The Nature of Life on Earth
(Chap. 5 - Bennett & Shostak)

Notes for Chapter 5
HNRS 228 - Astrobiology
Dr. H. Geller (with some slides from Dr. G. Taylor and HNRS 227)

Overview of Chapter 5
- Defining Life (5.1)
  - Its properties, evolution and definition
- Cells: The basic units of life (5.2)
  - Structure, composition, prokaryotes, eukaryotes
- Metabolism: The chemistry of life (5.3)
  - Energy needs and sources; water
- DNA and Heredity (5.4)
  - Structure, replication, genetic code

Overview of Chapter 5
- Life at the Extremes (5.5)
  - Extremophiles and their implications
- Evolution as Science (5.6)

Properties of Living Systems
- Not laws
- From Bennett & Shostak:
  - Order (hierarchy)
  - Reproduction
  - Growth and development
  - Energy use
  - Response to the environment (open systems)
  - Evolution and adaptation

Properties of Living Systems
- From Taylor (HNRS 227):
  - Hierarchical organization and emergent properties
  - Regulatory capacity leading to homeostasis
  - Diversity and similarity
  - Medium for life: water (H₂O) as a solvent
  - Information Processing

Properties of Living Systems: Order
- Define “random”
- Define “order” in an abiotic system
- Why is “order” an important property?
- Examples of “order” in living systems
  - Level of a biomolecule
  - Level of the cell
  - Level of the organelle
  - Level of an ecosystem
- Relate to hierarchical
Properties of Living Systems: Reproduction

• Define “reproduction” in abiotic terms
  - E.g., fire, crystals
• Define “reproduction” in biotic terms
  - Why is it important property of living systems?
• Examples in living systems
  - Microbes (fission)
  - Cells (mitosis)
  - Whole organisms
    - Donkey

Properties of Living Systems: Growth and Development

• Define “growth”
• Define “development”
• Why are “growth and development” important properties of living systems?
• Examples in living systems
  - Organisms grow
  - Organisms develop
• Examples in abiotic systems
  - Ice crystals
  - Fire

Properties of Living Systems: Energy Use

• Definitions
  - Energy capture
    - Autotrophs (photoautotrophs, chemoautotrophs)
    - Heterotrophs (saprovores, carnivores, omnivores, etc.)
  - Energy utilization (1st and 2nd Laws of Thermodynamics)
  - Energy storage
    - Chemical bonds (covalent C-C bonds) and exothermic reactions
    - ATP (adenosine triphosphate) and ADP (adenosine diphosphate)
  - Energy dissipation (2nd Law of Thermodynamics)
• Why is “energy use” and important property of living systems?

Properties of Living Systems: Energy Use

Metabolic “Class”

Properties of Living Systems: Response to the Environment

• Define an “open” versus “closed” system
  - Interaction with the environment
  - Stimulus followed by a response
• Why is “response to the environment” an important property?
• Examples in living systems
  - Leaf orientation to the sun
  - Eyes
  - Ears
Properties of Living Systems: Evolution and Adaptation

- Define “evolution”
- Define “adaptation”
- Why is “evolution and adaptation” an important property in living systems?
- Examples of evolution in living systems
  - Macroscale: origin of species and taxa
  - Microscale: microbes resistant to antibiotics, moths resistant to air pollution
- Examples of adaptation
  - Articulation of the joints in animals
  - Planar structure of leaves

Properties of Living Systems: Hierarchical Organization

- Define “hierarchical organization”
- Diagram of atoms to biomolecules to organelles to cells to tissues, etc.
- Define “emergent properties”
- Emergence of “novel and unanticipated” properties with each step of hierarchy
- Examples in living systems
  - Hierarchy
  - Emergent properties

Properties of Living Systems: Regulatory Capacity

- Define “regulatory capacity”
- Relate to open systems
- Define “homeostasis”
- Role of feedbacks (positive and negative) and cybernetics
- Why is “regulatory capacity and homeostasis” an important property of living systems?
- Examples
  - Molecular biology: gene regulation
  - Biochemistry: enzymes
  - Organisms: temperature
  - Globe: “Parable of the Daisyworld”

