UNIT 1.1

Origins and Evolution of Life

Presented by:
Dr. David J. Des Marais
Origins of Life: Approaches to the Problem

- **Divine Act**: Has been revealed in the scriptures; lies beyond the laws of science

- **Chance**: Understandable within the laws of science, but a product of several improbable, random events.

- **Deterministic Event**: Lies within laws of science, thus predictable and, in some cases, probable. “The origin of life can be understood as a consequence of the evolution of the elements, stars, solar systems and habitable planetary environments

  *H. Morowitz*
Four Approaches to Understanding the Origins of Life

- **Chemical Evolution**
  - Origin of Solar Systems, Planets and Environments Required for Life
  - Chemical Species and Mechanism Leading to the Origin of Life

- **Biological Evolution**
  - The Living Biochemical Record of Early Life
  - The Geological Record of the Early Biosphere

**Probability of Life in the Universe**

\[ B = R^* \cdot f_p \cdot n_e \cdot f_l \cdot L \]

where:

- **B** = Number of Biospheres
- **R^*** = Formation rate of stars suitable for life
- **f_p** = Fraction of those stars with planetary systems
- **n_e** = No. of planets per solar system suitable for life
- **f_l** = Fraction of **n_e** where life actually appears
- **L** = Lifetime of Biospheres
Life’s Basic Functions

- **Information Storage and Replication**
- **Energy Harvesting and Transduction**
- **Organic Biosynthesis**

- Light and/or Reactants
- Heat and/or Products
- CO₂
- Organic Matter
**Continuity Principle:**
For any postulated stage in biogenesis, there must be a continuous path backward to the prebiotic state of the earth and forward to modern organisms.

*H. Morowitz*

---

**Diagram:**
- **Space**
  - Sources of Organic Carbon on the Prebiotic Earth
  - UV catalysis
  - IDP's, Comets
  - Meteorites
  - Shock Synthesis

- **Atmosphere**
  - Lightning

- **Ocean**
  - Photoreduction of Carbon
  - Hydrothermal Organic Synthesis?
  - Reduced Inorganic Species

- **Crust**
  - Opportunities to concentrate chemical species

---

**Image:**
- D. Des Marais, 2003
INTRODUCTION

Metabolism Recapitulates Biogenesis

Metabolic intermediates of C, H, O and P

Lipids (vesicles)

Phosphorylated compounds

Keto acids

Amino acids

Nitrogen bases

Cofactors

Coding molecules

Reduced N and S

C, H, N, O, P, S compounds

Macromolecules

A. Pohorille

D. Deamer, U.C Santa Cruz
Meteorite Impacts and the Origins of Life: A Hypothetical Scenario
Introduction

Anaerobic Ecosystems

Sedimentary Organic C & Carbonates

Anoxic & Anaerobic Era

Oxygenic Photosynthesis Era

Prebiotic Era

Exogenous Organics

H₂ → CH₄

O₂

H₂S → CO₂

Fe²⁺

Abiotic Organic Synthesis

H₂S → CO₂

Fe²⁺

Anaerobic Ecosystems

H₂S → CO₂

Fe²⁺

Cyanobacteria & Ecosystems

O₂

H₂ → CH₄

H₂ → CH₄

Ocean Atmosphere Space


Prebiotic Era

Anoxic & Anaerobic Era

Oxygenic Photosynthesis Era

Space

Atmosphere

Ocean

Crust

Sedimentary Organic C & Carbonates

Abiotic Organic Synthesis

Anaerobic Ecosystems

Cyanobacteria & Ecosystems

Prebiotic Era

Anoxic & Anaerobic Era

Oxygenic Photosynthesis Era

Exogenous Organics

H₂ → CH₄

O₂

H₂S → CO₂

Fe²⁺

Abiotic Organic Synthesis

H₂S → CO₂

Fe²⁺

Anaerobic Ecosystems

H₂S → CO₂

Fe²⁺

Cyanobacteria & Ecosystems

O₂

H₂ → CH₄

H₂ → CH₄

Ocean Atmosphere Space


Prebiotic Era

Anoxic & Anaerobic Era

Oxygenic Photosynthesis Era

Exogenous Organics

H₂ → CH₄

O₂

H₂S → CO₂

Fe²⁺

Abiotic Organic Synthesis

H₂S → CO₂

Fe²⁺

Anaerobic Ecosystems

H₂S → CO₂

Fe²⁺

Cyanobacteria & Ecosystems

O₂

H₂ → CH₄

H₂ → CH₄

Ocean Atmosphere Space


Prebiotic Era

Anoxic & Anaerobic Era

Oxygenic Photosynthesis Era

Exogenous Organics

H₂ → CH₄

O₂

H₂S → CO₂

Fe²⁺

Abiotic Organic Synthesis

H₂S → CO₂

Fe²⁺

Anaerobic Ecosystems

H₂S → CO₂

Fe²⁺

Cyanobacteria & Ecosystems

O₂

H₂ → CH₄

H₂ → CH₄
INTRODUCTION

Finding Pale Blue Dots: Planetary vs Biospheric Signals

Stratosphere

Troposphere

Secondary chemical reactions

Biogenic emissions

Terrestrial biota

Aquatic biota

Region accessible by remote sensing

Direct photodissociation

Abiotic emissions

Temp., K

Crust
INTRODUCTION

Summary:

Origins of Life

- Basic concepts of life
  - Universal characteristics, defining life
  - Thermodynamics and kinetics
- Approaches to understanding life’s origins
  - Framing the approach
  - A divine act, a highly improbable event, or a deterministic process?
  - Scientific approaches: Astronomy, organic chemistry, molecular biology, Earth and planetary sciences
- Environments suitable for life’s origins
  - Drake equation: abundance and distribution in the cosmos
  - Water and organic carbon compounds: the only options?
  - Environmental niches and hazards on a young planet
- Comprehending the process of emergence
  - Continuity Principle
  - Monomers to biopolymers
  - Self-replicators (e.g., RNA) first versus cells/metabolism first
  - Protocells

Early Evolution of Life

- Why evolve?
  - Evolutionary imperatives (drivers): competition for limited resources, environmental change
  - Natural selection of a diverse, reproducing population
- The changing planetary environment
  - Drivers of planetary change that are shared by all rocky planets
  - Habitable environments: their nature and change over long timescales
- Earth’s earliest biosphere
  - Geological evidence of environments and ecosystems
  - Biological evidence of microbial physiologies
- Transition to a modern biosphere having multi-cellular life
  - Bioenergetics: innovations are evolutionary drivers
  - Atmospheric change: planetary versus biological effects
  - The “biogeologic clock”: major evolutionary events and their timing