

# Evidence for Evolution – The Fossil Record

(a) Strata of sedimentary rock with fossils embedded



(b) Fossilized sea urchin, at least 65 million years old



# Outline

- Conditions for fossilization
- Relative and absolute dating of fossils
- The story of life on Earth
- Missing links?

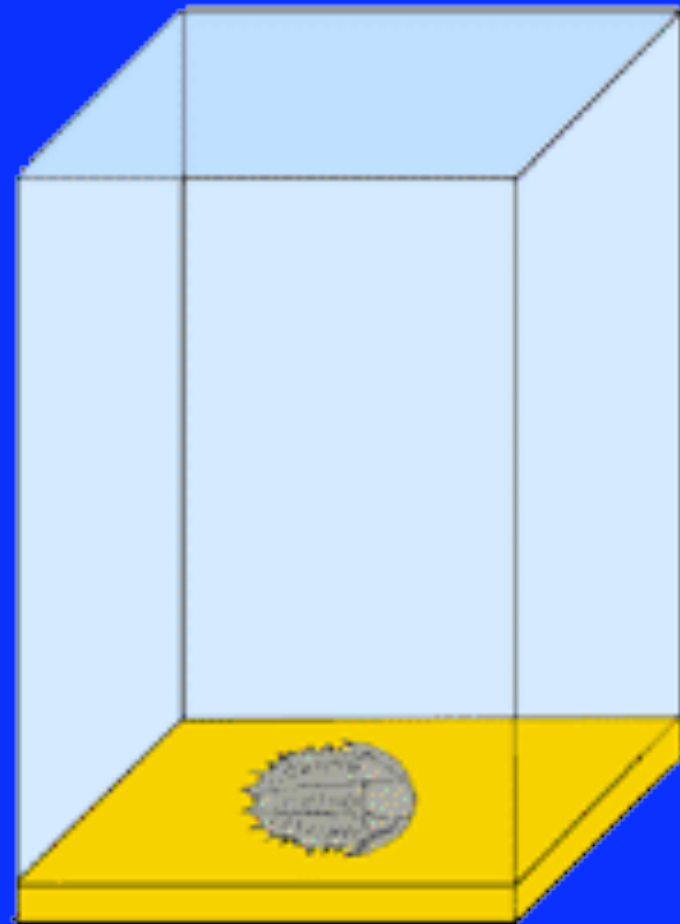
**NOTE:** many slides in the four evolution lectures obtained from Web sources: Ken Miller [“Hot Science, Cool Talks” at UT Austin], Elizabeth Saunders, Carl Wozniak, Caltech Bio 1

# The Basic Story

- Fossils are a record of life on Earth
- However, it is difficult to make a fossil  
**Even worse: biased towards some creatures**
- How does fossilization occur?

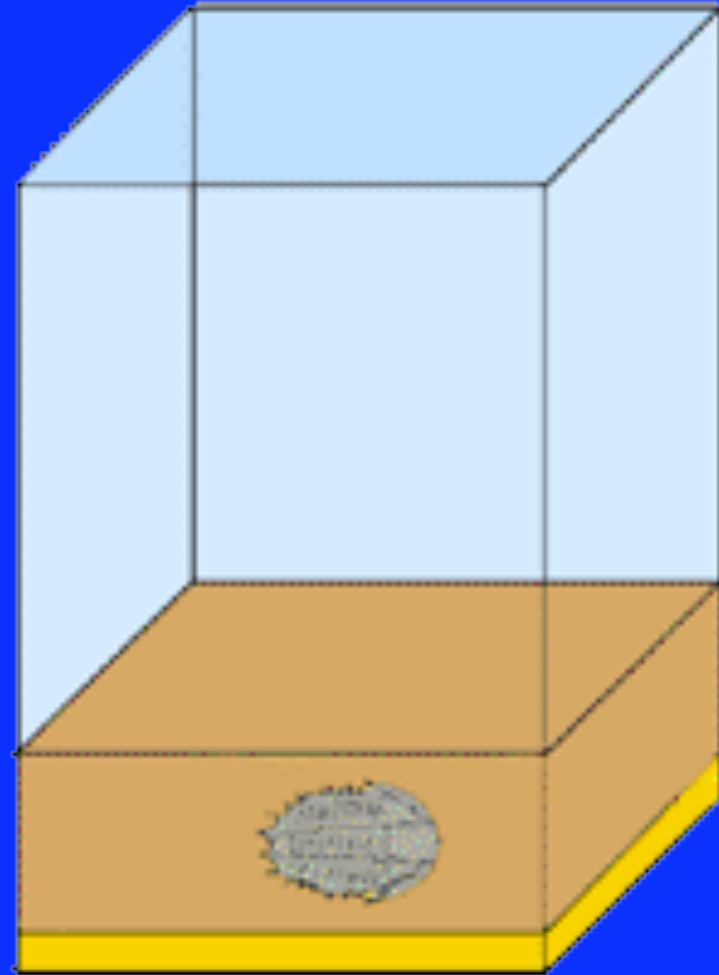
# 1. Dying In/Near Water

- Example: trilobite
- Water insulates from much decomp/weather
- Bacteria eat soft parts, leave exoskeleton



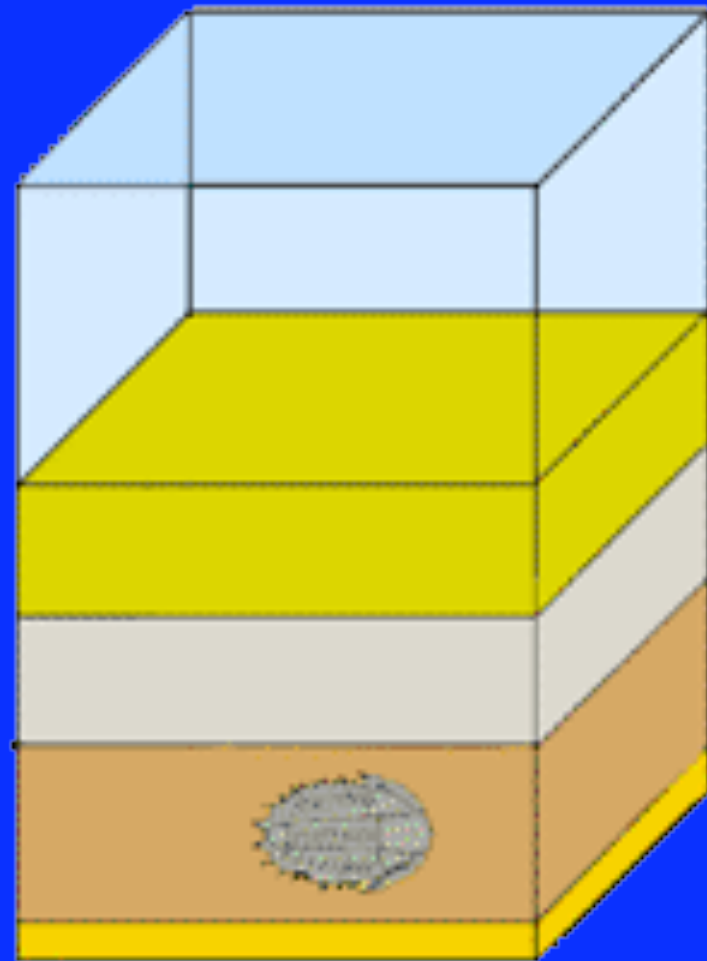
## 2. Rapid Sedimentation

- Rapid coverage reduces decomp  
Land/mudslides  
River delta
- Fine grains (clay) allow detail; coarse grains (sand) don't



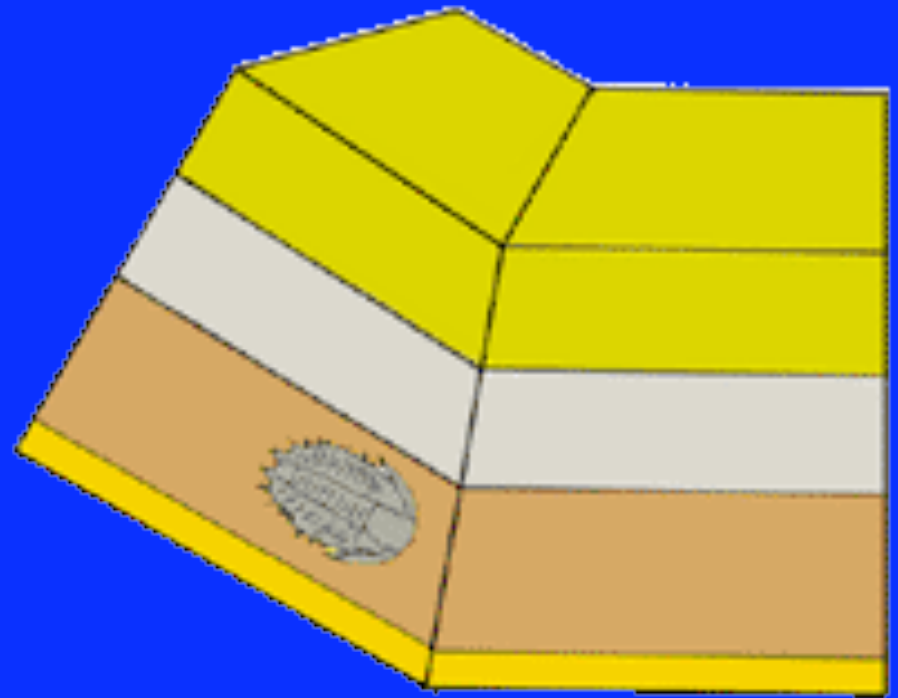
# 3. Permineralization

- Weight of additional layers compacts sediment, makes rock
- Mineral-rich water percolates down
- Glues together particles; can replace exoskeleton with rock
- Thus, trilobite-shaped rock is left



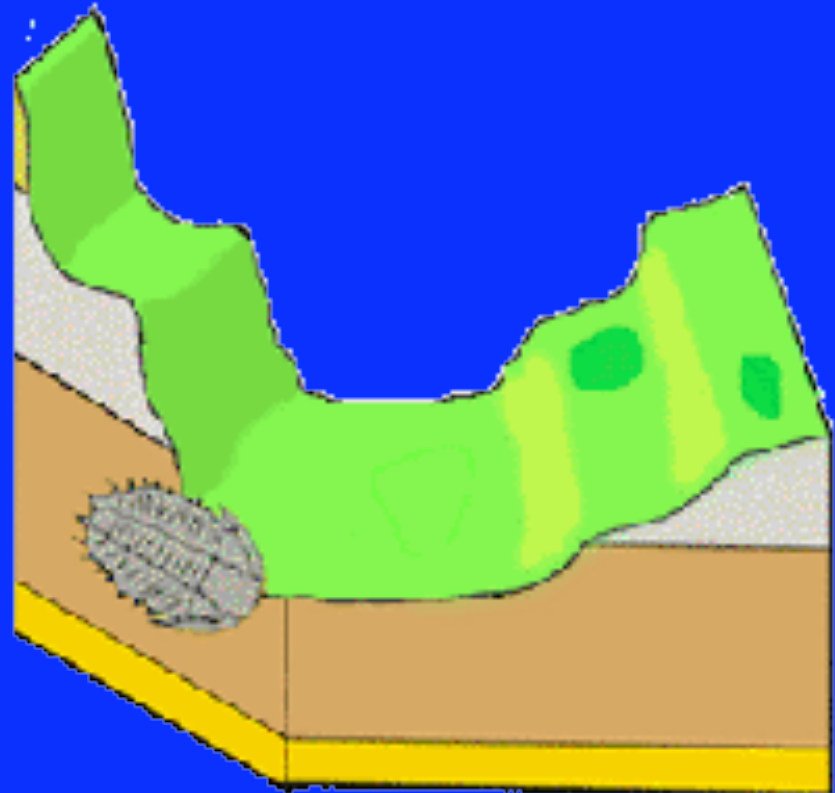
## 4. Uplift

- Great, but fossil now buried thousands of feet down!
- Tectonic motion can shift around; sea floors move to land
- Of course, many fossils are also destroyed this way



# 5. Erosion

- Still need exposure for discovery
- Wind, rain, freeze/thaw, etc. can reveal the fossil
- Hope that it isn't damaged in process!



