A Brief History of Life on Earth

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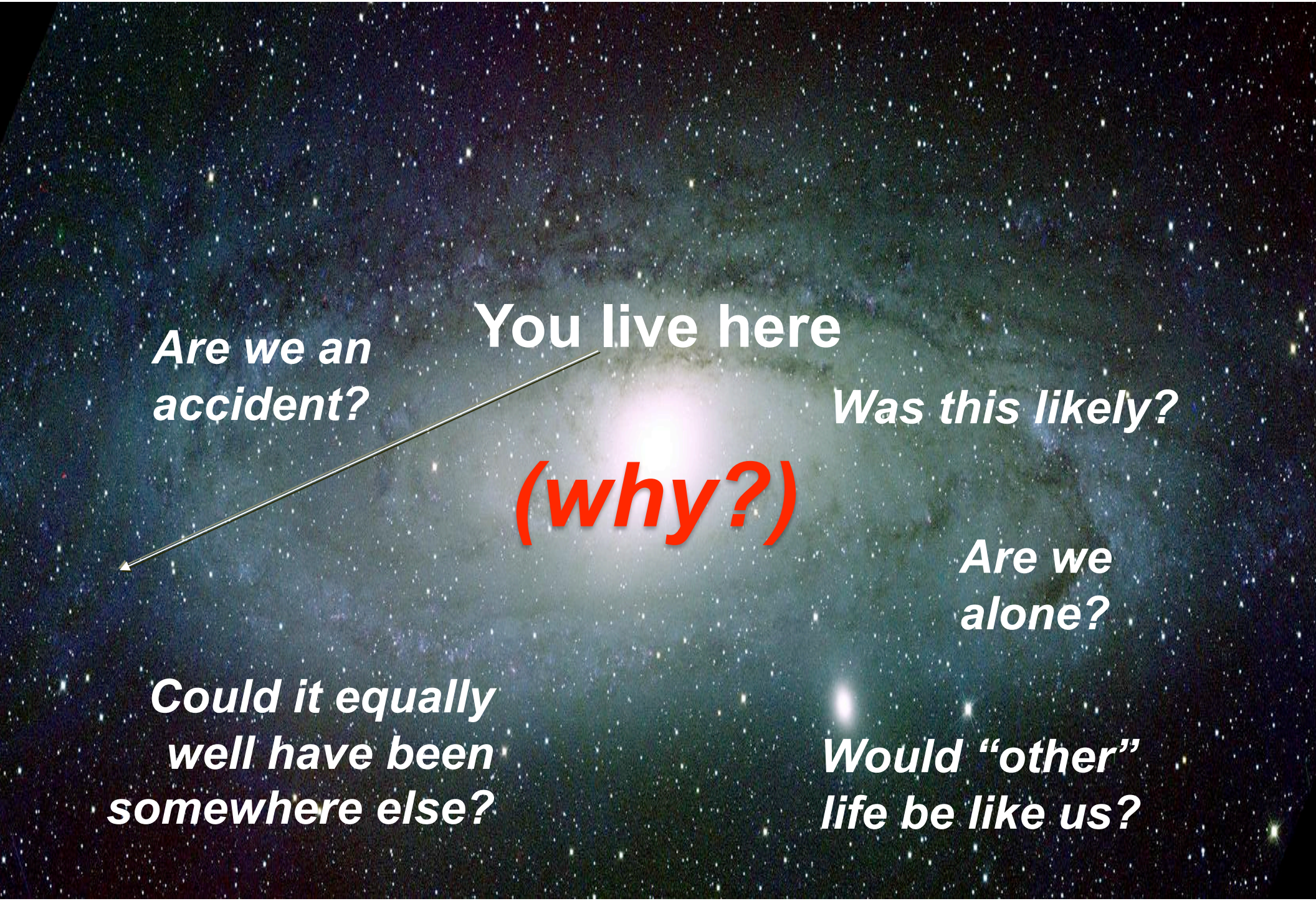
UMBC
AN HONORS UNIVERSITY IN MARYLAND

Astrobiology Institute
AT THE UNIVERSITY OF HAWAII

http://planetpixelemporium.com/images/fullsize/earth.jpg


You live here
Are we an accident?
Was this likely?
(why?)
Are we alone?
Could it equally well have been somewhere else?
Would "other" life be like us?

4 lectures…

(i) A History of Life on earth

(ii) The Evolution of the Genetic Code

(iii) The Evolution of the Amino Acid "Alphabet"

(iv) The origin of life –here and elsewhere?

4 lectures…

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(ii) The Evolution of the Genetic Code

(iii) The Evolution of the Amino Acid "Alphabet"

(iv) The origin of life –here and elsewhere?

What you are about to see is *not* what "evolutionary biologists" study, it is the work of...

Geneticists, Cell and developmental biologists, Anatomists, Physiologists, Botanists, Zoologists, Mycologists, Bioinformaticians, Paleontologists, Physiologists, Ecologists, Biochemists, Geochemists, Geophysicists, Geologists, Cosmochemists, Astronomers, Astrophysicists, Geographers, Cosmochemists, *etc.*

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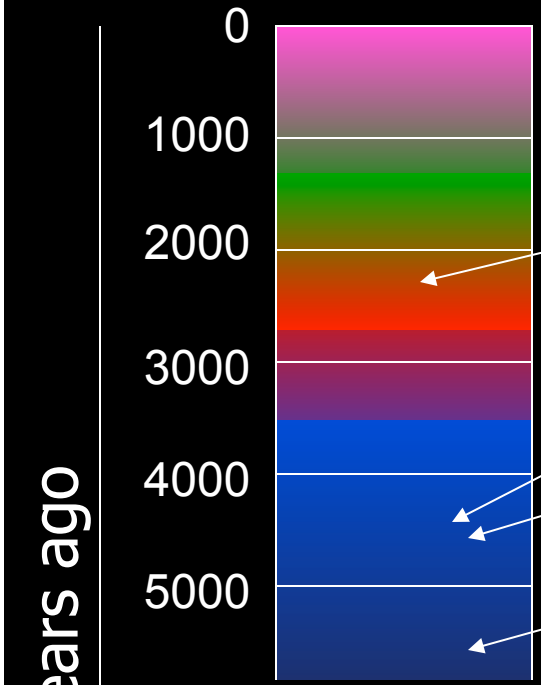
~ if this is deliberate conspiracy, then it dwarfs JFK's assassination, Roswell aliens or the moon landings into insignificance...

From History to Prehistory



≈350 BC

Iron Age

≈2,500 BC

Late Bronze Age

≈2,500 BC

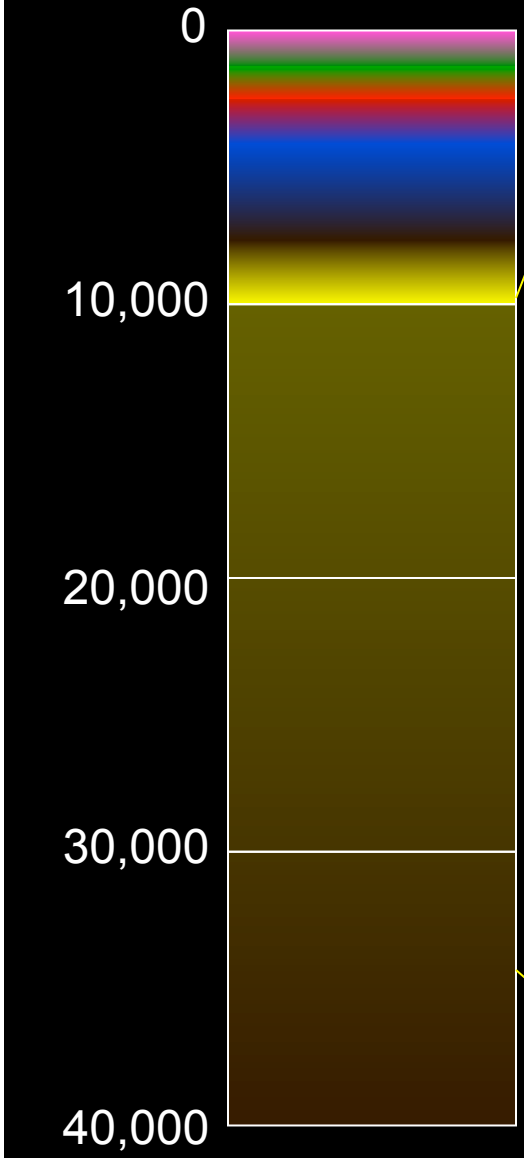
Early Bronze Age

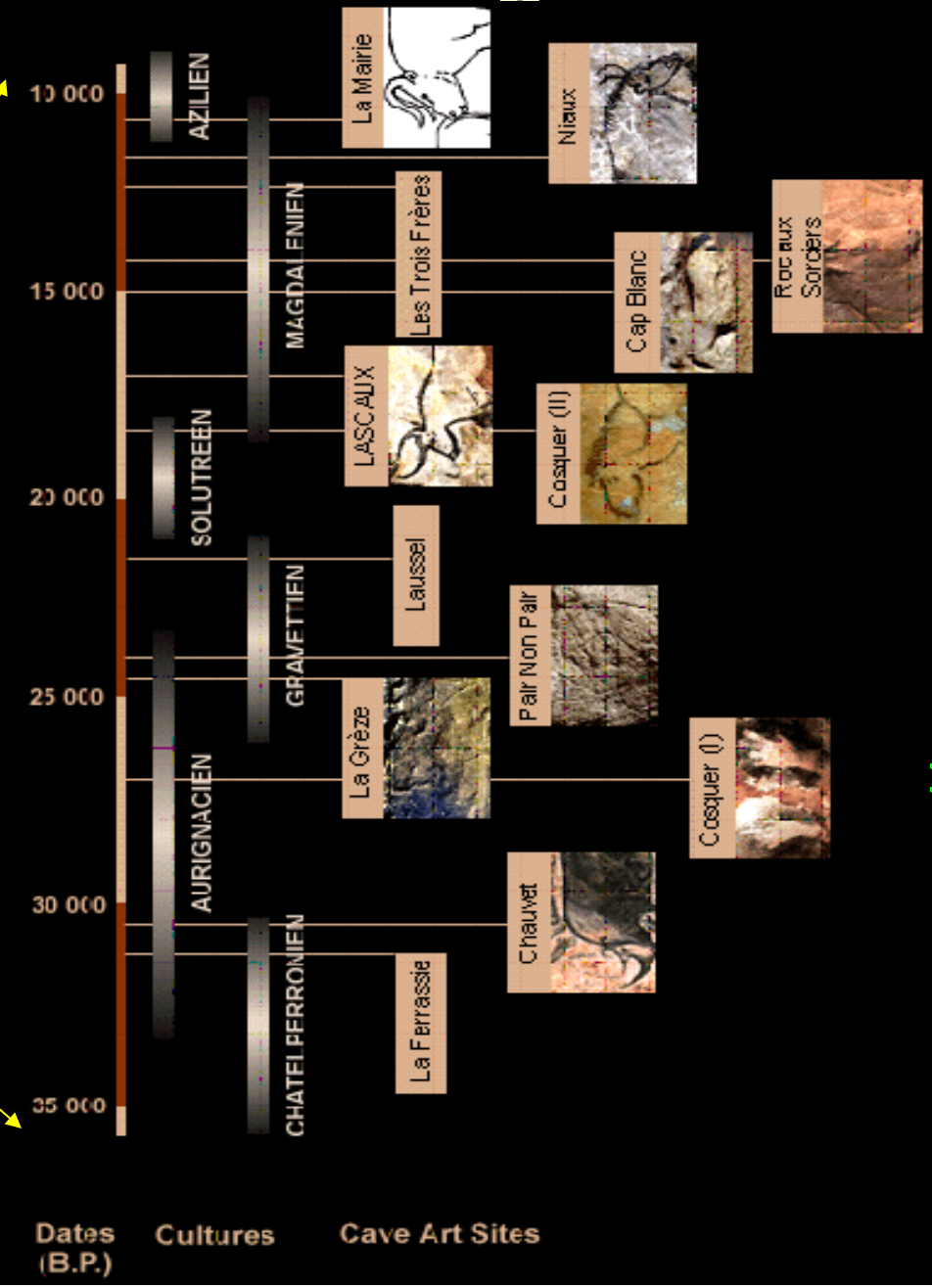
≈3,500 BC

(earliest writing)

Neolithic

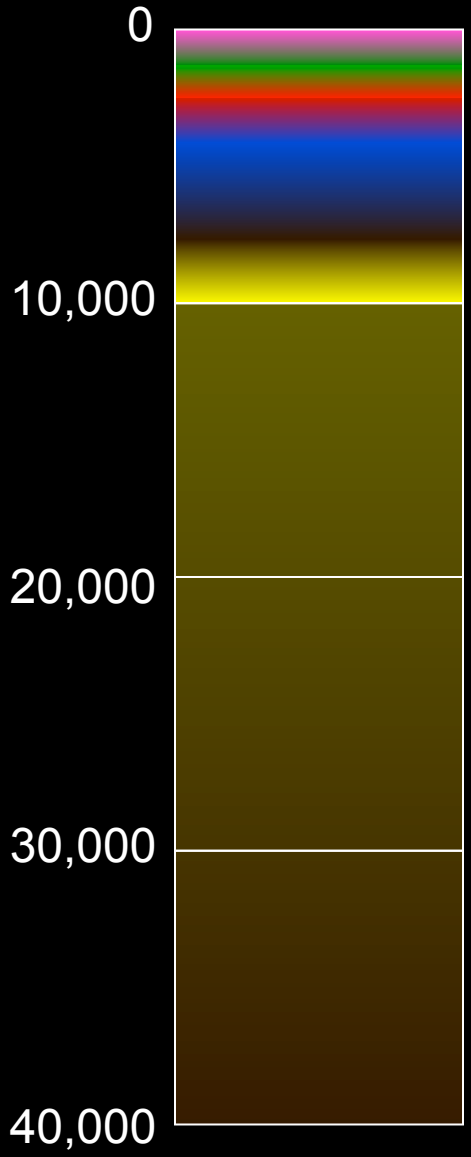
and back to the Stone-Age





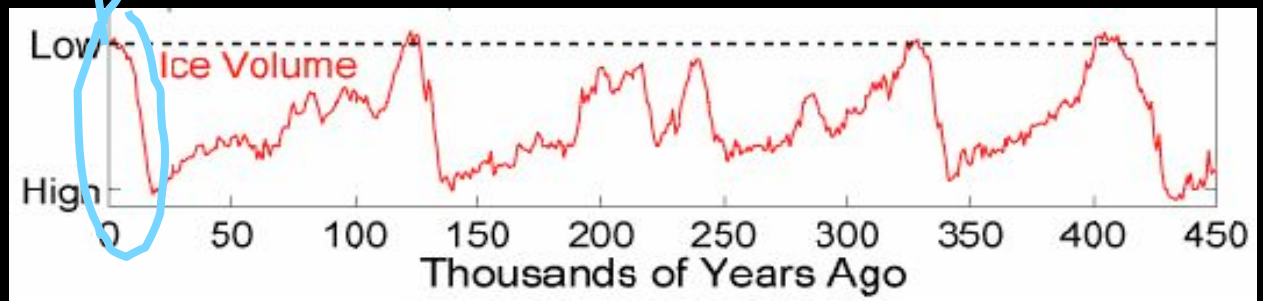
Paleolithic

and back to the Stone-Age

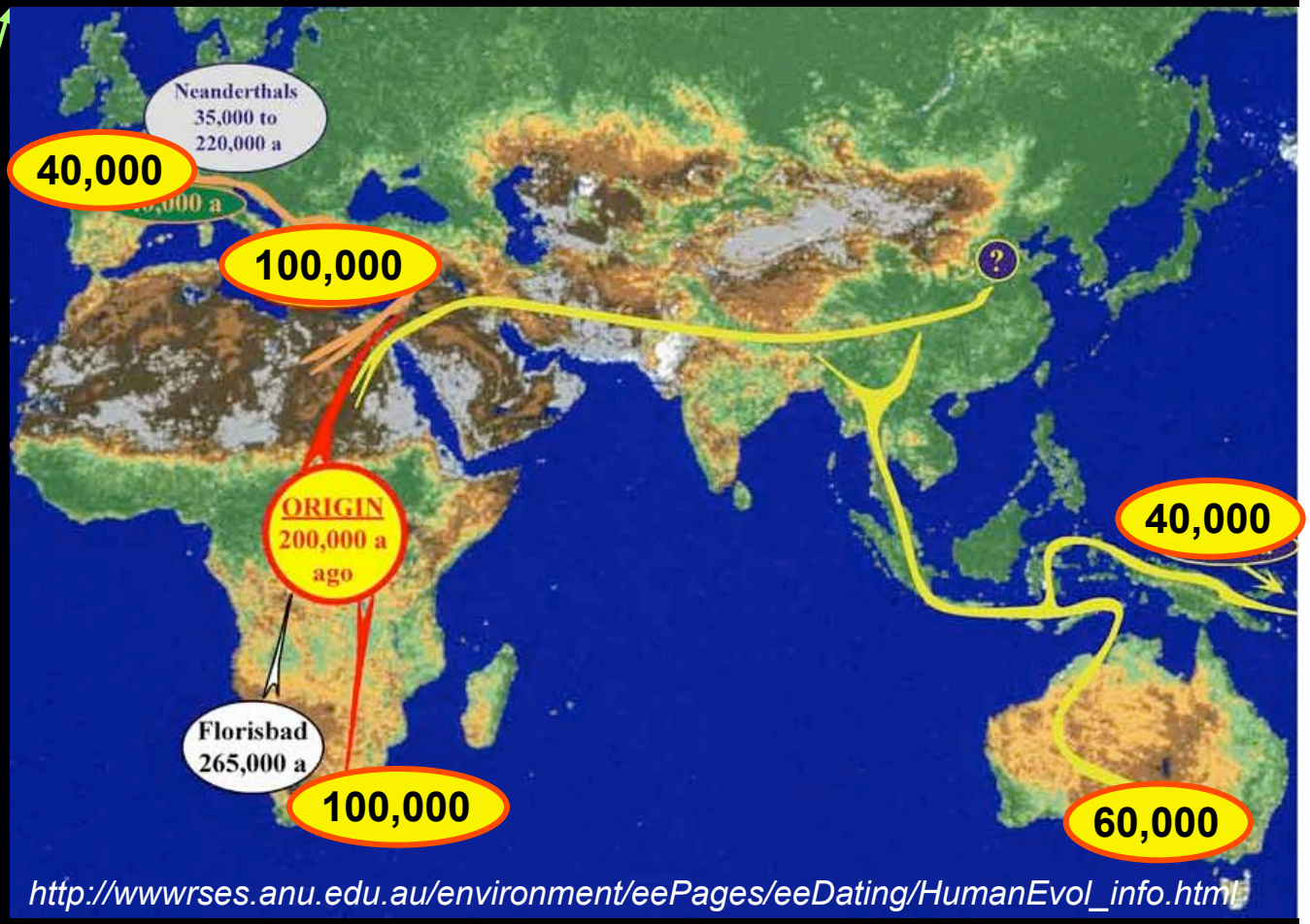


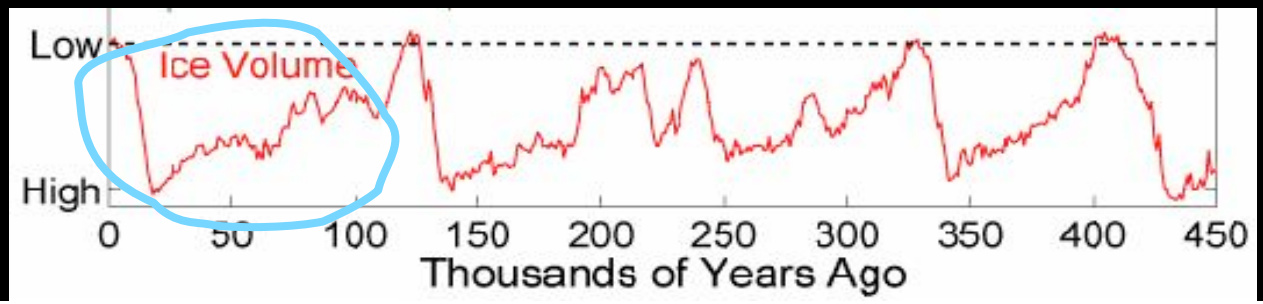
Paleolithic

Glaciation (Ice Ages) over the last 450,000 years



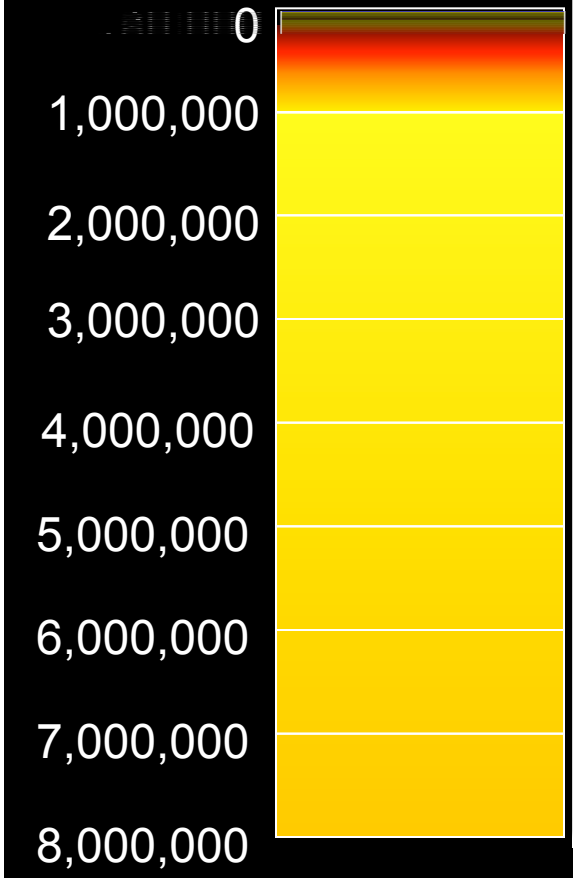
over the last 100,000 yrs *Homo sapiens* has spread from 'the cradle of life' in Africa



