Geology of the World’s Oceans

Life’s Origin

I Amino Acids – building blocks of life

II Nucleic Acids – control protein assembly, carry genetic code

III Procaryotes (3.5b) – first simple cells

IV Eucaryotes (1.5b) – advanced cells

V Metazoans (0.67b) – multicellular life

VI Skeletonized Life (0.54b)

VII Patterns in the History of Life – Diversification and Extinction

How did life begin on our planet?
How did life begin?

I Synthesis of Amino Acids – organic building blocks of life

Mechanism – Abiotic synthesis (Abiogenesis)

• Importance of water
  - UV shield
  - Catalyst for reactions
  - Concentrate organic compounds
• Darwin (and others) proposed an “Organic Soup”

The original spark of life may have begun in a “warm little pond, with all sorts of ammonia and phosphoric salts, lights, heat, electricity, etc. present, so that a protein compound was chemically formed ready to undergo still more complex changes. At the present day such matter would be instantly devoured or absorbed, which would not have been the case before living creatures were formed.” Charles Darwin, 1871
• Urey-Miller experiments (1950s) generated amino acids (building blocks of life – assembled into proteins by nucleic acids – e.g. RNA)

  - Required a reducing atmosphere (no oxygen)

  - Electricity, UV, or meteorite impacts could be energy source

  - Also common in comets, so formation is relatively “easy”
II How to Create Nucleic Acids?

- RNA controls synthesis of proteins
- DNA carries the genetic code
- More problematic
- Formed on clay templates?
III How to Create Cells?

• Fox experiments created proteinoid microspheres
  - Formed by hydration and dehydration of amino acids
  - Capable of “growth”
  - Problem – cell membranes are lipids, not proteins
  - Not really alive, not cells

• Wave foam (bubbles of oily organic matter) formed cells?
Tide Pools - Would allow hydration/dehydration
UV a potential problem

Thermoclines - Protected from UV
Would allow concentration of organic matter

Where did life begin?

• In the oceans?
  - Tide pools?
  - Pycnoclines/Thermoclines?
  - Deep ocean vents?

• Deep in the Earth?
  - Gold’s deep-hot biosphere model – “nanobes”
  - RNA– like material found

• Could life have come from elsew here?
  - Mars through meteorites?
  - Outside the solar system via comets?
Where did life begin?

- Deep Sea Vents?
  (e.g. Archaea – Thermophiles)

Protected from UV
Sulfur compounds provide an energy source
Problems – dispersal,
short-lived (~10a) environment
Where did life begin?

Allan Hills Antarctica meteorite and possible nannobacteria from Mars

Some bacteria can survive radiation in space

Potential problem – much smaller than modern bacteria, but similar to bacteria-like structures found deep in the earth
III The First Simple Cells (3.5b)

- First simple cells (procaryotes – Bacteria and Archaea) found in rocks dating back to 3.5b
- Carbon isotopes suggest life and photosynthesis was present earlier – perhaps by 3.85b, very shortly after cooling
- Formed "Algal" stromatolites
- Modified environment
  - Produced $O_2$
  - Evidenced by banded iron formation - BIF
  - Life could probably not begin again - Why?
Procaryotes vs Eucaryotes

Procaryotes are

- Much smaller
- Lack organelles
- Lack membrane-bound nucleus
- Reproduce asexually
IV The First Advanced Cells – Eucaryotes (1.5b)

- Note that it took at least 2 billion years for this step!

- Form a group called the Protista (all eucaryotic, all unicellular)

- Lynn Margulis – Endosymbiosis theory

- Evidence
  - Size and structure of organelles
  - Mitochondria have “own” DNA
V The First Metazoan (Multicellular) Life (0.67b)

• Origins
  - From colonial Protistans? (e.g. *Volvox*)
  - Most likely a choanoflagellate? (similar cells occur in sponges today)
  - Consequence of sexual reproduction by Protistans?