[http://www.fossils-facts-and-finds.com/fossil\\_formation.html](http://www.fossils-facts-and-finds.com/fossil_formation.html)



# Good Spots for Fossilization

- Montana badlands, western China, ...
  - But such treasure troves are rare
  - Also, very incomplete record
  - Hard parts easier to fossilize
- Poor tally of soft animals/plants/bacteria

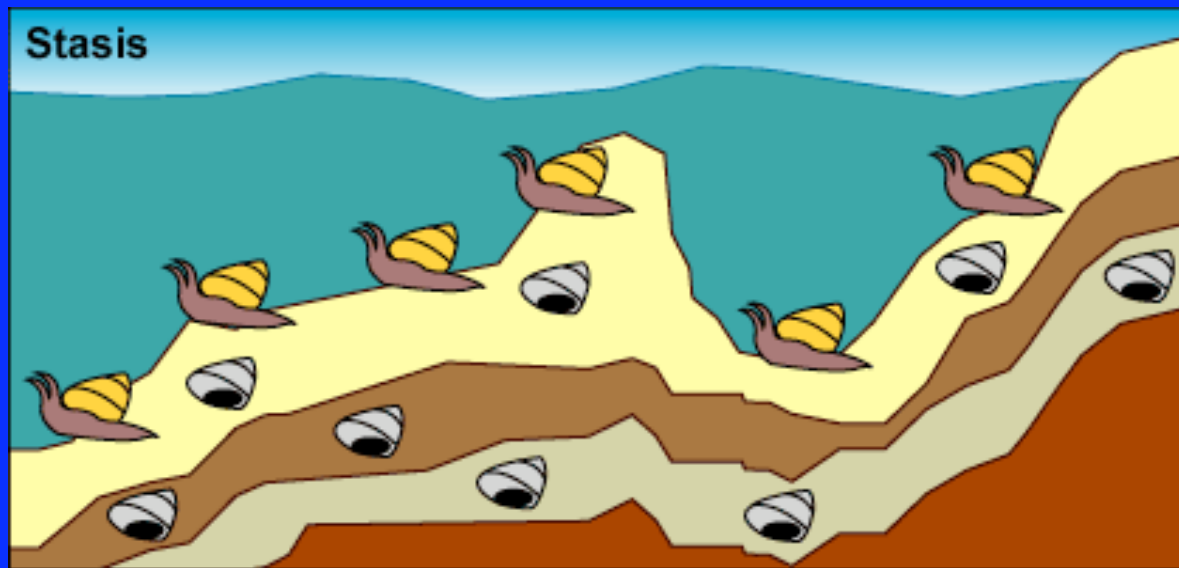


# Punctuated Equilibrium

- Another reason for “jumps” in fossil record
- Key ideas: isolation of sub-populations leads to rapid evolution; re-introduction can give impression of discontinuous change
- Does not contradict any core ideas of evolution
- Upcoming slides are from [evolution.berkeley.edu/evosite/evo101/VII/A1bPunctuated.shtml](http://evolution.berkeley.edu/evosite/evo101/VII/A1bPunctuated.shtml)

# Step 1: Stasis

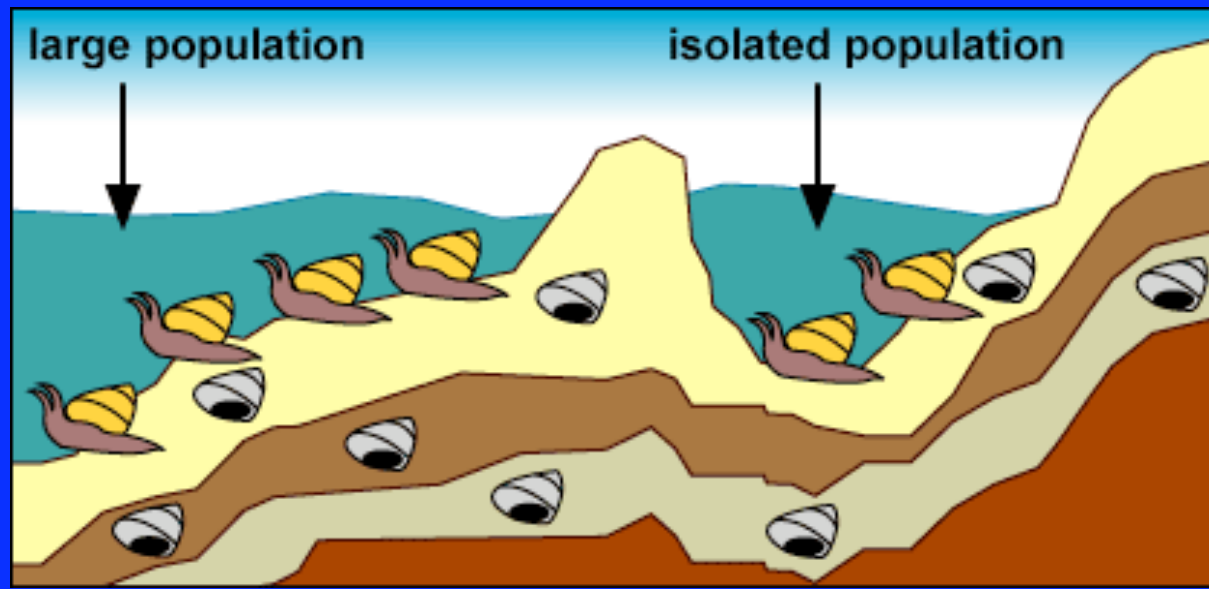
- In hypothetical case, a population of snails is well adapted to its niche
- Therefore, minimal changes and little apparent evolution in fossils



<http://evolution.berkeley.edu/evosite/evo101/VIA1bPunctuated.shtml>

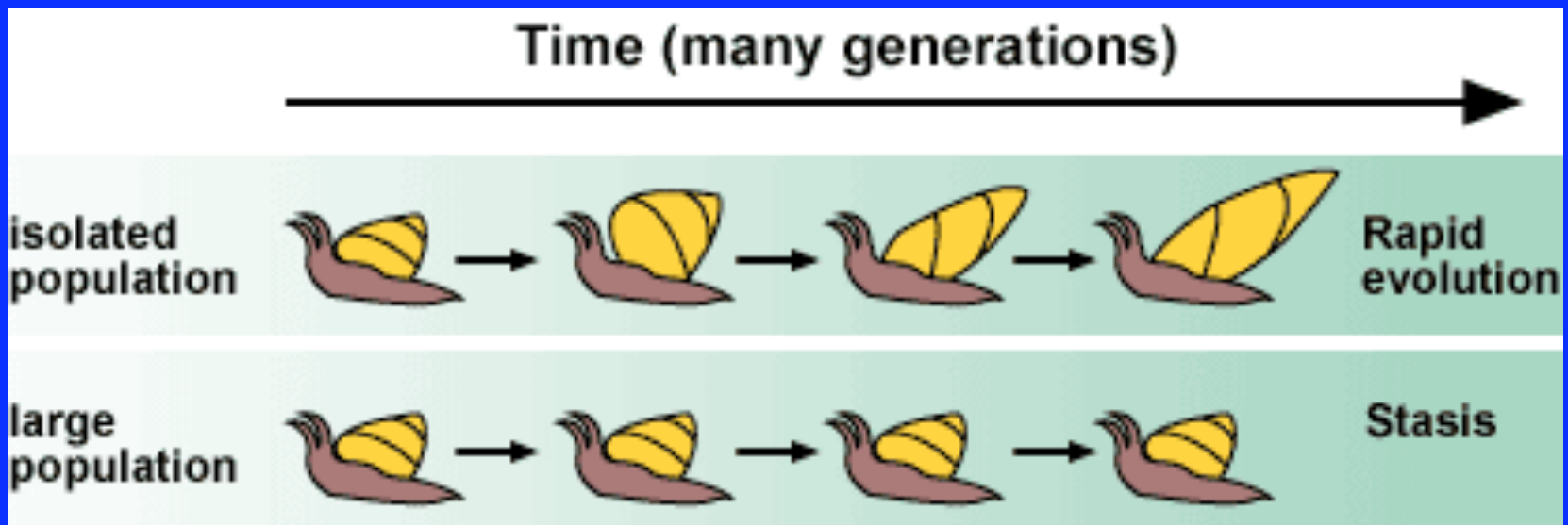
## Step 2: Isolation

- Water level drops, creating a lake and isolating a small subpopulation
- Conditions in lake are different, so snails are not currently as well adapted there