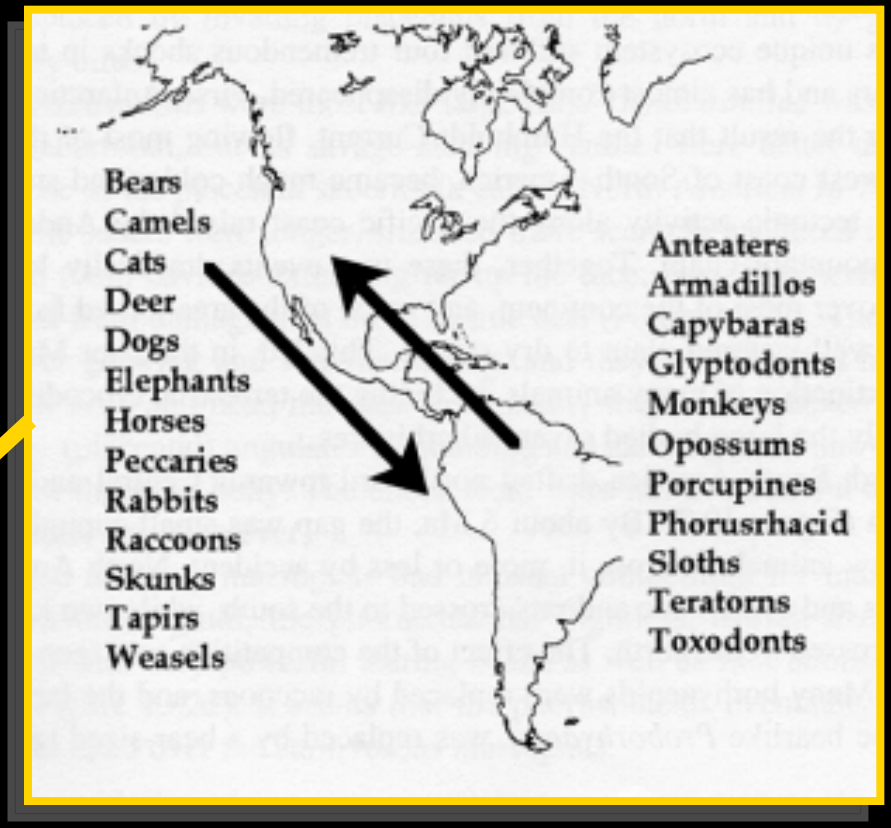


- **The emergence of humans as a species needs another 2 orders of magnitude….**



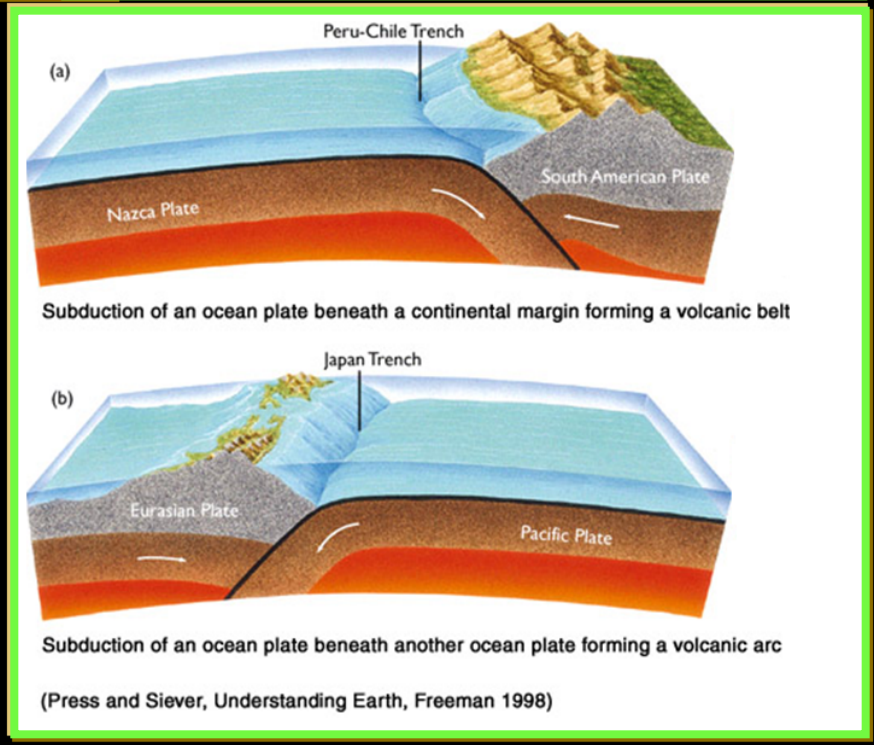




- **At this timescale, the world is a very different place…**



Just over 3 million years ago, the emergence of a land connection between North and South America (the isthmus of Panama) allowed interchange of species…in general the birds (e.g. phorusrhacids) and marsupials (e.g. giant sloths) fared worse when they met and competed with placental mammals from the north…

Plate Tectonics (used to be called “Continental Drift”)



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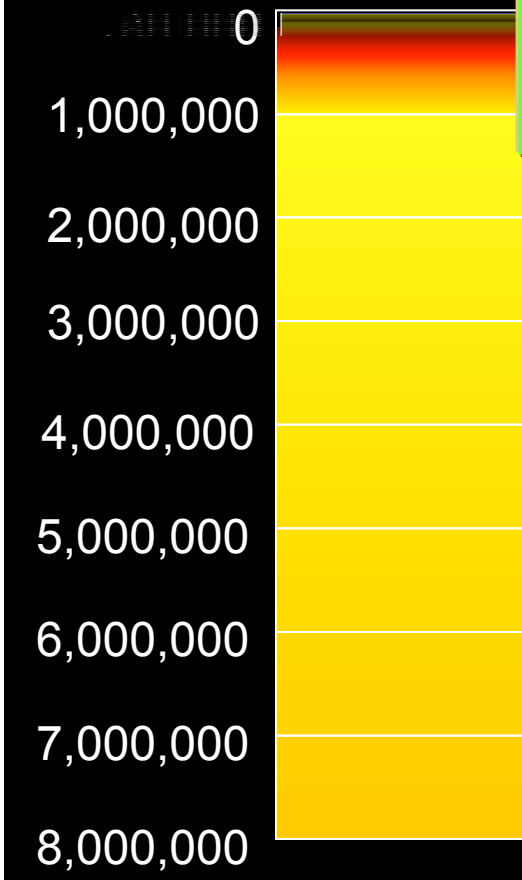
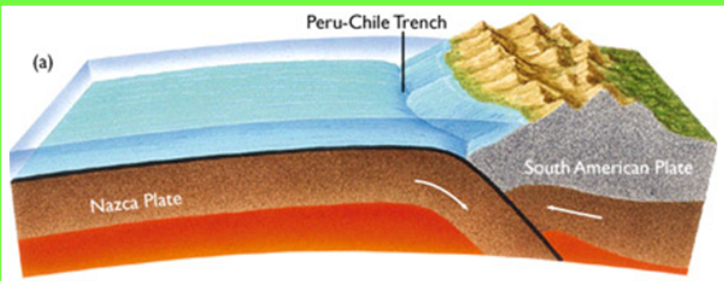
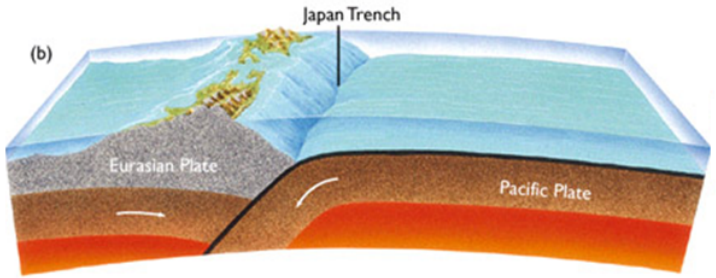




Subduction of an ocean plate beneath a continental margin forming a volcanic belt



Subduction of an ocean plate beneath another ocean plate forming a volcanic arc

(Press and Siever, Understanding Earth, Freeman 1998)

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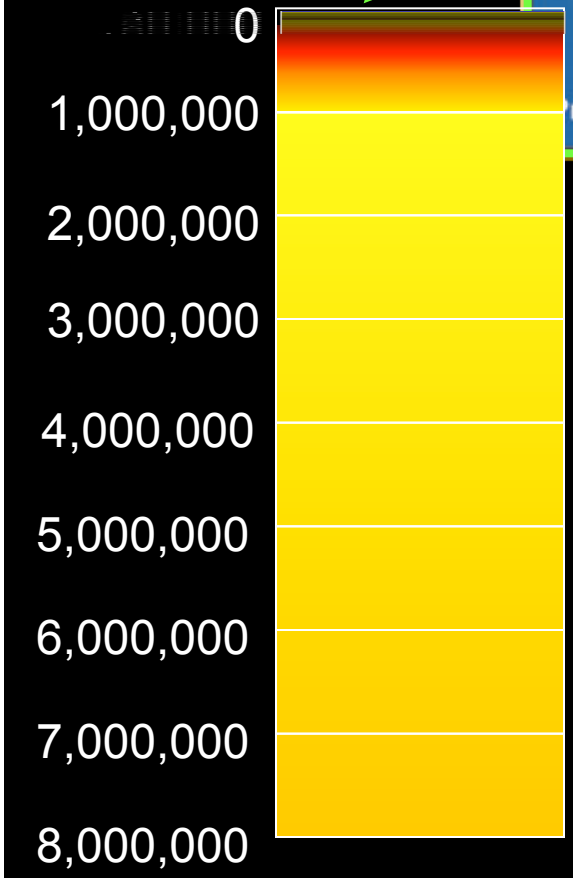

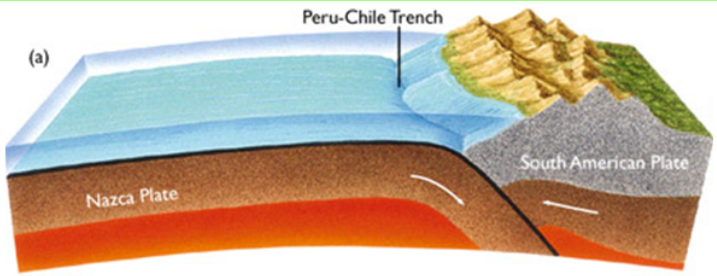

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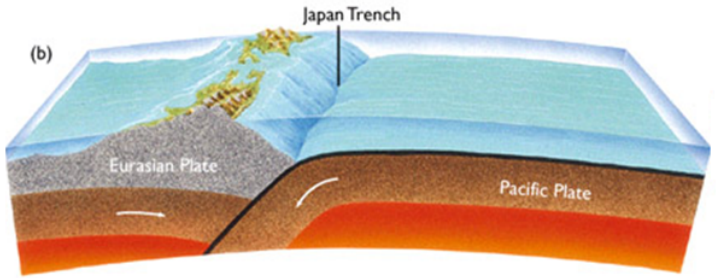
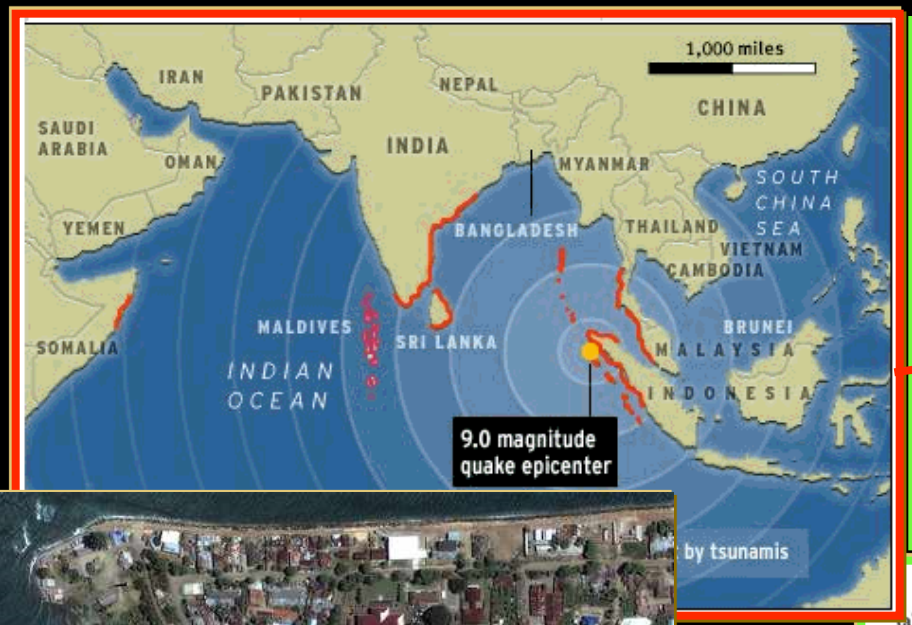
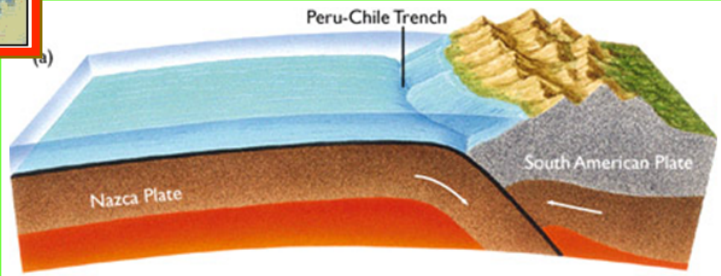


Subduction of an ocean plate beneath another ocean plate forming a volcanic arc

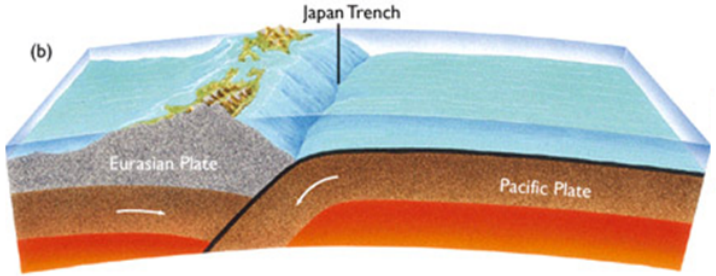
(Press and Siever, Understanding Earth, Freeman 1998)

(not always a gentle and gradual process!)





Subduction of an ocean plate beneath a continental margin forming a volcanic belt

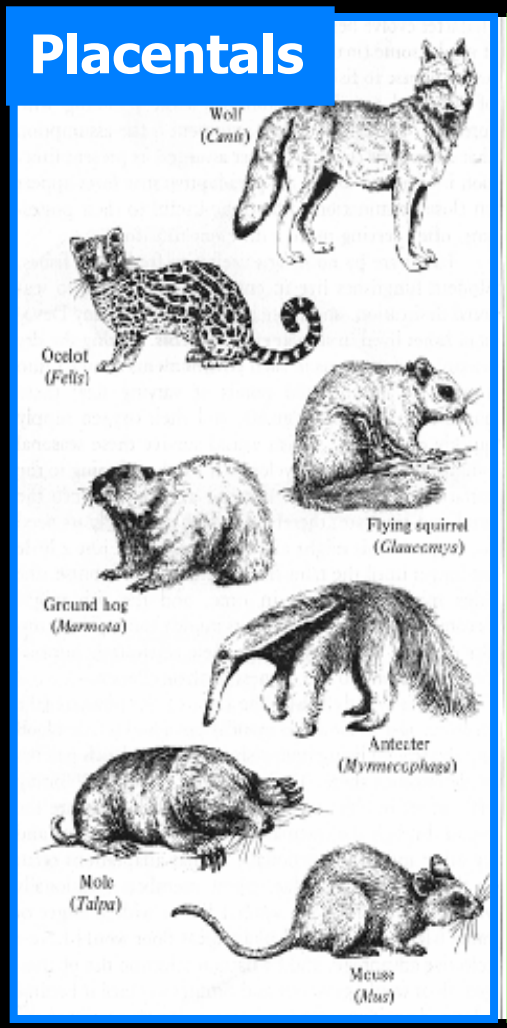


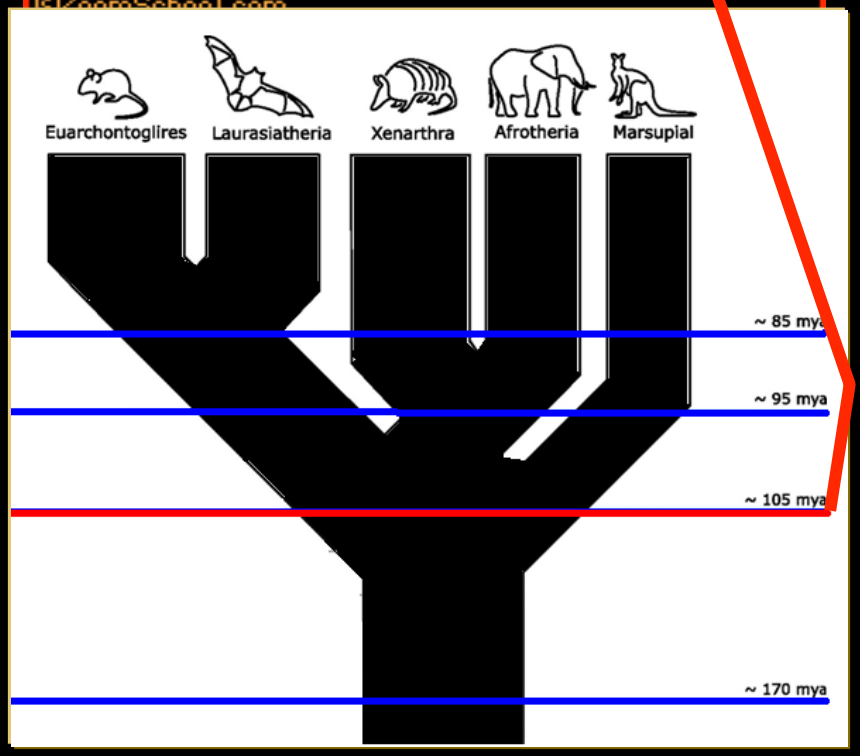
Subduction of an ocean plate beneath another ocean plate forming a volcanic arc

