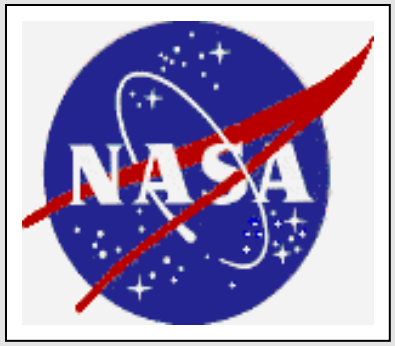
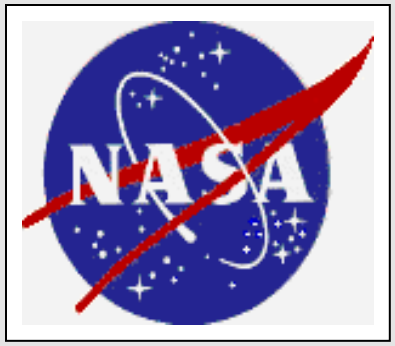


From the Big Bang to Broadway: How Things Evolve

March 20, 2010 – Sigma Xi Awards Banquet
Loyola Marymount Univ.

CARNEGIE INSTITUTION FOR SCIENCE



(Or, Should You Believe in Evolution?)

March 18, 2010 – Capital Science Lecture
Carnegie Institution

CARNEGIE INSTITUTION FOR SCIENCE

Do you believe in evolution?

OBJECTIVES

1. Define "evolution".
2. Explore possible alternatives to evolution.
3. Introduce "emergent complexity."
4. Present examples of complex evolving systems.
5. Review what Darwin said.
6. Explain why I "believe" in evolution.

Part I: What is Evolution?

1. Change over time.
2. An increase in complexity (i.e., diversity, behavior, structure)
3. Congruency
4. Common descent
5. Darwinian evolution by natural selection.

Part II: What are Alternatives to Evolution?

Consider life's origin (chemical evolution), which could have been:

1. **A miracle – an act of divine intervention**
2. **An event consistent with chemistry and physics, but extremely unlikely**
3. **An inevitable consequence of natural laws, given an appropriate environment and sufficient time**
4. **The result of intelligent design**

Chemical Evolution

Life arose by a natural process of "emergent complexity," consistent with natural laws.

This hypothesis predicts that life began as a sequence of chemical steps.

Intelligent Design

Life is "irreducibly complex." Therefore, a supernatural designer must have formed it.

This hypothesis requires a combination of natural and supernatural processes.

How Should Science Respond to ID?

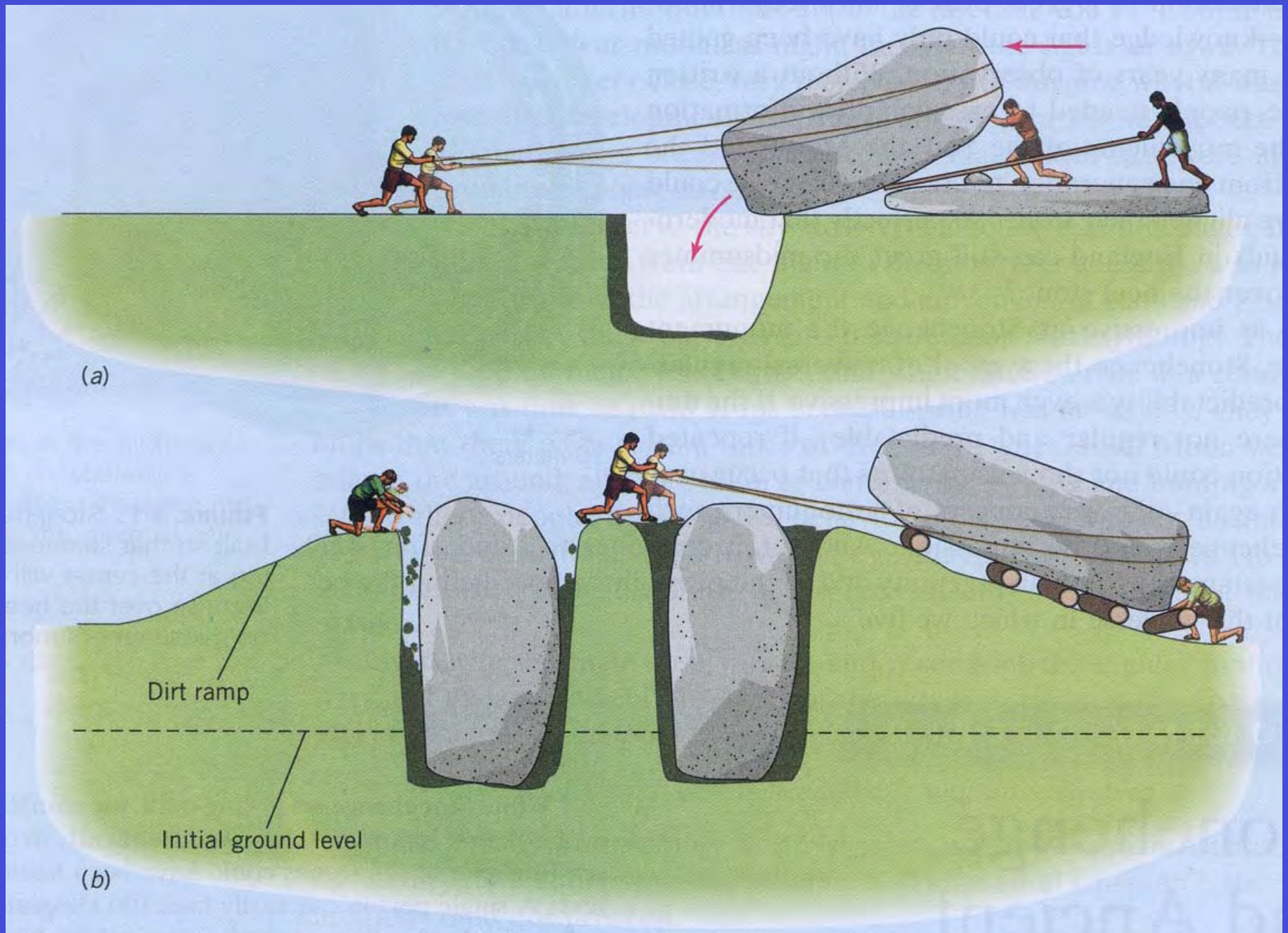
Design a research program that demonstrates the natural transition from chemical simplicity to emergent complexity.

How Should Science Respond to ID?

Design a research program that demonstrates the natural transition from chemical simplicity to emergent complexity.

If complexity can be shown to arise spontaneously as the result of natural processes, then ID is unnecessary.

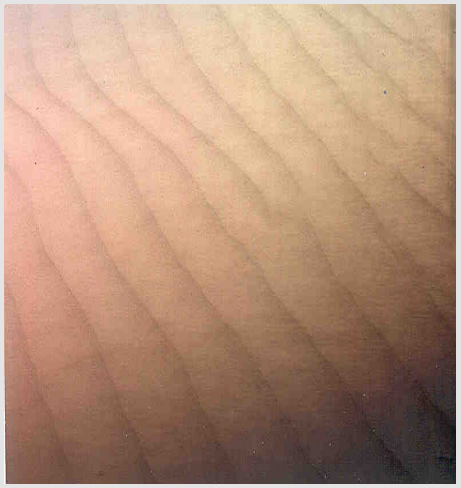
STONEHENGE

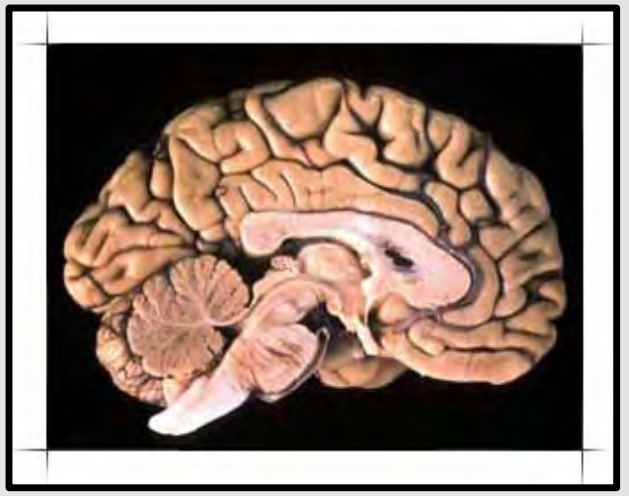

(a)
Dirt ramp
Initial ground level
(b)

Part III: Emergent Complexity

By this process systems can become more complexly patterned over time.

Emergent phenomena arise from interactions among numerous individual particles, or “agents.”

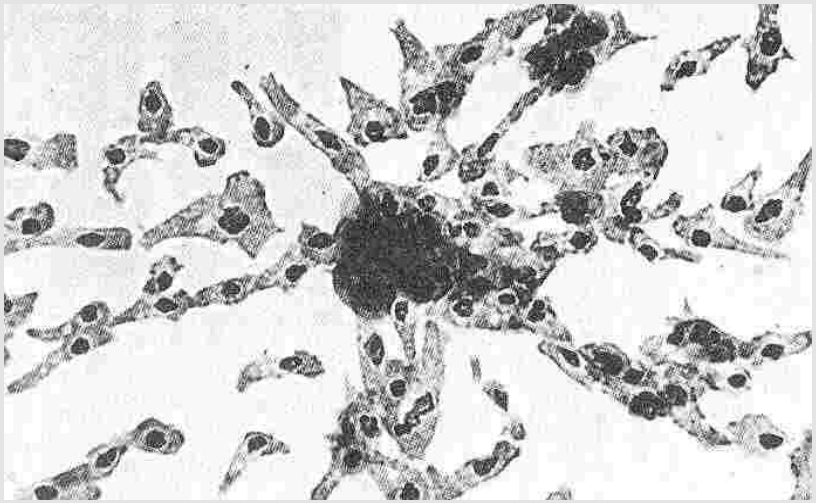


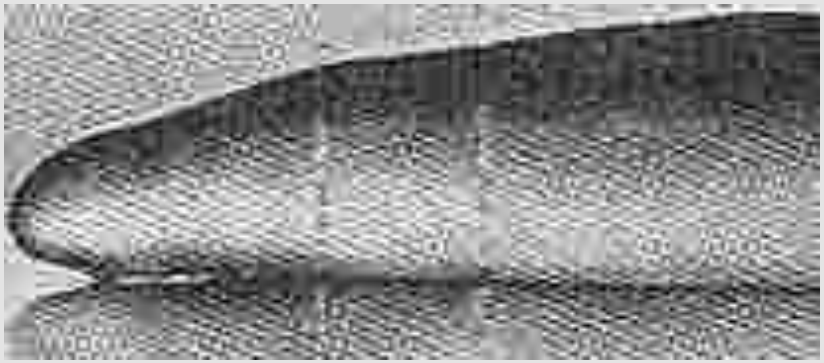


The Emergence of Slime Mold

→

Chemical
Potential
Gradients





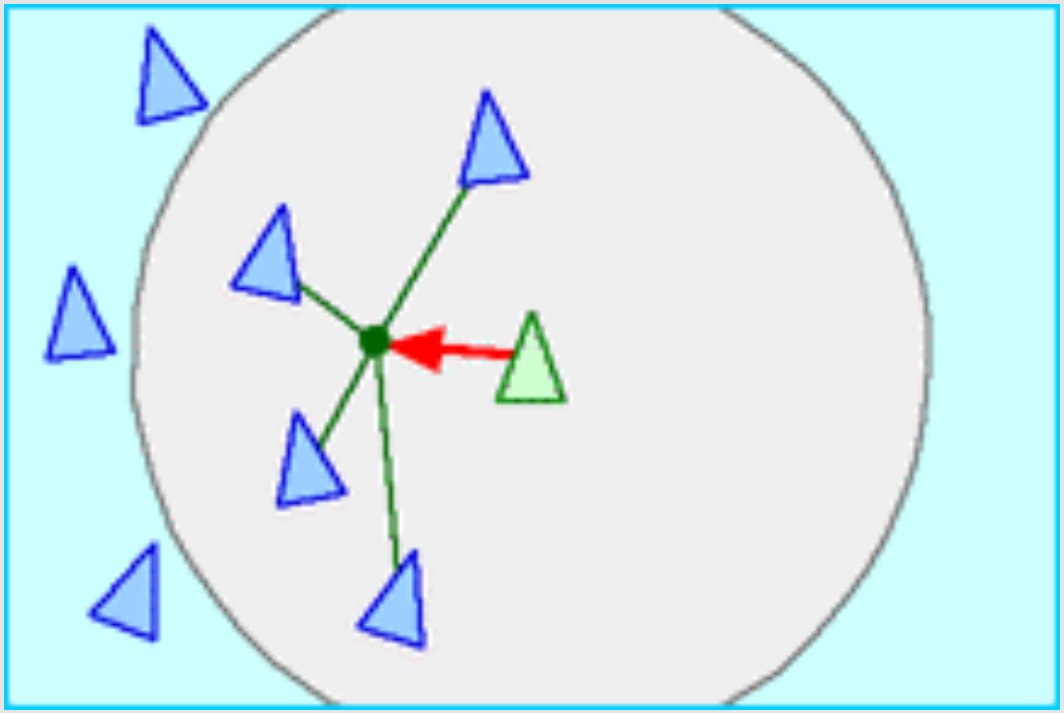
Dictyostelium

The Emergence of Slime Mold

Dictyostelium

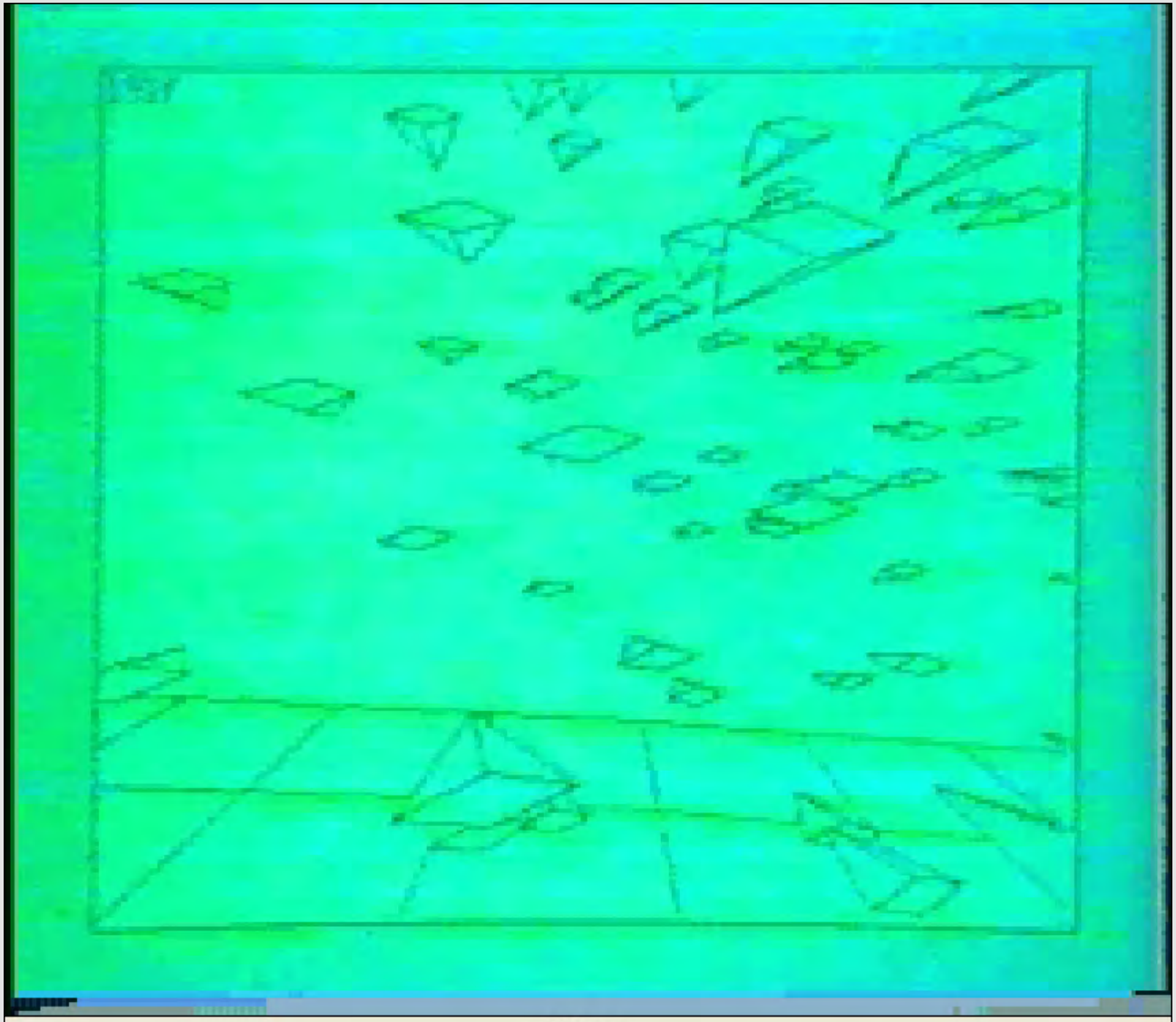
Emergent Complexity: Craig Reynold's BOIDS

Three steering rules for the flock:



1. Separation: Steer to avoid crowding local flockmates.
2. Alignment: Steer toward the average heading of local flockmates.
3. Cohesion: Steer to move toward the average position of local flockmates.