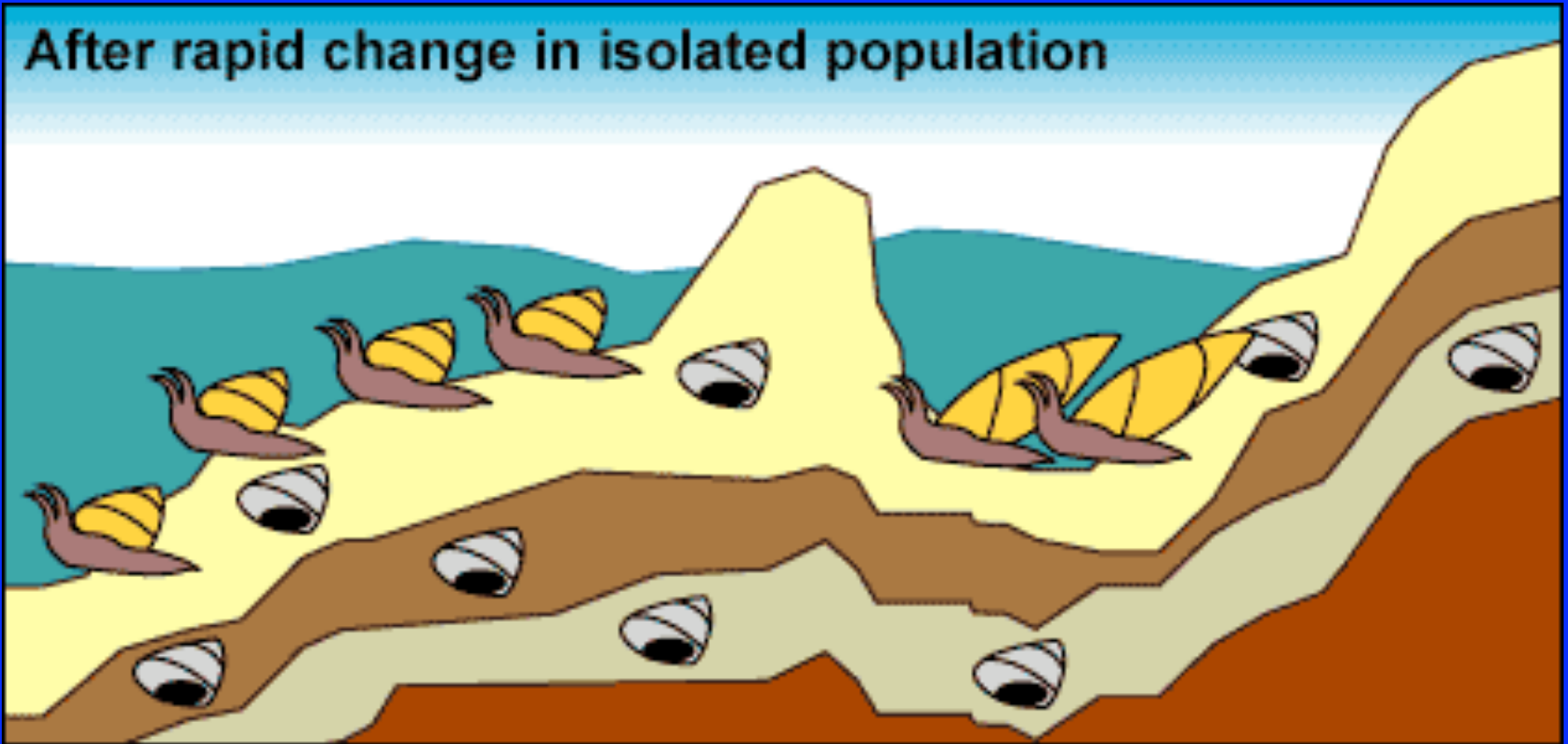


# Step 3: Strong Selection

- The new conditions cause the subpopulation to evolve rapidly
- In contrast, the original population is still in stasis



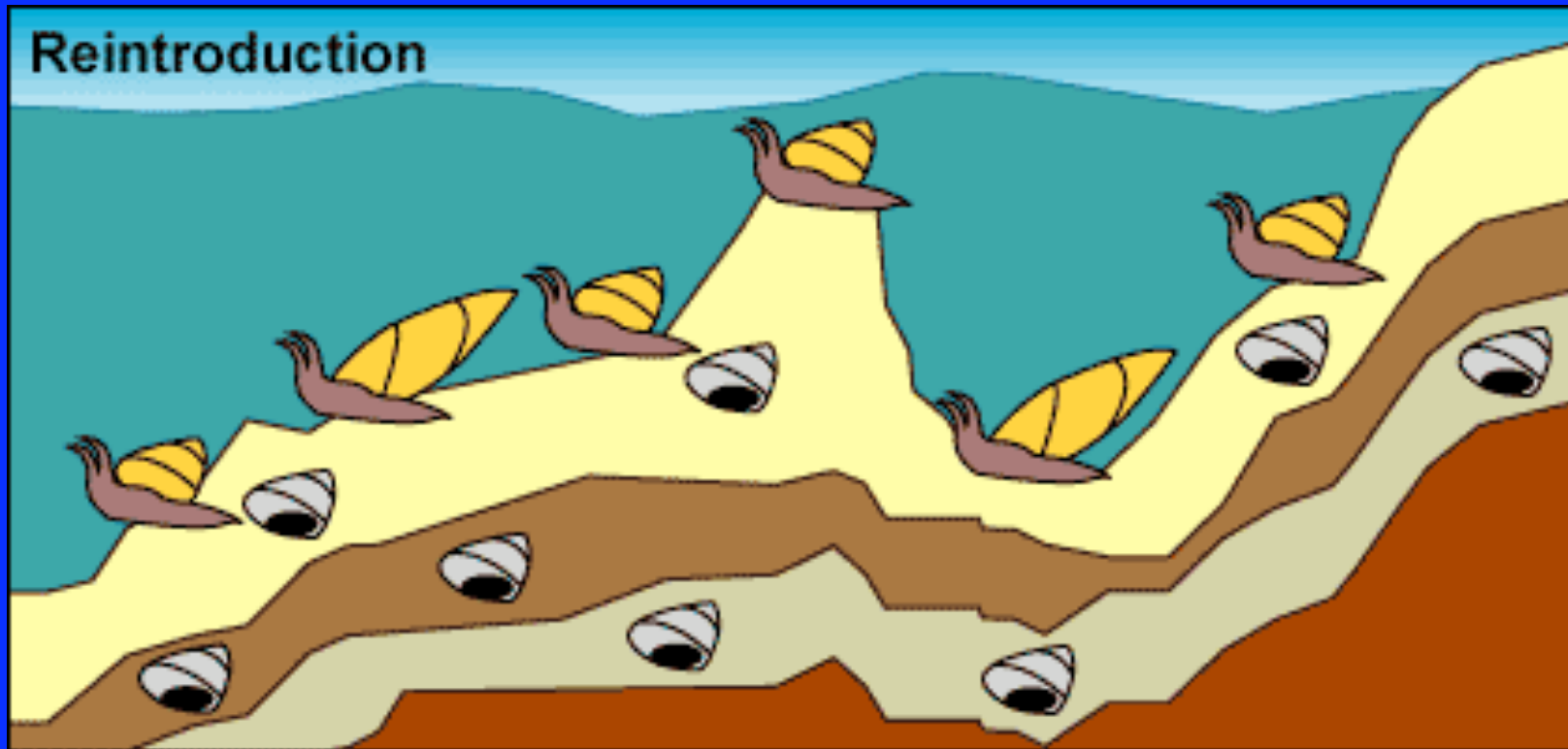
After rapid change in isolated population



<http://evolution.berkeley.edu/evosite/evo101/VIIA1bPunctuated.shtml>

# Step 4: Reintroduction

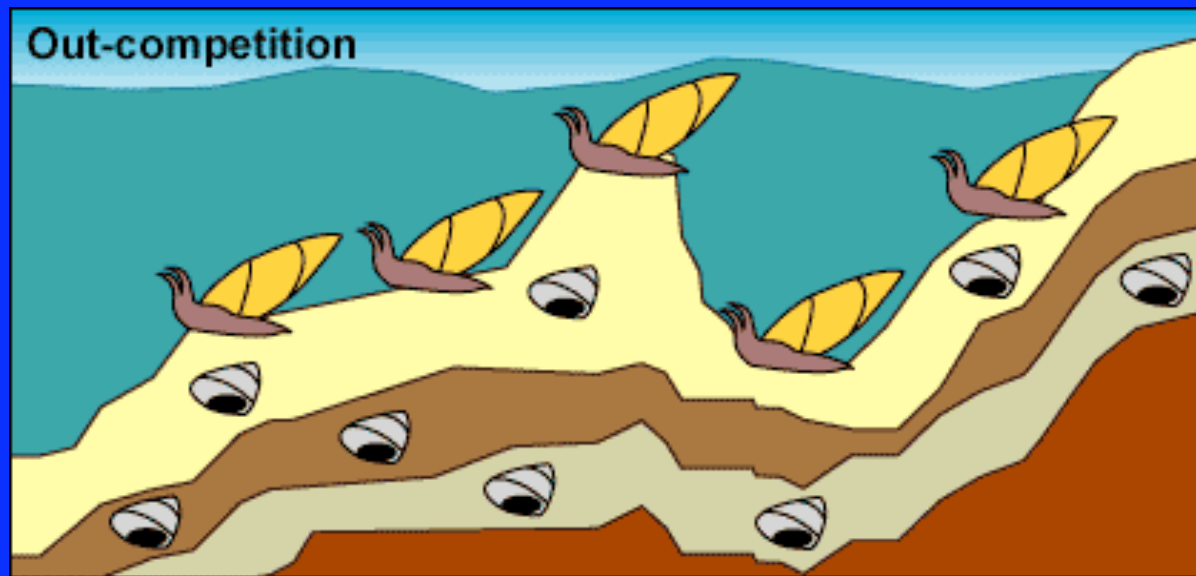
- When the water level rises again, the two populations come back into contact



<http://evolution.berkeley.edu/evosite/evo101/VIA1bPunctuated.shtml>

# Step 5: Competition and Stasis

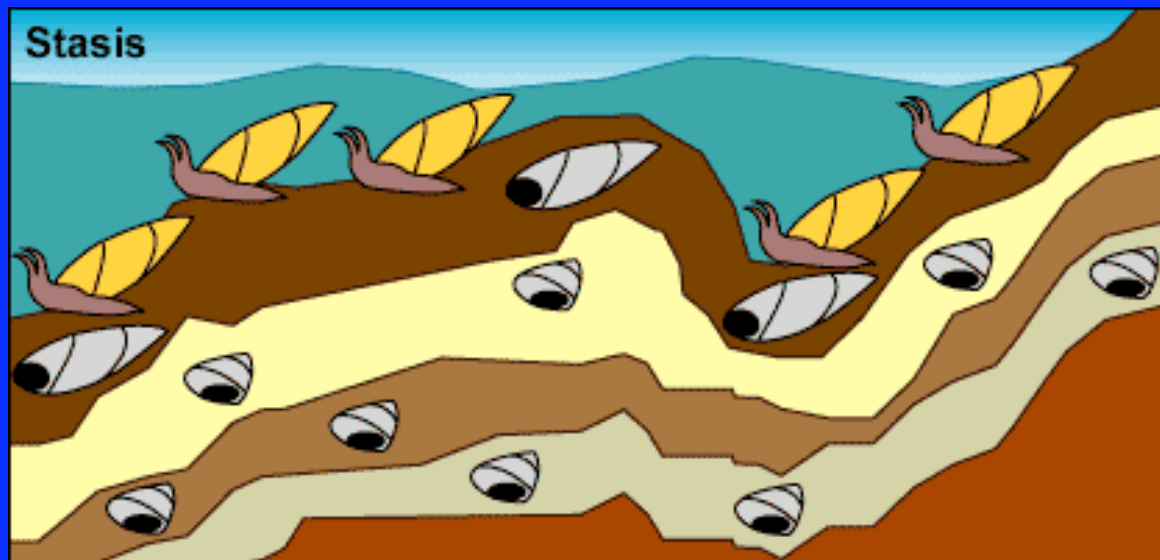
- Suppose the new, larger snails outcompete the original ones
- The smaller snails die off and are displaced
- Only the larger ones remain