• “Allowed” by increasing O$_2$?
  - Abundant stromatolites
  - Free oxygen in atmosphere by 2.0b
  - Red beds common
  - Ozone shield present
Ediacara Biota

• Large, flat, worm and jellyfish like – large surface area may have helped with oxygen absorption

• Odd - lacked mouth and anus – “Aliens on Earth”

• Endosymbiotic? (a common marine life mode today)
VI The First Skeletons (0.54b) to present

• First skeletonized life (trilobites and others)
  - Due to increasing $O_2$?
  - Upwelling of phosphorous?

• Cambrian “Explosion”
  - diversification of life

• Significance of Burgess Shale
  - Unusual preservation
  - Highly diverse
  - Highly complex
  - Evolution may proceed quickly
  - Chance (not just natural selection) may be important!
VII Patterns in the History of Life -- 0.54b to present

- Diversification and extinction events
  - Meteorite Impacts?
  - Icehouse/Greenhouse intervals?
  - “Dance” of the continents?
Marine Ecology

I Classification/Grouping – Relatedness

II Grouping - Life Modes

III Grouping – Habitat

IV Communities and Interactions

V Controls on Distributions

VI Controls on Diversity
I Classification/Grouping - Relatedness

All life is included in 3 Domains

- Bacteria – prokaryotes, important primary producers in the open ocean

- Archaea – prokaryotes, many are extremophiles, important at deep sea vents (and Yellowstone NP hot springs)

- Eukaryota – everything else!
Procaryotes are

- Much smaller
- Lack organelles
- Lack membrane-bound nucleus
- DNA in a single loop
- Reproduce asexually
I Classification/Grouping - Relatedness

Eucaryote Kingdoms

- Protista
- Fungii
- Plantae
- Animalia
I Classification/Grouping – Relatedness (cont.)

Taxonomic Hierarchy

- Kingdom
- Phylum
- Class
- Order
- Family
- Genus
- Species
Bacteria (Monera)

- Procaryotic
- Unicellular
- Photosynthetic or Heterotrophic

Archaea

- Procaryotic
- Unicellular
- Chemosynthetic

Protista

- Eucaryotic
- Unicellular
- Photosynthetic or Heterotrophic
Fungii

• Eucaryotic
• Multicellular
• Saprophitic (Decomposers)
• Relatively unimportant in oceans

Plantae
(Macrophytes)

• Eucaryotic
• Multicellular
• Photosynthetic

Note: some scientists would break the Plantae into several Divisions based on photosynthetic pigments used
Animalia

- Eucaryotic
- Multicellular
- Heterotrophic
II Grouping - Life Modes

Primary producers (autotrophs)

- Macrophytes
- Phytoplankton
- Microplankton
- Chemoautotrophs

II Grouping - Life Modes

Consumers (heterotrophs)

- Filter/Suspension feeders
- Grazers
- Carnivores
- Deposit feeders
III Grouping – Habitat

Pelagic (Note: Plankton vs Nekton)

- Neritic vs. Oceanic
- Photic vs. Aphotic

- Epipelagic
  - Mesopelagic
  - Bathypelagic
  - Abyssopelagic

Benthic (Note: Epifauna vs Endofauna)

- Littoral (tidal)
- Shelf
- Bathyal (slope)
- Abyssal (plain)
- Hadal (trench)
IV Communities

• Energy flows through

• Energy is transferred inefficiently

• Energy sources

  - Photosynthesis-based
    Rely directly on sun’s energy — most communities

  - Detritus-based
    Indirectly based on sun’s energy — e.g. rain forest detritus and deep sea floor sediments

  - Chemosynthesis-based
    Independent of sun — deep sea vents
IV Communities (cont.)

