Key topics for today:

DKN
- How did life on Earth get started?
- What is the early history of life on Earth?
- How do we study the past?

MMN
- Before and after the Cambrian Explosion
- The when and how of colonizing land
- Mass extinction
Talk about challenge of learning about the past in a rigorous way when the Earth has done the experiment for you and all you have left are clues.
Hadean  Archean  Proterozoic  Phanerozoic

PRECAMBRIAN  Cambrian Exp
Setting the boundary condition: Age of the Earth
Prof. Clair Patterson (Caltech, GPS)

1956 – determined age of Earth to be 4.55 ± 0.07 billion years

$^{204}\text{Pb}$ (primordial), $^{206}\text{Pb}$, $^{207}\text{Pb}$ (decay products of $^{238}\text{U}$, $^{235}\text{U}$) but also primordial

\[
\frac{R_{1a} - R_{1b}}{R_{2a} - R_{2b}} = \frac{(e^{\lambda_1 T} - 1)}{k (e^{\lambda_2 T} - 1)}
\]

\[R_1 = \text{Pb}^{207}/\text{Pb}^{204} \quad R_2 = \text{Pb}^{206}/\text{Pb}^{204}\]

\[k = \frac{\text{U}^{238}}{\text{U}^{235}} \text{ today (137.8)}\]

\[\lambda_1 = \text{U}^{235} \text{ decay constant (9.72 } \times 10^{-10} \text{ yr}^{-1})\]

\[\lambda_2 = \text{U}^{238} \text{ decay constant (1.537 } \times 10^{-10} \text{ yr}^{-1})\]

Solved for $T$ using values from different meteroites!

How did life first emerge? (EXIST)

I. Need building blocks:

Pre-biotic soup
Late 19th century: Enrst Haekel
1953 Miller-Urey experiments
Pre-biotic synthesis experiment under an early Earth atmosphere (CH$_4$, NH$_3$, H$_2$O, H$_2$)
Electric charge (lightening)
→ Amino acids, nucleotides
NEW THEORY: WRONG ATMOSPHERE!!

Mineral surface catalysis
1980s Günter Wächtershäuser (with Claudia Huber)

→ Mineral surface (e.g. pyrite; black smokers!)
catalysis of aa formation, peptide chains, lipids, nucleic acids (DNA, RNA)

http://exploringorigins.org
How did life first emerge? (PERSIST)

II. Need to be able to replicate
Ask class: What molecule is the hereditary material for life? (DNA) Was this used for early replication? NO!

Clue: the Ribosome (will come back to in week 6) has RNA at its core: catalyzes assembly of polypeptide (protein) chain: translation (will hear about this in section and again in week 6!)

T. Cech and S. Altman found evidence in 1980s (Nobel Prize) for:

A Ribozyme! It had the capacity to store genetic information & catalyze making copies of itself. Earlier forms of life may have relied solely on RNA to store genetic information and to catalyze chemical reactions.

Show movie 1! Note that while based on an existing ribozyme, no ribozyme has yet been made that can copy its full length.

http://exploringorigins.org
How did life first emerge? (EXIST & PERSIST EFFICIENTLY)

Solving the problem of separating self from rest: membranes

- Why is compartmentalization useful?
  make copies of the right thing!
How did life first emerge? (EXIST & PERSIST EFFICIENTLY)

Solving the problem of separating self from rest: membranes

- Why is compartmentalization useful?

  - SHOW MOVIE

http://exploringorigins.org
Once the first life forms arose, then what happened/when?

How do we know?

Guess what earliest evidence is?
Stromatolite

Billions of Years Ago ($10^9$)

Shark Bay, Australia
Small conical stromatolites often grow into fields with a regular spacing between neighboring structures.

- Write equation
- Iterative cycle between Theory, experiment and fieldwork

Petroff et al. (2010) Biophysical basis for the geometry of conical stromatolites PNAS 107:9956-9961
Banded Iron Formation

Billions of Years Ago ($10^9$)
What types of clues do we have to work with?

**Morphological**  
δ\(^{13}\)C %\(_o\), δ\(^{34}\)S %\(_o\), δ\(^{56}\)Fe %\(_o\)

**Molecular**

**Genomic**

Point out will cover Genomic part in recitation section  
Will learn HOW to make these trees in Week 8; in  
This lecture, I will give examples of Morphology & Molecular  
Because they constrain genomic!!!
Some important early dates

4.4 $\delta^{18}$O content of zircons points to existence of water

3.85 $\delta^{13}$C content of graphite inclusions from Akilia, Greenland

3.46? Cyanobacterial fossils? [morphological fossils]

3.4 Stromatolite platforms in western Australia
   Photosynthetic microbial mats

2.7? Sterols, first eukaryotes? [molecular fossils]

2.4 MIF $\delta^{33}$S, $^{34}$S, $^{36}$S reveals atmospheric oxygen
The Archean Cyanobacterial Microfossil Debate

- New 3D microscopy revealed shapes inconsistent with 2D interpretation
- Abiotic alternatives to generating the same micro-geochemistry

ADD REFS!!
The Molecular Fossil (a.k.a. “Biomarker”) Brawl

Prof. Roger Summons, MIT

Prof. Jochen Brocks, ANU
Archean Molecular Fossils and the Early Rise of Eukaryotes

Jochen J. Brocks,1,2* Graham A. Logan,2 Roger Buick,1 Roger E. Summons2

Molecular fossils of biological lipids are preserved in 2700–million-year-old shales from the Pilbara Craton, Australia. Sequential extraction of adjacent samples shows that these hydrocarbon biomarkers are indigenous and syngenic to the Archean shales, greatly extending the known geological range of such molecules. The presence of abundant 2α-methylhopanes, which are characteristic of cyanobacteria, indicates that oxygenic photosynthesis evolved well before the atmosphere became oxidizing. The presence of steranes, particularly cholestane and its 28–to 30–carbon analogs, provides persuasive evidence for the existence of eukaryotes 500 million to 1 billion years before the extant fossil record indicates that the lineage arose.

Let’s take a look at some of the key assumptions here…

2-Me-hopanols made by cyanobacteria

cyanobacteria make $O_2$

Sterols only in euks
(biosynthesis requires $O_2$)

2-Me-hopanetetrol

2-Me-hopane

cholesterol

cholestane
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Reassessing the first appearance of eukaryotes and cyanobacteria

Birger Rasmussen1, Ian R. Fletcher1, Jochen J. Brocks2,3 & Matt R. Kilburn4

→ Pushes date to first euks back to 1.78-1.68 Ga, cyanos back to 2.1 Ga!
What happened? What went wrong?

- Draw out biomarker pathway
- Draw out drilling; discuss problem of contamination
What happened? What went wrong?

- Draw out biomarker pathway
- Draw out drilling; discuss problem of contamination

Technological advance behind the change in interpretation?

→ Increasing analytic precision of detection (microscale vs. bulk!)
Topic for Thursday: Can we define generic “biosignatures” that could help us search for life on other planets? What would you look for if you were the chief scientist?

Mars Science Laboratory (MSL) “Curiosity” lands Aug. 5, 2012