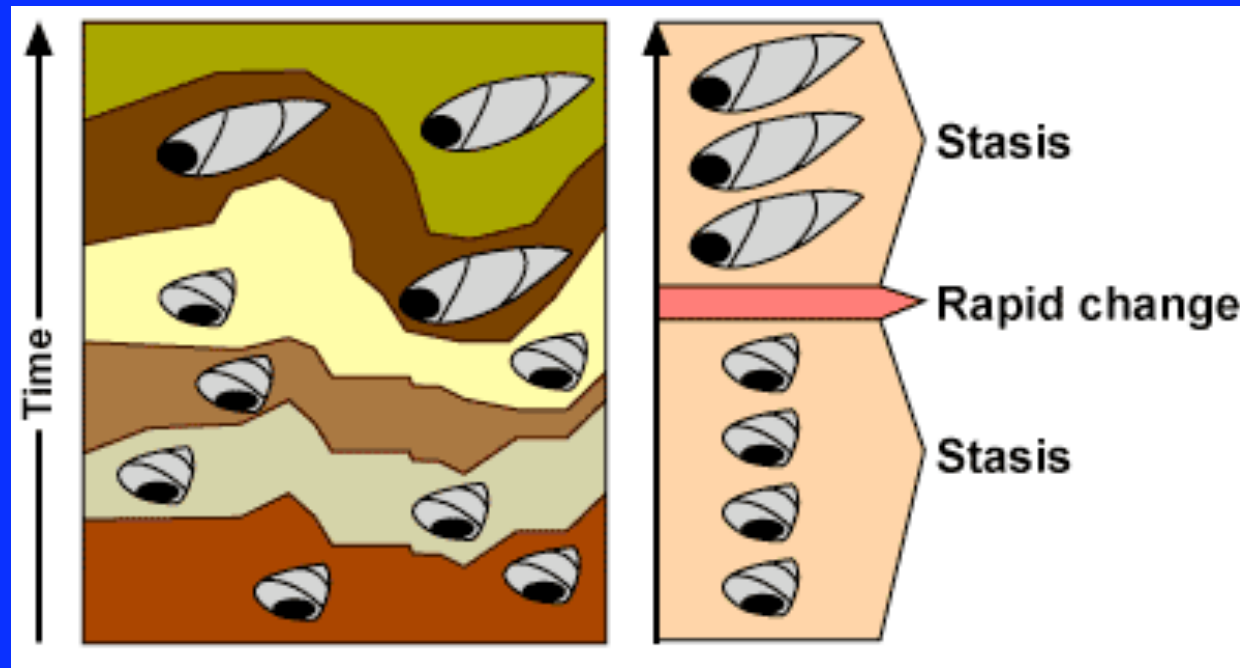
# Step 6: Preservation

- Population now moves back to stasis, since well adapted to environment
- Fossils left are now only of the larger variety



# Result for Fossil Record

- Suppose fossils are decently preserved in original location
- Looks like a rapid jump instead of gradual change
- But gradual change happened, just in smaller area that was not preserved as well



## Takeaway Message:

Conditions for fossilization are extremely rare.

Guaranteed to give at best an incomplete, and at worst a biased view of life on Earth. Since we only see fossils when they have been brought up by crustal movement, does this affect dating of fossils?

# Stratigraphy

- William Smith (1769-1839), English
- Created first national geological map
- Humble education: was plagiarized, spent time in debtor's prison
- Noticed that rock types were always in predictable pattern

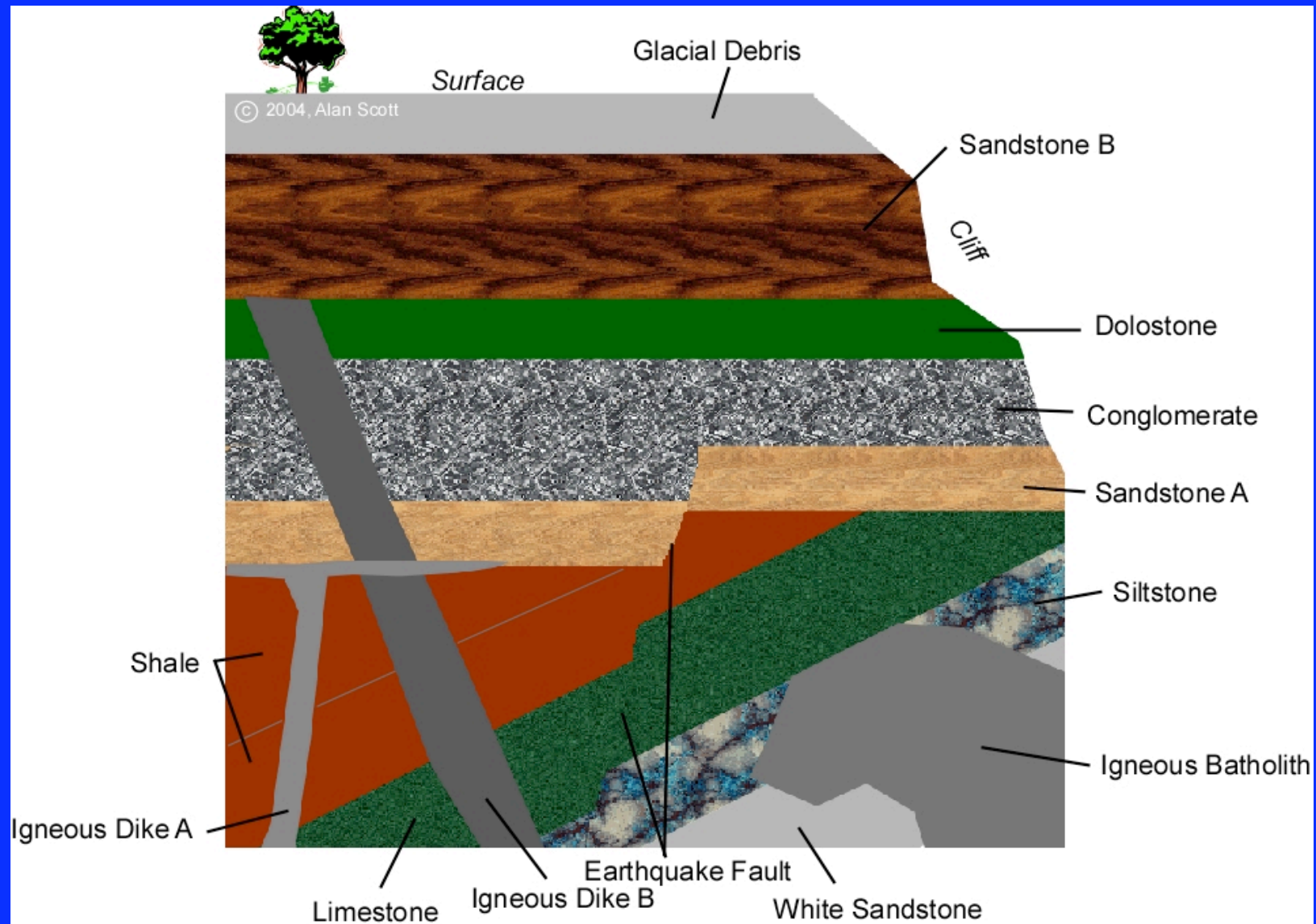


# Rock Strata: Real



*Copyright Nigel Purchon*

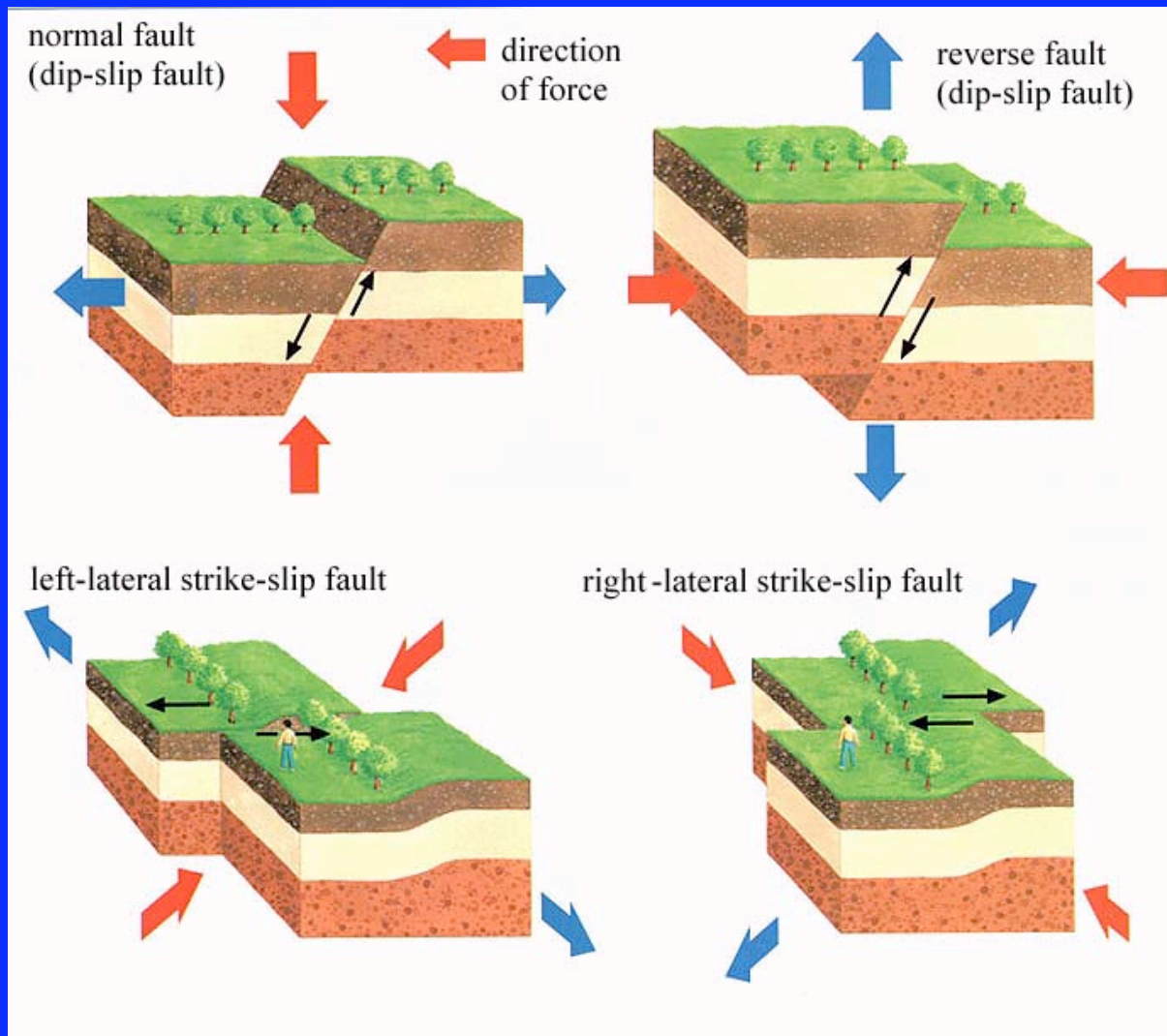
# Rock Strata: Idealized



# Relative Dating of Strata

- “Law of Superposition” (Avicenna 1027!!):  
Higher strata deposited more recently  
Also, assume originally horizontal  
And, continuous laterally
- With these assumptions, can establish proper relative dating of rocks throughout world

# Problem? Slip Faults



Faults in rock  
can shift strata  
around.