(Press and Siever, Understanding Earth, Freeman 1998)

Plate Tectonics (used to be called "Continental Drift")

explains things like Australia contains marsupial counterparts to placental mammals…

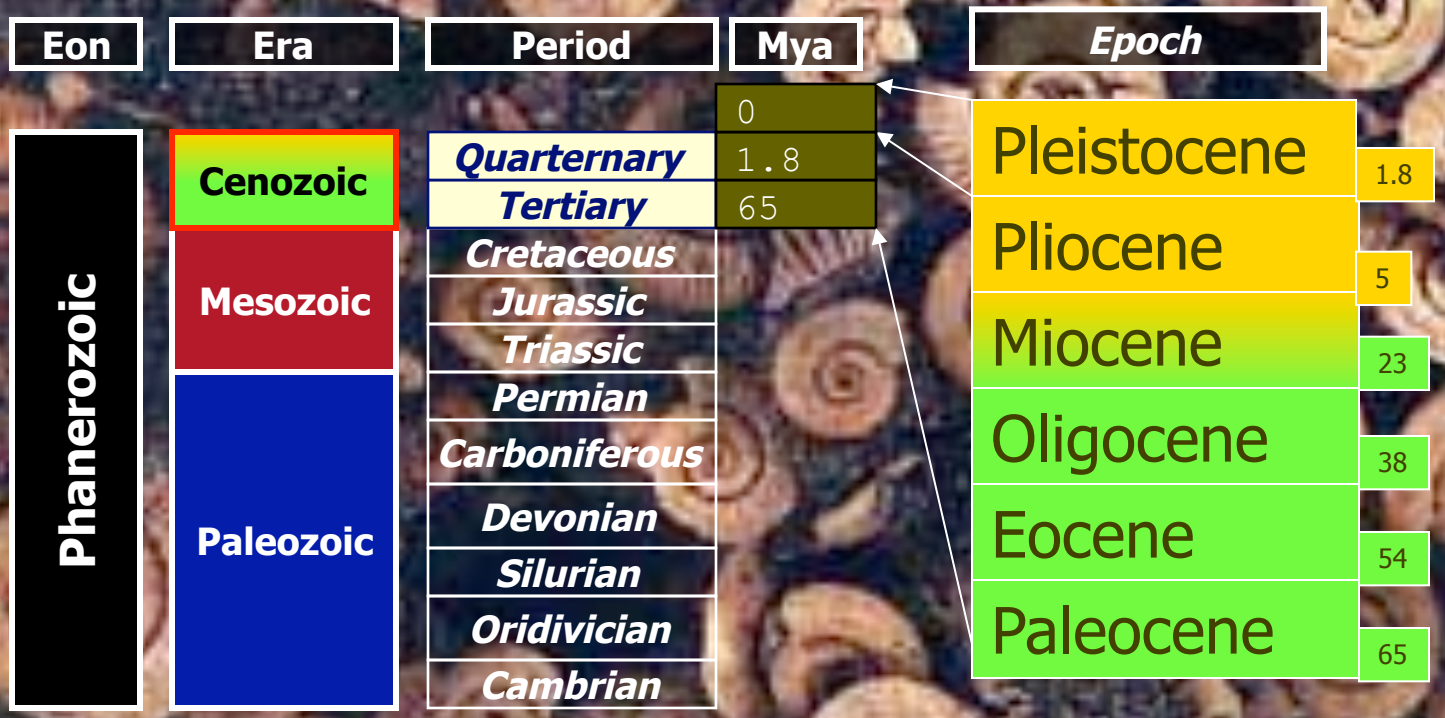




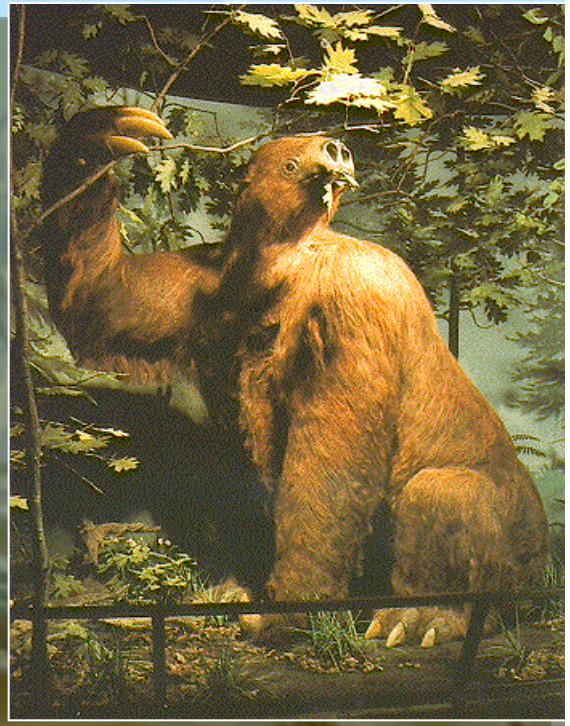
Geological Time

The boundaries of geological periods, are generally denoted by significant extinctions (changes in the organisms we find, from one rock layer to the next).

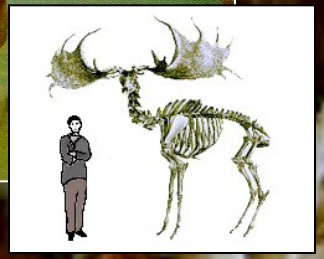
(According to fossils, approximately 99.9% of species that have lived are extinct)



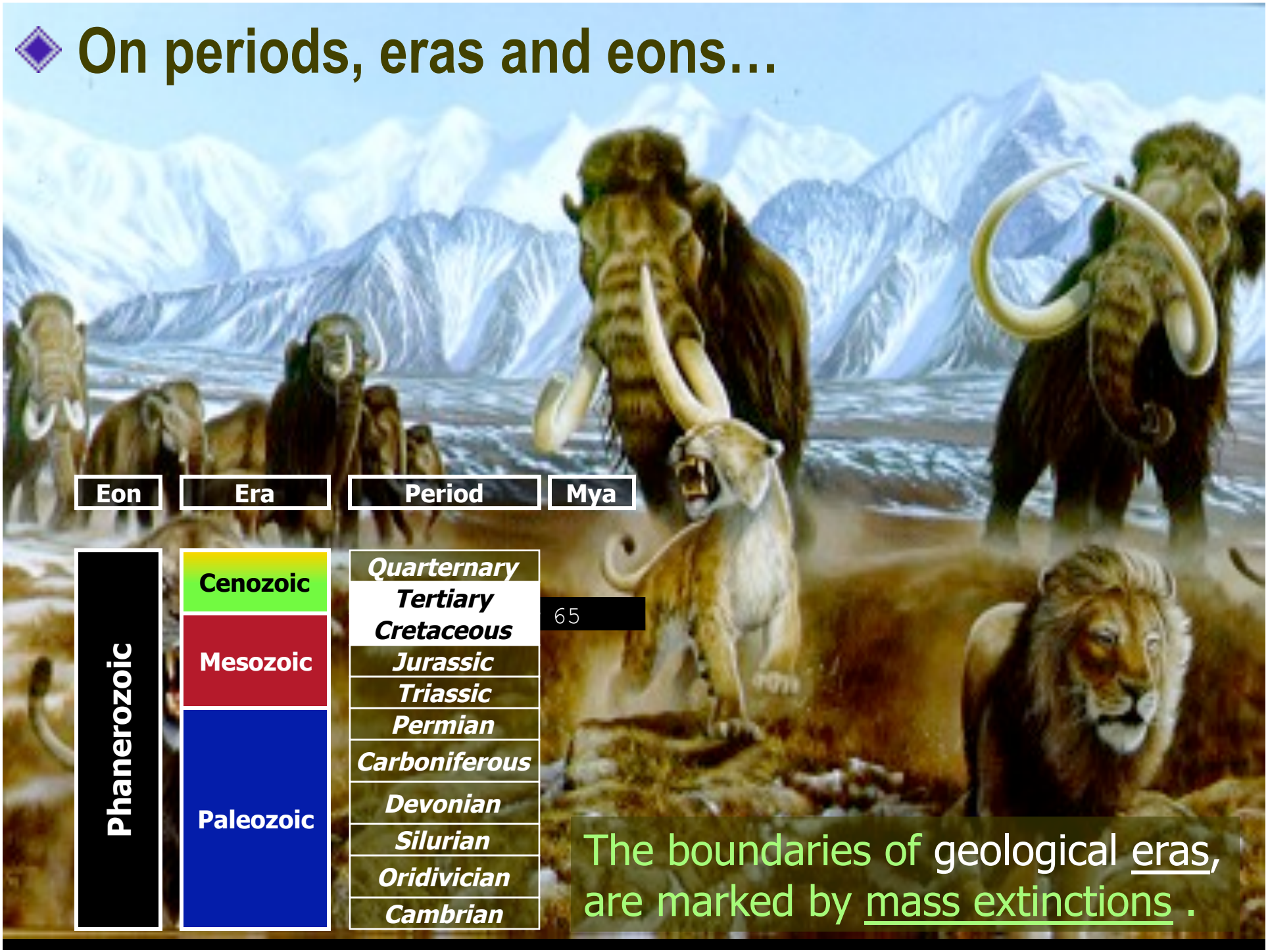
Cenozoic: the age of mammals



Eon	Era	Period	Mya
			0
Phanerozoic	Cenozoic	*Quarternary*	1.8
		Tertiary	65
	Mesozoic	*Cretaceous*	
		Jurassic	
		Triassic	
	Paleozoic	*Permian*	
		Carboniferous	
		Devonian	
		Silurian	
		Oridivician	
		Cambrian	



On periods, eras and eons…



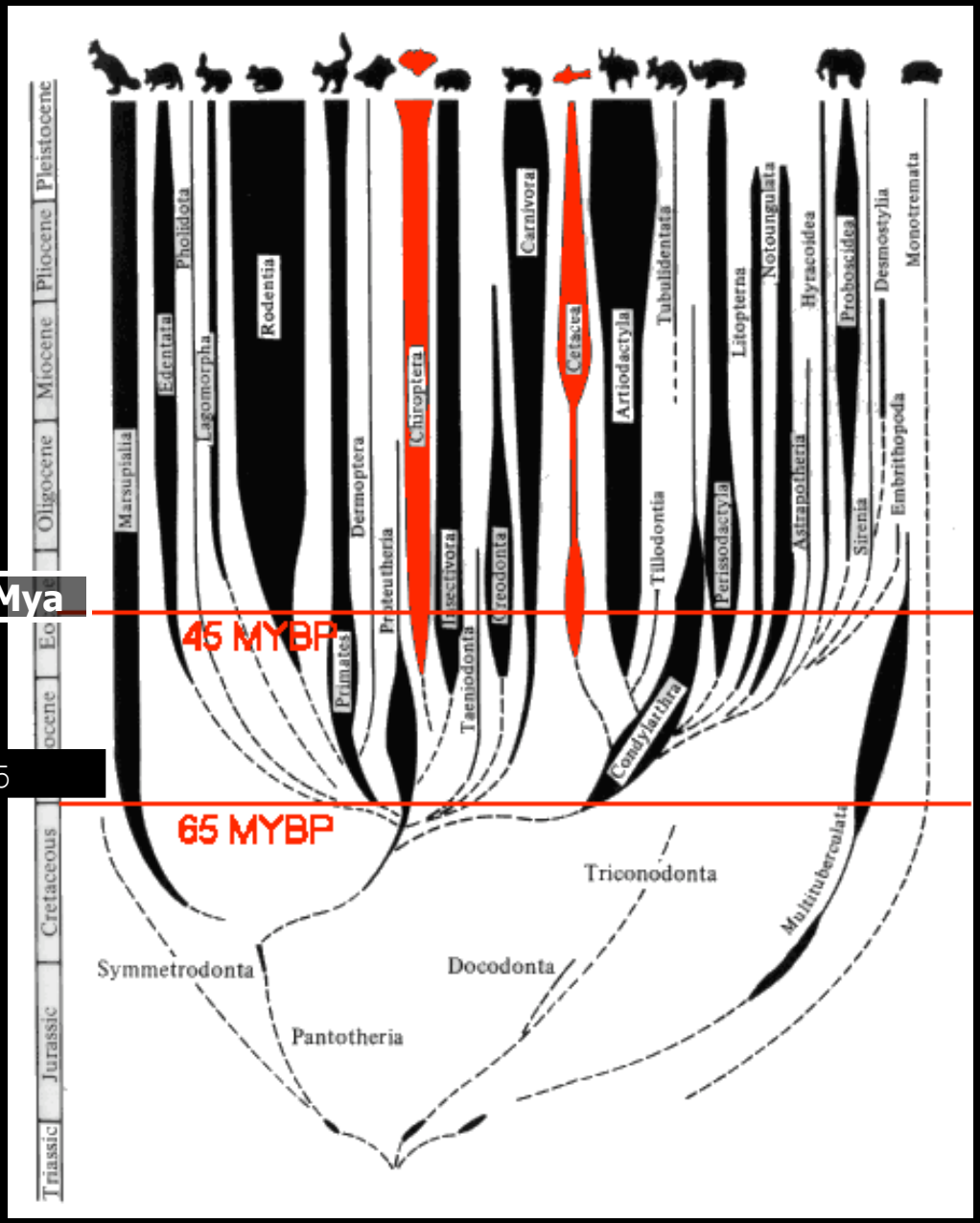
Eon	Era	Period	Mya
Phanerozoic	Cenozoic	Quarternary	
		Tertiary	65
	Mesozoic	Cretaceous	
		Jurassic	
		Triassic	
	Paleozoic	Permian	
		Carboniferous	
		Devonian	
		Silurian	
		Oridivician	
		Cambrian	

The boundaries of geological eras, are marked by mass extinctions .

65*mya* mammals underwent an adaptive radiation

The most recent of these (the Cenozoic/Mesozoic boundary) is known as the *KT mass extinction*

Eon	Era	Period	Mya
Phanerozoic	Cenozoic	*Quarternary*	
		Tertiary	
	Mesozoic	*Cretaceous*	65
		Jurassic	
		Triassic	
	Paleozoic	*Permian*	
		Carboniferous	
		Devonian	
		Silurian	
		Oridivician	
		Cambrian	



So what brought on the “age of the mammals”?

“Barringer” Meteor Crater in northern Arizona, is 180m deep and 1.2km in diameter. The crater was formed sometime between 25,000 and 50,000 years ago by an iron meteorite, somewhere between 30 and 100m in diameter, weighing roughly 60,000 tons. The energy released by the impact was roughly equivalent to 3.5 million tons of TNT

Mammal species evolve to fill a void…

A worldwide layer of compressed ash from 65 mya

Eon	Era
Phanerozoic	Cenozoic
	Mesozoic
	Paleozoic

Tertiary
Cretaceous
65 mya

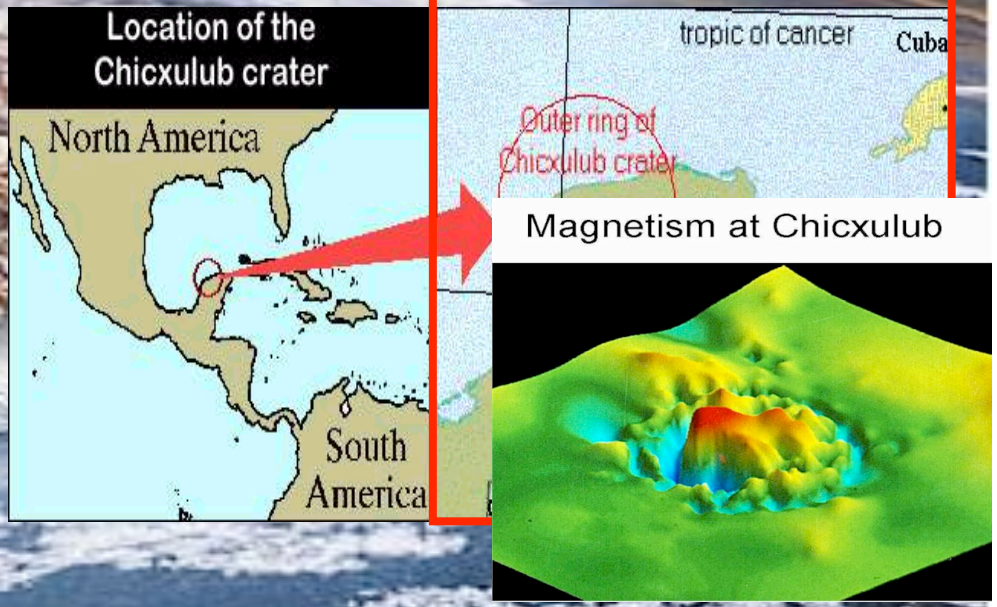
Location of the Chicxulub crater

Mammal species evolve to fill a void…

a ≈10 km diameter meteorite hit earth, triggering huge tsunamis and throwing up a wall of rocks and dust that, carried high into the atmosphere, surrounded the earth as a thick cloud and blacked out the sun. This caused freezing, and the darkness killed plants/plankton – the primary producers of earth's ecosystem…

Eon	Era
Phanerozoic	Cenozoic
	Mesozoic
	Paleozoic

Tertiary Cretaceous 65 mya



Mesozoic: The age of reptiles

Lasted about 190 million years...

Cynodont - 220mya (a mammal like reptile)

Allosaurus – 152 mya (a forerunner of Tyrannosaurus)

Quetzalcoatlus – 65 mya (with a 50 ft wingspan, the largest creature ever to fly)

Eon	Era	Period	
Phanerozoic	Cenozoic	*Quarternary*	
		Tertiary	65
	Mesozoic	*Cretaceous*	144
		Jurassic	206
		Triassic	248
	Paleozoic	*Permian*	
		Carboniferous	
		Devonian	
		Silurian	
		Oridivician	
		Cambrian	

(compare mammals @ 65 my or humans @ 7my)

Cretaceous: age of flowering plants

Oaks, Maples, Walnuts and Magnolia

Eon	Era	Period	
Phanerozoic	Cenozoic	*Quarternary*	
		Tertiary	65
	Mesozoic	*Cretaceous*	144
		Jurassic	206
		Triassic	248
	Paleozoic	*Permian*	
		Carboniferous	
		Devonian	
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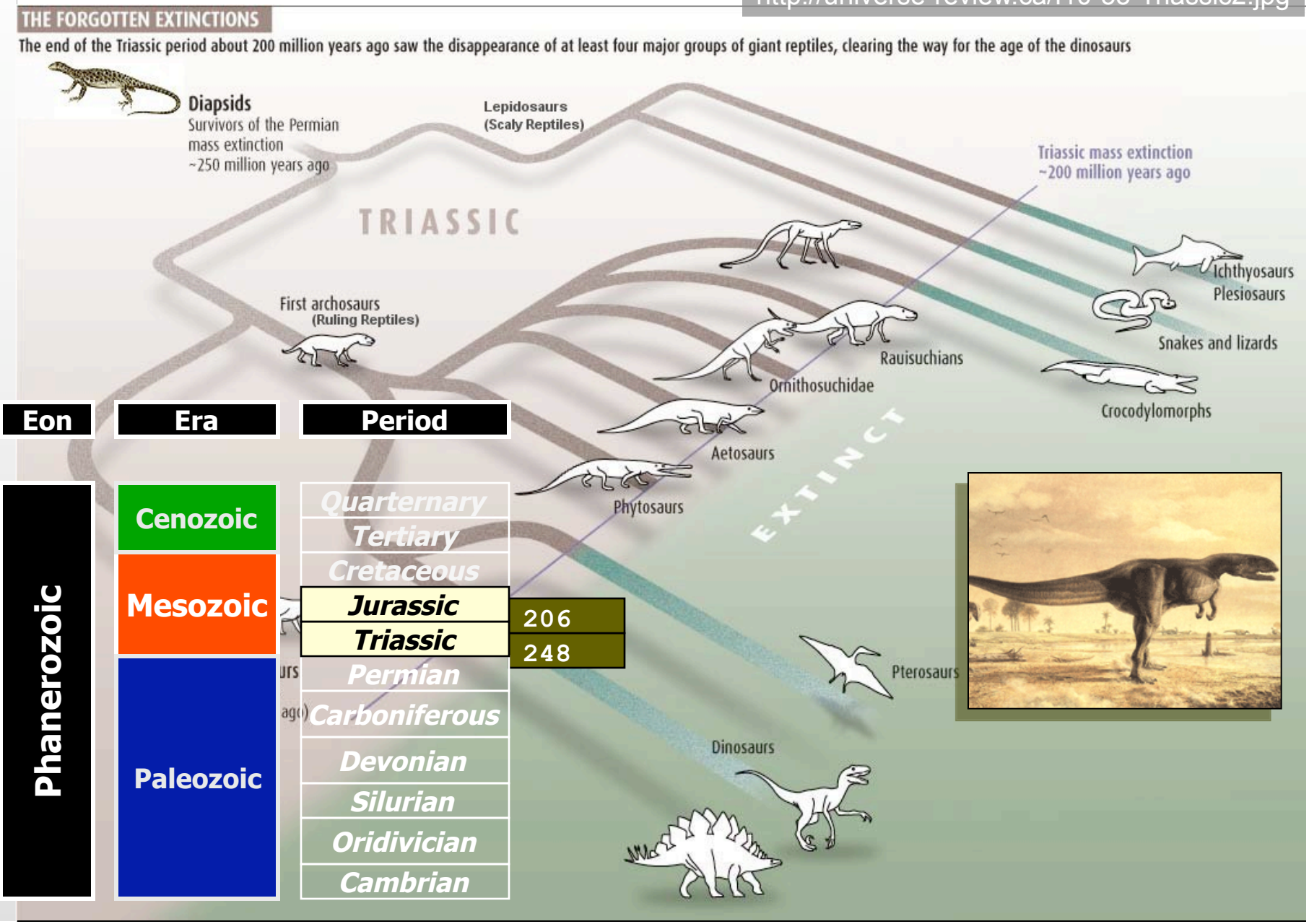
		Oridivician	
		Cambrian	

Mesozoic: age of reptiles

http://universe-review.ca/I10-33-Triassic2.jpg



The greatest mass extinction of them all...