Selection Rule Approach: BOIDS

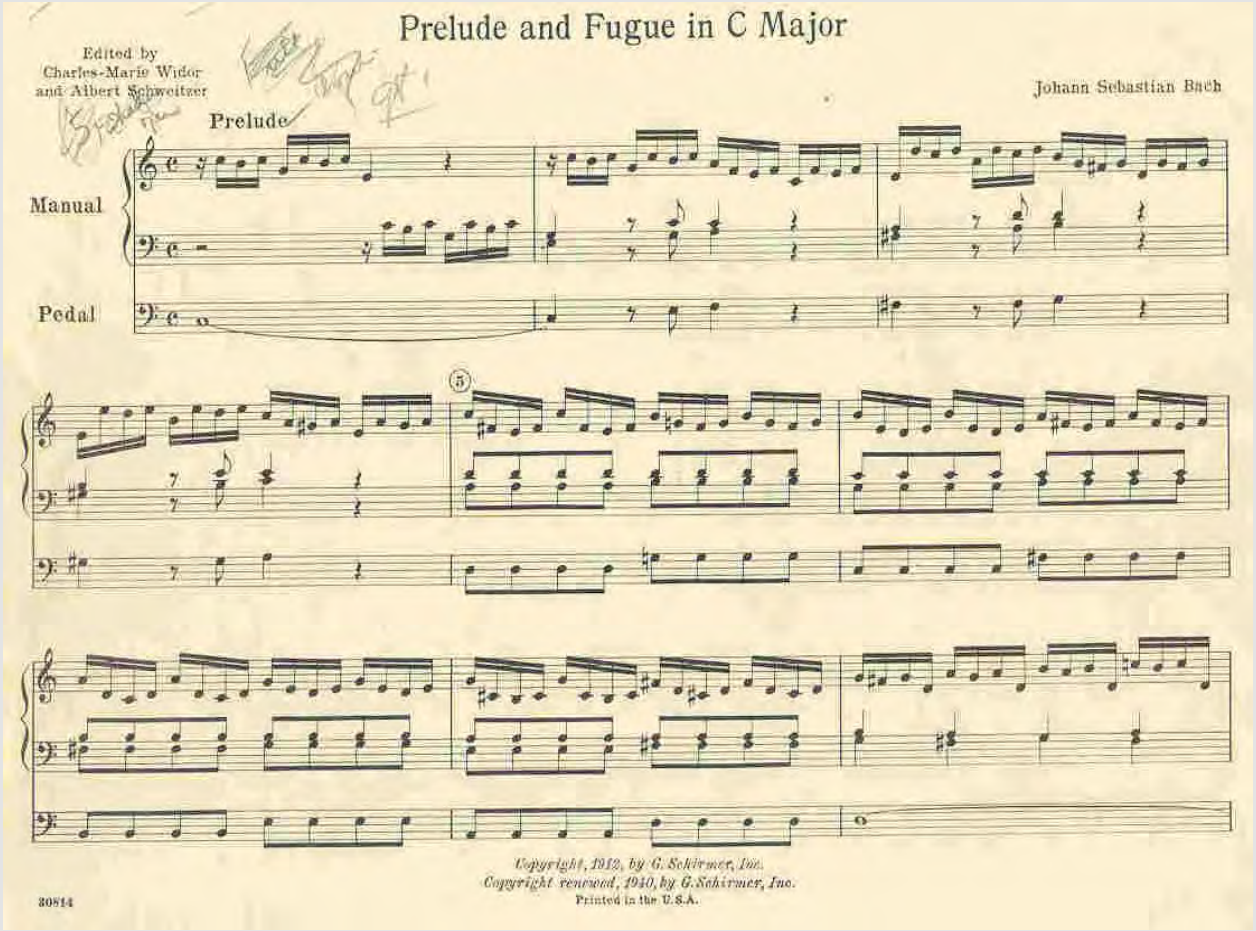


BOIDS-Movie

Flocking starlings over Rome

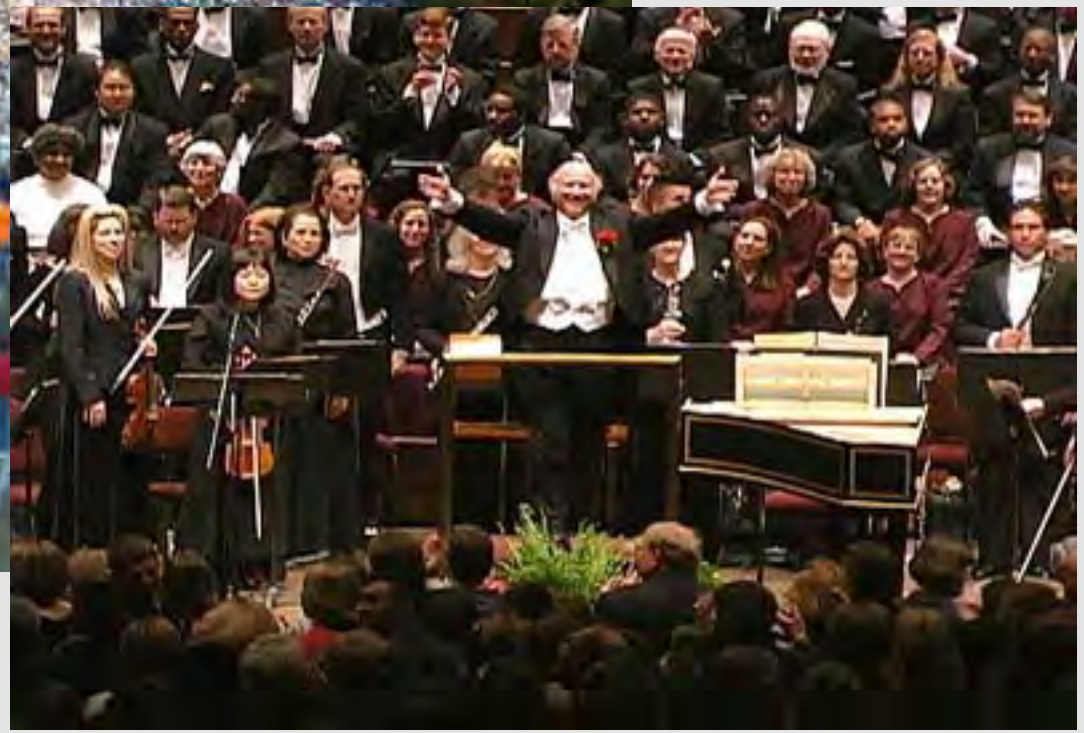
Emergent Complexity: Music

Interactions by rules of harmony and counterpoint



Emergent Phenomena – Life

Emergent Phenomena – Society



Complex Evolving Systems:

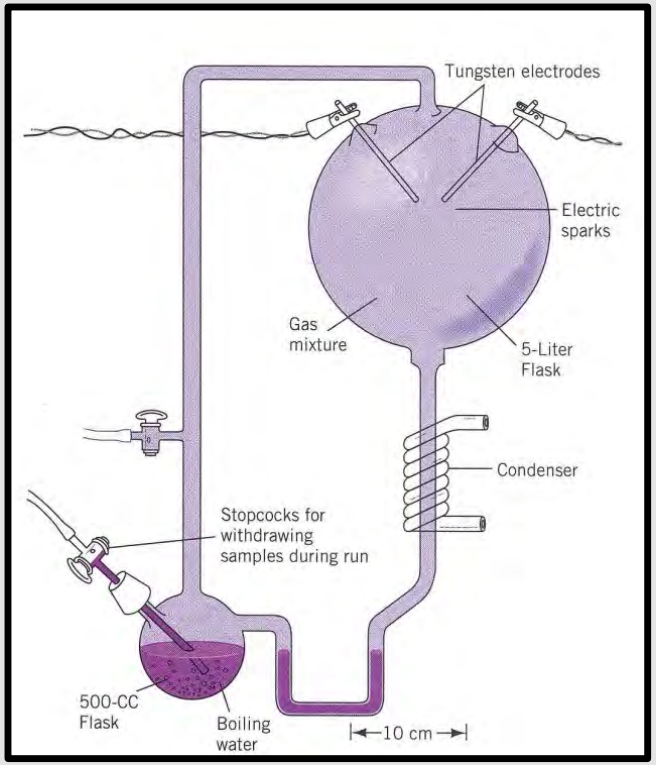
Examples: Elements and isotopes

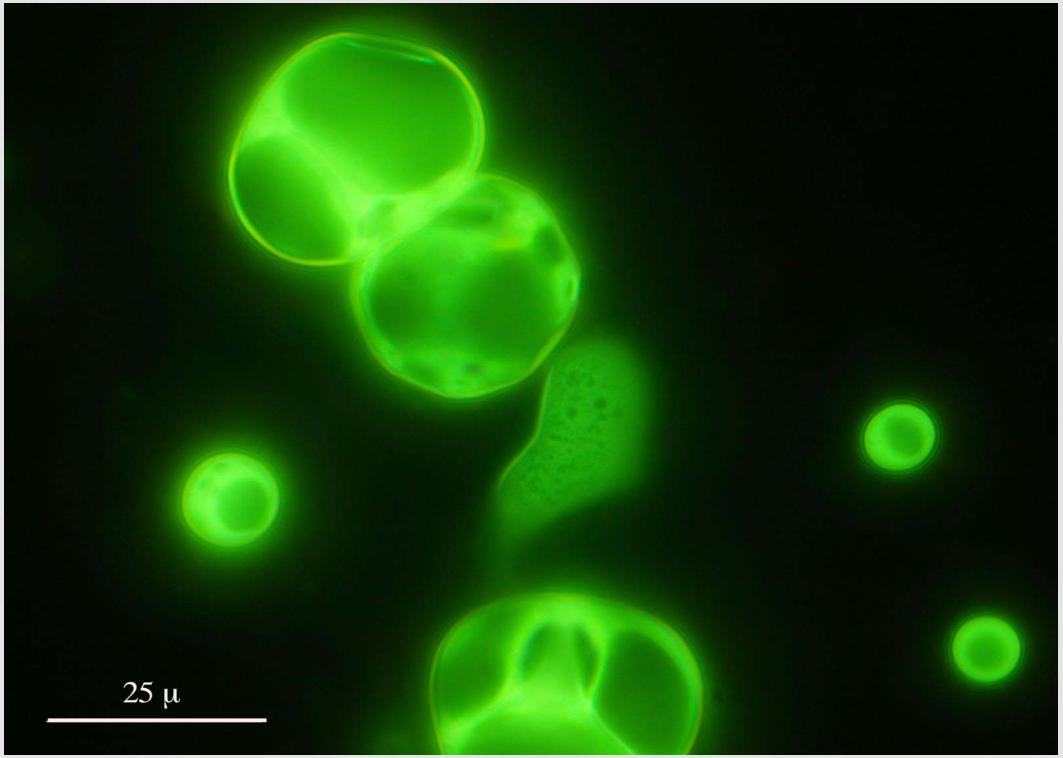
Complex Evolving Systems:

Examples: **Elements and Isotopes**
Minerals

Complex Evolving Systems:

Examples: Elements and isotopes
Minerals
Prebiotic chemicals

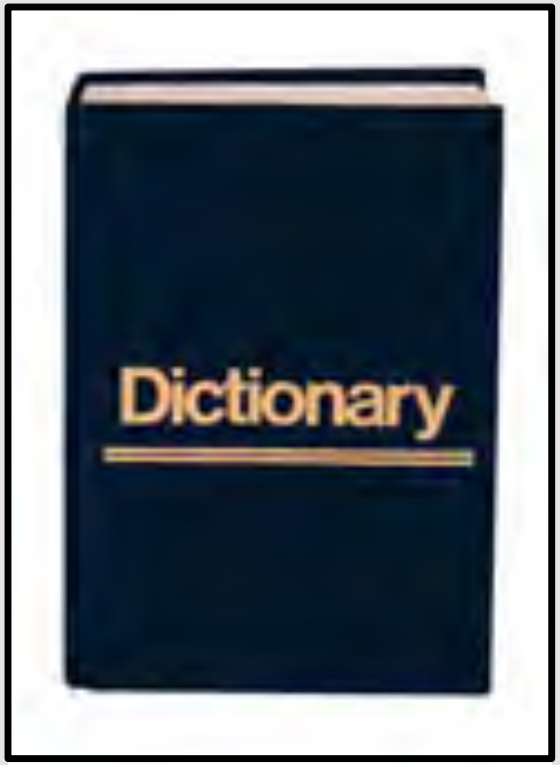




Complex Evolving Systems:

Examples:

Elements and isotopes
Minerals
Prebiotic chemicals



Languages

Complex Evolving Systems:

Examples:

Elements and isotopes
Minerals
Prebiotic chemicals

Languages
Material culture

Complex Evolving Systems:

Examples:

Elements and isotopes
Minerals
Prebiotic chemicals

Languages
Material culture
Popular culture

Complex Evolving Systems:

Examples:

- Elements and isotopes
- Minerals
- Prebiotic chemicals

- Languages
- Material culture
- Popular culture
- Biological evolution

Complex Evolving Systems: Six Themes

Species

Selection

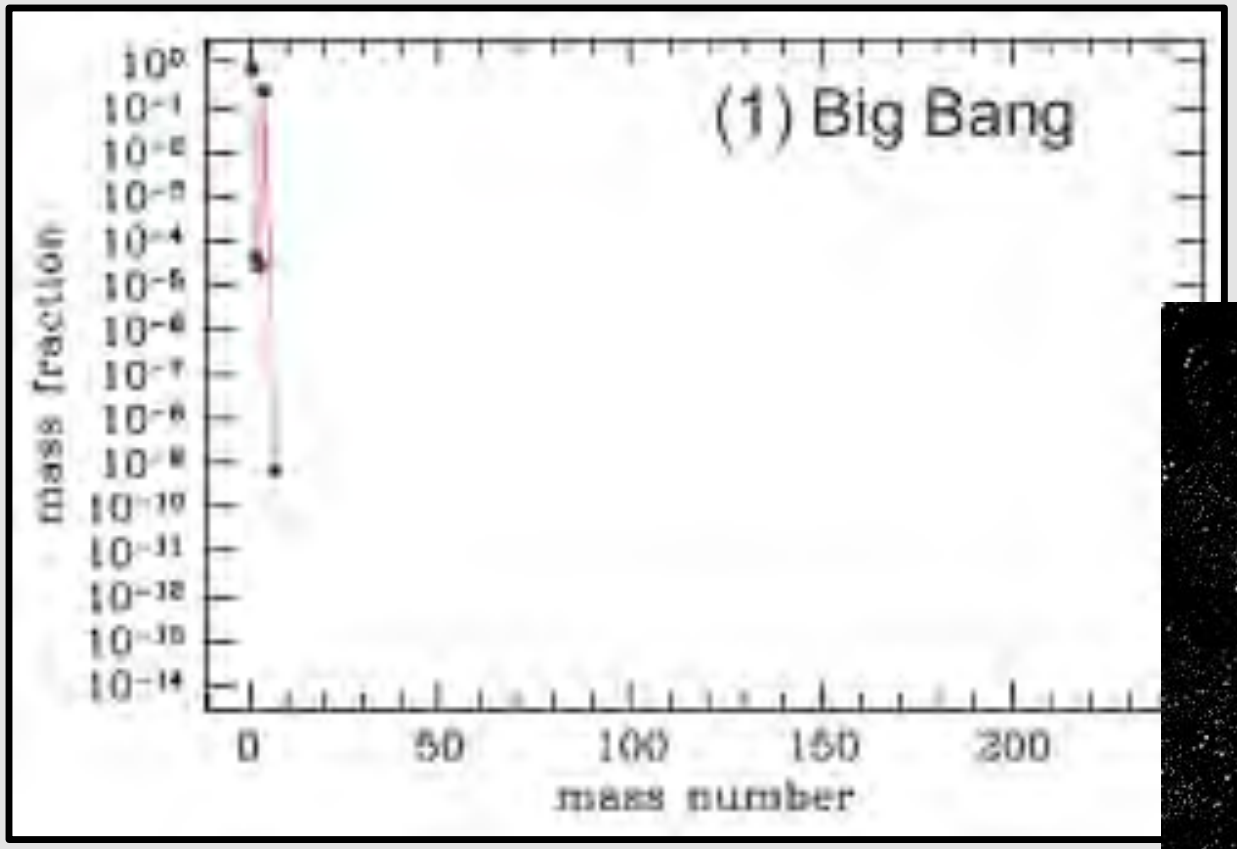
Diversification

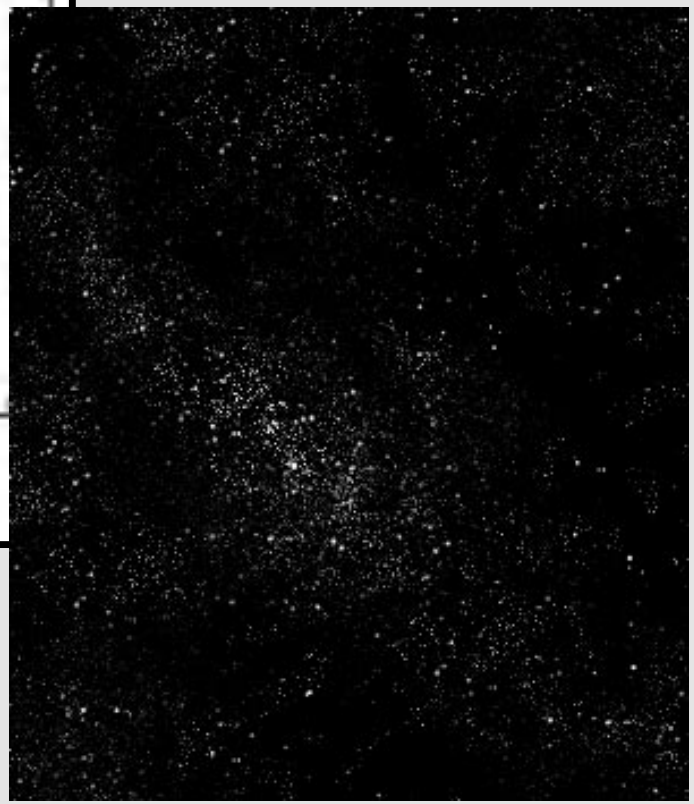
Niches

Punctuation

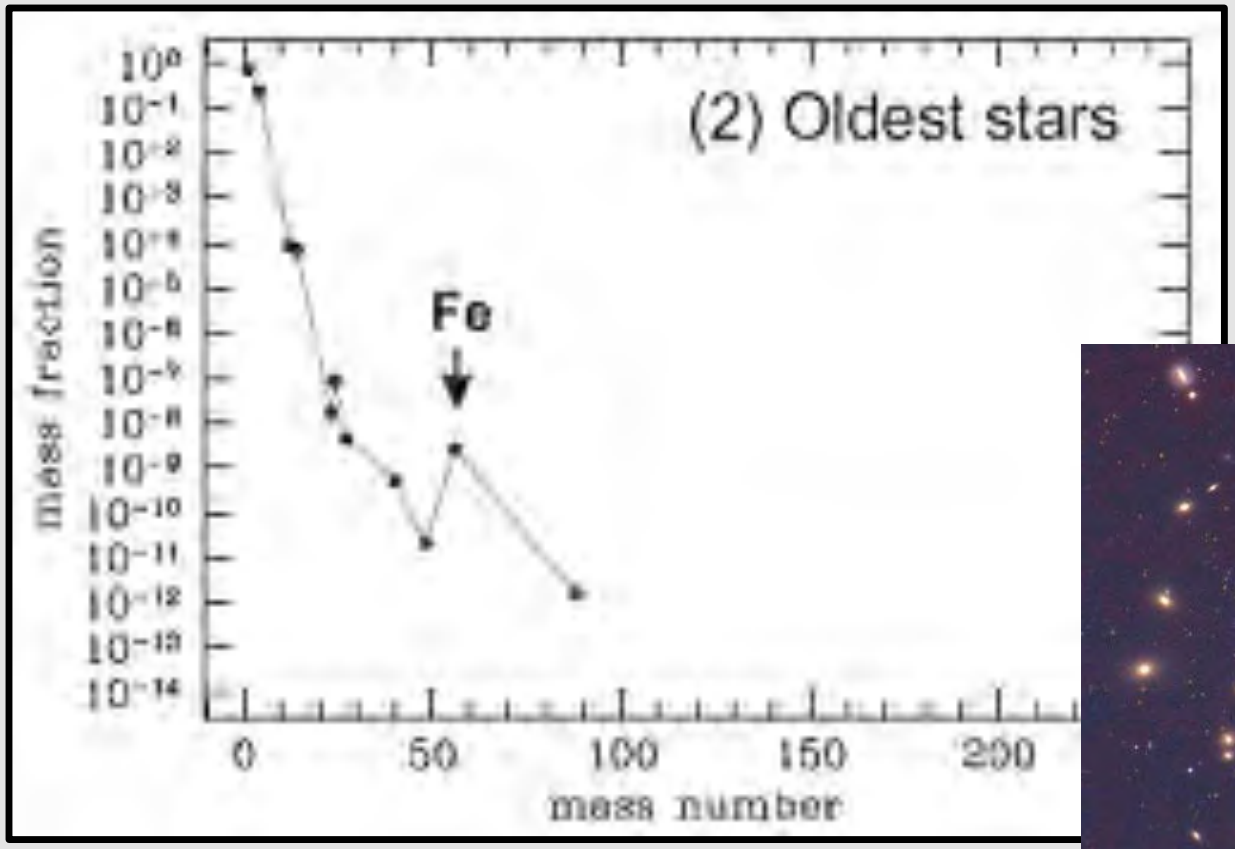
Extinction

Elements and Isotopes

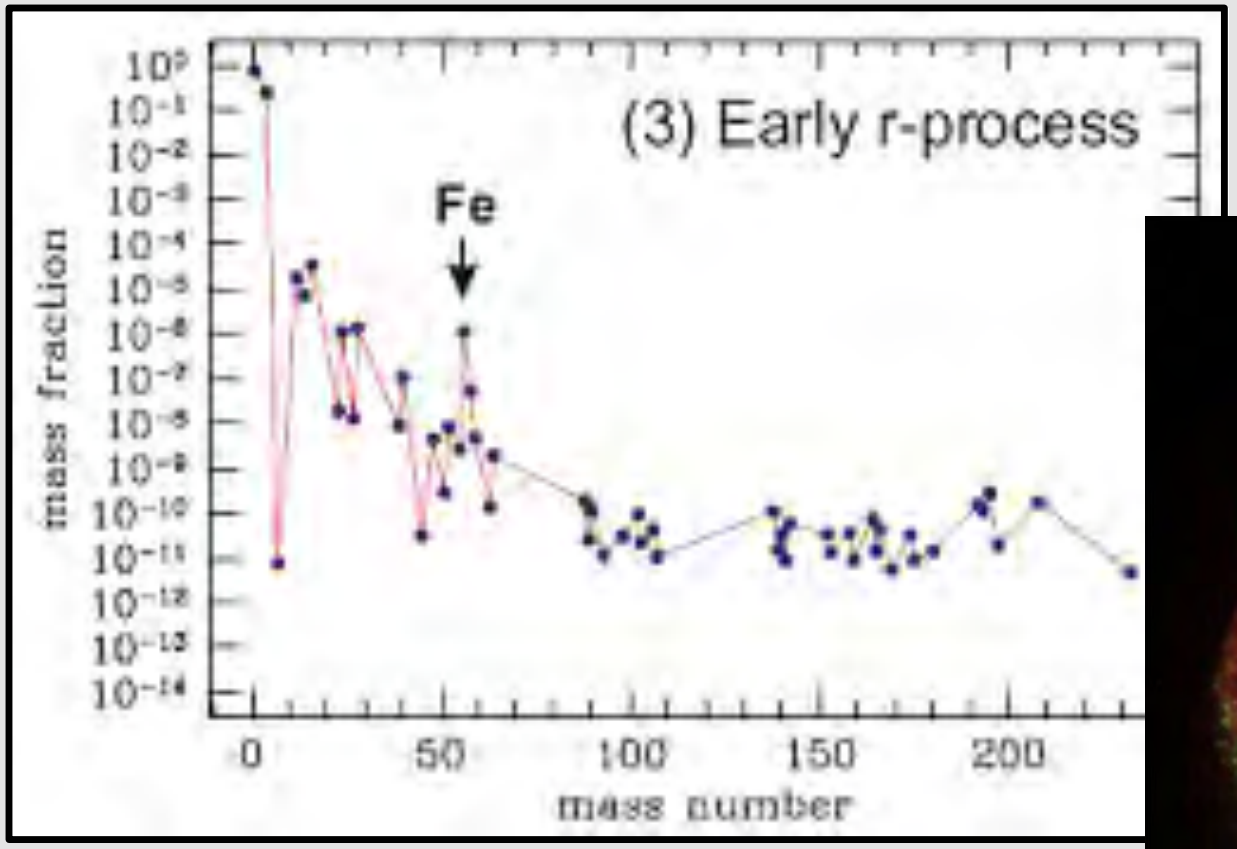




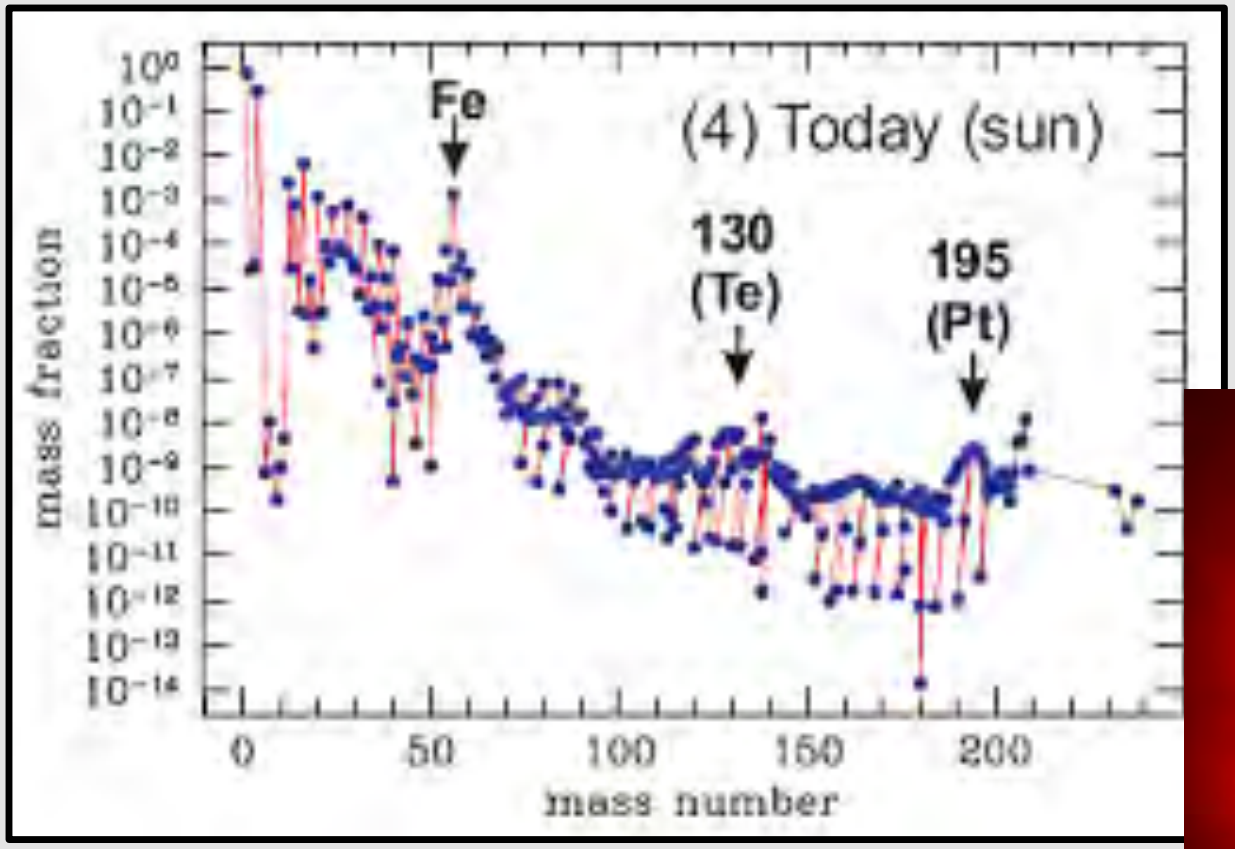
Elements and Isotopes

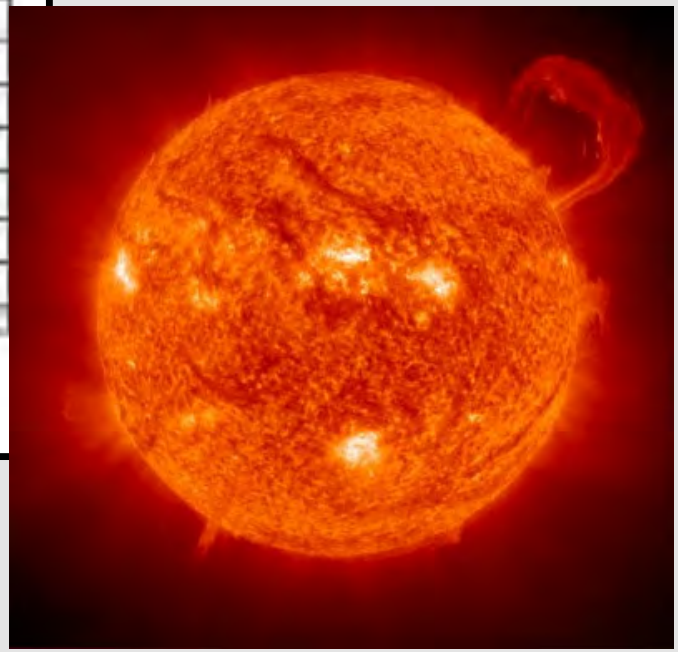


Elements and Isotopes

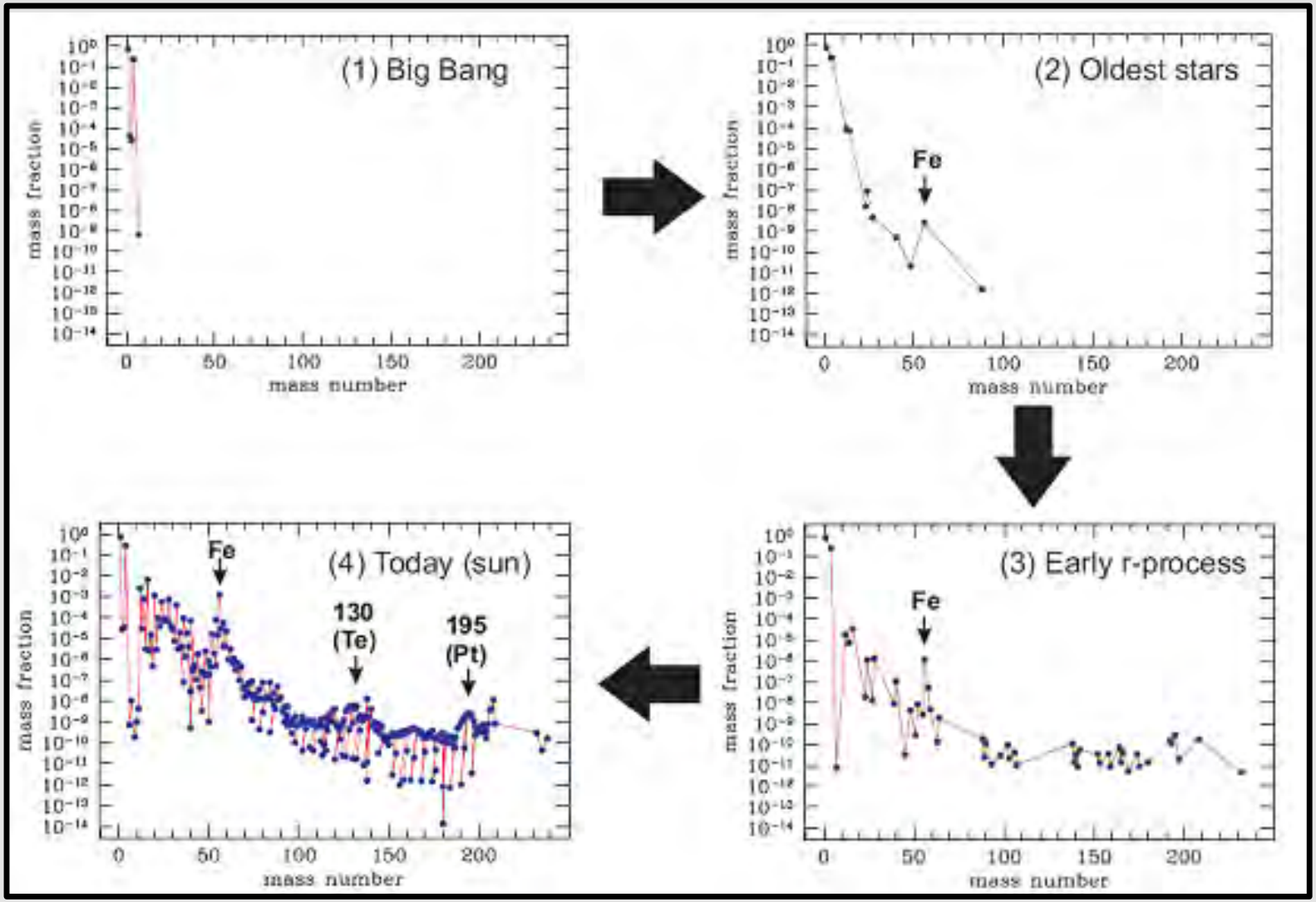


Elements and Isotopes





Elements and Isotopes



Minerals

Mineral evolution is a change over time in:

- **The diversity of mineral species**
- **The relative abundances of minerals**
- **The compositional ranges of minerals**
- **The grain sizes and shapes of minerals**

Minerals

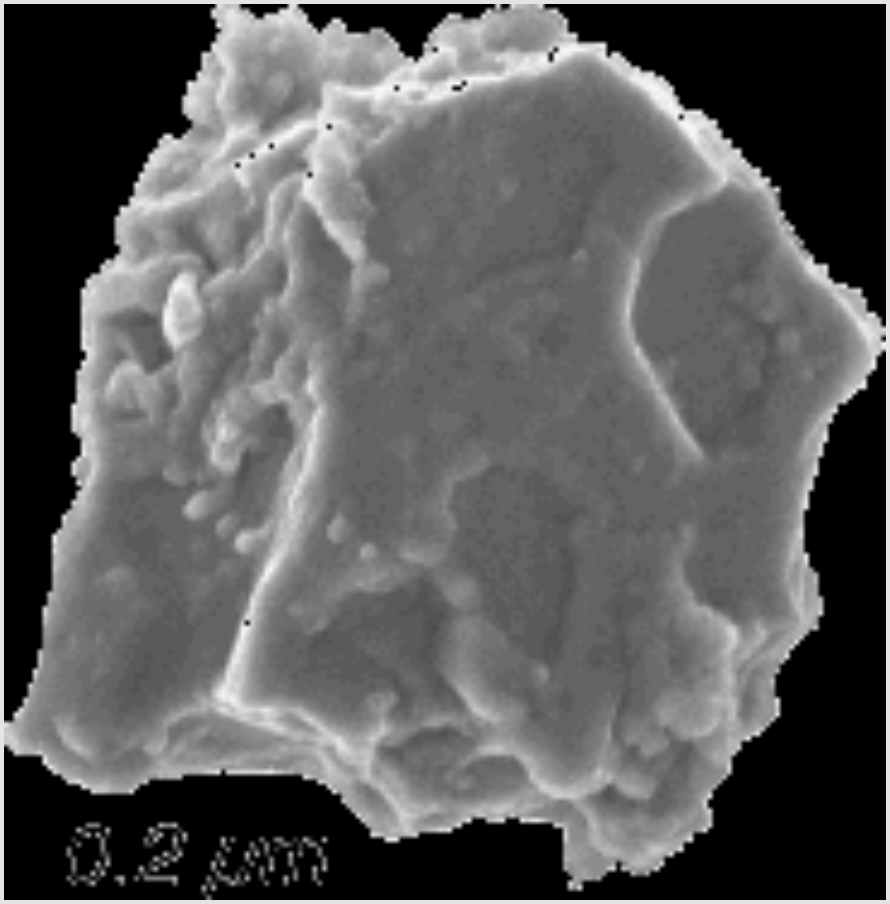
Mineral evolution is a change over time in:

- **The diversity of mineral species**
- **The relative abundances of minerals**
- **The compositional ranges of minerals**
- **The grain sizes and shapes of minerals**

"Ur"-Mineralogy

Pre-solar grains contain about a dozen different minerals:

- Diamond (C)
- Graphite (C)
- Moissanite (SiC)
- Osbornite (TiN)
- Nierite (Si_3N_4)
- Rutile (TiO_2)
- Corundum (Al_2O_3)
- Spinel ($MgAl_2O_4$)
- Hibbonite ($CaAl_{12}O_{19}$)
- Forsterite (Mg_2SiO_4)



How did we get from a dozen minerals to >4400 on Earth today?

What Drives Mineral Evolution?

Three processes that might occur on any planet or moon:

Separation & concentration of chemical elements

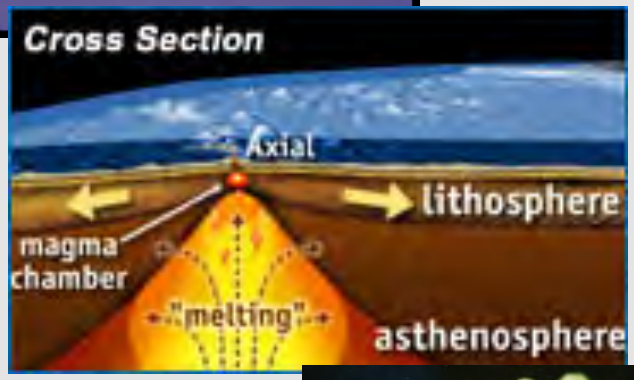
Increased ranges of temperature and pressure.

The influence of life.