Can still look  
at patterns

But, need ways  
to check relative  
ages



# Biostratigraphy

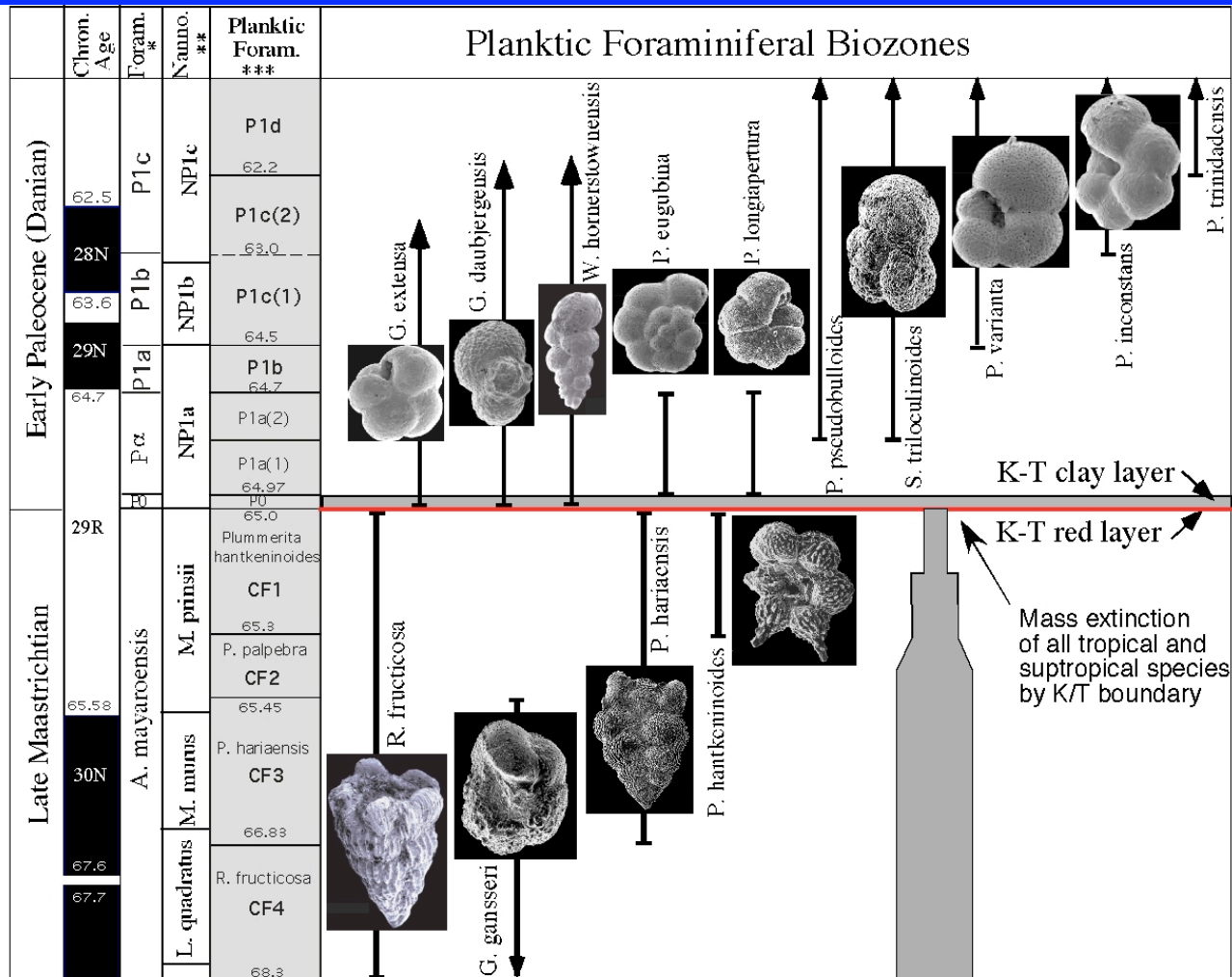


Figure 2

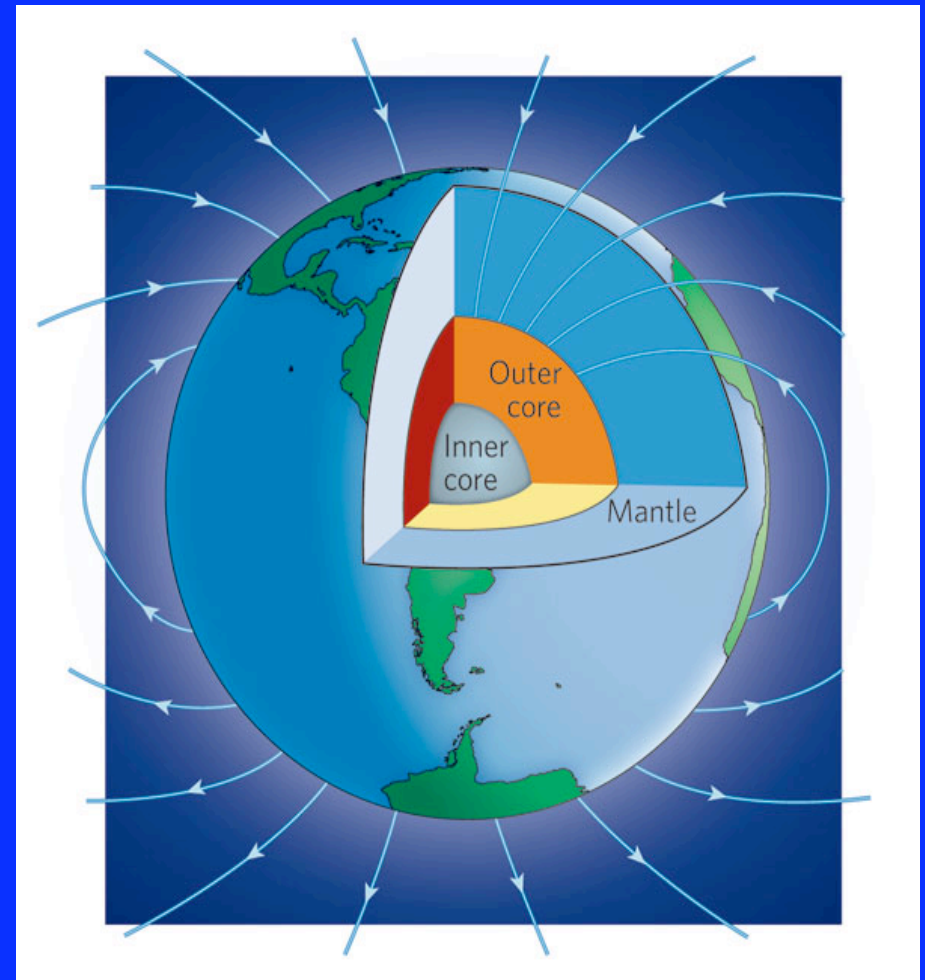
Smith again:  
same fossils  
found in same  
layers.

Therefore, can  
tell when there  
has been a slip.

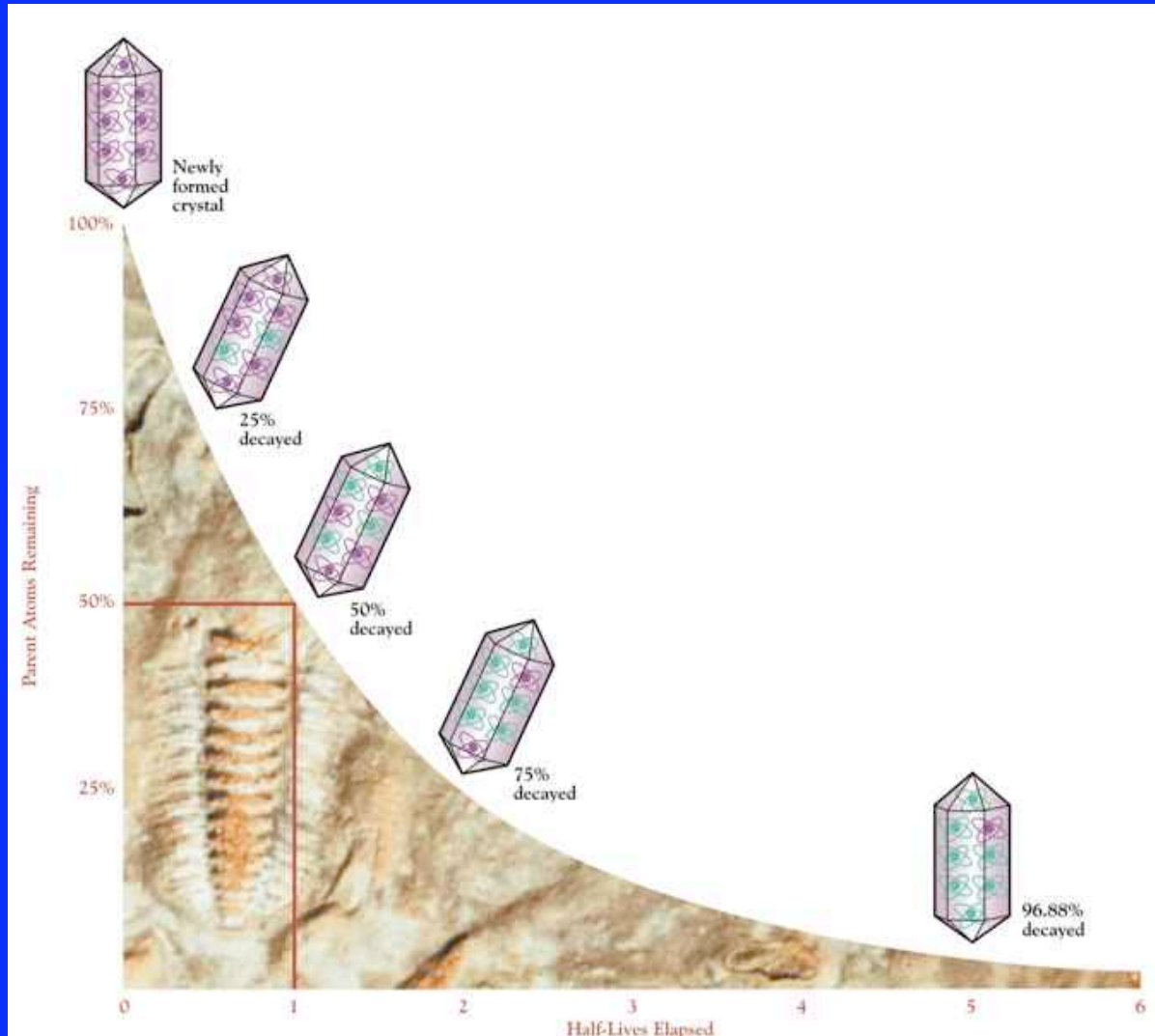
If this were the  
*only* method,  
it could be  
accused of  
being circular

# Magnetostratigraphy

- Earth's magnetic field reverses irregularly on  $\sim 10^5$  year periods
- Newly formed iron in rock retains memory of direction
- Can therefore tell relative ages
- Was key evidence for plate tectonics



# Radioactive Dating



Can tell age of rock from the isotopes in it.