~ 95% of known life went extinct.

Super-volcanic activity, possible asteroid impact and drastic change in climate wrought havoc...

Eon	Era	Period
Phanerozoic	Cenozoic	Quarternary
		Tertiary
	Mesozoic	Cretaceous
		Jurassic
		Triassic
		Permian
	Paleozoic	Carboniferous
		Devonian
		Silurian
		Oridivician
		Cambrian

248

http://www.lpi.usra.edu/education/timeline/gallery/slide_53.html

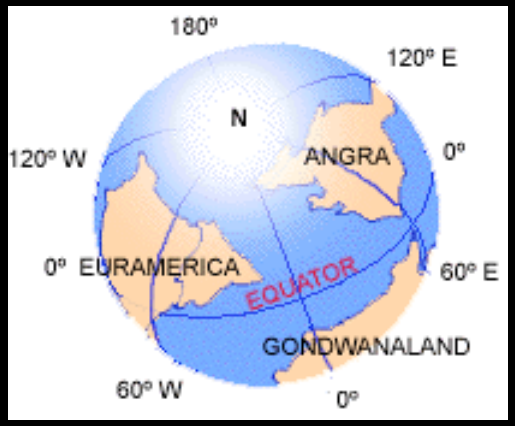
Permian: Large tetrapod animals dominate land

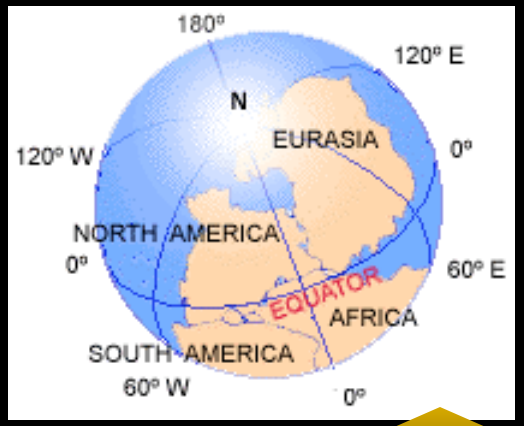
Dimetrodon (a pelycosaur – actually a forerunner of mammals!)

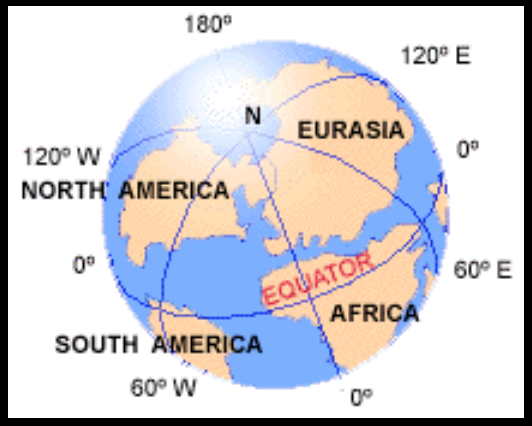
Eon	Era	Period	
Phanerozoic	Cenozoic	Quarternary	
		Tertiary	
	Mesozoic	Cretaceous	
		Jurassic	
		Triassic	248
	Paleozoic	Permian	290
		Carboniferous	
		Devonian	
		Silurian	
		Oridivician	
		Cambrian	

University of Michigan Exhibit Museum of Natural History -- Life Through the Ages Diroama

Where did large land animals come from?







325 mya *230 mya* *65 mya*

Eon	Era	Period
Phanerozoic	Cenozoic	*Quarternary*
		Tertiary
	Mesozoic	*Cretaceous*
		Jurassic
		Triassic
	Paleozoic	*Permian*
		Carboniferous
		Devonian
		Silurian
		Oridivician
		Cambrian

248
290

250 mya

During the late Paleozoic, all land masses converged for the first and only time in the history of multicellular life to form a supercontinent known as *Pangaea*

The Carboniferous: age of coal forests (and diversifying insects)

Vast forest-swamps of tree-ferns, horsetails & club mosses, producing atmospheric oxygen levels of 35% (twice what we have today)

Eon	Era	Period	
Phanerozoic	Cenozoic	*Quarternary*	
		Tertiary	
	Mesozoic	*Cretaceous*	
		Jurassic	
		Triassic	
	Paleozoic	*Permian*	290
		Carboniferous	362
		Devonian	
		Silurian	
		Oridivician	
		Cambrian	

Meganeura **– a dragonfly with a 3 ft wingspan…there were also enormous flies, cockroaches and so on!**

http://www.fieldmuseum.org/research_collections/ecp/ecp_sites/NPI_web/models_images/geo75400.JPG

Devonian: the First Large Land Animals

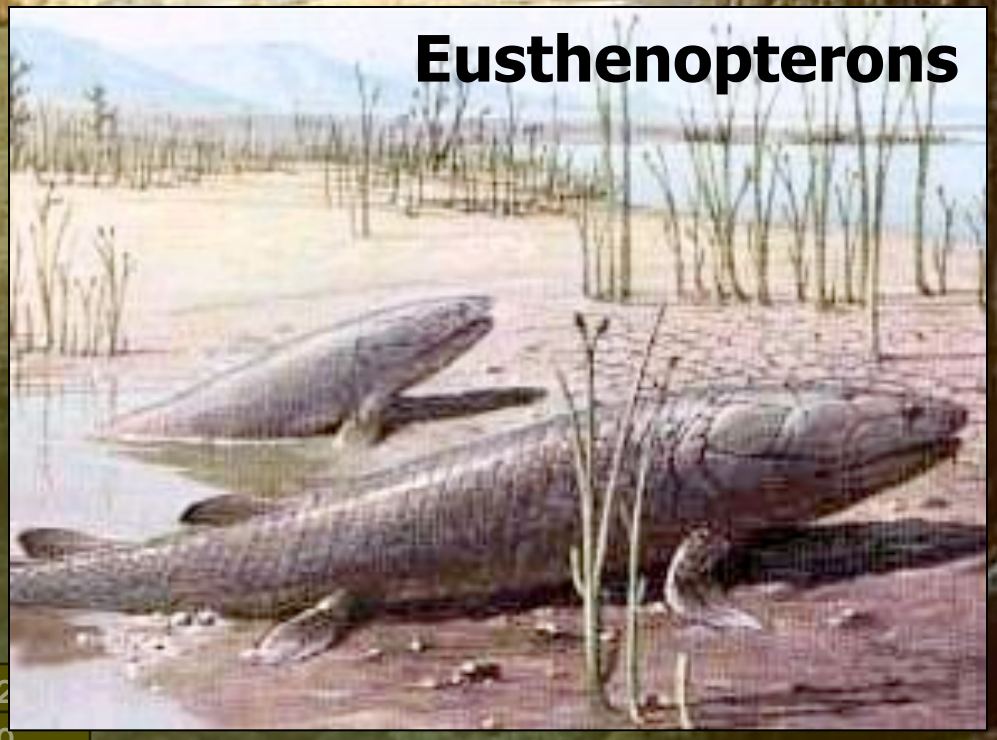
- *amphibians...*

Eon	Era	Period	
Phanerozoic	Cenozoic	*Quarternary*	
		Tertiary	
	Mesozoic	*Cretaceous*	
		Jurassic	
		Triassic	
	Paleozoic	*Permian*	
		Carboniferous	
		Devonian	362
			290
		Silurian	
		Oridivician	
		Cambrian	

Icthyostega

Devonian: the First Large Land Animals

- Evolved from lobe-finned fish…



Eon	Era	Period
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	Mesozoic	Cretaceous
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		Triassic
	Paleozoic	Permian
		Carboniferous
		Devonian
		Silurian
		Oridivician
		Cambrian

362

290

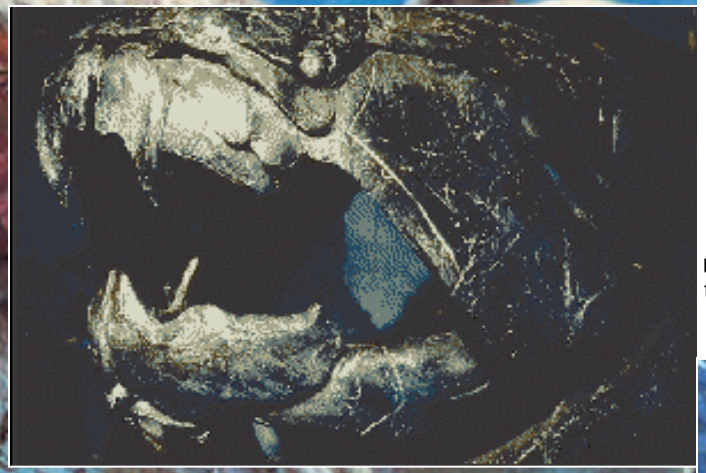
Devonian: the First Large Land Animals

...emerged to eat...

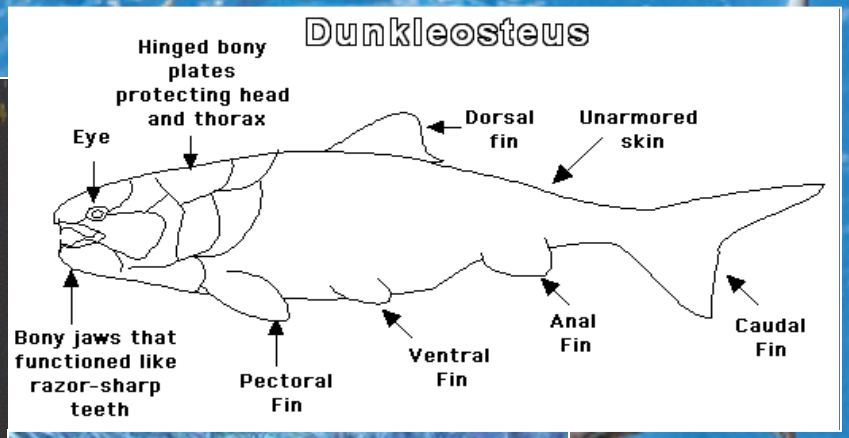
Eon	Era	Period	
Phanerozoic	Cenozoic	*Quarternary*	
		Tertiary	
	Mesozoic	*Cretaceous*	
		Jurassic	
		Triassic	
	Paleozoic	*Permian*	
		Carboniferous	
		Devonian	362
			408
		Silurian	
		Oridivician	
		Cambrian	

Insects, myriapods and arachnids evolve from crustaceans and horseshoe-crabs

Devonian: an age of fish...



36 ft long



Eon	Era	Period		
Phanerozoic	Cenozoic	*Quarternary*		
		Tertiary		
	Mesozoic	*Cretaceous*		
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		Oridivician		
		Cambrian		

http://thunderlizard.gn.apc.org/devonian.jpg

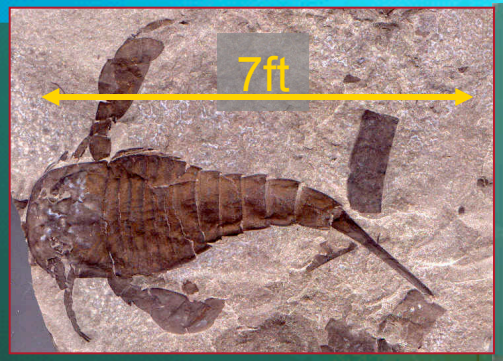
Devonian: an age of fish...

Eon	Era	Period
Phanerozoic	Cenozoic	Quarternary
		Tertiary
	Mesozoic	Cretaceous
		Jurassic
		Triassic
	Paleozoic	Permian
		Carboniferous
		Devonian
		Silurian
		Oridivician
		Cambrian

362
408

Jawless Fishes
Placoderms
Sharks, Ratfishes
Acanthodians
Ray-Finned Fishes
Lungfishes
Lobe-Finned Fishes

Silurian: complex marine reef ecosystems



a eurypterid ~ fierce, top carnivore of the age

Eon	Era	Period
Phanerozoic	Cenozoic	Quarternary
		Tertiary
	Mesozoic	Cretaceous
		Jurassic
		Triassic
	Paleozoic	Permian
		Carboniferous
		Devonian
		Silurian
		Oridivician
		Cambrian

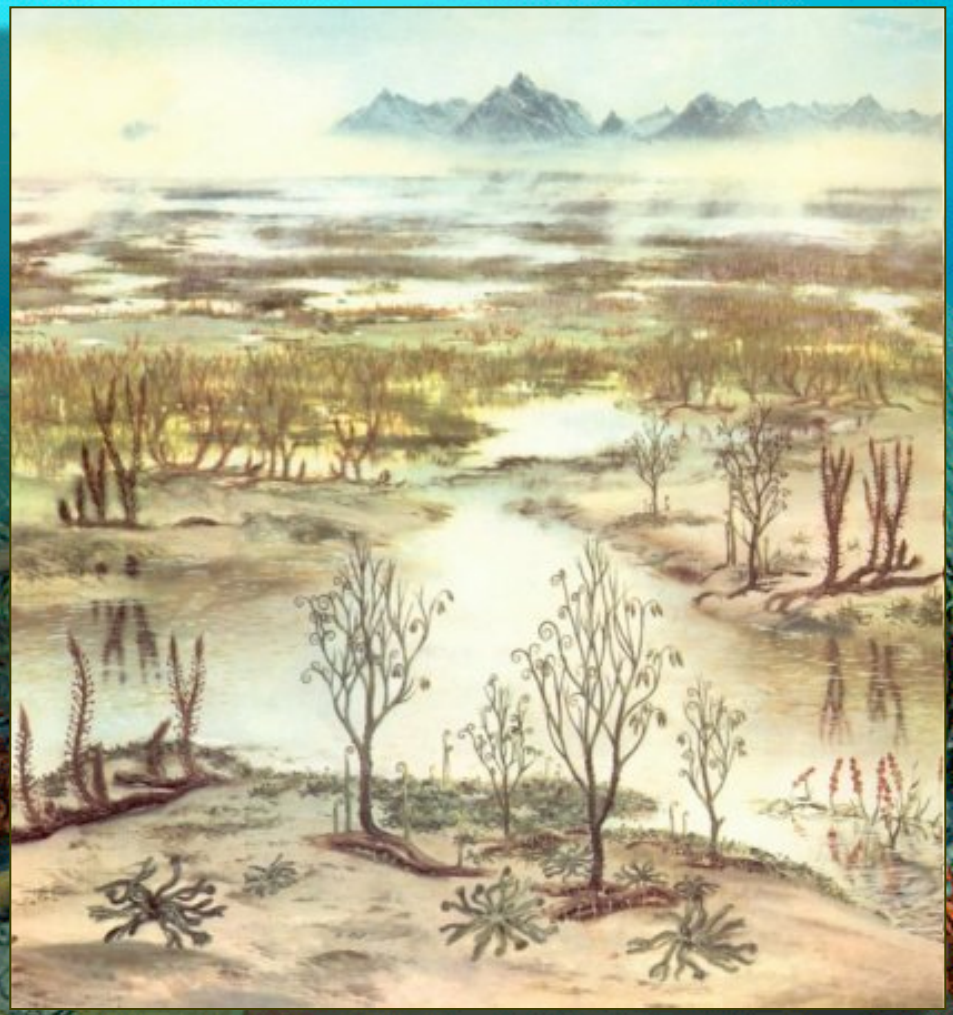
408

443

http://www.karencarr.com/Images/Gallery/2004_detail_silurian.jpg

http://universe-review.ca/I10-29-Silurian.jpg

Silurian: first land plants



Eon	Era	Period
Phanerozoic	Cenozoic	Quarternary
		Tertiary
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		Devonian
		Silurian
		Oridivician
		Cambrian