Three Eras of Earth's Mineral Evolution

1. The Era of Planetary Accretion

2. The Era of Crust and Mantle Reworking



3. The Era of Bio-Mediated Mineralogy

First Era: Planetary Accretion

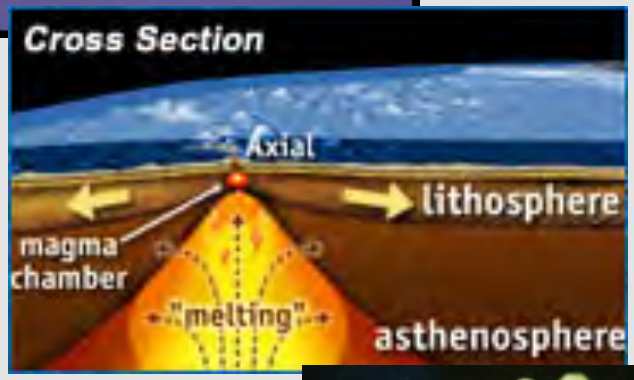
~60 primary mineral species

~250 total known mineral species

Three Eras of Earth's Mineral Evolution

1. The Era of Planetary Accretion

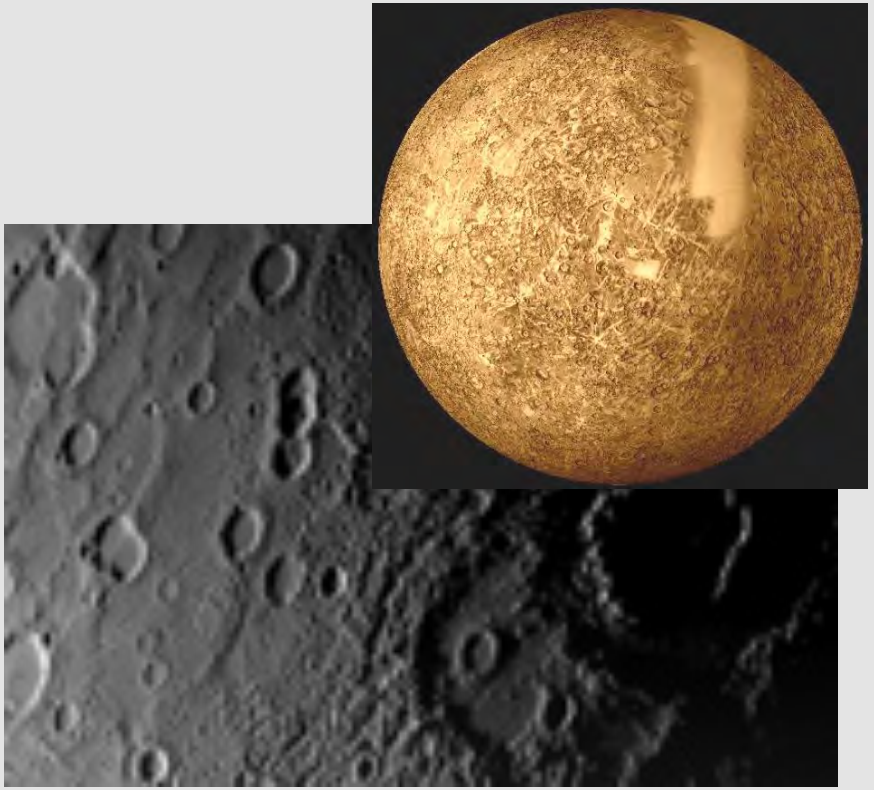
2. The Era of Crust and Mantle Reworking



3. The Era of Bio-Mediated Mineralogy

Second Era: Igneous Rock Evolution on a Water-Poor Body

~350 mineral species?

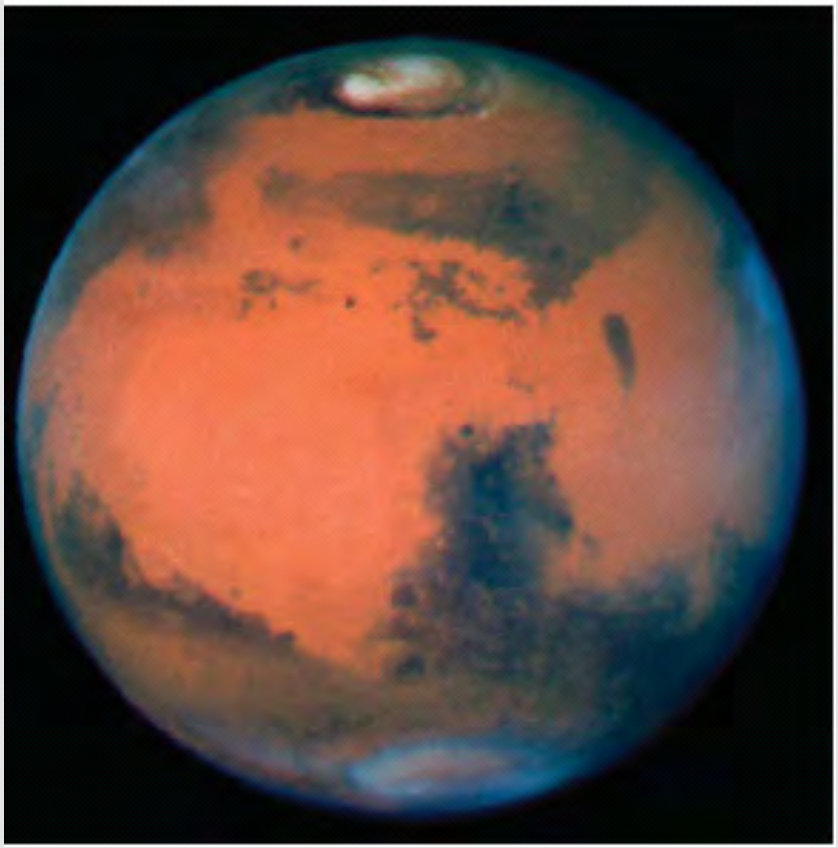


Is this the end point of the Moon and Mercury?

Second Era: Igneous Rock Evolution on a Water-Rich Body

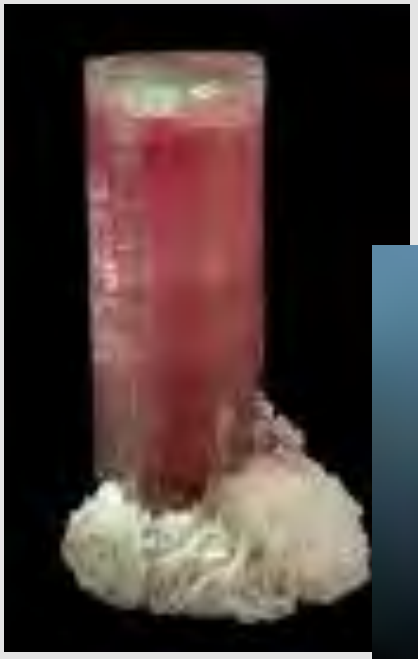
>500 mineral species

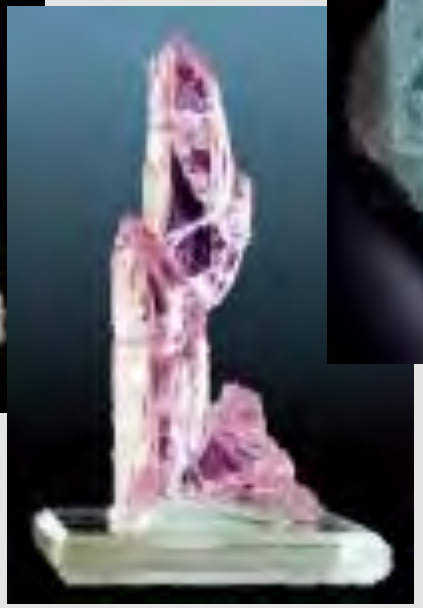
Second Era: Igneous Rock Evolution on a Water-Rich Body

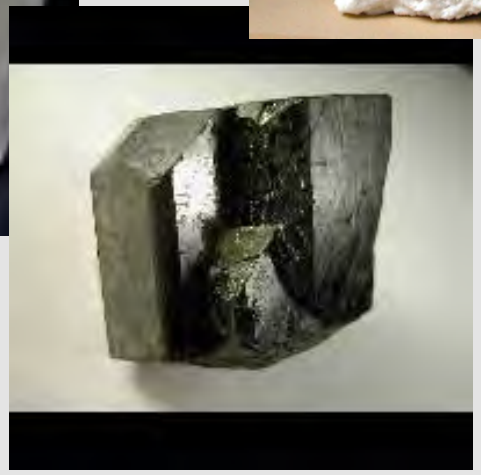


Is this as far as Mars or Venus progressed?

Rare Pegmatite Minerals



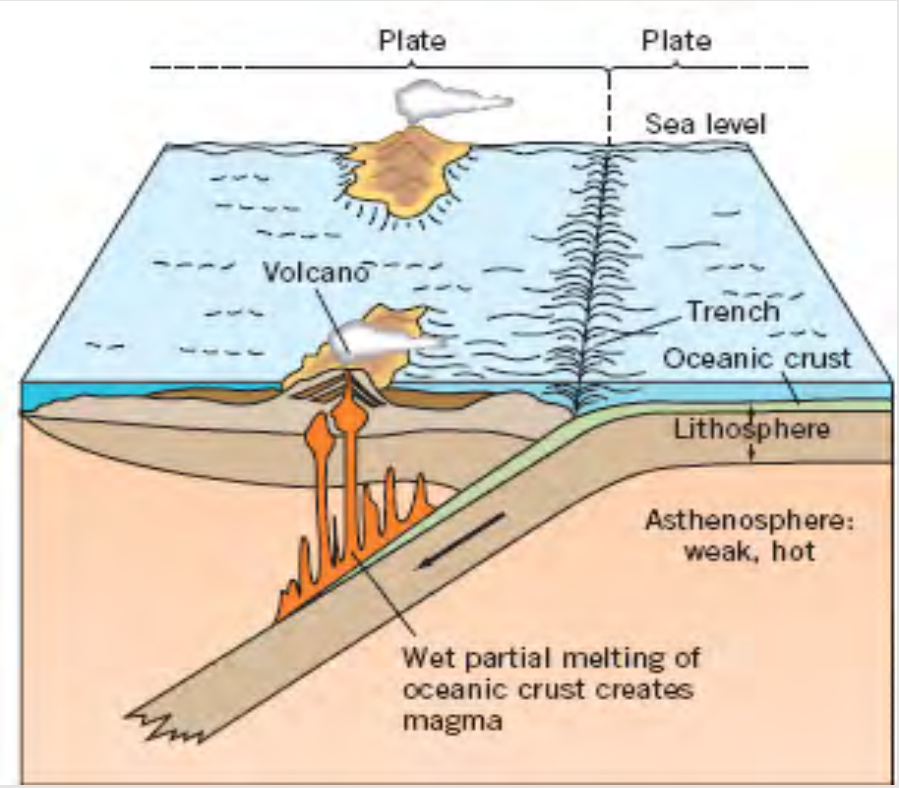




It took at least a billion years on Earth before these minerals could have formed!

Second Era: Plate Tectonics on a Water-Rich Body

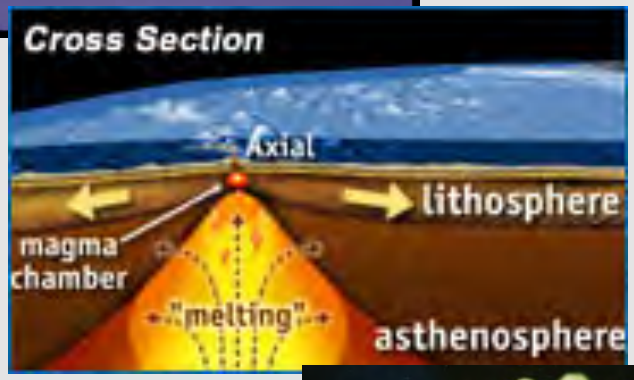
1,500 mineral species



Three Eras of Earth's Mineral Evolution

1. **The Era of Planetary Accretion**

2. **The Era of Crust and Mantle Reworking**



3. **The Era of Bio-Mediated Mineralogy**

Third Era: The Influence of Life

>4000 mineral species, most formed by weathering in an oxygen-rich atmosphere.

Thousands of New Minerals!

“Biomineralization”

Two Phases of Life's Evolution

1. **Chemical Evolution:**

   The "origin of life"

2. **Natural Selection:**

   Once a reproducing cell exists, complexity arises from competition.

Central Assumptions of Origin-of-Life Research

The first life forms were carbon-based.

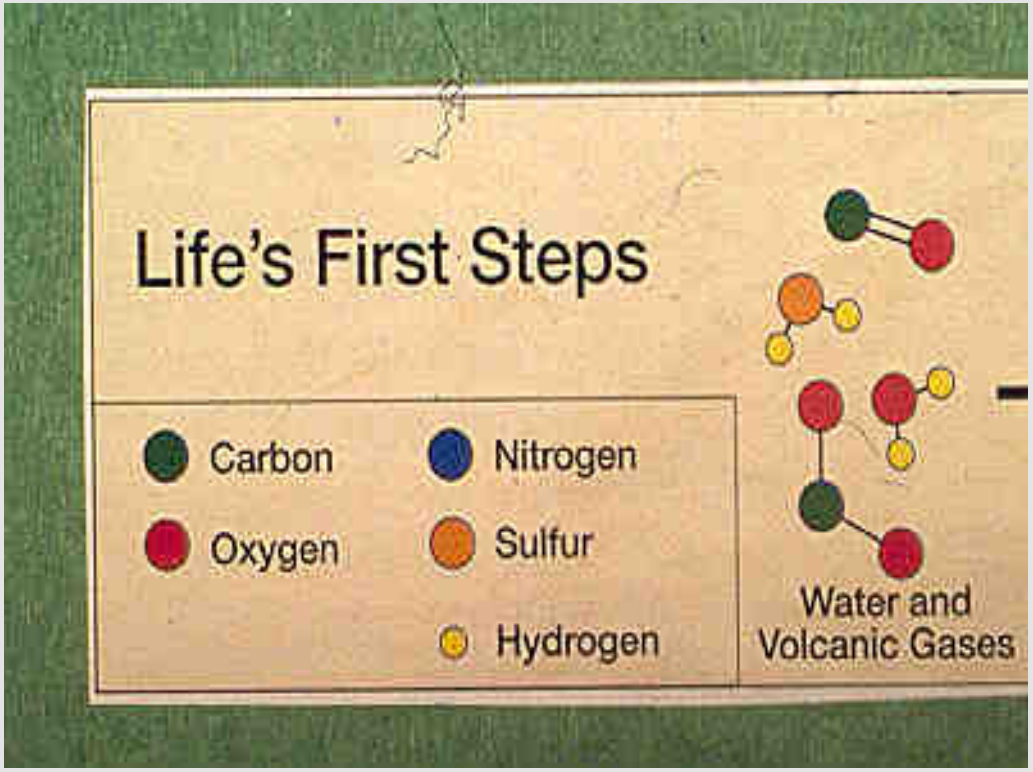
Life's origin was a chemical process that relied on water, air, and rock.

The origin of life required a sequence of emergent steps of increasing complexity.

Four Emergent Steps

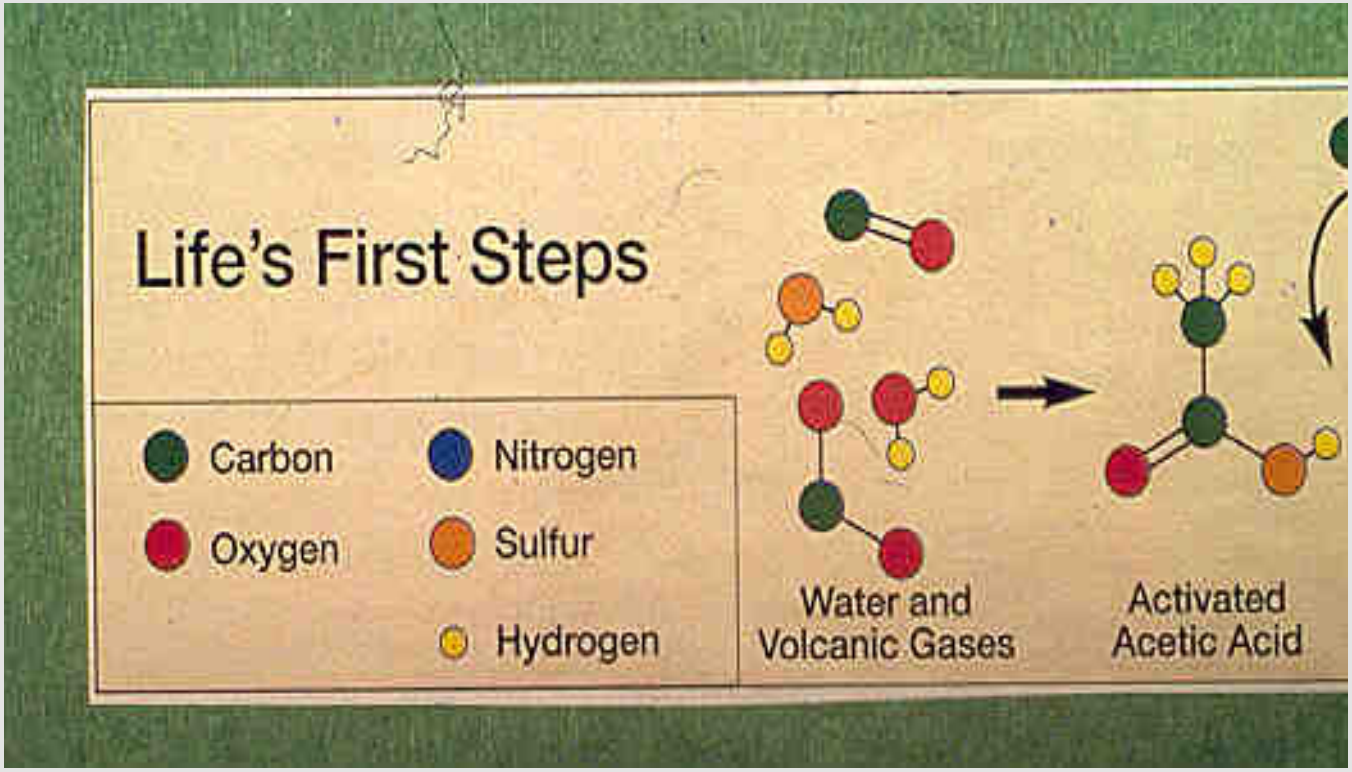
1. Emergence of biomolecules
2. Emergence of organized molecular systems
3. Emergence of self-replicating molecular systems
4. Emergence of natural selection (biological evolution)

Emergence of Biomolecules



The strategy is to use simple molecules to build larger molecules.

Emergence of Biomolecules



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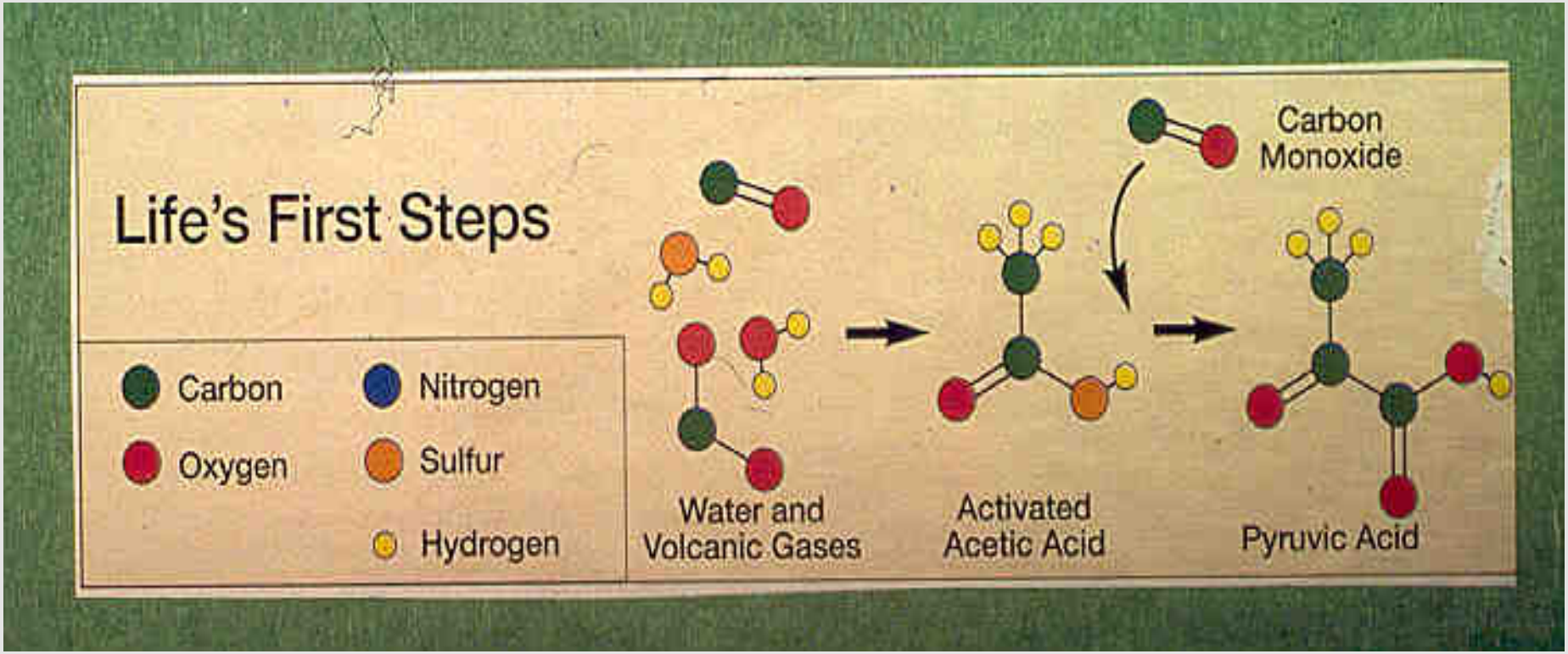
Emergence of Biomolecules



The strategy is to use simple molecules to build larger molecules.