Interactions Occur

- Symbiosis (general term for close, long-term interactions)
  - Commensalism (0,+ )
  - Mutualism (+,+ )
  - Parasitism (-,+ )

- Grazing and Predation (-,+ )
  - Interactions lead to “Arms Race”
  - May drive evolution

- Competition (-,- )
Antipredation Strategies (Strong selective pressure to develop these)

- Camouflage/Protective Coloration
- Hiding/Cryptic behavior
- Allelochemicals
- Armor
- Nocturnal Behavior
- Schooling
Strategies for Spatial Competition
(Very important for sessile organisms)

- Direct Overgrowths – grow fast
- Overtopping/Shading
- Sweeper Tentacles - corals
- Extracoelenteric Digestion - corals
- Allelochemicals
V Controls on Distributions

- Latitudinal patterns
- Bathymetric patterns – PACs
- Physical
  - Substrates - rocky, firm, soft, soupy
  - Waves, currents
  - Light
  - Temperature
- Chemical
  - $O_2$
  - $CO_2$
  - Traces
  - Nutrients - Si, N, P
VI Controls on Diversity

- Latitude?
- Temperature?
- Environmental stability?
- Time?
- Depth?
- Environmental heterogeneity?
- Nutrients?
- Disturbance - IDH?

- Pacific vs Atlantic Oceans
VI Controls on Diversity

- Latitude?
- Temperature?
- Environmental stability?
- Time?
- Depth?
- Environmental heterogeneity?
- Nutrients?
- Disturbance - IDH?

- Pacific vs Atlantic Oceans
Pacific Vs. Atlantic Oceans

Pacific Ocean diversity is much higher

- e.g. 300 vs 60 species of corals (same applies to sponges, molluscs, fish)

Why is this?

Larger area?

More localities?

But diversity at a *single* site is higher as well.
Production and Life

I Primary Production
II Controls
III Global Patterns
IV Measurement
I Primary Production

• Total/gross = amount produced
  \( \text{gC/m}^2/\text{yr, } \sim 50-100\text{g} = 2-4\text{ oz} \)

• Net = total - that lost to respiration
  = amount available to consumers

• Standing crop - at any instant in time

  • Usually based on phytoplankton and bacterioplankton (microplankton)

  • In shallow water may be based on macrophytes (2-10%)

  • Paradox of the plankton (inverted trophic pyramid)
II Controls

- Light
  - Intensity varies with latitude and season and depth (~20m max production)

- Nutrients
  - Available from land and from upwelling
  - Mixing/turnover important

- Response of organisms may show a lag
III Global Patterns

- Coastal areas - high
- Upwelling zones - high
- Surface convergence zones (center of gyres) – low
- Higher latitudes productive
- The enigma of the coral reef (‘oasis’ in a nutrient ‘desert’)
- Area effects
<table>
<thead>
<tr>
<th>Environment</th>
<th>Primary Production (gC/m²/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Ocean</td>
<td>120 (~ 4 oz.)</td>
</tr>
<tr>
<td>Open ocean</td>
<td>50 - 160</td>
</tr>
<tr>
<td>Coastal ocean</td>
<td>100 - 250</td>
</tr>
<tr>
<td>Estuary</td>
<td>200 - 500</td>
</tr>
<tr>
<td>Upwelling</td>
<td>300 - 800</td>
</tr>
<tr>
<td>Salt marsh</td>
<td>1000 – 4000</td>
</tr>
<tr>
<td></td>
<td>(2 – 9 lbs)</td>
</tr>
<tr>
<td>All land</td>
<td>150</td>
</tr>
<tr>
<td>Desert, grassland</td>
<td>50</td>
</tr>
<tr>
<td>Forests, pastures</td>
<td>25 - 150</td>
</tr>
<tr>
<td>Rain forests</td>
<td>150 - 500</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>500 - 1500</td>
</tr>
</tbody>
</table>
IV Measurement

• Do light/dark bottle experiments (to get net production)

• Count plankton/volume

• Extract chlorophyll

• Measure sea surface chlorophyll from satellite
GEOLOGY OF THE WORLD’S OCEANS

Survey of Marine Life

Four Eucaryote Kingdoms

- Protista
- Fungii
- Plantae
- Animalia

Plus, the Procaryotes
- Bacteria
- Archaea
Domain Bacteria (Monera)

- Procaryotic
- Unicellular
- Photosynthetic or Heterotrophic
- Planktonic or benthic

Base of many marine food chains

Domain Archaea

- Procaryotic
- Unicellular
- Chemosynthetic
- Often inhabit extreme environments - extremophiles