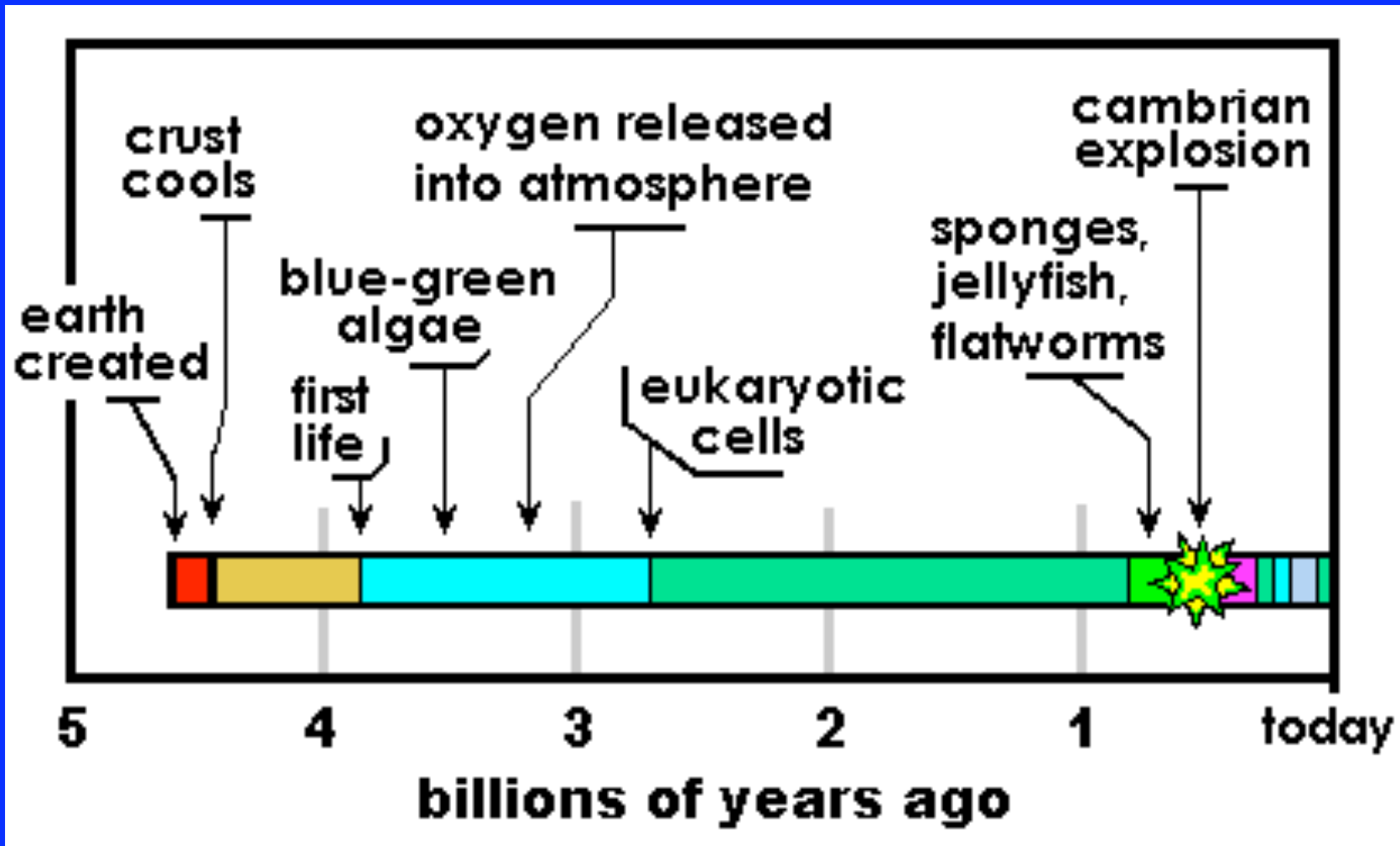
Again, consistent through world for given layer.

Fossil age is age of rock

# Takeaway Points

- As always, when measuring things far beyond our experience, must be careful
- Rock order and absolute dating is done with multiple independent methods
- All are consistent with each other
- What does this tell us about life's history?

# Life on Earth, Part 1



# First Impressions...

- Bacterial life emerged really quickly  
Started around 3.8 Gyr ago  
Earlier, impacts would have wiped out
- But it took a long time for animals, plants  
About 3 billion years!  
Diversification at Cambrian Explosion  
What happened?

# The Burgess Shale



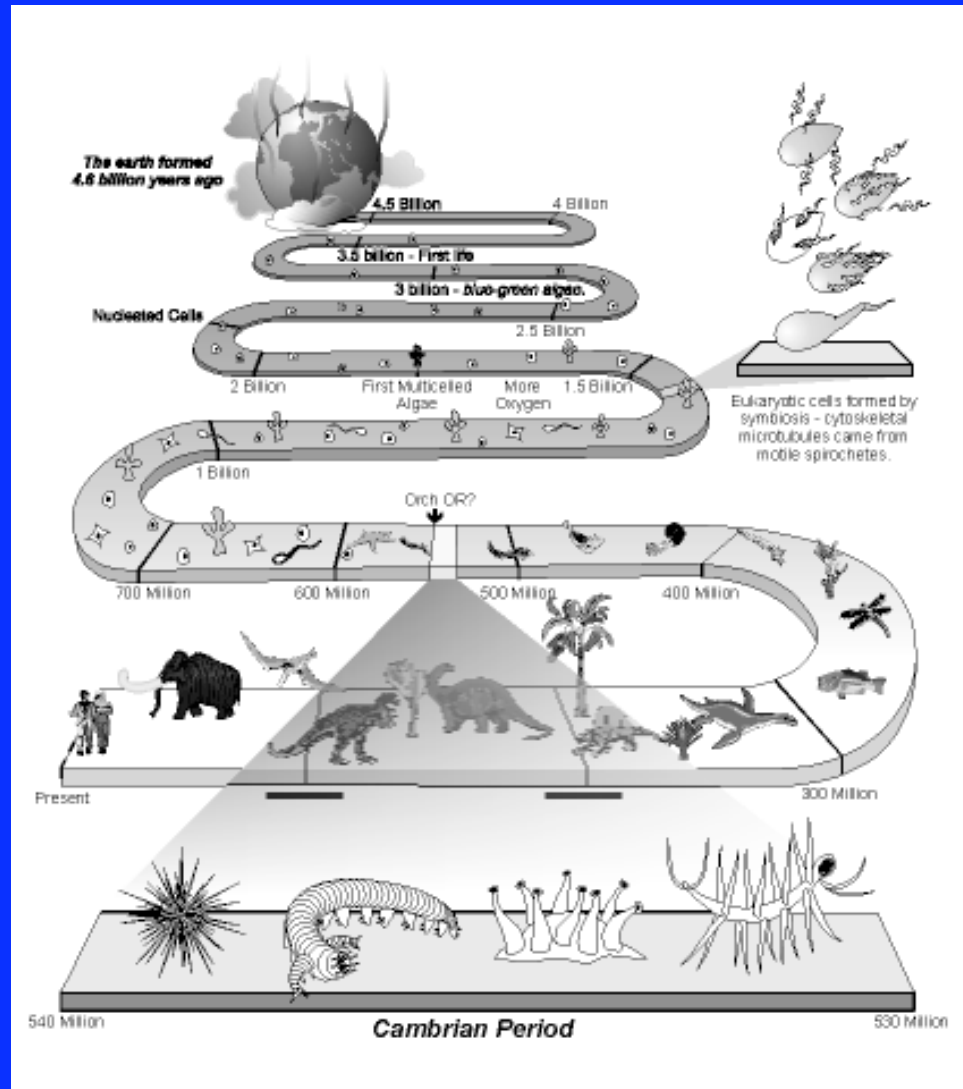
[http://www.field.ca/images/large/burgess\\_trilobite\\_lg.jpg](http://www.field.ca/images/large/burgess_trilobite_lg.jpg)

# The Cambrian Explosion

- About 550 million years ago, in a “burst” of tens of millions of years, basic animal body plans all emerged
- Why? Not clear.  
Maybe mass extinction, snowball Earth opened up many ecological niches
- Since that time, fossils have been a lot more interesting!



# Later Life on Earth



Since 550 Myr ago  
fish, insects, land  
plants, amphibians,  
dinosaurs, birds,  
mammals, ...

...have all emerged

Modern humans:  
about 100,000 yrs!

# Carl Sagan: Cosmic Calendar

January	February	March	April	May	June	July	August	September	October	November
										
New Year's Day: The Big Bang		Mily Way forms					Sun and planets form	Oldest known life (single celled).		First multi-cellular organisms
December										
1	2	3	4	5	6	7	8	9	10	11
12	13	14	15	16	17	18	19	20	21	22
23	24	25	26	27	28	29	30	31		
15 Cambrian Explosion (burst of new life forms)		17 Emergence of first vertebrates	18 Early land plants		20 First four-limbed animals	21 Variety of insects begin to flourish		27 First known birds		
		24 First dinosaurs appear	25 First mammalian ancestors appear					10:15am Apes appear 9:24pm First human ancestors to walk upright 10:48pm Homo erectus appears 11:54pm Anatomically modern humans appear 11:59:45pm Invention of writing 11:59:50pm Pyramids built in Egypt 1 second before midnight: Voyage of Christopher Columbus		
29 Dinosaurs wiped out by asteroid or comet										

# What About Missing Links?

- Commonly heard: there are large gaps in the fossil record
- Sure, there have to be gaps; fossilization is difficult
- But are there any unbridgeable ones?
- Case study: evolution of whales from land animals about 60 Myr ago