The Miller-Urey Experiment

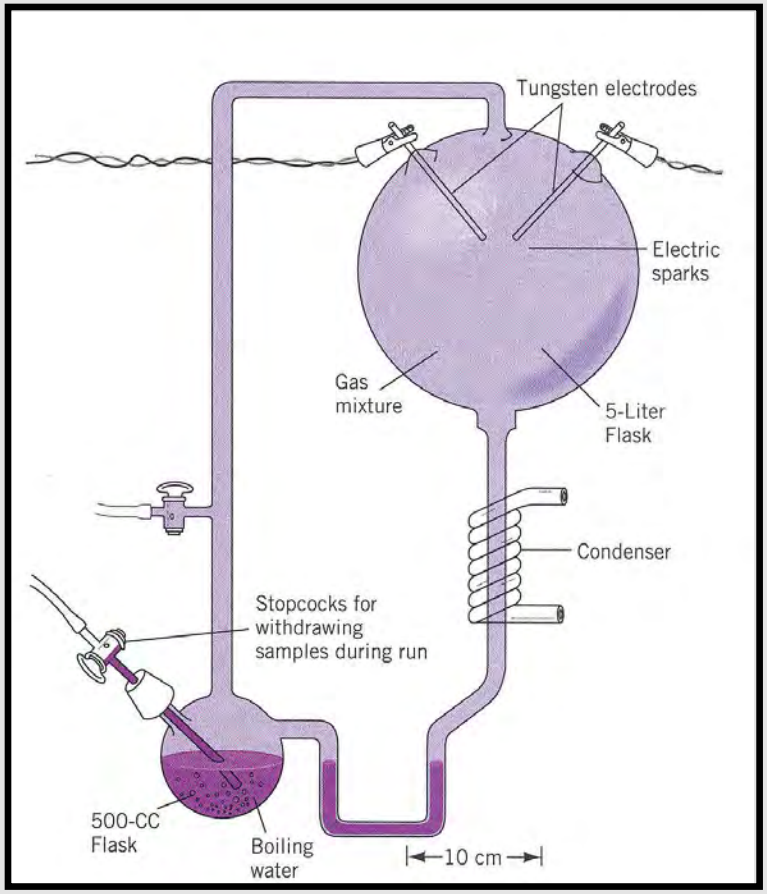


Table 3–8 Some of the products shown to form under prebiotic conditions

Amino acids
- Glycine
- Alanine
- α-Aminobutyric acid
- Valine
- Leucine
- Isoleucine
- Proline
- Aspartic acid
- Glutamic acid
- Serine
- Threonine

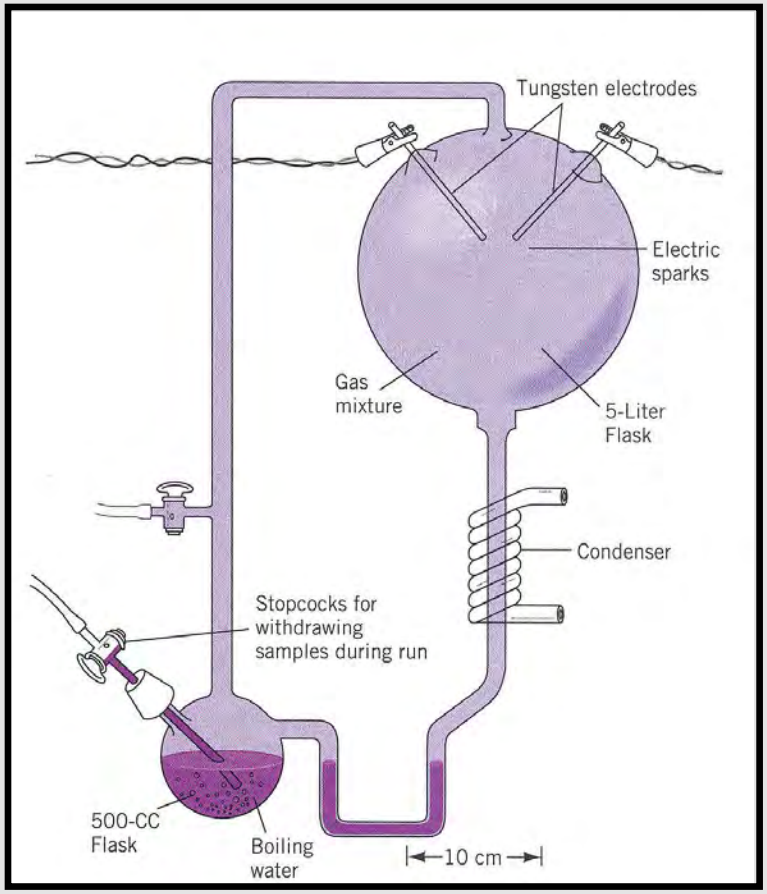
Sugars
- Straight and branched pentoses and hexoses

Carboxylic acids
- Formic acid
- Acetic acid
- Propionic acid
- Straight and branched fatty acids (C_4–C_{10})
- Glycolic acid
- Lactic acid
- Succinic acid

Nucleic acid bases
- Adenine
- Guanine
- Xanthine
- Hypoxanthine
- Cytosine
- Uracil

Organic synthesis near the ocean-atmosphere interface.

The Miller-Urey Experiment



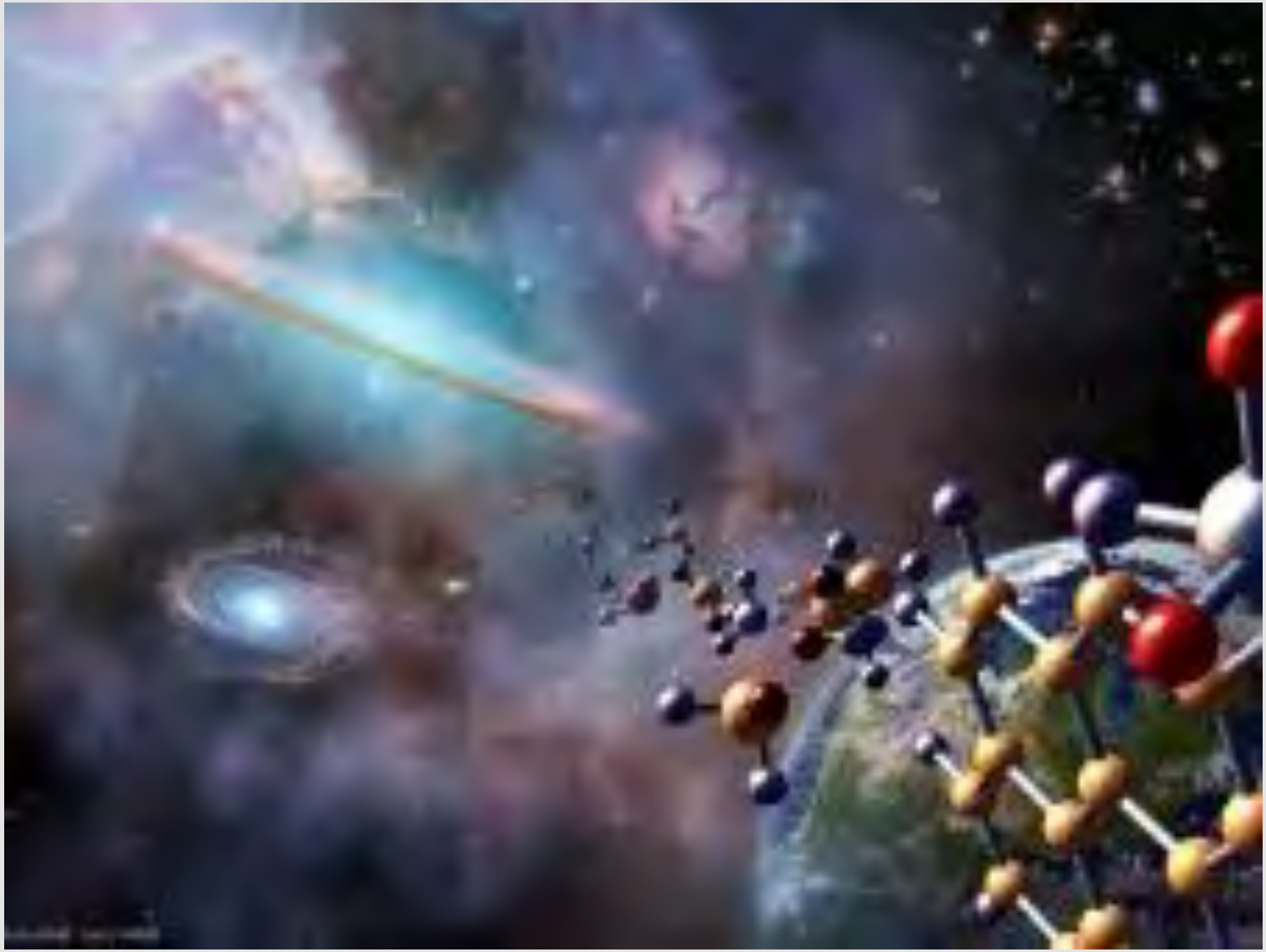
Nutrition Facts

Serving Size 1 cup (30g)
Servings Per Container 17

Amount Per Serving	Wheaties	with ½ cup skim milk
Calories	110	150
Calories from Fat	10	10
	% Daily Value**	
Total Fat 1g*	**1%**	**2%**
Saturated Fat 0g	**0%**	**0%**
Trans Fat 0g		
Polyunsaturated Fat 0g		
Monounsaturated Fat 0g		
Total Carbohydrate 24g	**8%**	**10%**
Dietary Fiber 3g	**12%**	**12%**
Sugars 4g		
Other Carbohydrate 17g		
Protein 3g		

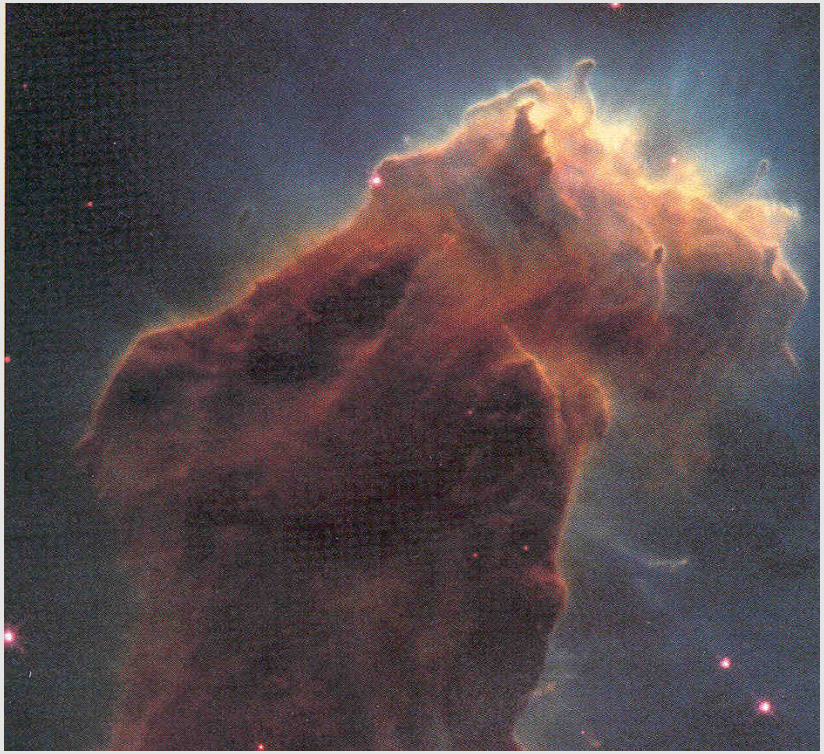
Organic synthesis near the ocean-atmosphere interface.

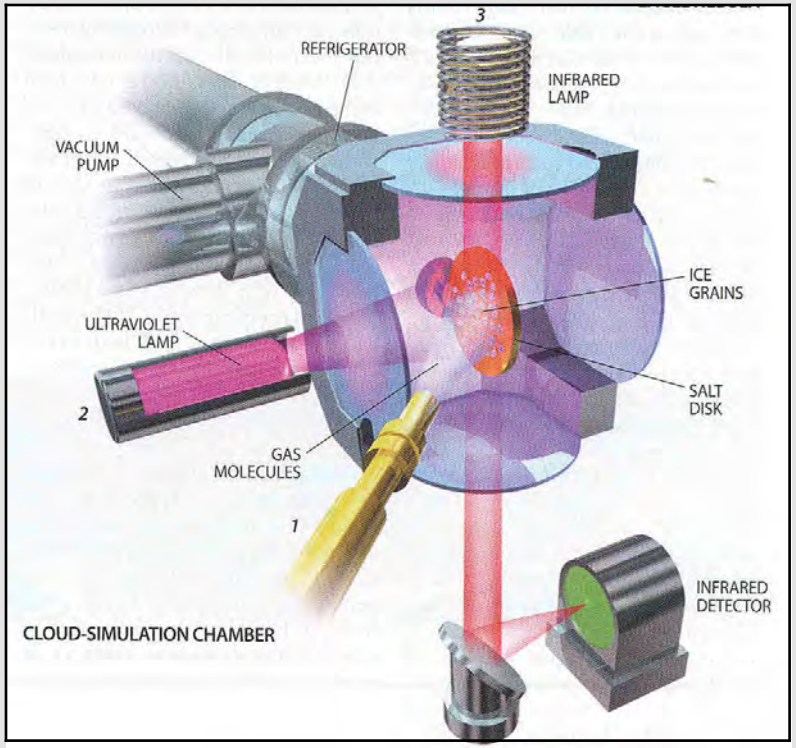
Organic Synthesis in Interstellar "Dense" Molecular Clouds



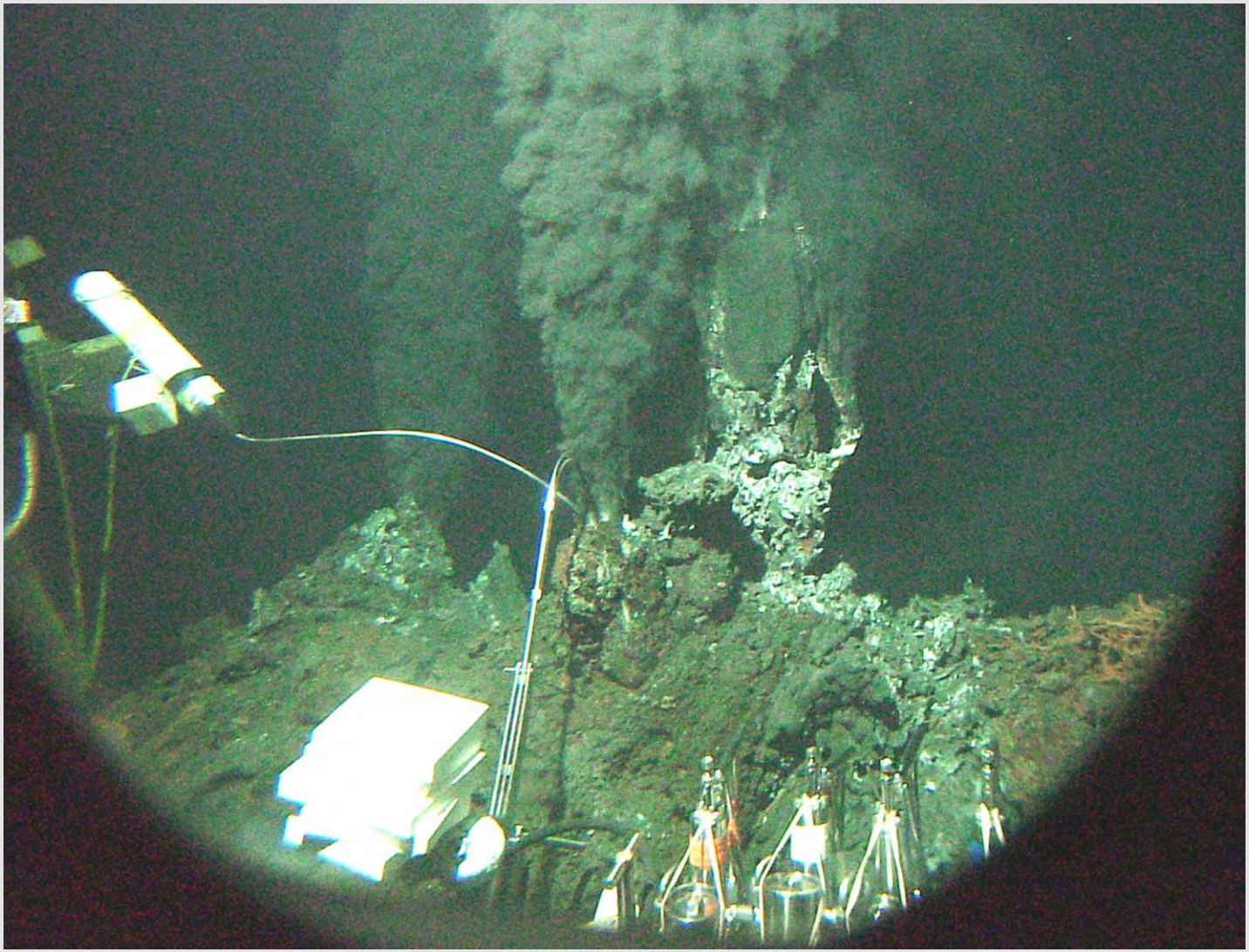
Organic Synthesis in Interstellar "Dense" Molecular Clouds

Experiments at NASA Ames simulate this environment.