(base of food chain at deep sea vents)
Kingdom Protista

- Eucaryotic
- Unicellular (tiny)
- Planktonic or Benthic
- Photosynthetic
  - Diatoms
  - Coccoliths
  - Dinoflagellates
- Heterotrophic
  - Forams
  - Radiolarians
Diatoms

• Siliceous
• Photosynthetic
• Planktonic or Benthic
• Base of many marine food chains
• Main component of many deep-sea siliceous oozes

Coccoliths

• Calcareous
• Photosynthetic
• Planktonic

Form chalks – Kansas and England, France
Dinoflagellates

- Organic Walled
- Photosynthetic
- Planktonic or Endosymbiotic

Responsible for red tide and phosphorescence. Some are symbiotic with corals.

Zooxanthellae (single-celled algae) living in symbiosis with “Killer Clam” and Coral
Forams

- Calcareous
- Heterotrophic
- Planktonic and Benthic
- Amoeba-like

Main component of many deep-sea calcareous oozes

Radiolaria

- Siliceous
- Planktonic
- Heterotrophic
- Amoeba-like

Important component of many deep-sea siliceous oozes
Kingdom Fugii

- Eucaryotic
- Multicellular
- Saprophitic (decomposers)
- Relatively unimportant in oceans
Kingdom Plantae (Macrophytes)

- Eucaryotic
- Multicellular
- Photosynthetic
- Mainly benthic
- Algae and marine angiosperms (flowering plants)

Kelp
Phaeophyta (Brown Algae)

Chlorophyta (Green Algae)

Rhodophyta (Red Algae)
Kingdom Animalia

- Multicellular
- Heterotrophic
- Eucaryotic

Phylum Porifera
“Parazoa”

- Simple – no true tissues
- Filter feeders
Phylum Cnidaria (Coelenterata)

- Very simple - Two tissue layers, incomplete gut
- Stinging cells
- Suspension feeders
- Corals, sea fans, anemones, jellyfish, hydroids
GEOLOGY OF THE WORLD’S OCEANS

Survey of Marine Life 2

Phylum Mollusca
- Nonsegmented
- Calcareous shell (most)

Clams
Snails
Octopus and squid
Others

Mollusca
Cephalopoda (“head foot”)
- Tentacles, intelligent, adaptive camouflage
- Octopus, squid & cuttlefish, nautilus
- Shell greatly reduced in most
- Carnivores
Phylum Annelida

Polychaeta

- Segmented marine worms
- Some are free living
- Some live inside calcareous tubes
- Carnivores, deposit feeders, suspension feeders

fire worms, feather-duster worms, plume worms, Christmas-tree worms
Phylum Arthropoda

- Jointed appendages
- Segmented exoskeletons
- Walking appendages
- Insects, scorpions (land only)
- Crustaceans, horseshoe crabs (marine)

Crustacea

- Crabs and shrimp
  Carnivores and scavengers

- Copepods, barnacles
  Suspension feeders
Echinodermata

- Spiny skinned
- Five fold symmetry
- Tube feet
- Suspension feeders, carnivores, deposit feeders

- Starfish and brittle starfish
- Sea urchins
- Crinoids
- Sea cucumbers
Animals with backbone (or notochord in primitive forms)
Fish, amphibians, reptiles, birds, mammals

“Agnaths” - Lack vertebrae and jaws
hagfish and lampreys

Pisces
Chondrichthyes
(Cartilaginous fish)

• Sharks, sawfish, rays
• Carnivores
Pisces
Osteichthyes
(Bony Fish)

Fish Life Modes

• Pelagic Plankton Feeders

• Benthic Grazers and Algae Farmers

• Shell Crushers

• Carnivores on Fish
  (Fast Swimmers, Ambush Predators)
Reptilia

- Turtles
- Sea snakes
- Marine iguanas
- Salt water crocs
Mammalia

• Whales & Dolphins

• Manatees/Dugongs

• Sea Otters

• Seals, Sea Lions, & Walruses

• Polar Bears
Aves

- Penguins *
- Pelicans *, Gulls, Terns, Frigate Birds, etc.

* Piscivores