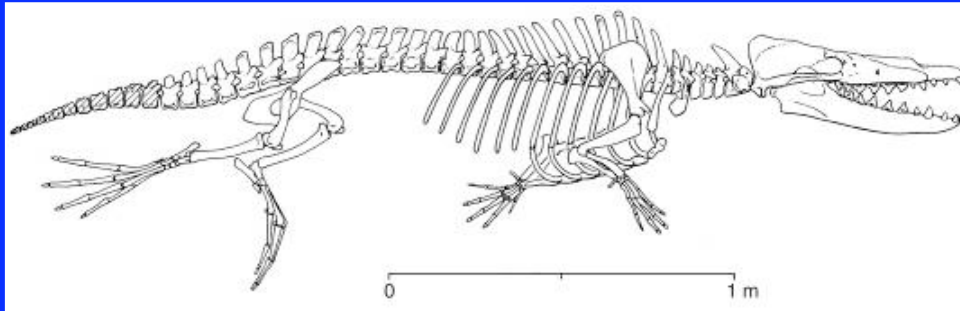
# Arguments based on the fossil record as a “problem” for evolution backfired

## No Intermediate Forms in the Fossil Record?

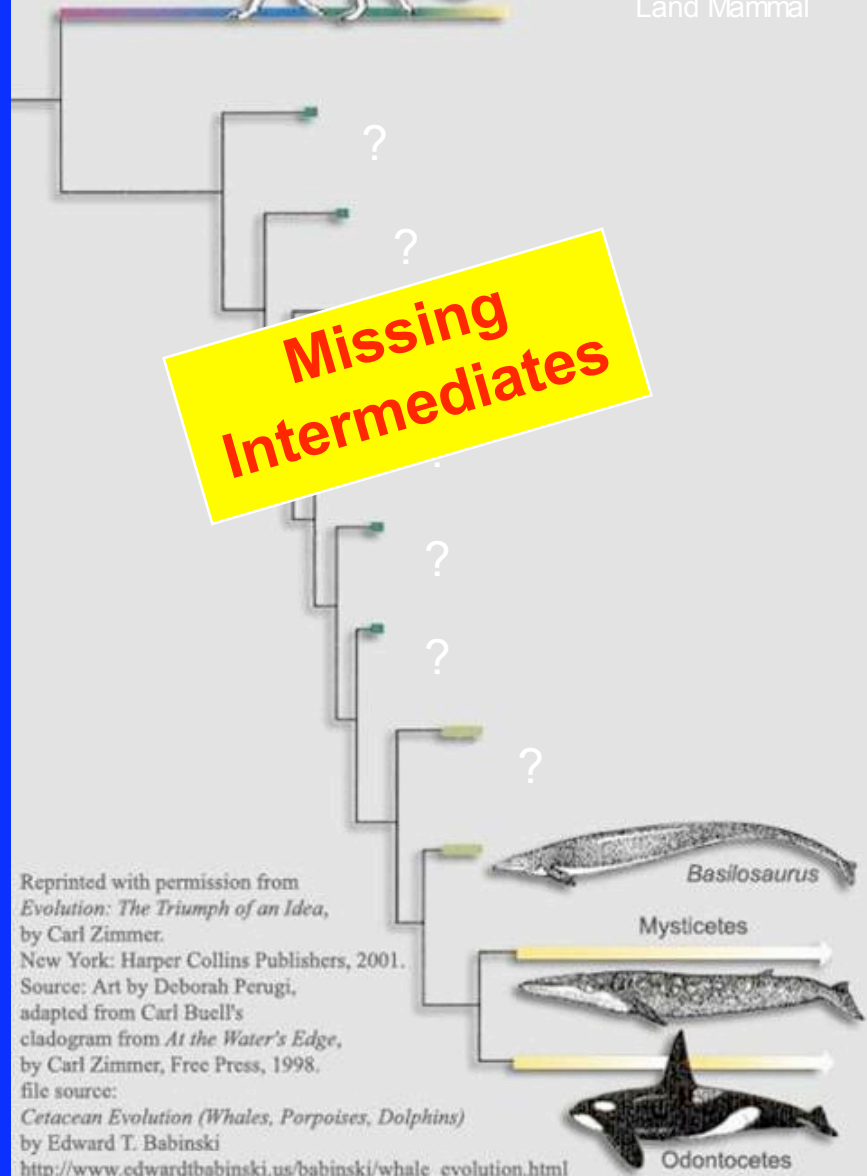


“So many intermediate forms have been discovered between fish and amphibians, between amphibians and reptiles, between reptiles and mammals, and along the primate lines of descent that it often is difficult to identify categorically when the transition occurs from one to another particular species.”

- National Academy of Sciences, 1999



Land Mammal



**Missing Intermediates**

Reprinted with permission from *Evolution: The Triumph of an Idea*, by Carl Zimmer. New York: Harper Collins Publishers, 2001.

Source: Art by Deborah Perugi, adapted from Carl Buell's cladogram from *At the Water's Edge*, by Carl Zimmer, Free Press, 1998.

file source:

*Cetacean Evolution (Whales, Porpoises, Dolphins)* by Edward T. Babinski

[http://www.edwardtbabinski.us/babinski/whale\\_evolution.html](http://www.edwardtbabinski.us/babinski/whale_evolution.html)



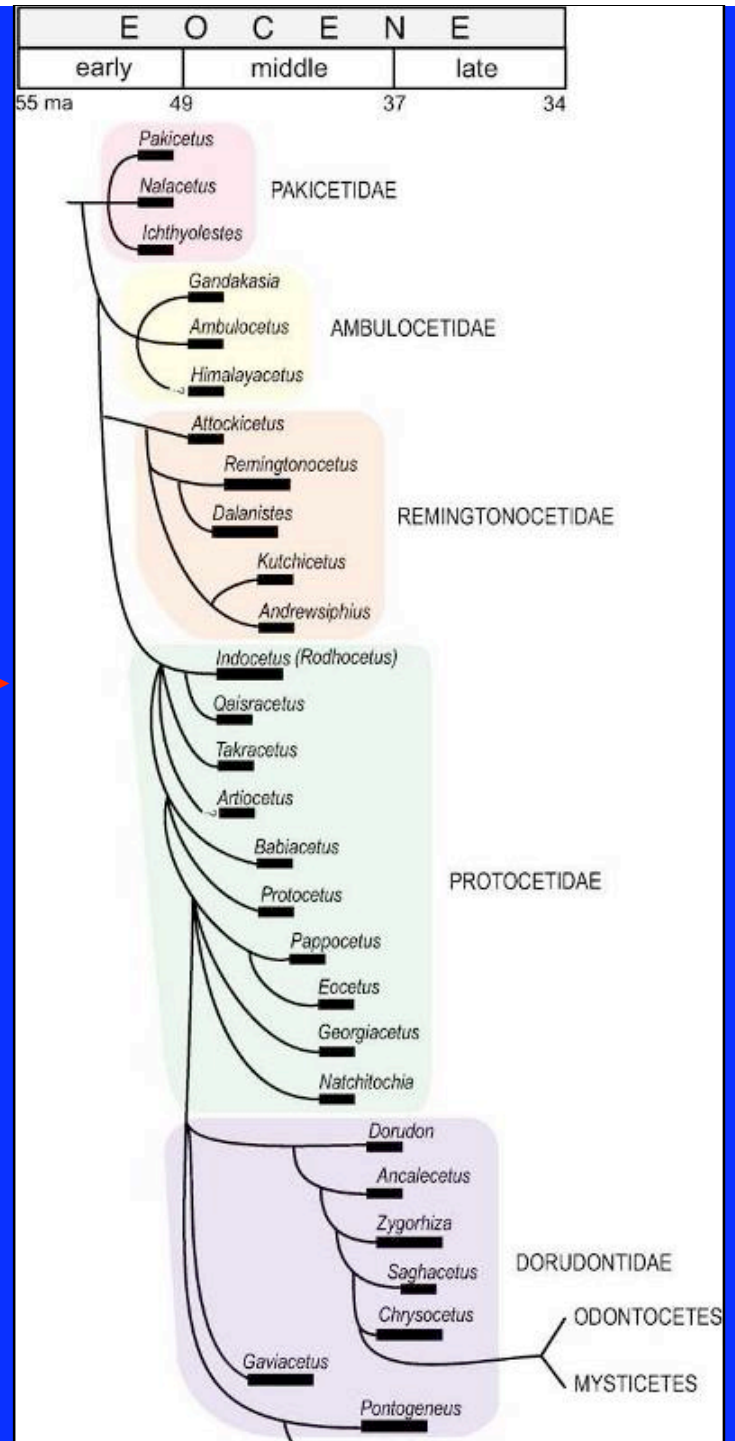
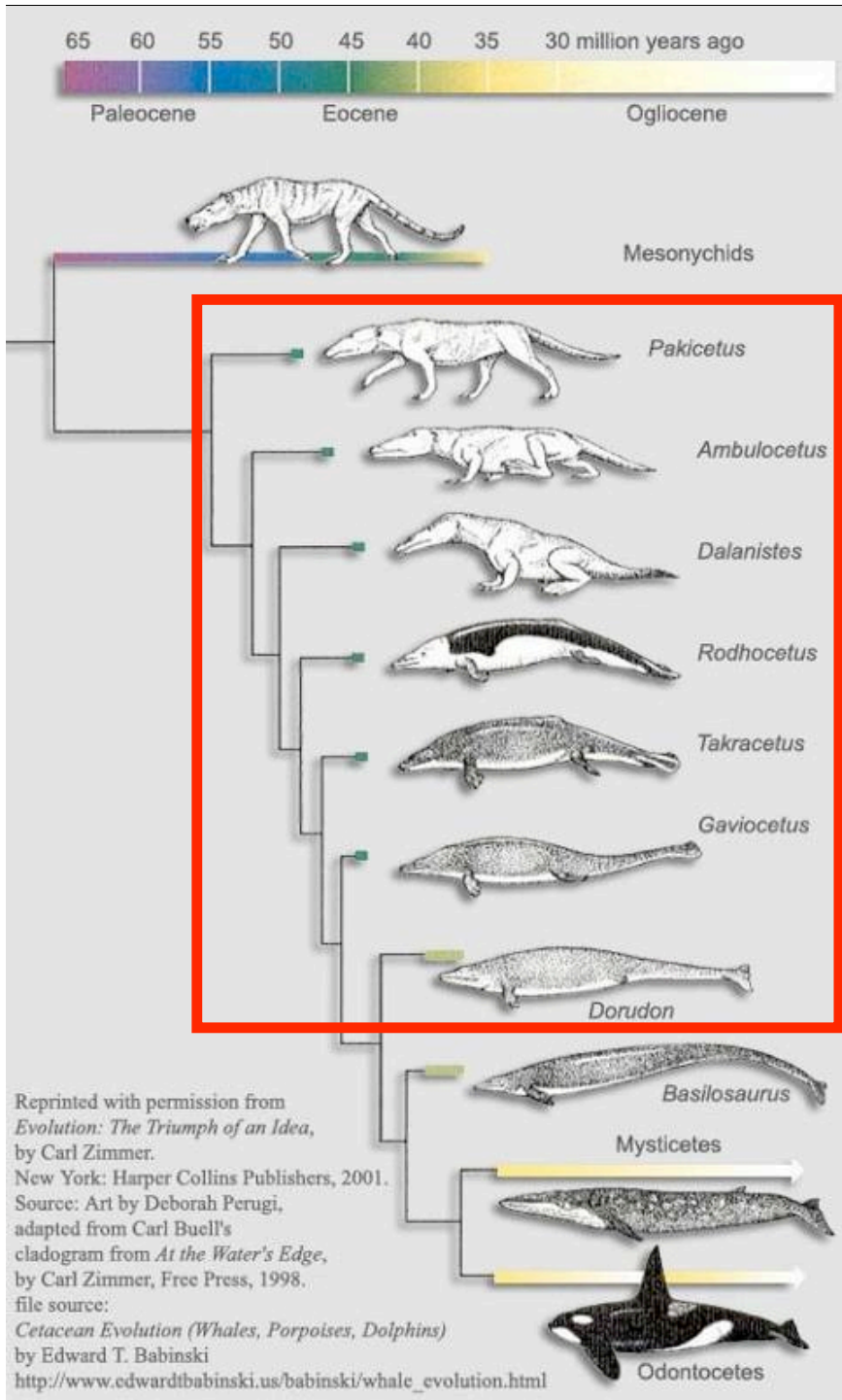
Basilosaurus