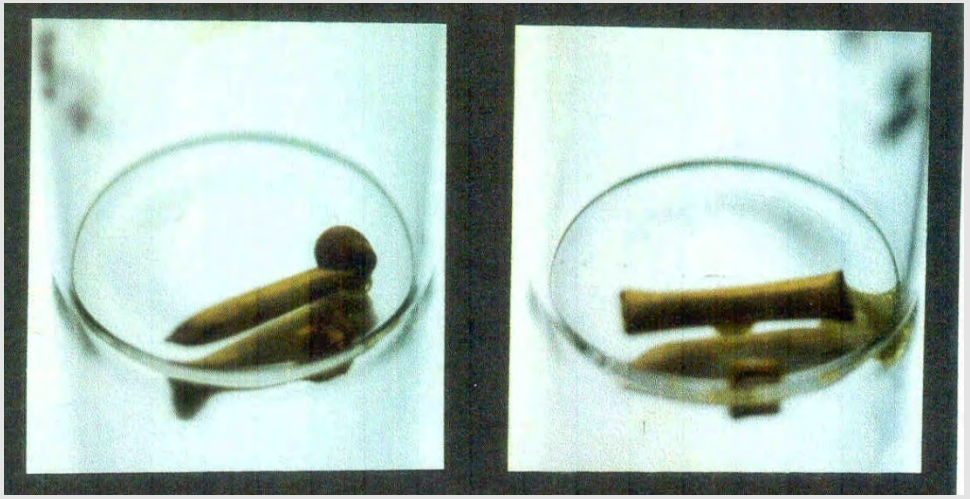
Organic Synthesis at "Black Smokers"

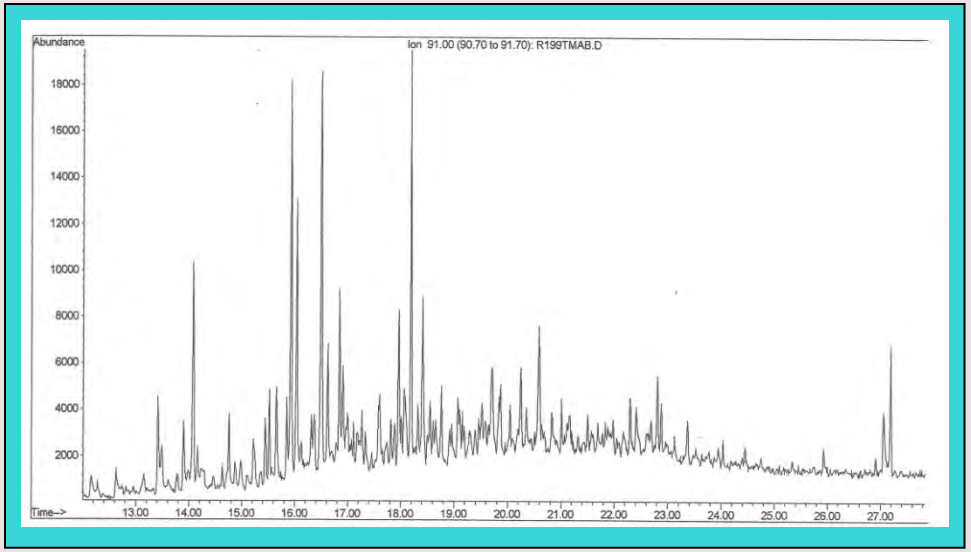


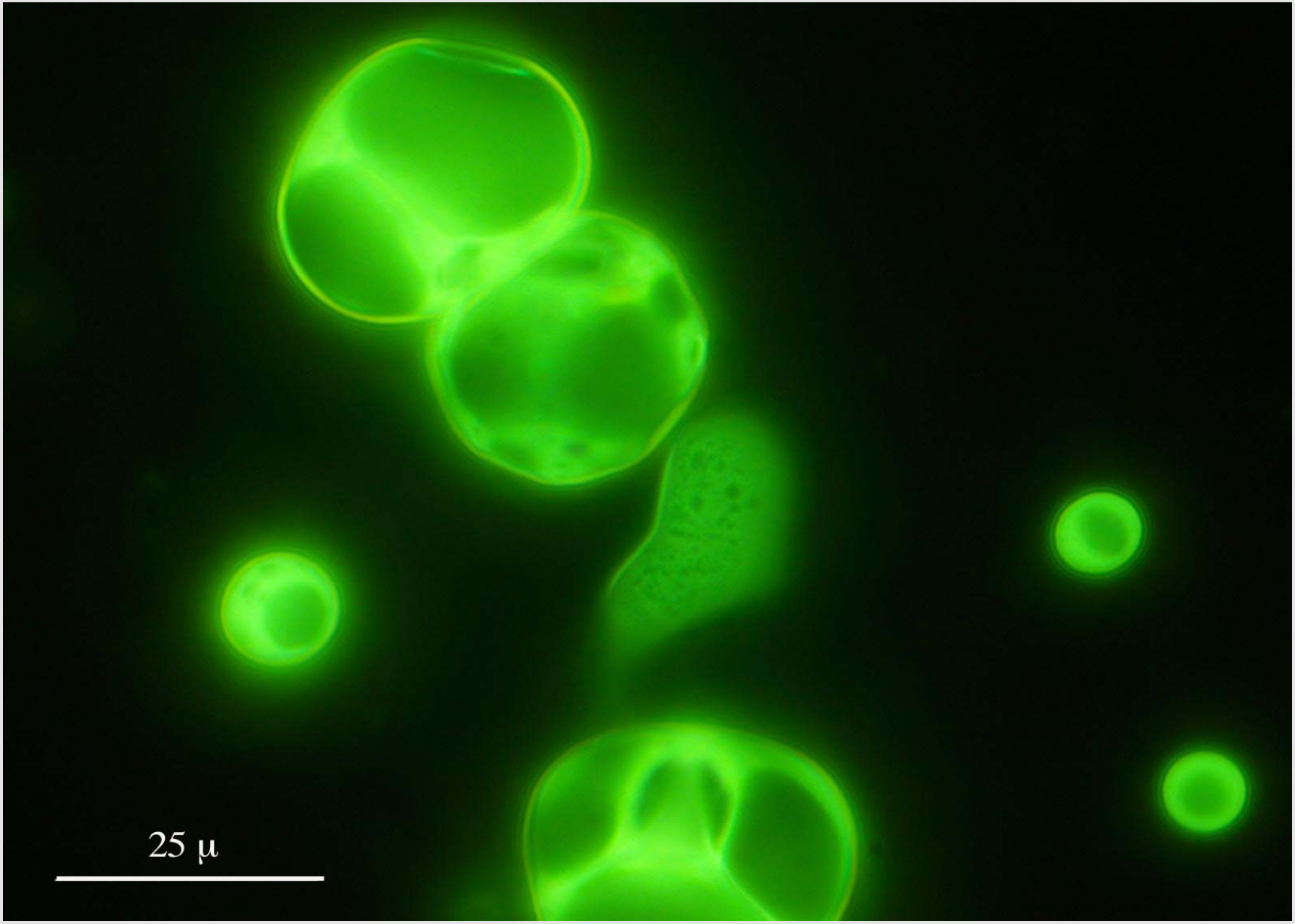
A "BLACK SMOKER"

Organic Synthesis at "Black Smokers"

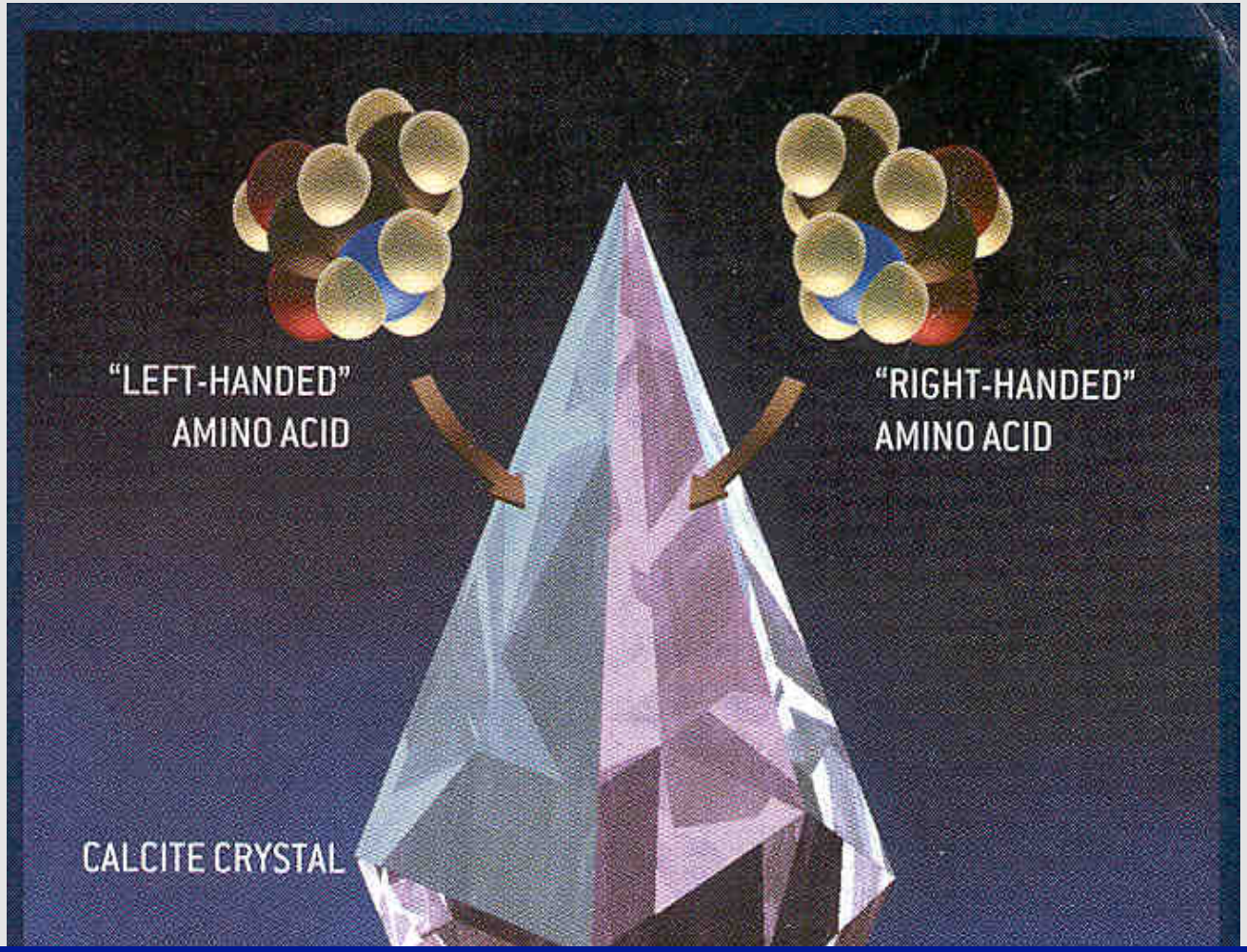
- **Reactants:**
  Pyruvic acid + CO_2 + H_2O
- **Conditions:**
  200°C
  2,000 atm
  2 hours
- **Products: A diverse suite of organic molecules**





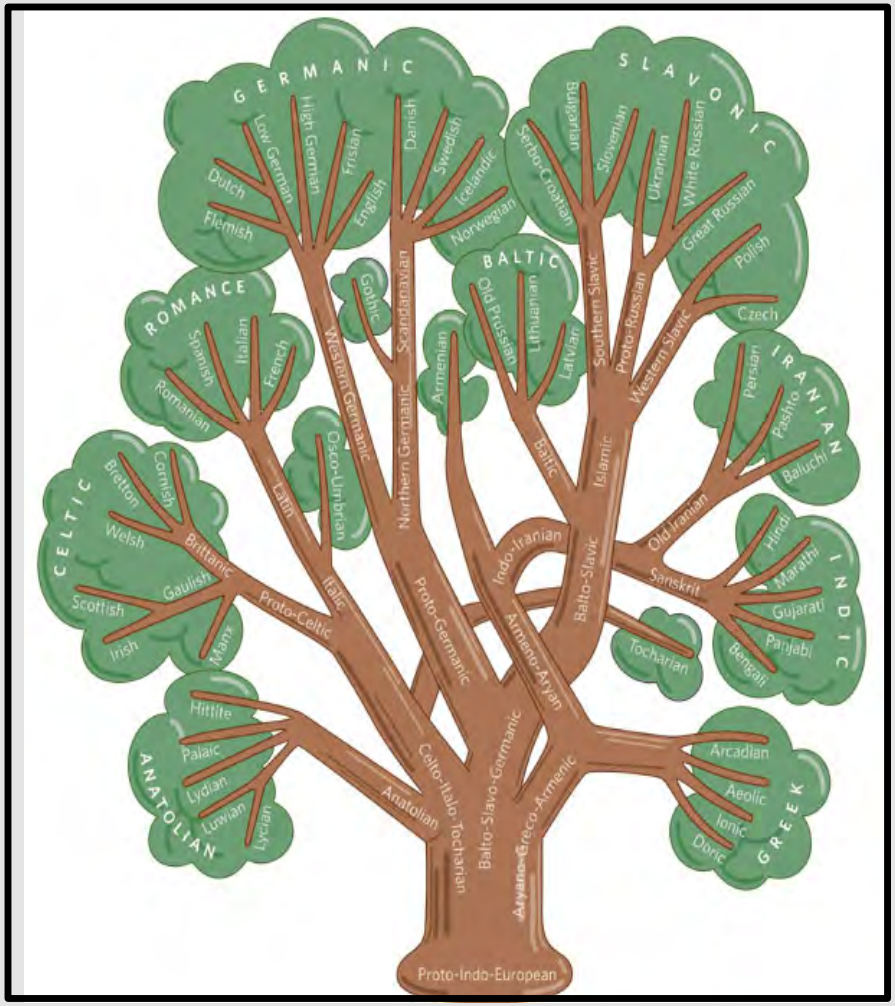

25 μ

Minerals and Chiral Selection



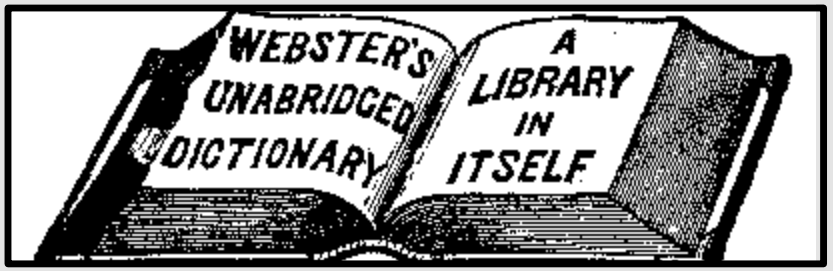
Mineral surfaces select chiral amino acids

Complex Evolving Systems: Languages



Extinction

Punctuation



Material Culture: Trumpets

1600-1810

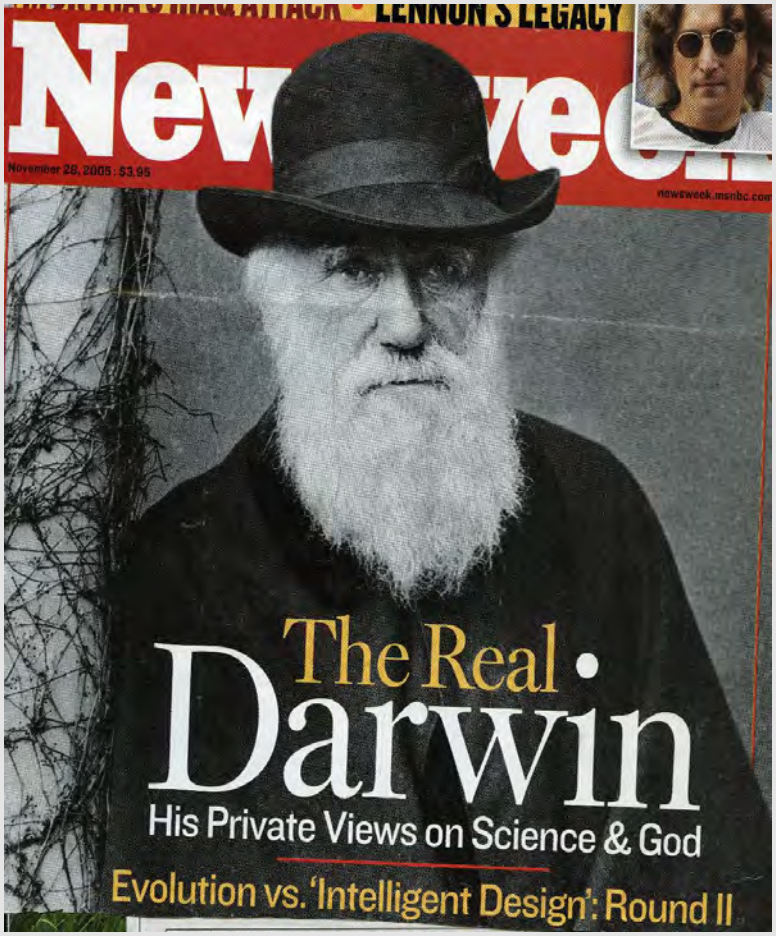
1800-1850

1820-2010

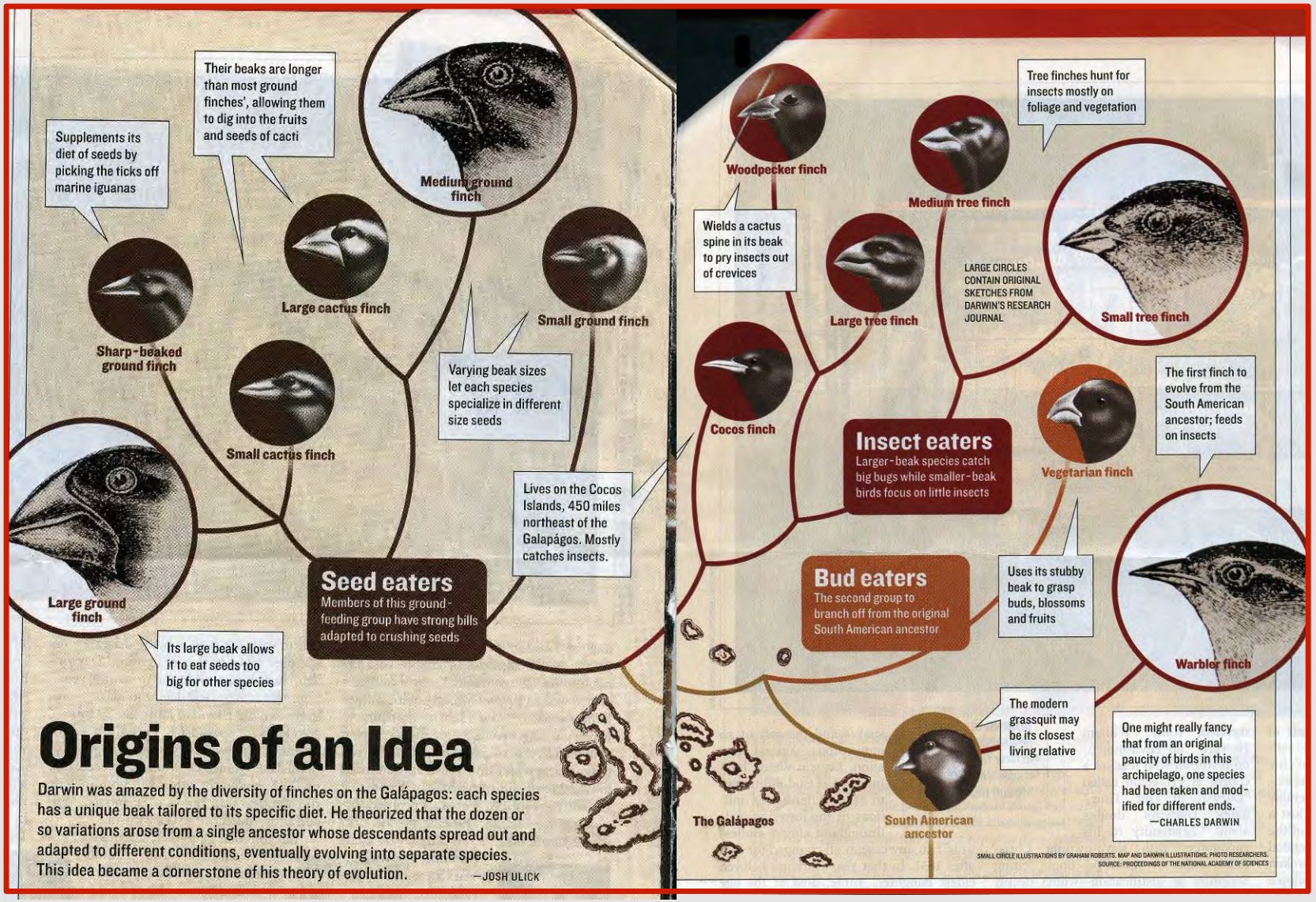
Popular Culture: Broadway Musicals

Part V: What did Darwin Say?