408

443

http://www.karencarr.com/Images/Gallery/2004_detail_silurian.jpg

http://universe-review.ca/I10-29-Silurian.jpg

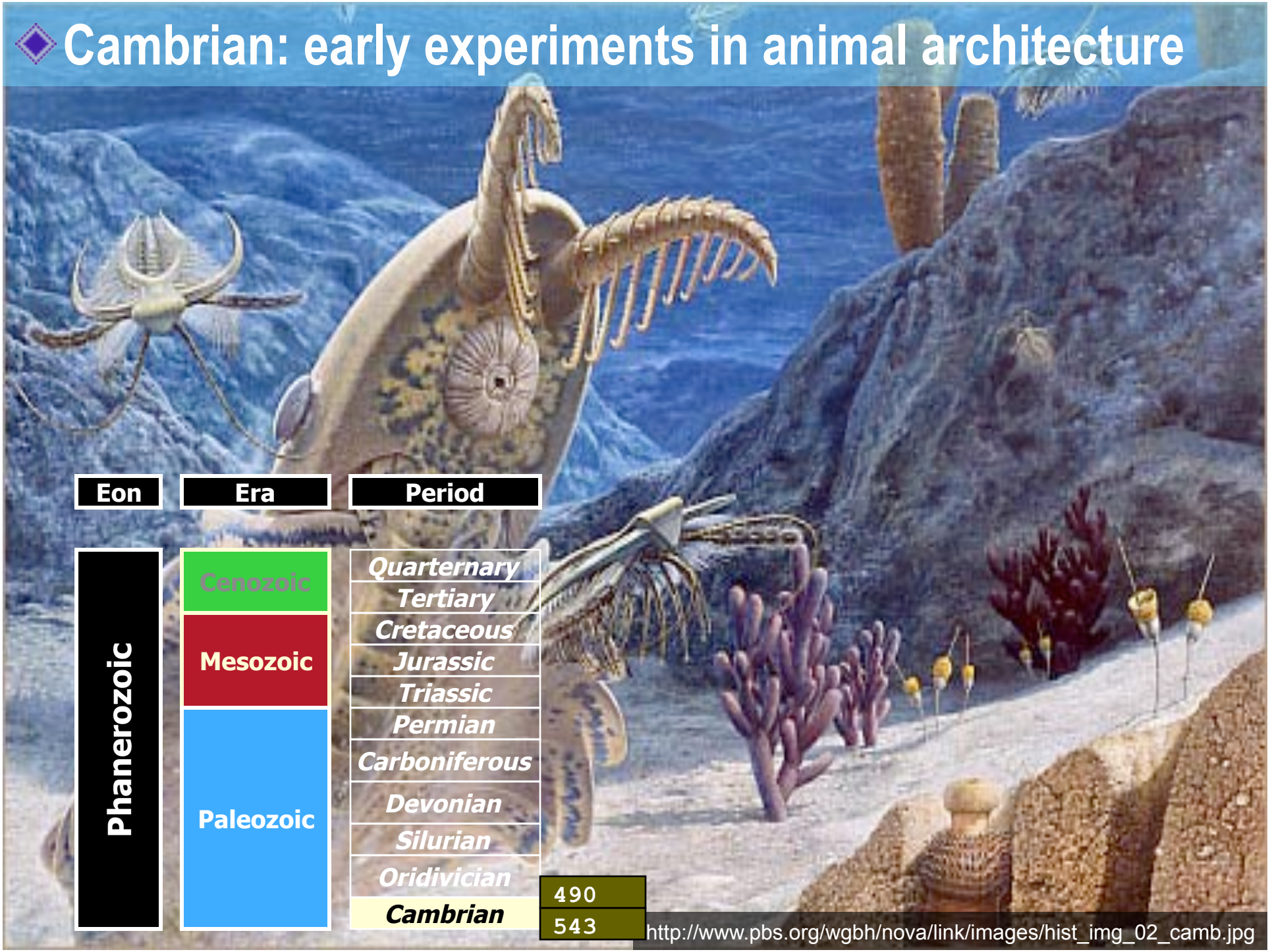
Ordivician: the first coral reefs

Rugose Corals – long extinct

Eon	Era	Period	
Phanerozoic	Cenozoic	*Quarternary*	
		Tertiary	
	Mesozoic	*Cretaceous*	
		Jurassic	
		Triassic	
	Paleozoic	*Permian*	
		Carboniferous	
		Devonian	
		Silurian	
		Oridivician	443
		Cambrian	490

http://www.columbia.edu/itc/eeeb/baker/N0316/Lecture%205/Images/ordovician.JPG

Cambrian: early experiments in animal architecture



Eon	Era	Period		
Phanerozoic	Cenozoic	*Quarternary*		
		Tertiary		
	Mesozoic	*Cretaceous*		
		Jurassic		
		Triassic		
	Paleozoic	*Permian*		
		Carboniferous		
		Devonian		
		Silurian		
		Oridivician		
		Cambrian	490	543

http://www.pbs.org/wgbh/nova/link/images/hist_img_02_camb.jpg

Cambrian: early experiments in animal architecture

Eon	Era	Period
Phanerozoic	Cenozoic	Quarternary
		Tertiary
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		Jurassic
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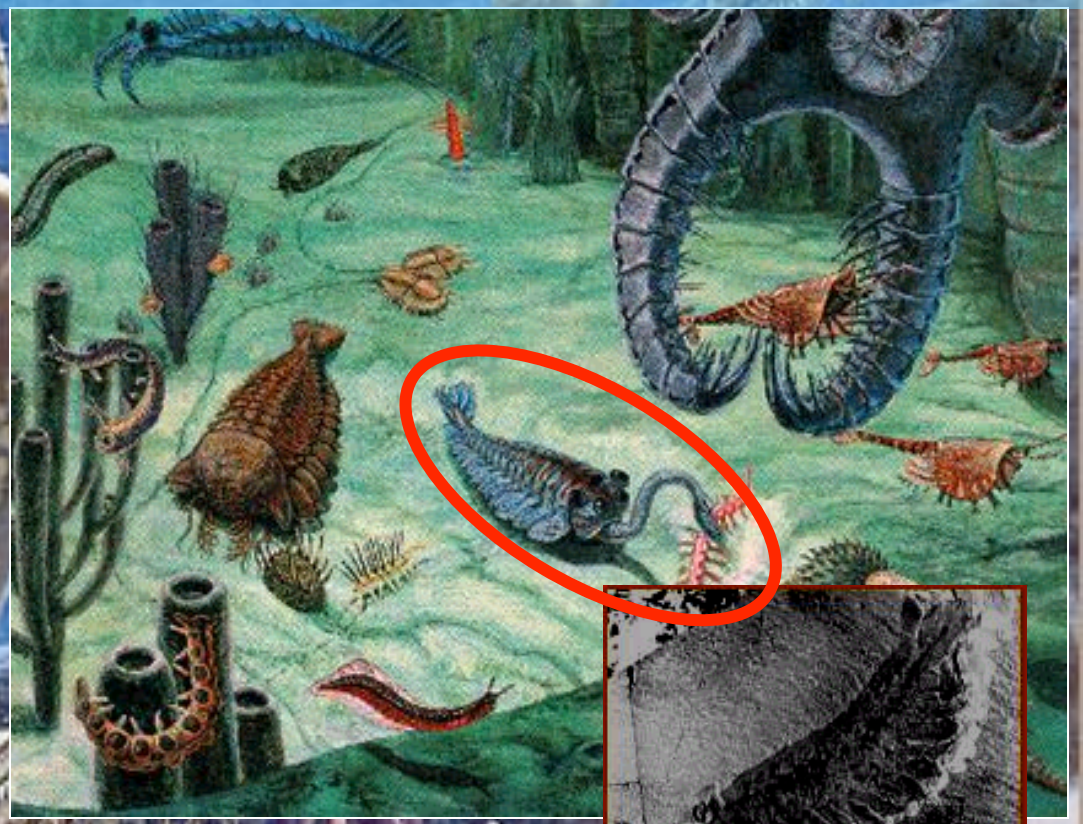
490

543

http://www.pbs.org/wgbh/nova/link/images/hist_img_02_camb.jpg

Cambrian: early experiments in animal architecture



Eon	Era	Period
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		Carboniferous
		Devonian
		Silurian
		Oridivician
		Cambrian

490

543

http://www.pbs.org/wgbh/nova/link/images/hist_img_02_camb.jpg

Cambrian: early experiments in animal architecture

5 eyes, and one long 'snout' with jaws at the end

Opabinia

Marrella

Oridivician

Cambrian

490

543

http://www.pbs.org/wgbh/nova/link/images/hist_img_02_camb.jpg

Cambrian: early experiments in animal architecture

Notochord: a fore runner of the spinal cord

Myotomes: muscle blocks

http://www.3d-art.co.uk/3dpages/3ded/dk-3.html

Eon	Era	Period
nerozoic	Cenozoic	Quarternary
		Tertiary
	Mesozoic	Cretaceous
		Jurassic
		Triassic
		Permian
		Carboniferous
		Cambrian
		543

~ representative of the group that gave rise to all vertebrates (fish, amphibians, reptiles, birds mammals, humans)

http://www.pbs.org/wgbh/nova/link/images/hist_img_02_camb.jpg

Life on earth to scale...

Today

1,000 Mya

2,000 Mya

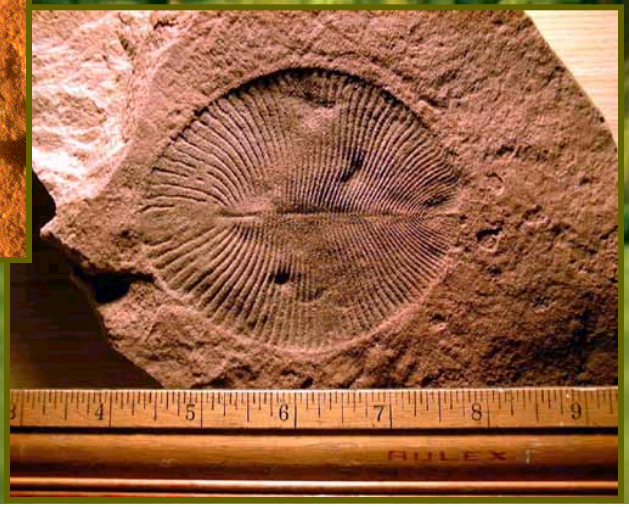
3,000 Mya

4,000 Mya

Up until the 1960's, the lack of a pre-Cambrian fossil record was still being widely cited as evidence for a divine creation:

Ediacaran fauna: earliest multicellular fossils...

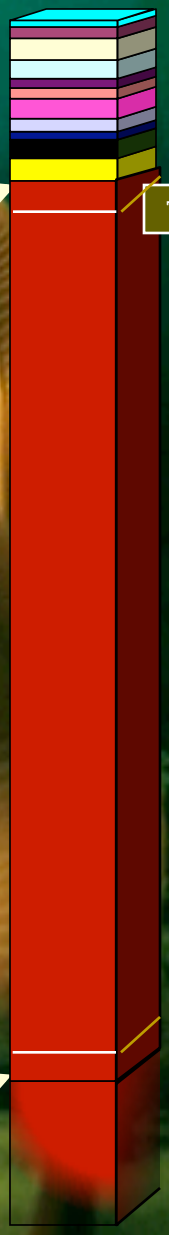
Pteridium – a modern cnidarian (jellyfish)



Cambrian explosion

Earliest Multicellular Fossils

Oldest known fossils



Today

730 mya

1,000 Mya

2,000 Mya

3,000 Mya

4,000 Mya

The big picture...

Life in a day...

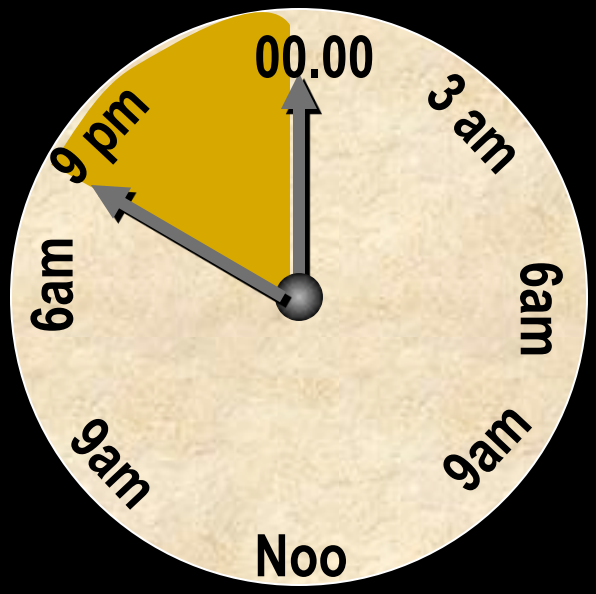
Recorded history starts at 11:59pm, 59s

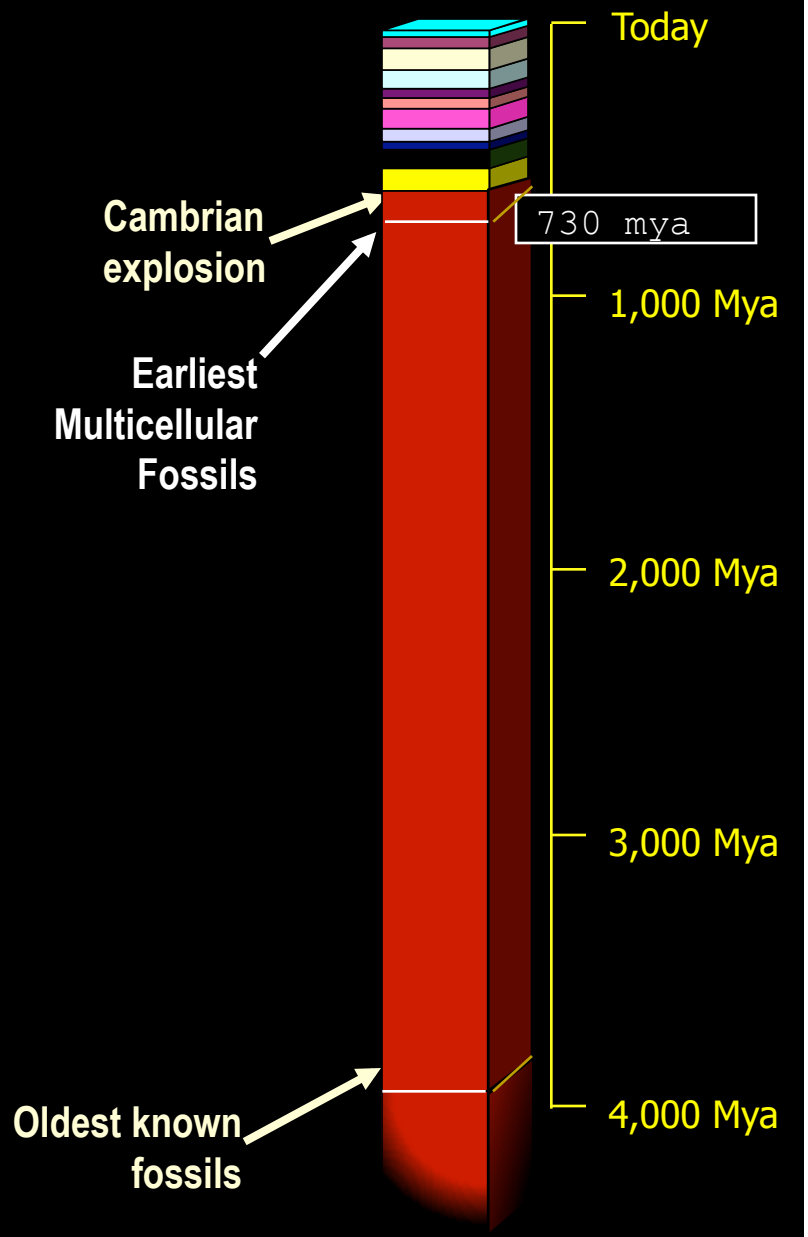
Homo sapiens arrives at 11:59pm

Dinosaurs go extinct at 11:00pm

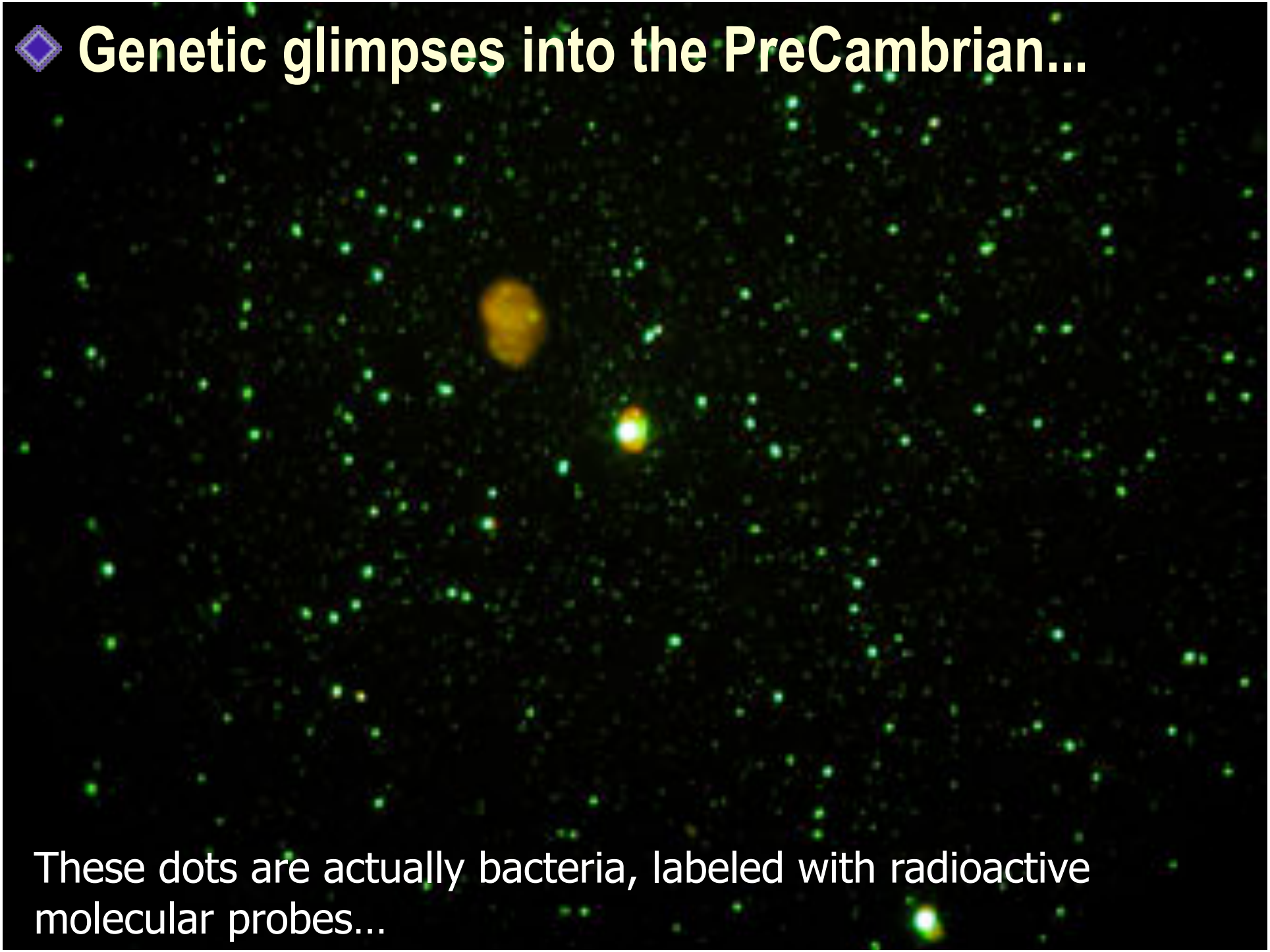
Cambrian explosion at 9:00pm

Earliest multicellular organisms 8:45pm





Genetic glimpses into the PreCambrian...



These dots are actually bacteria, labeled with radioactive molecular probes…

Genetic glimpses into the PreCambrian...

A collection of marine microbes. The darkest ones are a very common filamentous form that at present have not been formerly identified in scientific literature. The large pink ovoid is a cell of Chromatium a purple sulphur bacterium, the green is a cyanobacterium. The curving structure at about 2 o'clock is a diatom (Nitzschia), which is a photosynthetic eukaryote. Photo credit: D. J. Patterson, L. Amaral-Zettler and V. Edgcomb

"One litre of seawater can contain more than 20,000 different types of bacteria, scientists have found.

The extraordinary number has been established by an international project attempting to catalogue all ocean life.

