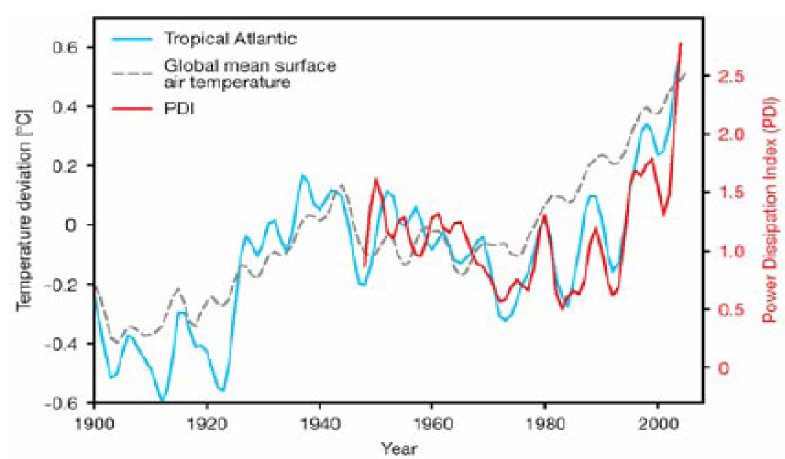
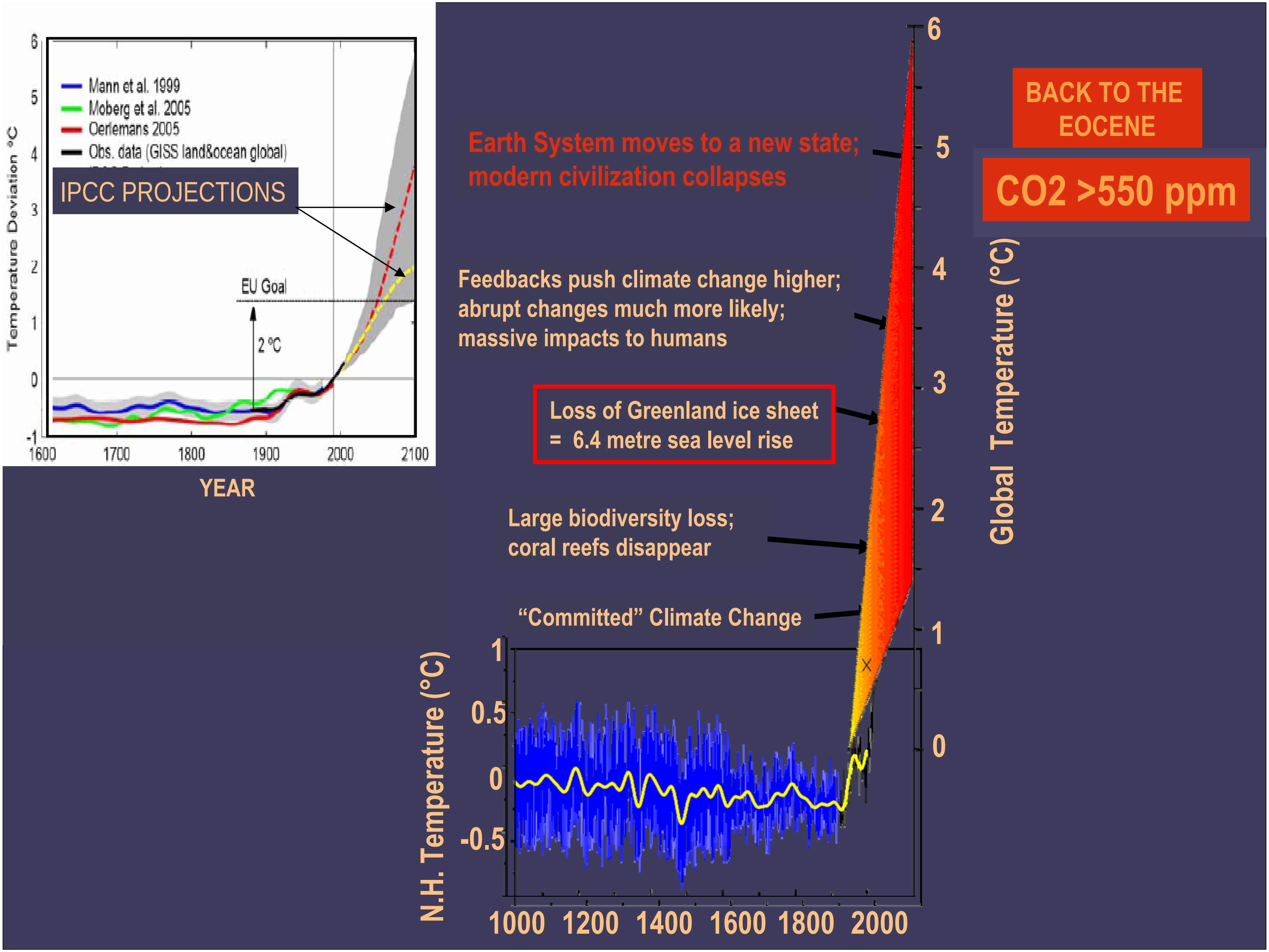


Fig. 4. Temporal development of the energy of tropical storms (Power Dissipation Index – PDI, red) and the average sea-surface temperature in the tropical Atlantic from August to October (blue). For comparison the evolution of the globally averaged near-surface air temperature is shown (dashed grey line). Source: after Emanuel, 2005


Mann et al. 1999
Moberg et al. 2005
Oerlemans 2005
Obs. data (GISS land&ocean global)
IPCC PROJECTIONS
EU Goal
2 °C
Temperature Deviation °C
6
5
4
3
2
1
0
-1
1600
1700
1800
1900
2000
2100
YEAR
Earth System moves to a new state;
modern civilization collapses
Feedbacks push climate change higher;
abrupt changes much more likely;
massive impacts to humans
Loss of Greenland ice sheet
= 6.4 metre sea level rise
Large biodiversity loss;
coral reefs disappear
"Committed" Climate Change
BACK TO THE
EOCENE
CO2 >550 ppm
Global Temperature (°C)
N.H. Temperature (°C)
1
0.5
0
-0.5
1000
1200
1400
1600
1800
2000

The life force