- The first cell on Earth
  - Had no competition
  - Multiplied rapidly
  - Evolved through cycles of mutation, competition and selection



Charles Darwin:
The Beagle at Galapagos



Eye Evolution

"To suppose that the eye, with all its inimitable contrivances for adjusting the focus to different distances, for admitting different amounts of light, and for the correction of spherical and chromatic aberration, could have been formed by natural selection, seems, I freely confess, absurd in the highest possible degree …"

Charles Darwin, *On the Origin of Species*

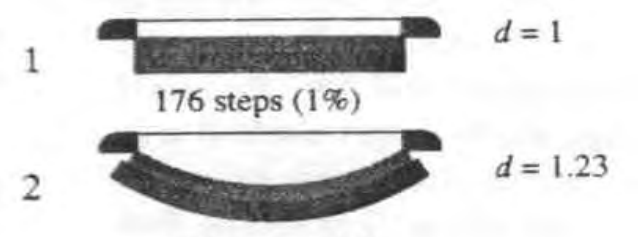
Feedback: Eye Evolution

D. Nilsson & S. Pelger, "A pessimistic estimate for the time required for an eye to evolve." *Proc. R. Soc. Lond. B* 256, 53-58 (1994).

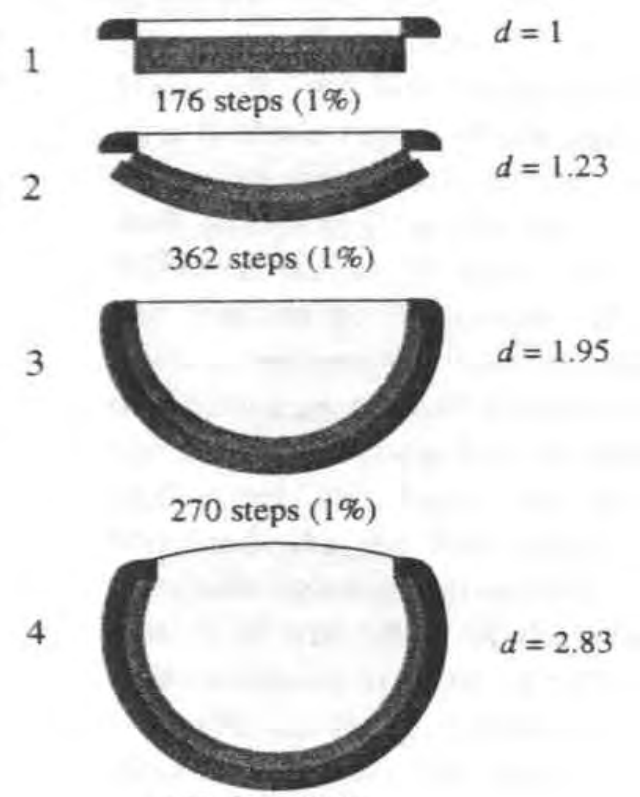
Selection rules for model eye evolution:

1. Vary curvature, aperture, and central refractive index randomly by ±1%.
2. If visual acuity (spatial resolution) increases, then retain that variation.

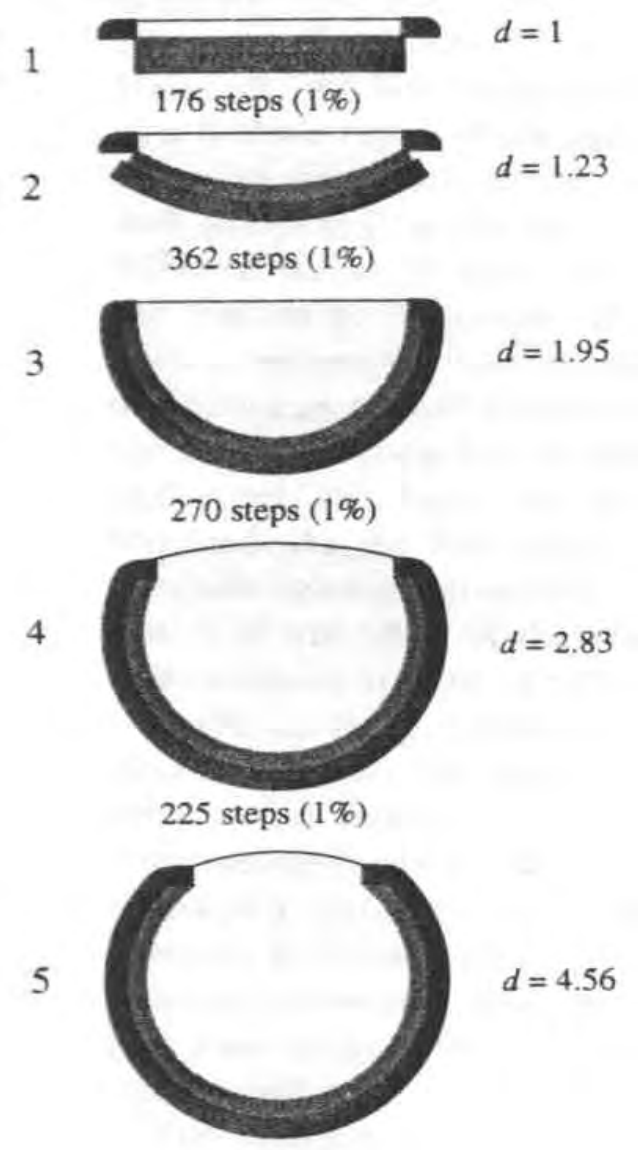
Feedback: Eye Evolution



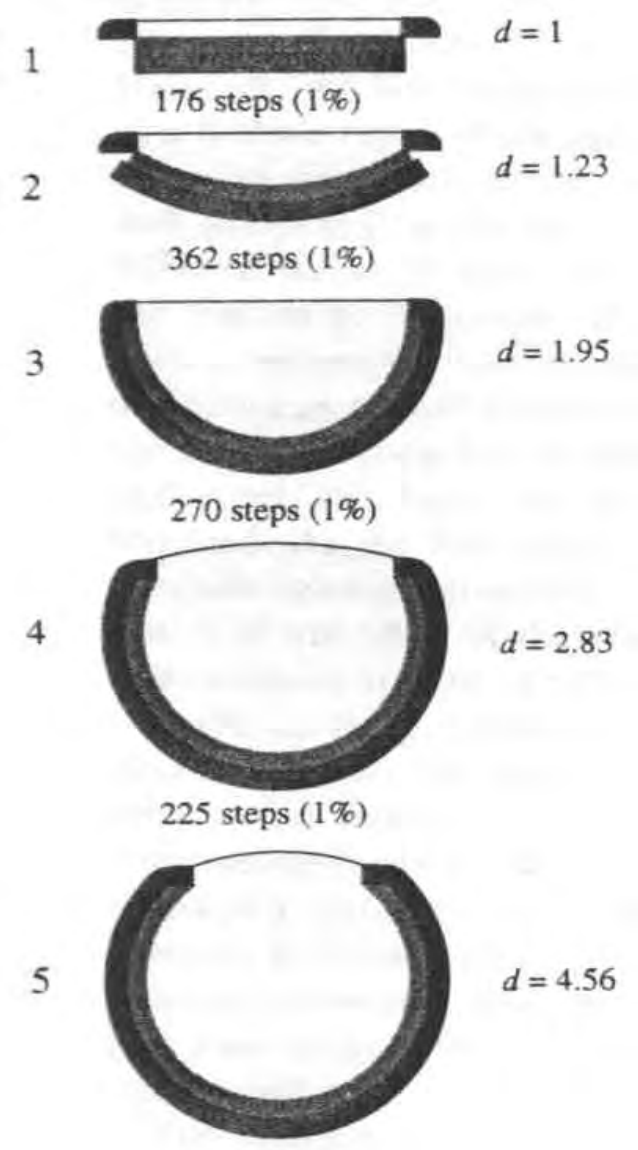
Feedback: Eye Evolution

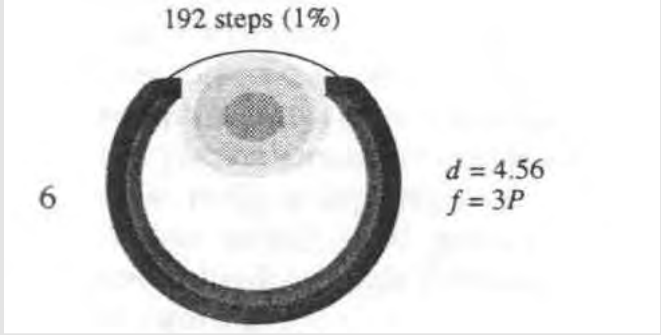


Feedback: Eye Evolution

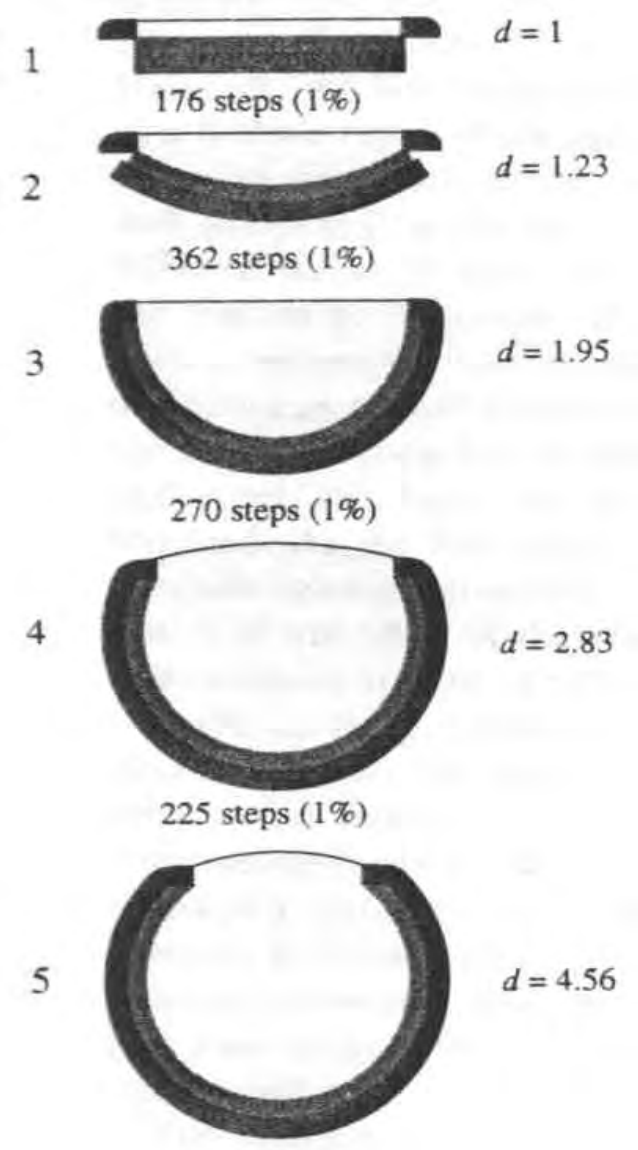


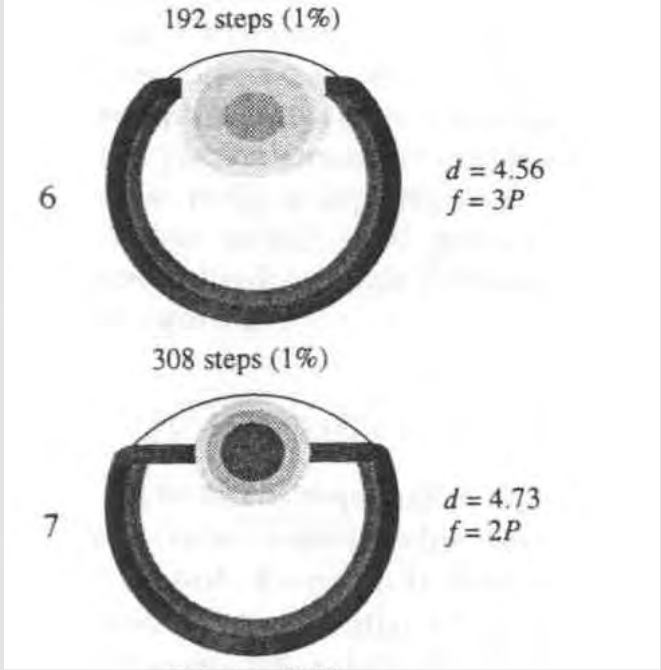
Feedback: Eye Evolution



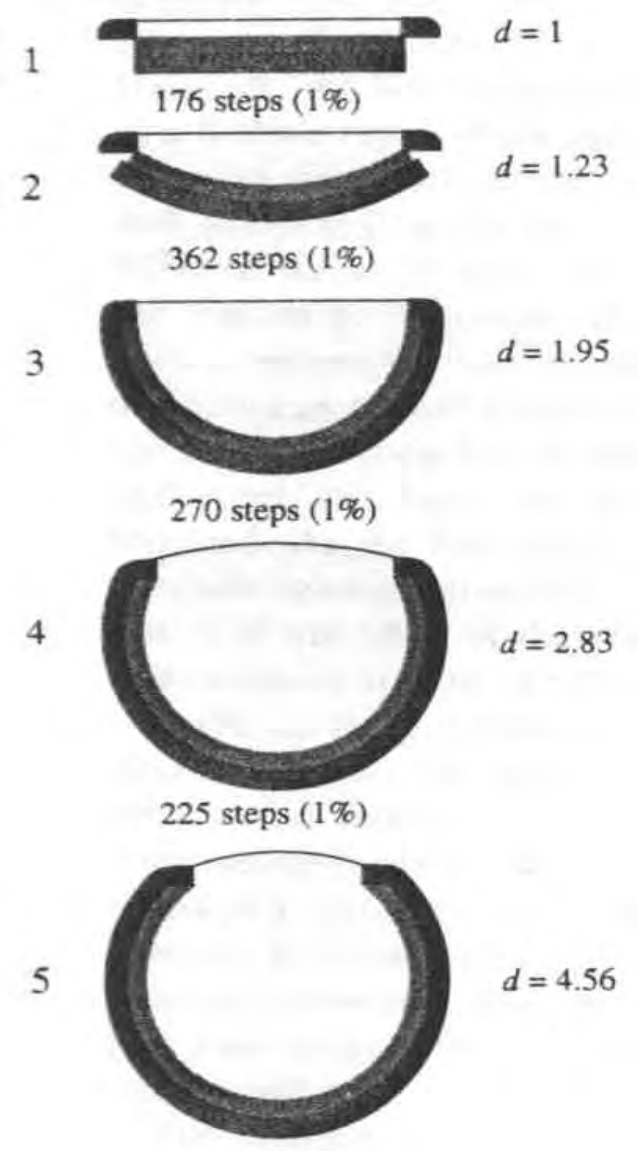


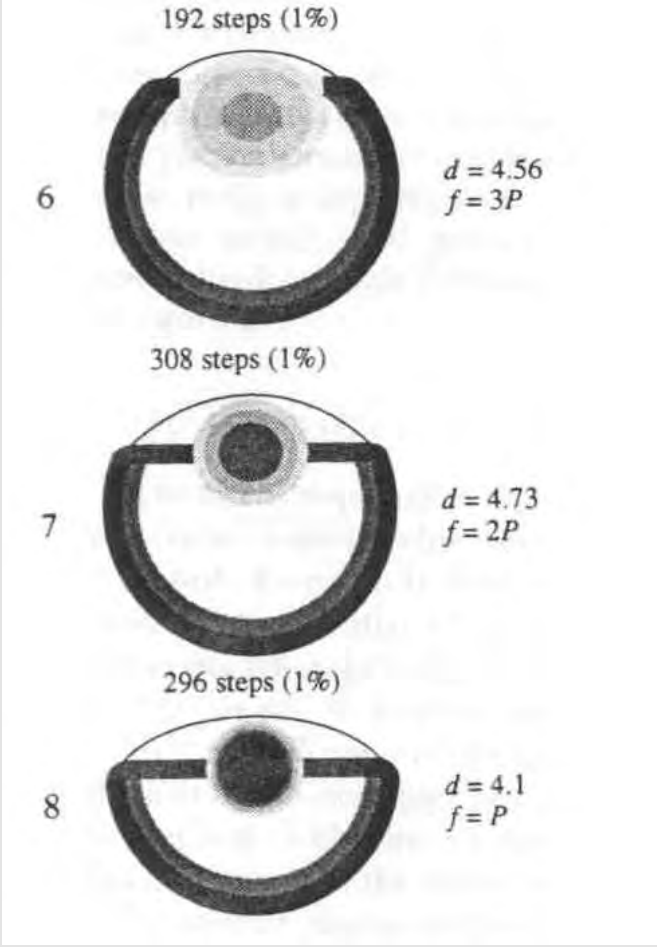
Feedback: Eye Evolution





Feedback: Eye Evolution





This evolutionary sequence is continuously driven by selection and is deterministic.