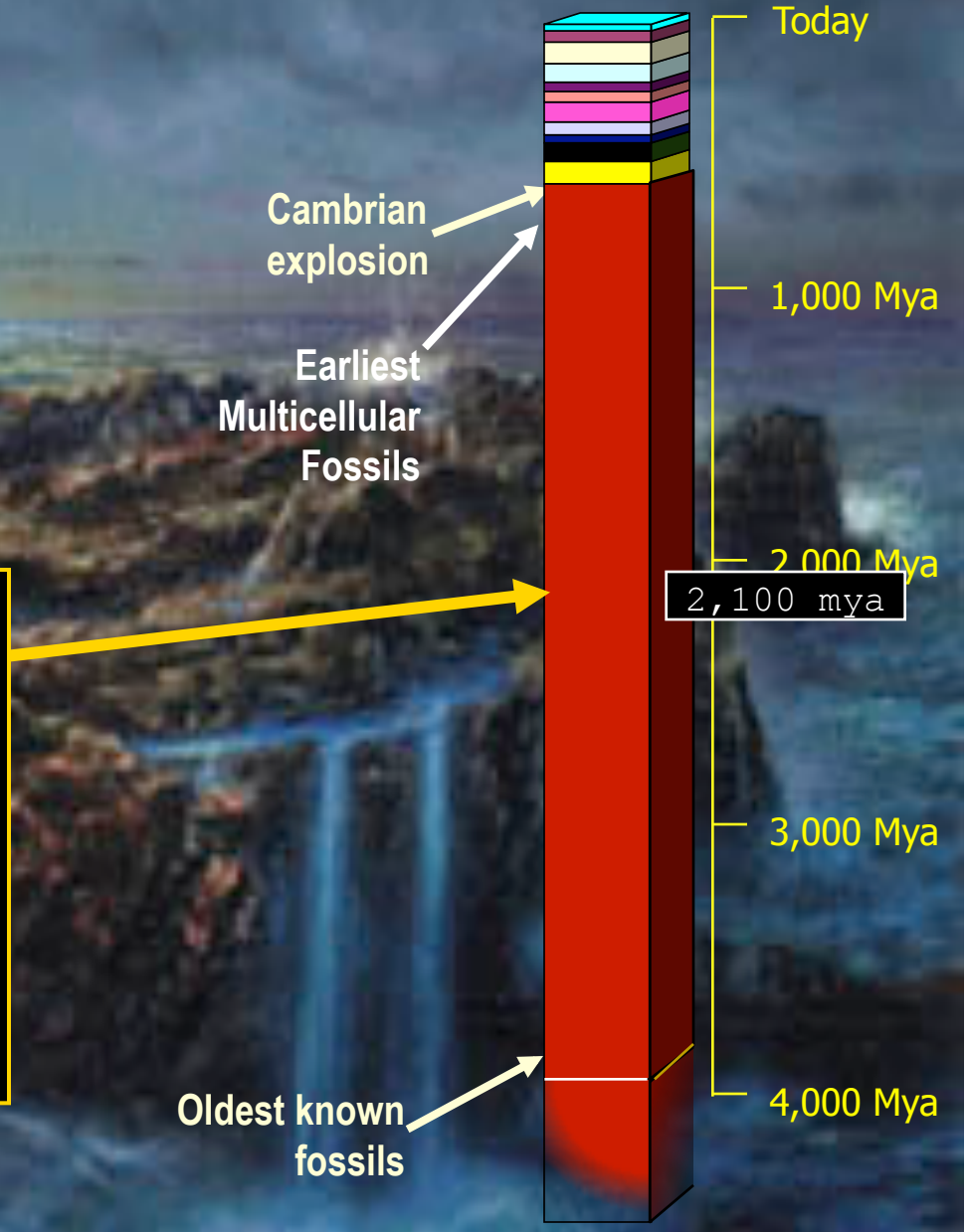
It suggests microbial biodiversity is much greater than previously thought, say Mitchell Sogin and colleagues.

…It was undertaken using a new technique that allows for the rapid identification of distinct organisms by probing just small snippets of DNA. "

BBC News, July 21st 2006

These dots are actually bacteria, labeled with radioactive molecular probes…

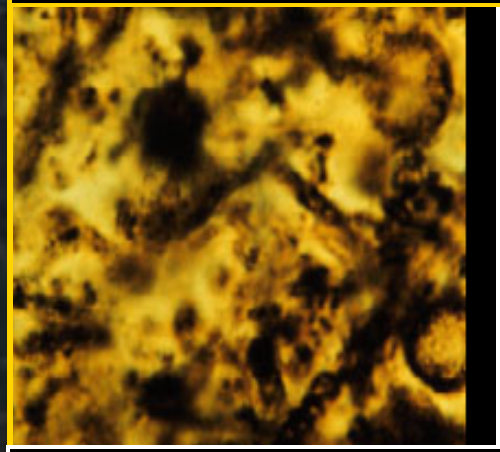
The Pre-Cambrian (Paleozoic)

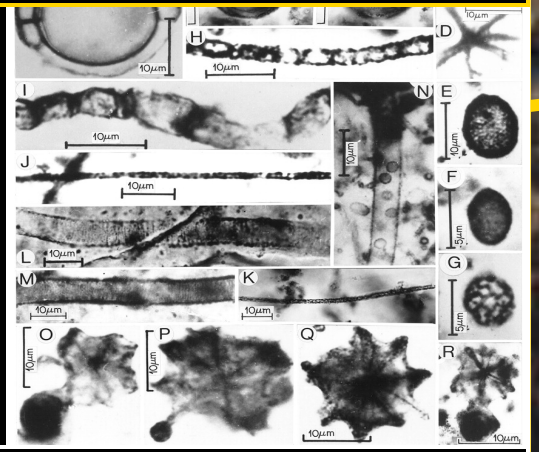


1953: American geologist Stanley Tyler sets out to investigate the geology of the Gunflint Formation, a mid-Precambrian (2,100-Ma-old) iron-rich rock unit that straddles the U.S.-Canada border between northern Minnesota and southern Ontario

The Pre-Cambrian (Paleozoic)

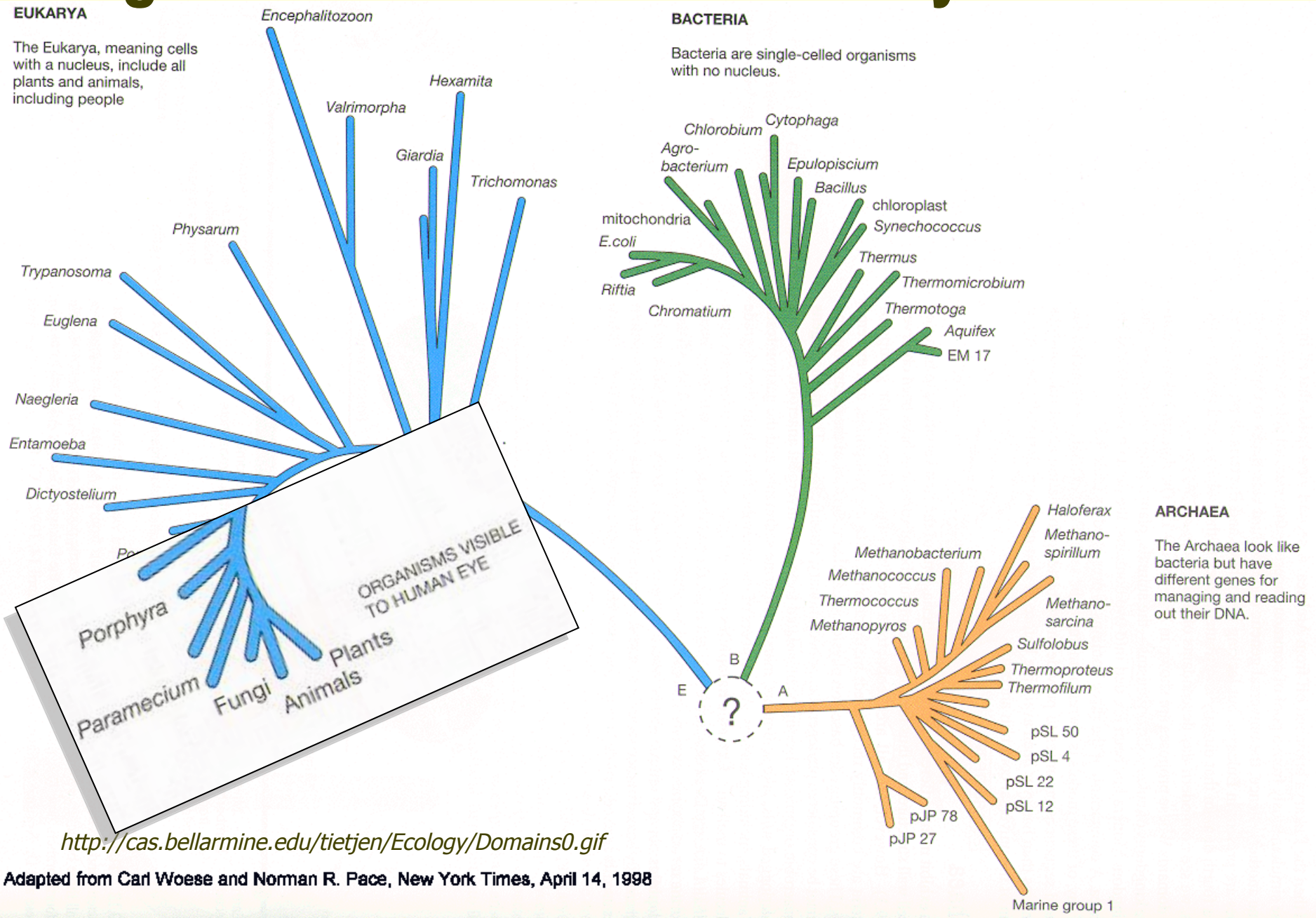
He finds a curious black chert, unlike known rocks of this type. Placing it under the microscope, he sees the following





(from the right rocks) we now recognize that the Pre-Cambrian was teaming with life ~ microscopic life. These are now found as microfossils

A genetic tree of life's diversity...



http://cas.bellarmine.edu/tietjen/Ecology/Domains0.gif

Adapted from Carl Woese and Norman R. Pace, New York Times, April 14, 1998

The Pre-Cambrian (Paleozoic)

Today

1,000 Mya

Cambrian explosion

earliest metazoa

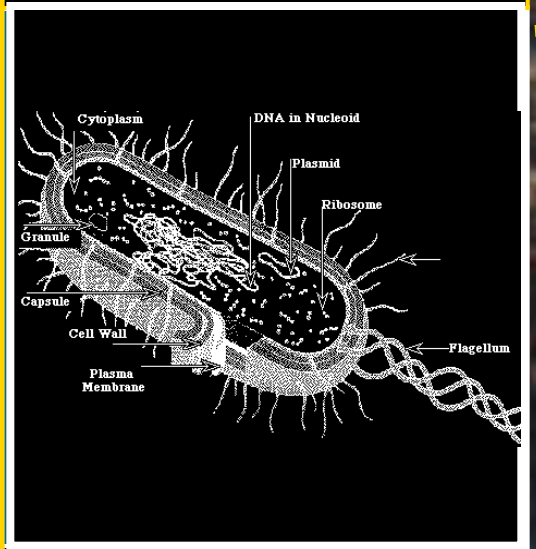
2,000 mya

3,000 Mya

Oldest known fossils

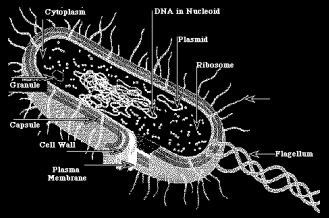
4,000 Mya

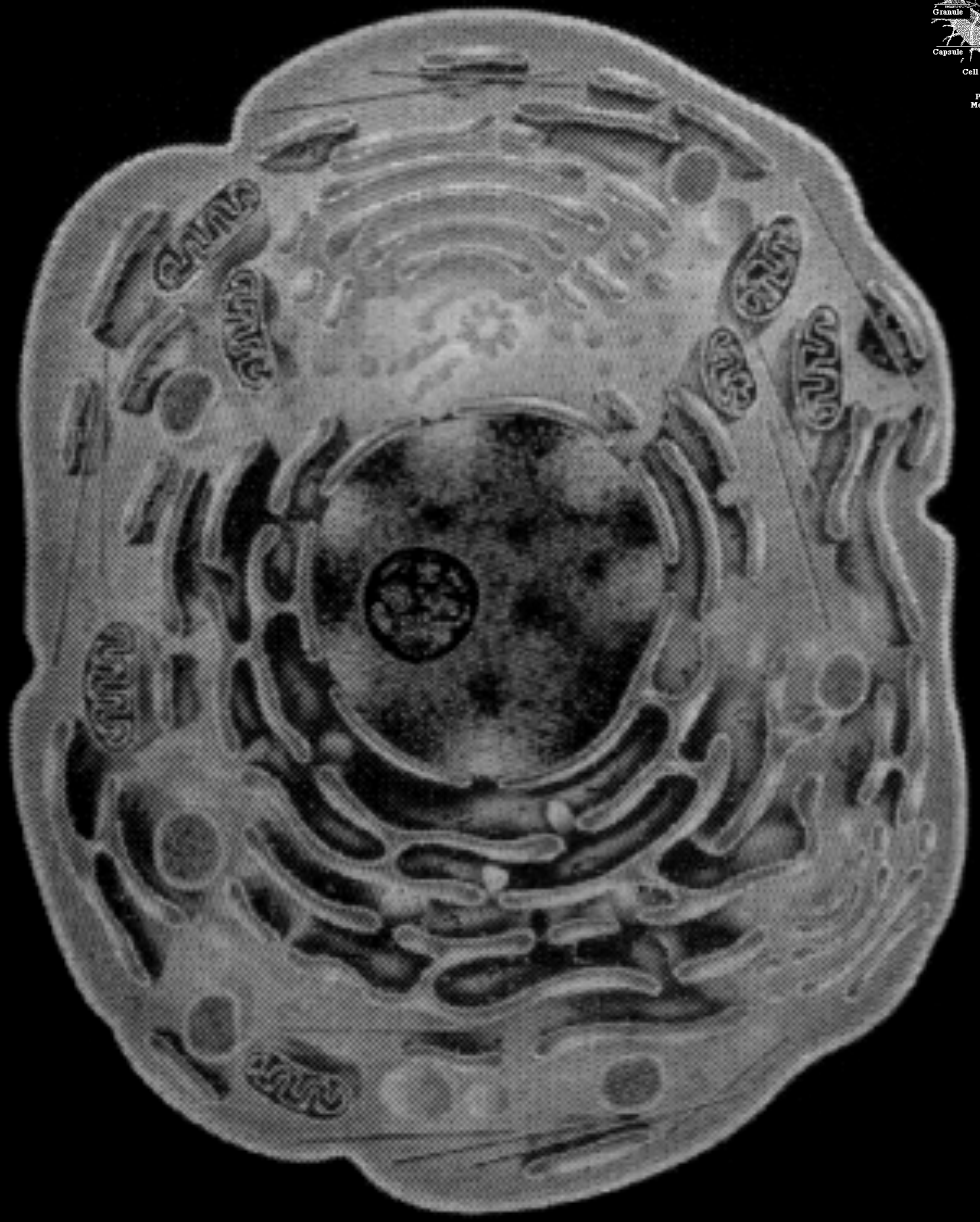
Eukaryotes originate about 2 bya



(distinguished by size and morphology within the microfossil fauna/flora)

Oxygen: the most toxic gas on earth





All aerobic eukaryotes use mitochondria to process oxygen (controlling its corrosive powers by using it to burn sugar, producing energy)

Stromatolites ~ the oldest 'living fossils'

2.3 bya stromatolites, Transvaal

Today

1,000 Mya

2,000 Mya

2,300 mya

3,000 Mya

4,000 Mya

Cambrian explosion

Earliest Multicellular

Oldest known fossils

Stromatolites ~ the oldest 'living fossils'

Today's stromatolites, Shark Bay

2.3 bya stromatolites, Transvaal

Today

1,000 Mya

2,000 Mya

2,300 mya

3,000 Mya

4,000 Mya

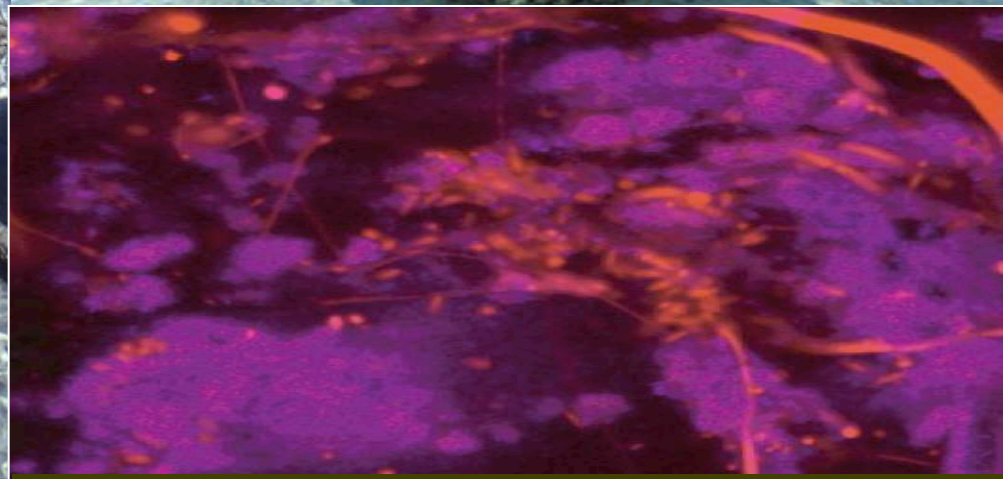
Cambrian explosion

Earliest Multicellular Fossils

Oldest known fossils

Stromatolites ~ the oldest 'living fossils'

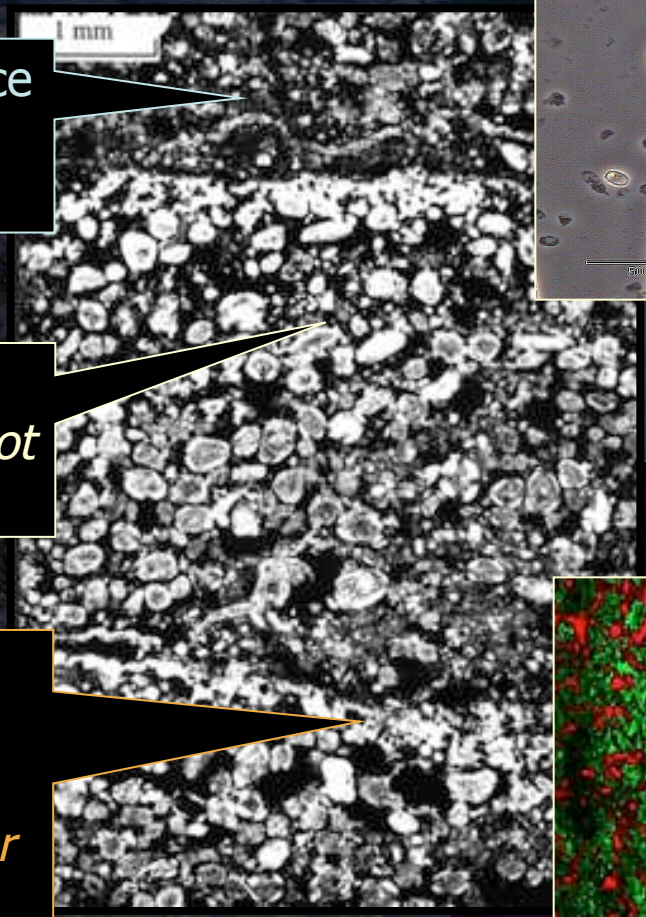
these ecosystems are "microbial coral reefs" in terms of rich, complex species interactions



Bacteria (red) are intimately associated with carbonate precipitates (blue).