Mysticetes



Odontocetes



# Whale Origins as a Poster Child for Macroevolution

J. G. M. THEWISSEN AND SUNIL BAJPAI

**W**hales indisputably are mammals, which is clear from their means of oxygen intake (they breathe with lungs), their care of newborns (mothers nurse their calves with milk), and a host of other features. This implies that whales

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FOSSILS COLLECTED IN THE LAST DECADE DOCUMENT THE WAYS IN WHICH CETACEA (WHALES, DOLPHINS, AND PORPOISES) BECAME AQUATIC, A TRANSITION THAT IS ONE OF THE BEST DOCUMENTED EXAMPLES OF MACROEVOLUTION IN MAMMALS

ignorance on the part of those unaware of published research. However, the sheer volume and pace of recent research also cause problems. For those outside of the circle of specialists actively studying whale origins, it is hard to keep up with all the new discoveries.

Reconstructions of representative Eocene cetaceans. Clockwise from top: a beached *Dorudon* (Dorudontidae), *Ambulocetus* (Ambulocetidae), *Pakicetus* (Pakicetidae), *Kutchicetus* (Remingtonocetidae), and *Rodhocetus* (Protocetidae). These cetaceans are shown together for comparison, but they were not contemporaries and lived in different environments. Artwork by Carl Buell.

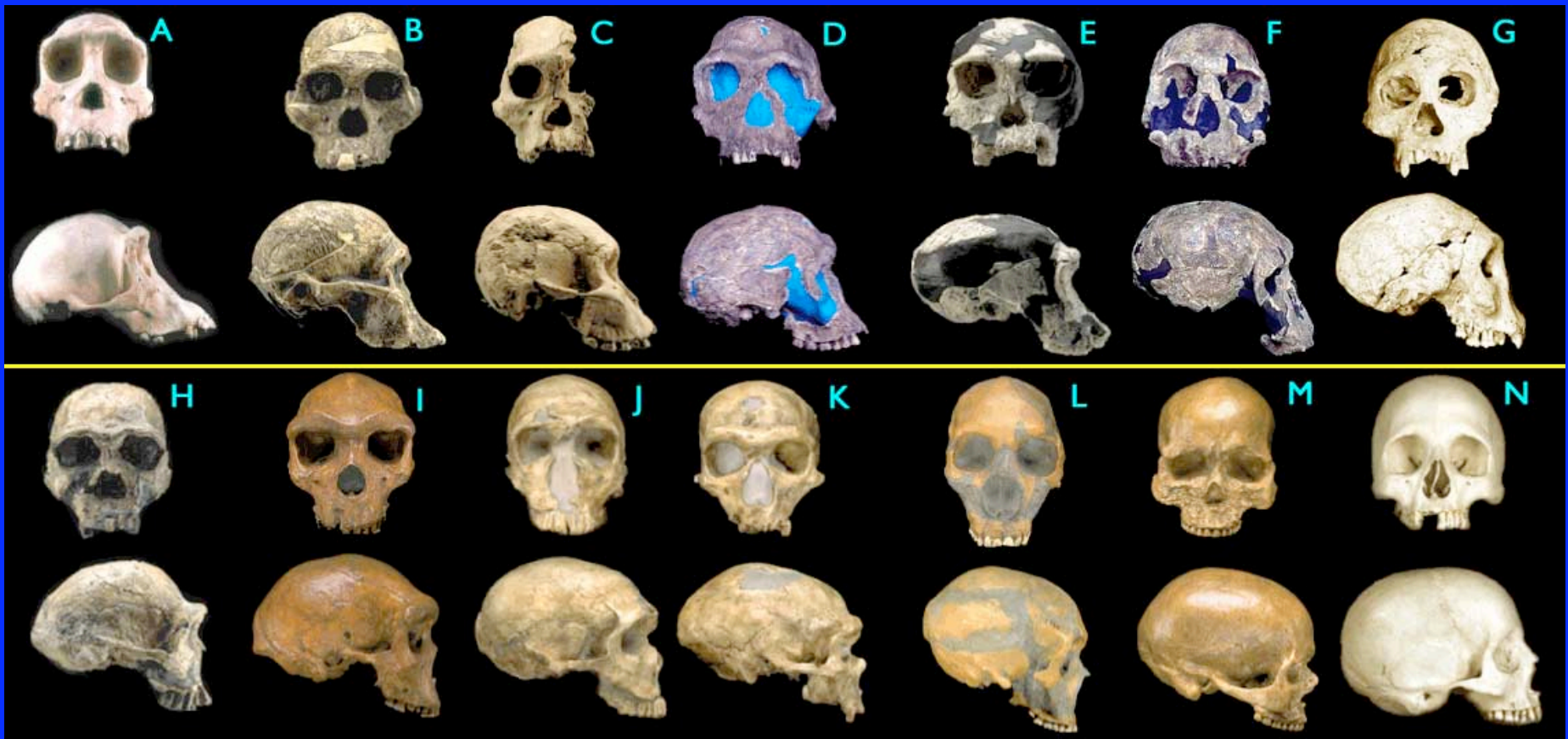
# Human Evolution

- From the standpoint of some people, however, the really threatening fact is that humans evolved
- How well is this established in the fossil record?

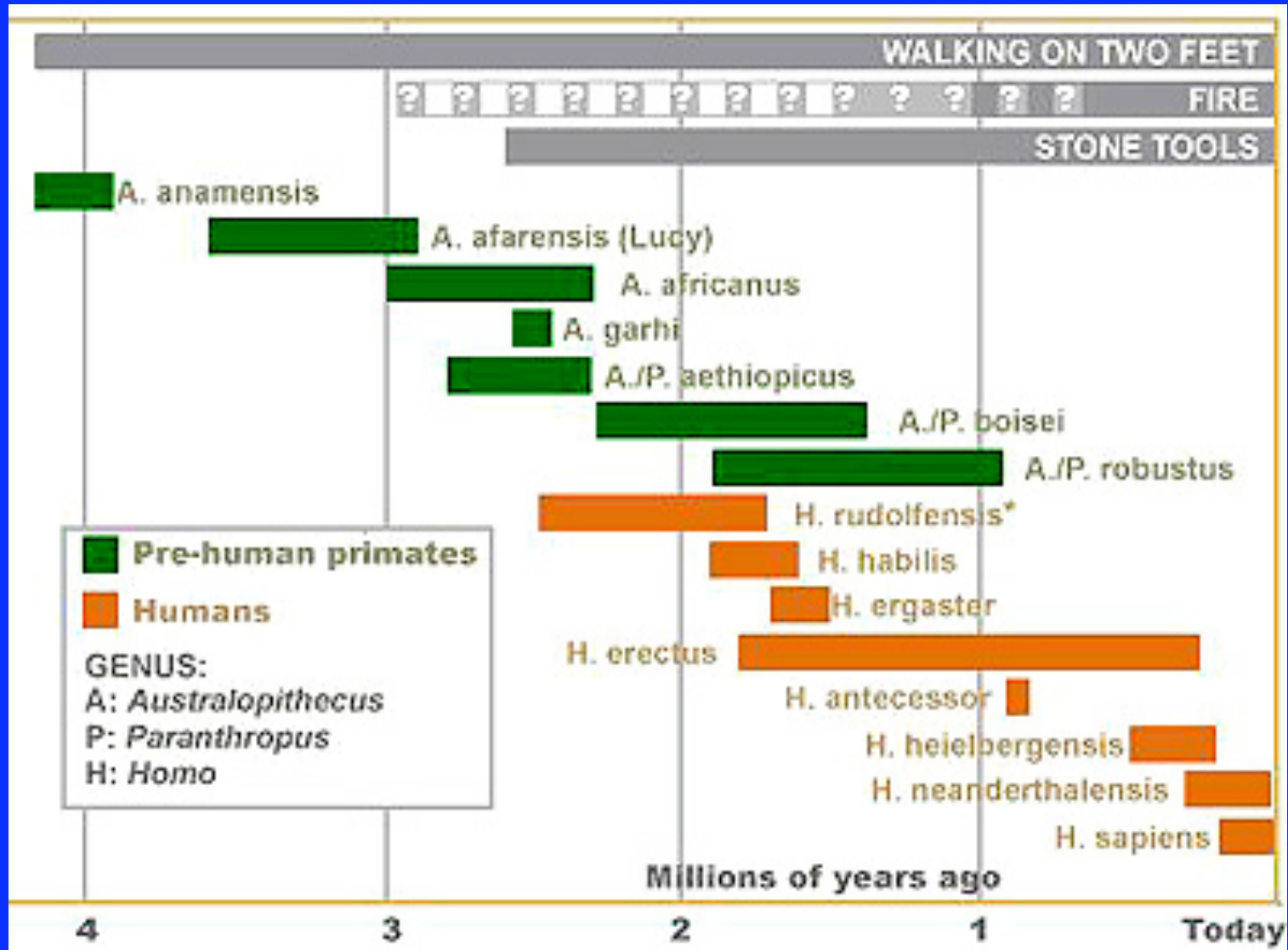


# Skulls, in Chronological Order

Note: *non-human* primate record much spottier.  
For example, (independent) chimp evolution.



# Overall Timeline



# Out of Africa



[http://discovermagazine.com/2003/mar/featsurvivor/survivor\\_63jpg](http://discovermagazine.com/2003/mar/featsurvivor/survivor_63jpg)

# Yes, Humans Evolved

- Not clear why our brain sizes increased with such (relative) rapidity
- We are still evolving  
Biologically, slow as always  
But we can communicate, so our society is evolving extraordinarily quickly
- Will we artificially guide our evolution in the future with genetic or other engineering?  
Human-computer hybrids?

# Summary

- Fossil record, though incomplete, is a rich history of life on Earth
- Squarely in line with evolutionary expectations (e.g., simple creatures appear first)
- More discoveries are being made every day  
**All could potentially falsify evolution**  
**So far, evolution has passed every test**