Part VI: Why do I "believe" in evolution

1. We observe complex evolving systems all around us, all the time.
   - Elements and isotopes
   - Minerals
   - Prebiotic chemicals
   - Languages
   - Material culture
   - Popular culture
   - Biological evolution

Part VI: Why do I "believe" in evolution

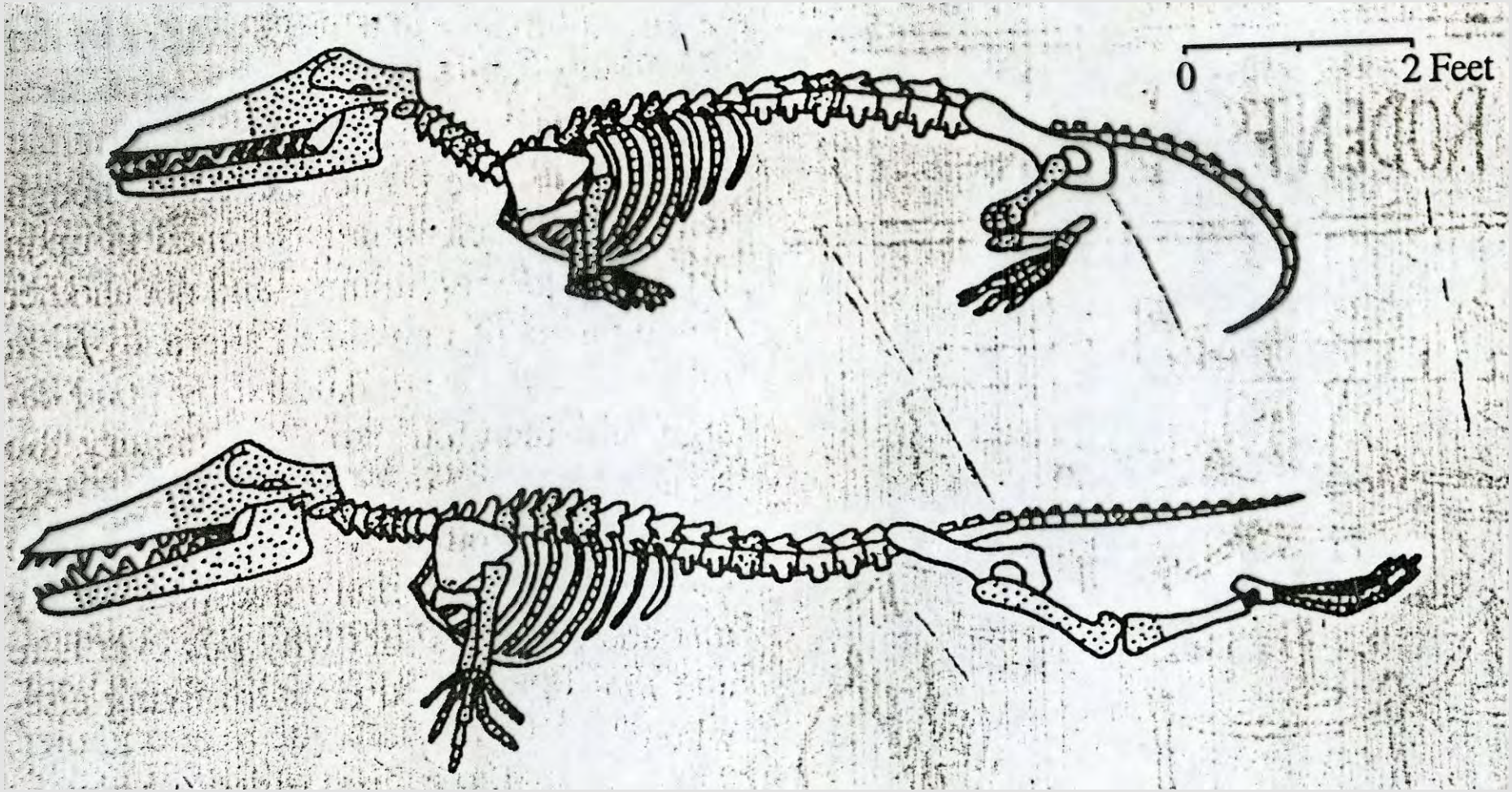
1. We observe complex evolving systems all around us, all the time.
2. The theory of evolution makes testable predictions.

Objections to Darwinian Evolution

"Darwinists rarely mention the whale because it presents them with one of their most insoluble problems. They believe that somehow a whale must have evolved from an ordinary land-dwelling animal, which took to the sea and lost its legs. … A land mammal that was in the process of becoming a whale would fall between two stools – it would not be fitted for life on land or sea, and would have no hope of survival."

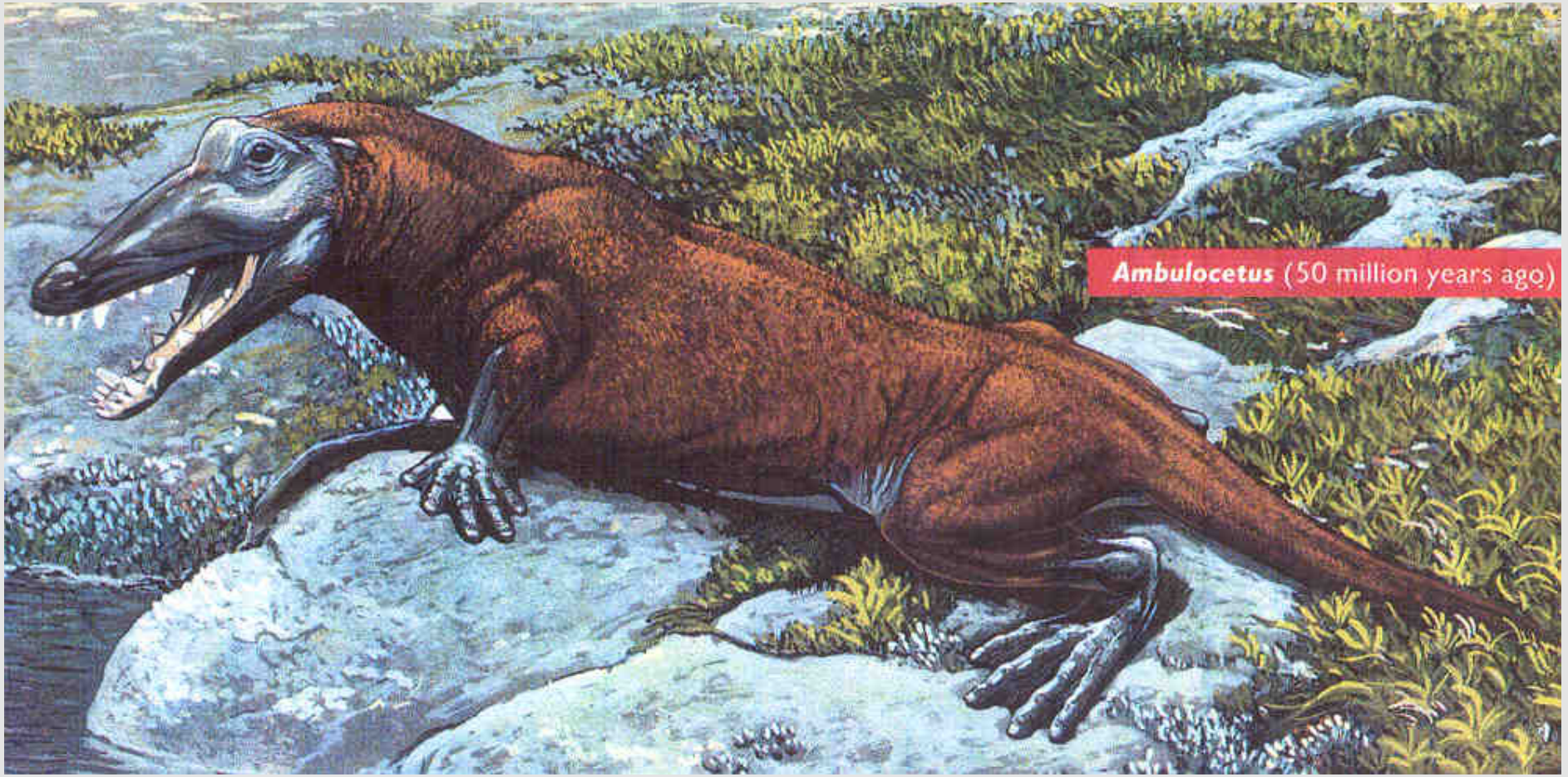
Alan Haywood, 1985

Whale Evolution



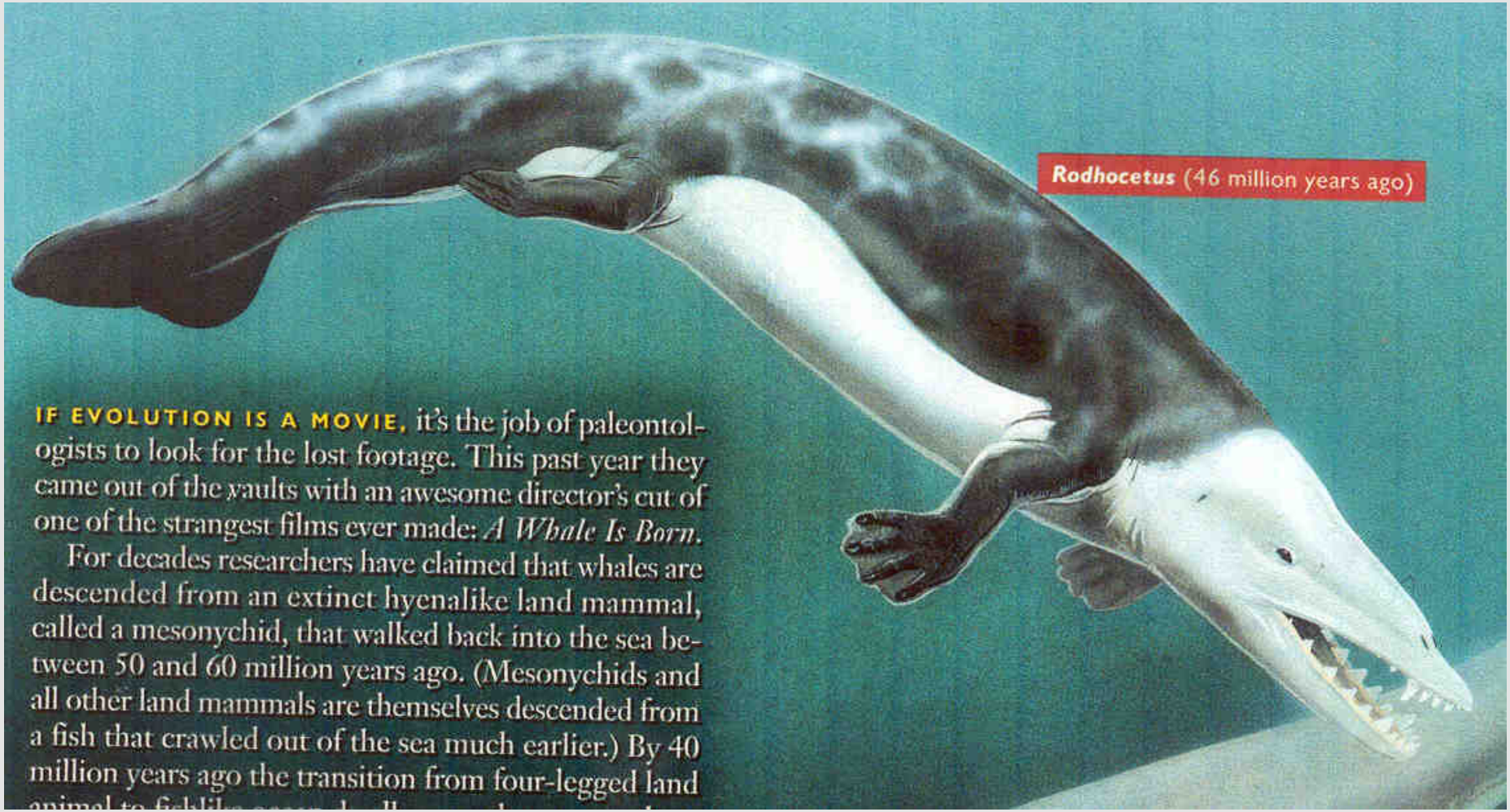
Ambulocetus

Whale Evolution



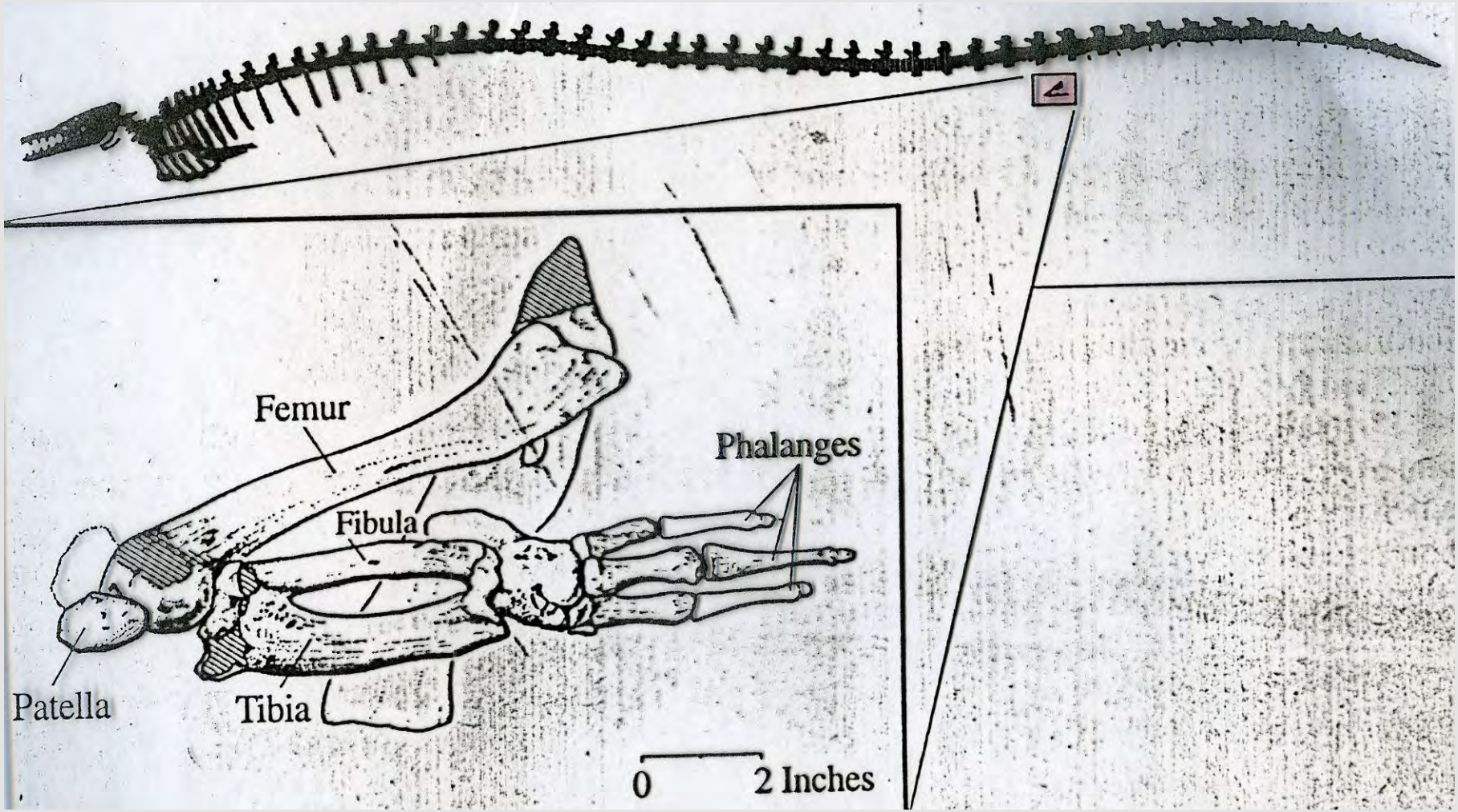
Ambulocetus

Whale Evolution

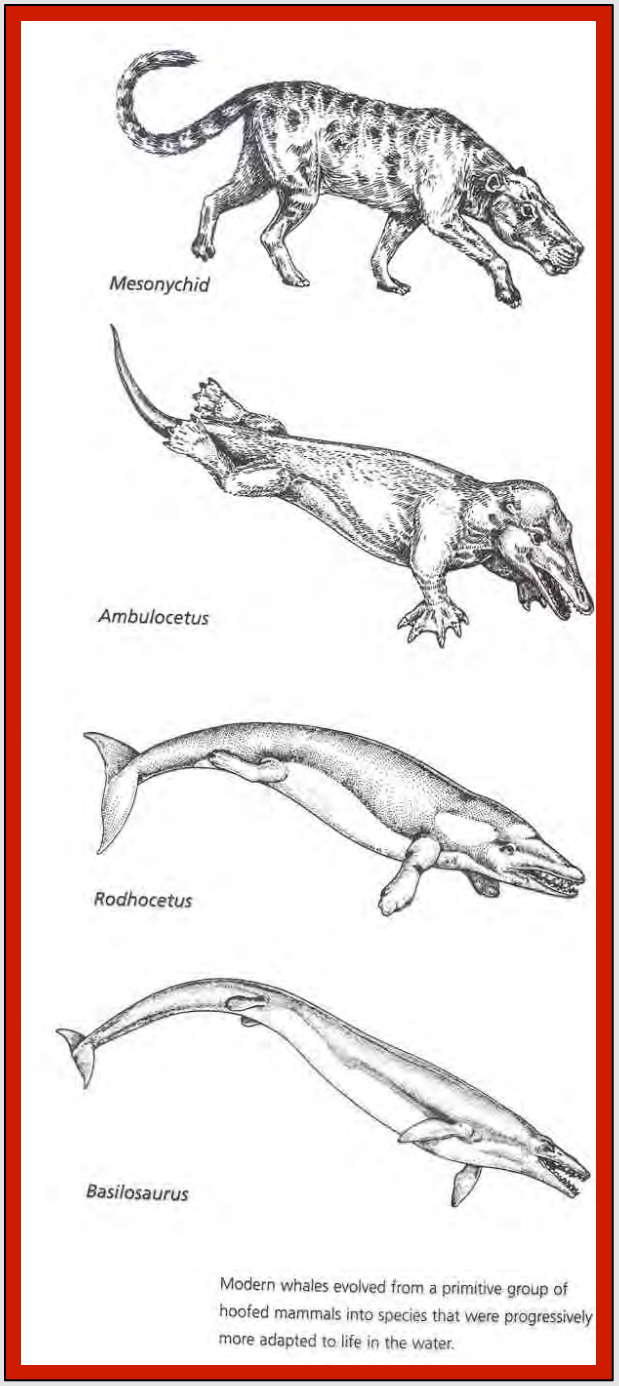


Rodhocetus

Whale Evolution



Basilosaurus



Whale Evolution

The power of the theory of evolution by natural selection lies in its unparalleled predictive power. If we see a gap in the fossil record, then we can predict what kind of rock and what age of rock to search, and we can make a pretty good guess as to what kind of fossil we're likely to find.

Part VI: Why do I "believe" in evolution

1. We observe complex evolving systems all around us, all the time.
2. The theory of evolution makes testable predictions.
3. The alternative ("God in the gaps") is philosophically unacceptable.

Trilobites

Dolichoharpes reticulatus Whittington 194
Platteville Formation, Middle Ordovician
Gr