Stromatolites ~ community structure

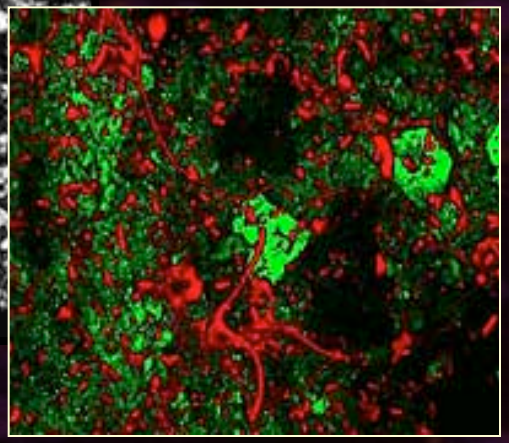
exterior



Cyanobacteria produce oxygen through photosynthesis

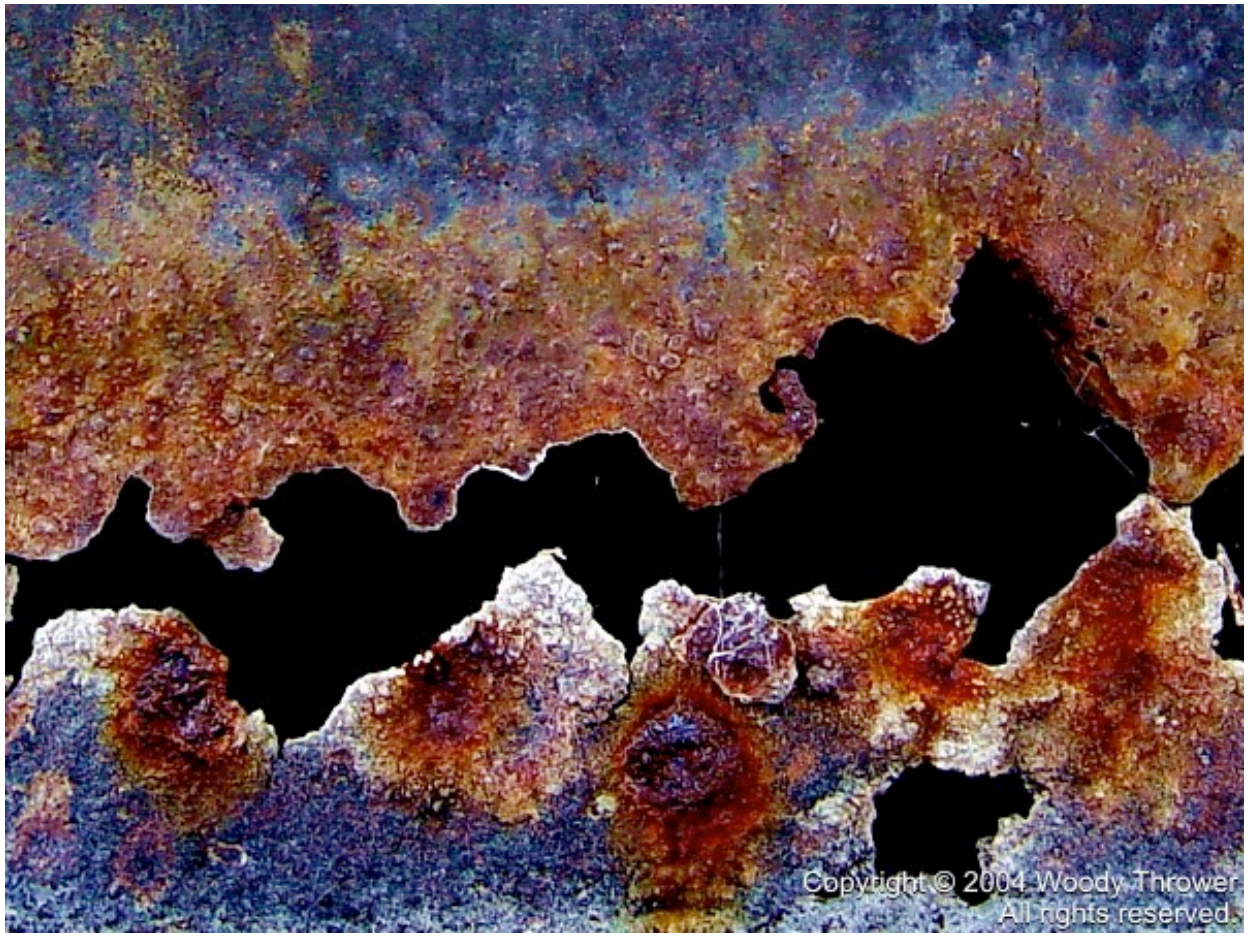
Various bacteria that are tolerant to, but not reliant on, oxygen

Various bacteria that are poisoned by oxygen, and photosynthesize other chemicals, e.g. methane



interior

Oxygen: the most toxic gas on earth



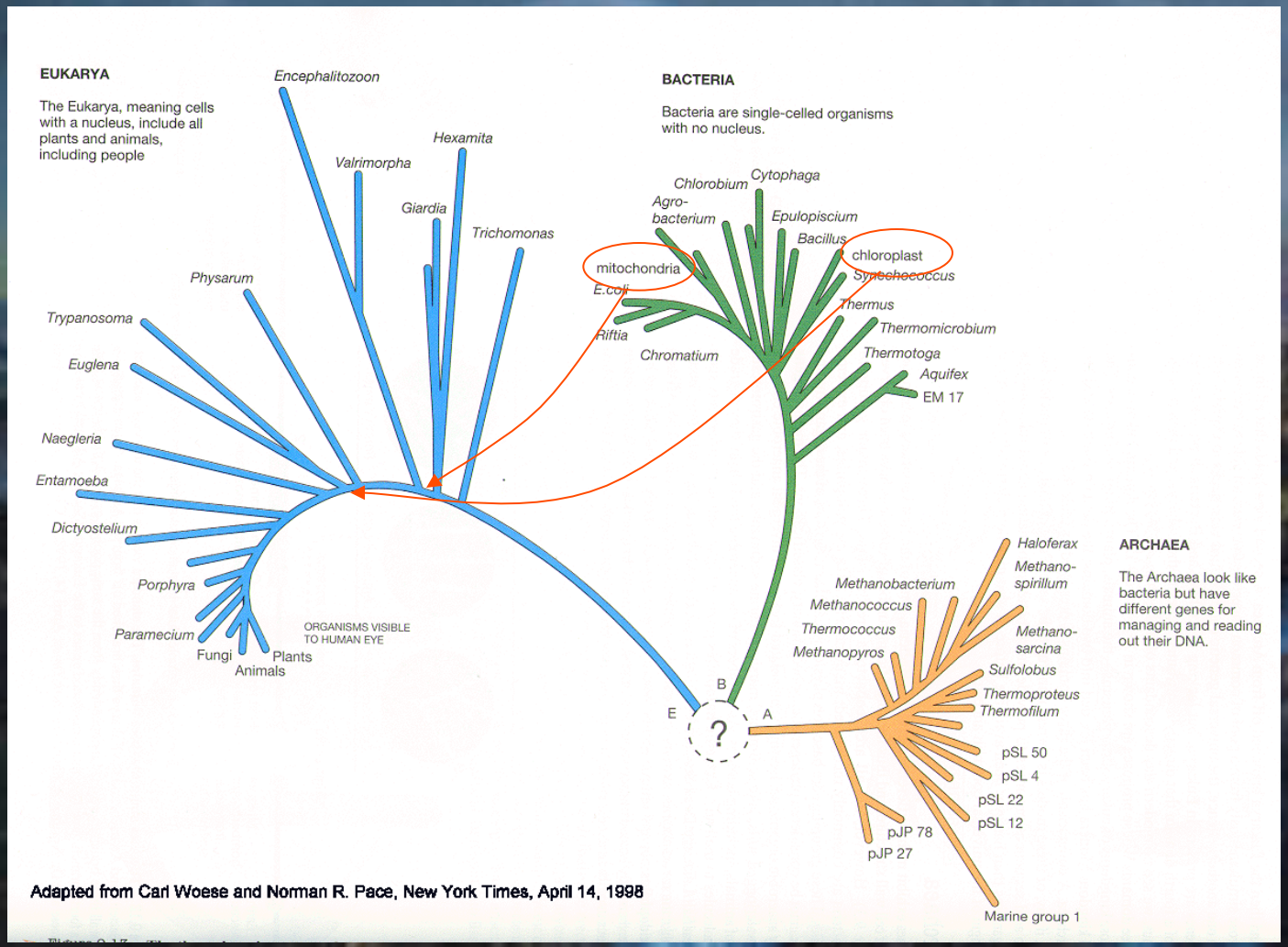
BIF's, oxygen and eukaryotes

Banded Iron Formation (BIF) From Michigan, dating to around 2.5 Bya

Dissolved iron is slowly oxidized to rust (O_2 producing cyanobacteria evolve and spread)

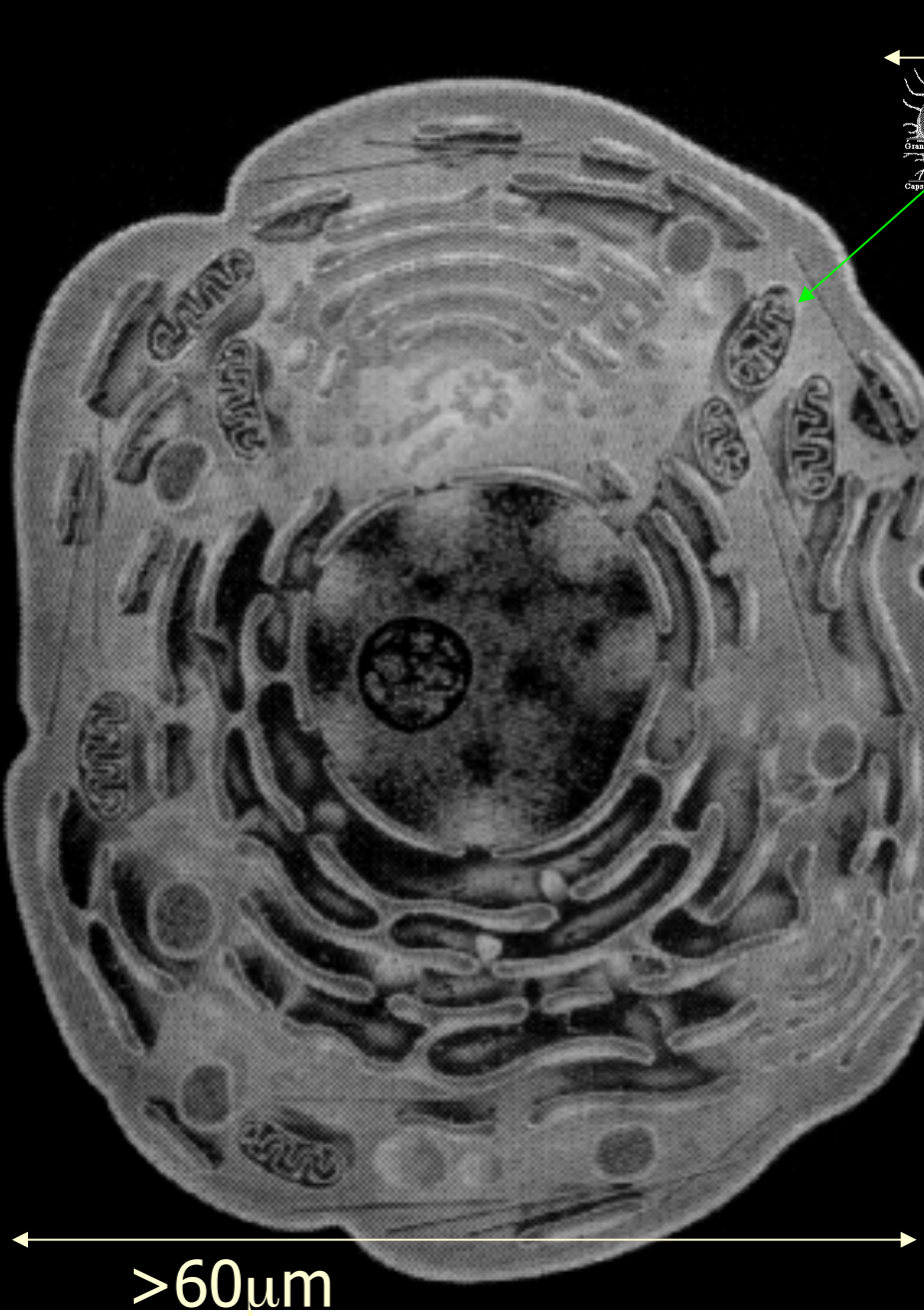
Iron is washed from rocks into the ocean

(Genetic data adds detail to the endosymbiont theory)



Adapted from Carl Woese and Norman R. Pace, New York Times, April 14, 1998

Eukaryotes, mitochondria (and choloroplasts)

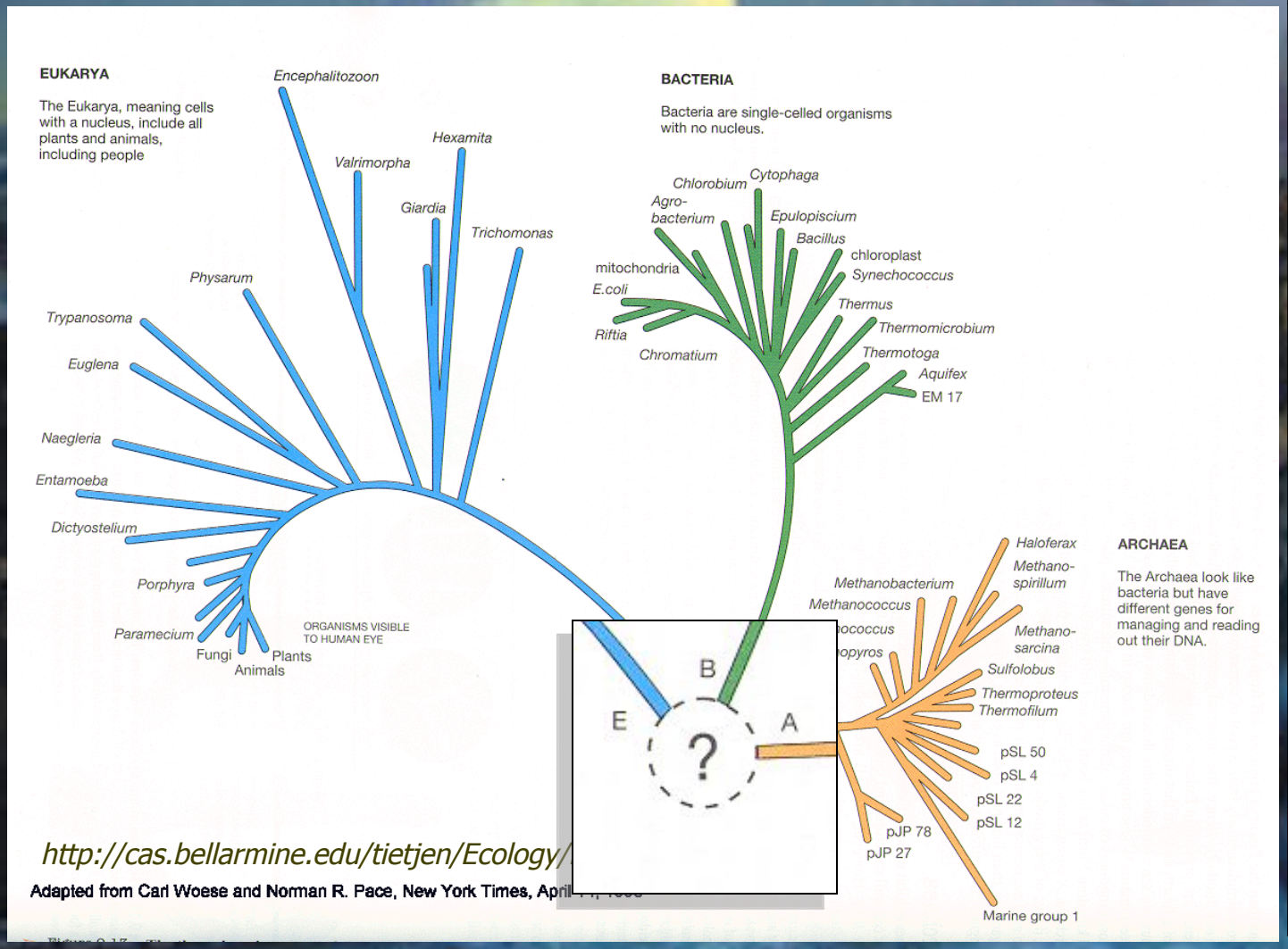


All aerobic eukaryotes use mitochondria to process oxygen
Photosynthetic plants use chloroplasts to process light, carbon dioxide and water into sugars (that store energy)

- ~ *mitochondria and chloroplasts are about the same size as bacteria;*
- ~ *they display a double membrane*
- ~ *they retain small amounts of DNA genomes*

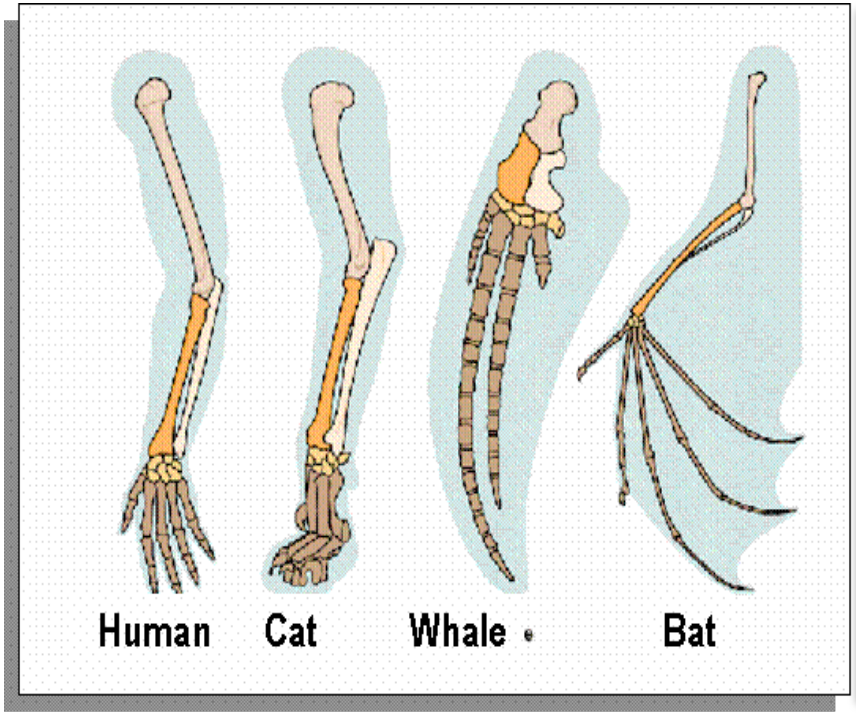
The last universal common ancestor of life (LUCA)

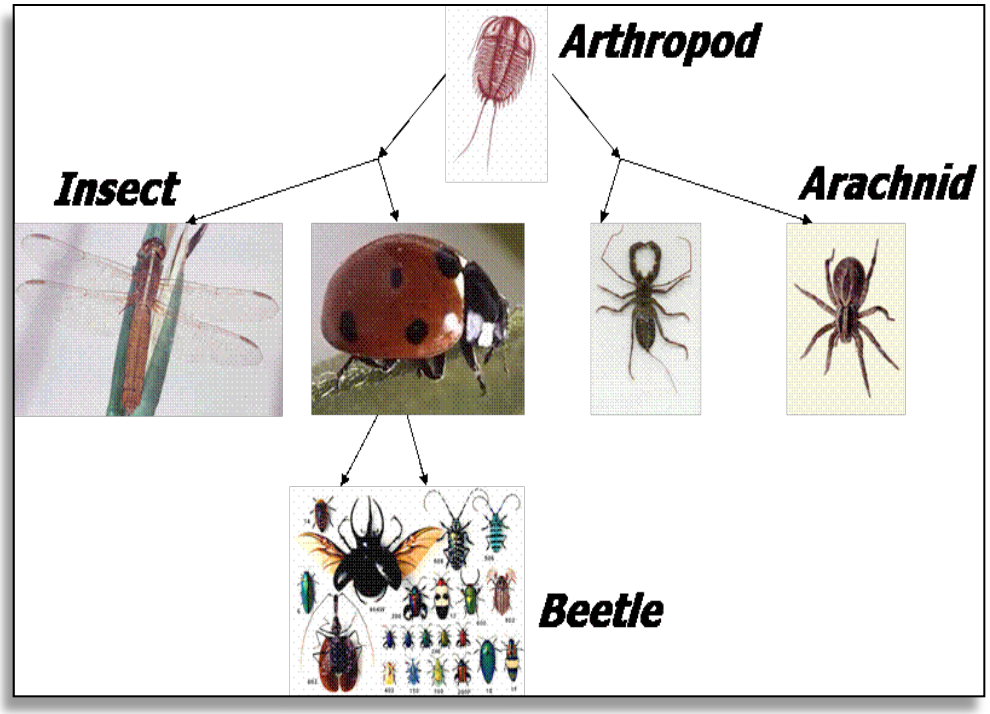
What was it like?



Evolutionary homology gives us insight into the past

Different species have separated from one another at different times. The time since divergence (separation) will determine their overall level of similarity

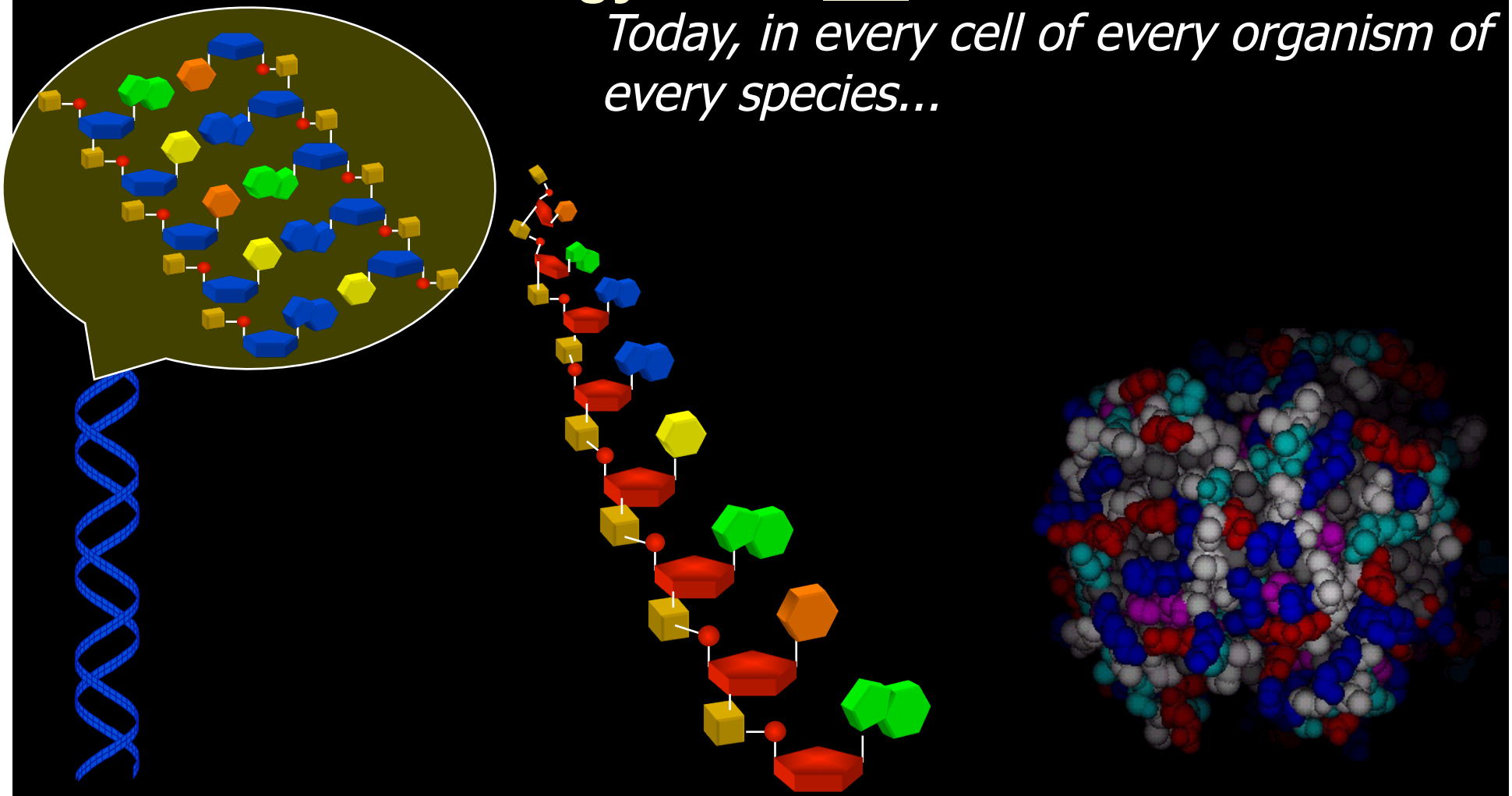




Treated carefully, the similarities can indicate the nature of a common ancestor…

So what homology does *all* of life share?

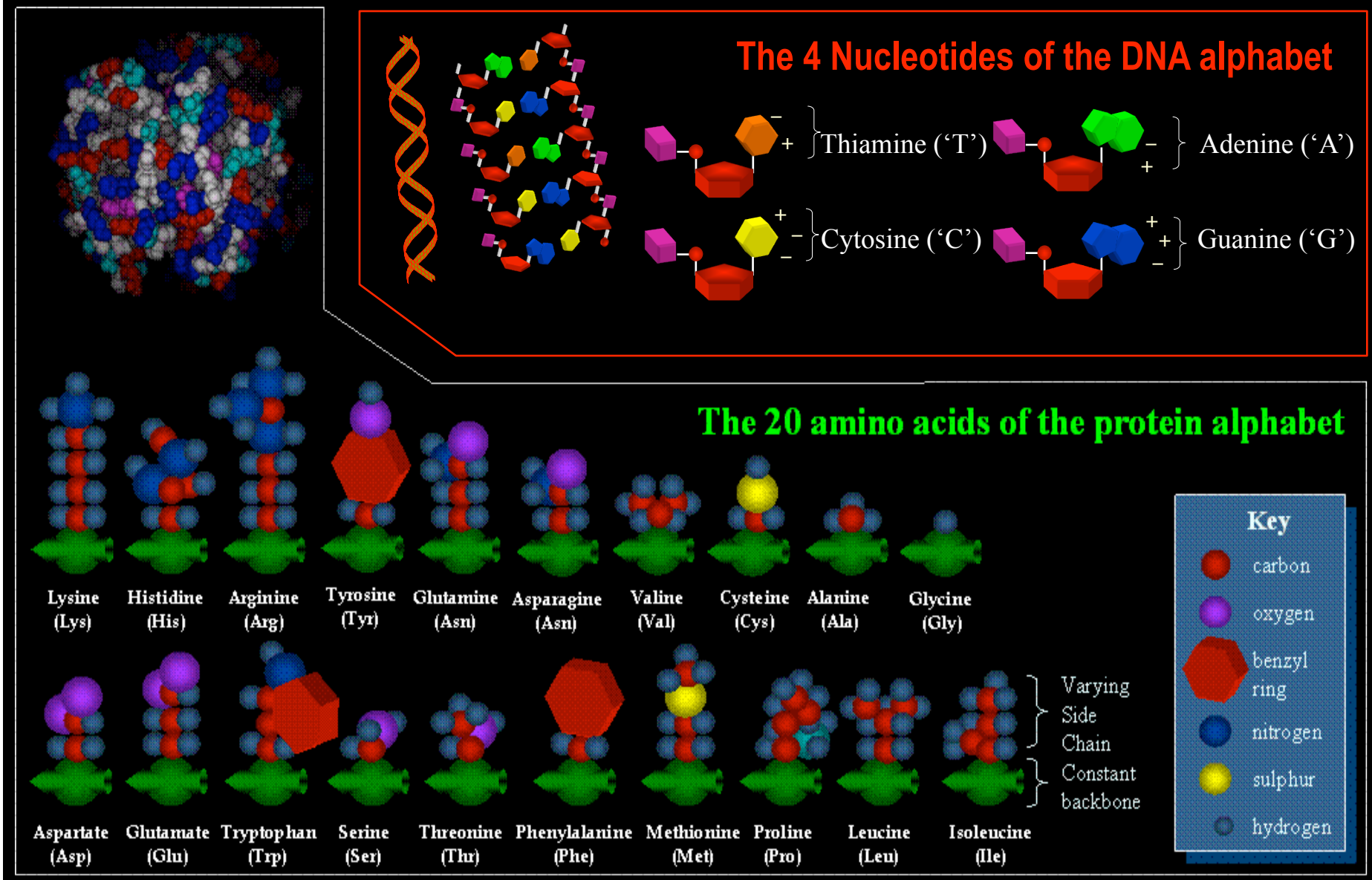
Today, in every cell of every organism of every species...



DNA (information) → RNA ('temporary' gene) → Protein (phenotype)

DNA genes are transcribed into RNA "messages" that are then translated into proteins. Proteins can be structural (e.g. keratin in hair) or enzymatic ~ catalyzing particular chemical reactions

The Chemical Alphabets of Life



The Genetic Code maps genetic words into amino acids

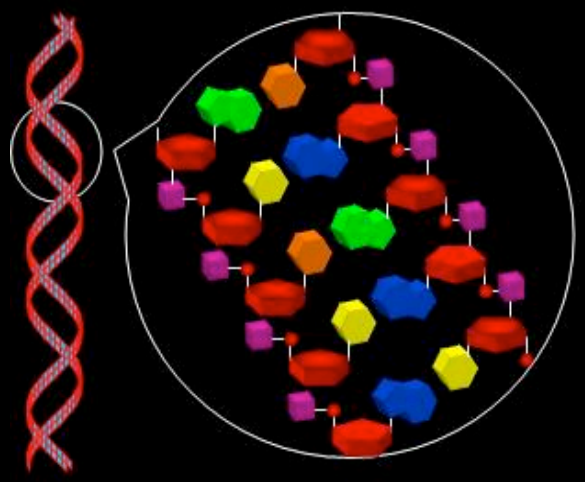
UUU	Phe	UCU	Ser	UAU	Tyr	UGU	Cys
UUC		UCC		UAC		UGC	
UUA	Leu	UCA		UAA		UGA	
UUG		UCG		UAG		UGG	Trp
CUU	Leu	CCU	Pro	CAU	His	CGU	Arg
CUC		CCC		CAC		CGC	
CUA		CCA		CAA	Gln	CGA	
CUG		CCG		CAG		CGG	
AUU	Ile	ACU	Thr	AAU	Asn	AGU	Ser
AUC		ACC		AAC		AGC	
AUA		ACA		AAA	Lys	AGA	Arg
AUG	Met	ACG		AAG		AGG	
GUU	Val	GCU	Ala	CAU	Asp	GGU	Gly
GUC		GCC		CAC		GGC	
GUA		GCA		CAA	Glu	GGA	
GUG		GCG		CAG		GGG	

3 nucleotides, read as a 'codon' are translated into 1 amino acid

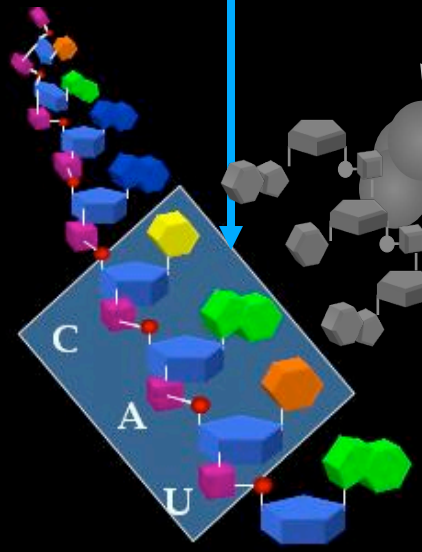
A triplet '*Codon*' of mRNA

tRNA – the 'adaptor' molecule

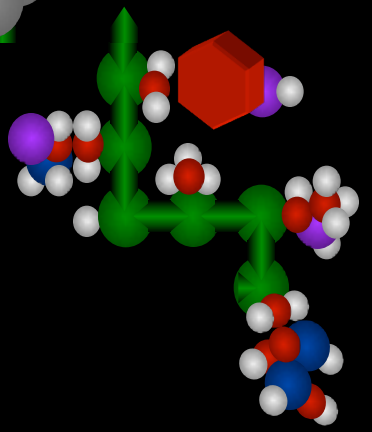
Histidine (His)



The double helix of DNA

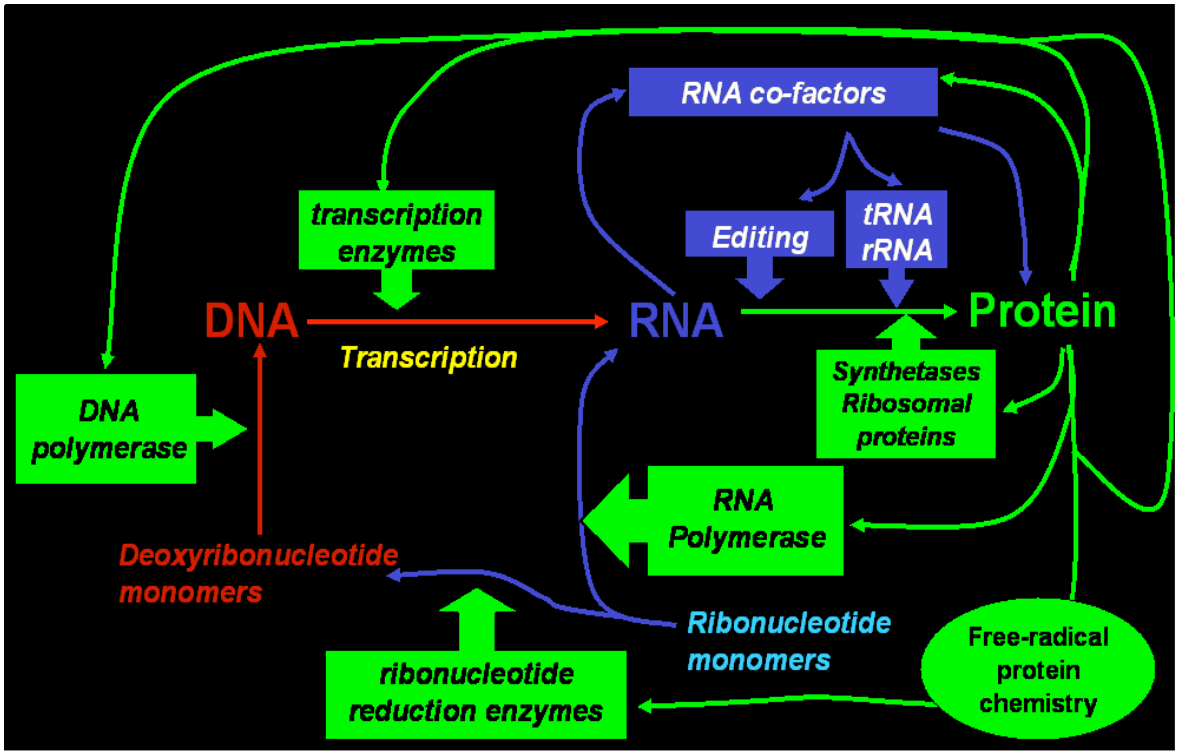


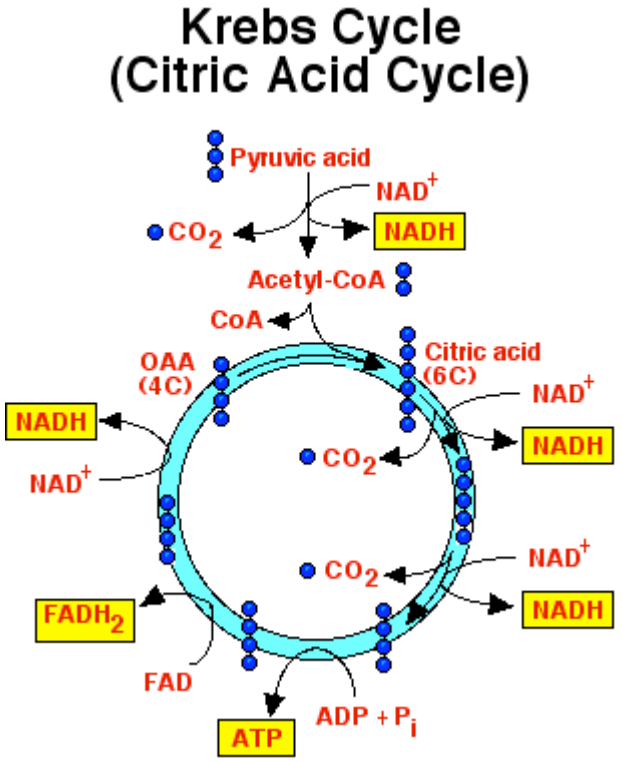
Messenger RNA (mRNA)



Protein

In fact a lot of fundamental biochemistry is shared





Life on Earth gets off to an early start...

Nature (1996) 384:55-9. "**Evidence for life on Earth before 3,800 million years ago**", *Eiler JM, Mojzsis SJ, Arrhenius G.*

"It is unknown when life first appeared on Earth…Here we … provide evidence for the emergence of life on Earth by at least 3,800 Myr before present."

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known
igns of

The earth was a molten mass, pummeled by BIG impacts

Life on Earth gets off to an early start...

One of which is thought to have created our moon...

Oldest known fossil signs of life

Today

1,000 Mya

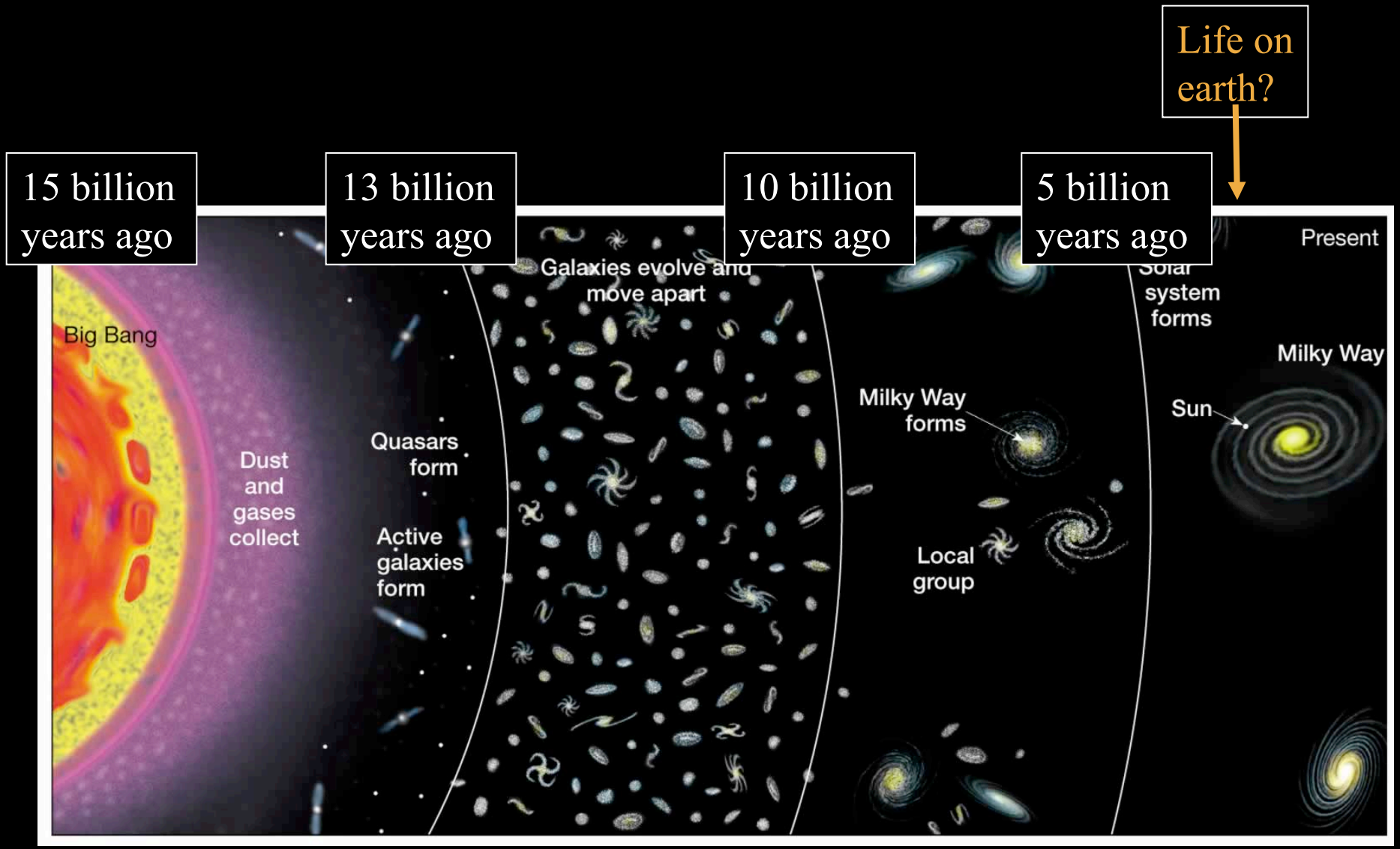
2,000 Mya

3,000 Mya

4,000 Mya

The earth was a molten mass, pummeled by BIG impacts

Physics suggests the following timeline



So do we expect a galaxy teaming with life?











STAR TREK

Or are we likely to be alone?

STAR TREK

3 more lectures…

(i) A History of Life on earth

(ii) The Evolution of the Genetic Code

(iii) The Evolution of the Amino Acid "Alphabet"

(iv) The origin of life –here and elsewhere?