Properties of Living Systems: Regulatory Capacity (Continued)

- State Variable
- Sensor
- Set Point
- Positive Feedback
- Negative Feedback

Properties of Living Systems: Diversity and Similarity

- Define “diversity”
  - Hallmark of all life (1.5 M known species; 100 M expected)
- Define “similarity”
  - Hallmark of all life
- Why are “diversity and similarity” important properties of living systems?
- Examples of similarity
  - Biochemistry
  - Structure and Morphology
  - DNA and RNA

Properties of Living Systems: Medium for Metabolism

- Define a “medium for metabolism” and why an important property of living systems?
- Role of “water” as medium
  - Physical properties
    - Abundance in universe, state as a function of temperature, freezing properties
  - Chemical properties
    - Bonding, polarity, diffusion, osmosis
**Properties of Living Systems: Information**

- Define “information” and relate to order
- Why is “information” an important property of living systems?
- Necessary states of “information”
  - Storage
  - Translation
  - Template/Copying
  - Correcting (spell check)
- Examples
  - DNA
  - RNA

**Properties of Living Systems: Recapitulation**

- Diversity and similarity of structure and function
- What does above suggest?
  - Recurrent theme of similar properties
    - High fitness value
    - Common ancestor
  - Recurrent theme of diverse properties
    - High fitness value
    - Diversity of habitats
    - Creativity and spontaneity of evolution
- What mechanism can account for both similarity and diversity?

**Evolution as a Unifying Theme**

- Darwin’s Origin of Species (1850)
- Observations while on the HMS Beagle
- Model: Evolution
  - Individuals vary in their fitness in the environment
  - Struggle for existence and survival of the most fit
  - Origin of species via incremental changes in form and function (relate back to observation while on the Beagle)
- Link to Mendel and the Particulate Model of Inheritance (1860’s)
- Link to Watson and Crick (1956) and the discovery of DNA
- Examples of evolution in action
- Significance of evolution as a theory in Biology

**Structural Features of Living Systems**

- Ubiquitous nature of “cells” and its hierarchy
  - Physical, chemical and biological basis for a cell (adaptation)
  - Suggestion of a common progenitor/ancestor
  - Physical dimensions of a cell (maximum size)
- Ubiquitous nature of “organelle”
  - Efficacy of metabolism (random)
  - Diversity of function
  - Diversity of structure
  - Similarity of structure

**Structural Features of Living Systems (continued)**

- Evolution of cell types
  - Prokaryotes
    - Cell, membranes but no nucleus
    - Examples: bacteria
  - Eukaryotes
    - Cell, membrane, and nucleus
    - All higher plants and animals

**Biochemical Features of Living Systems**

- Carbon-based economy
  - Abundance in the universe
  - Atomic structure (electrons, protons, etc.)
  - Chemical properties (bonding)
- Metabolism
  - Catabolism and biosynthesis
  - Energy capture and utilization
    - ATP and ADP
Biochemical Features of Living Systems (continued)
- Biochemicals or biomacromolecules
  - Define polymer (recall HNRS 227)
  - Carbohydrates (CH₂O)
  - Lipids (fatty acids + glycerol)
  - Proteins (amino acids & polypeptides)
  - Nucleic Acids (nucleotides)
- Points to a common ancestor

Biochemical Pathways

Molecular Features of Living Systems
- Genes and genomes
- Replication of DNA
- Transcription, translation, and the genetic code
- Polypeptides and proteins
- Biological catalysis: enzymes
- Gene regulation and genetic engineering
- Points to a common ancestor

Molecular Features of Living Systems (continued)

Instructional Features of Living Systems: Genetic Code
- Sequence of base pairs (ATCG) on mRNA (DNA) used to “program” sequence of amino acids
- 20 different amino in living systems (60+ total in nature)
- Reading the ‘tea leaves” of the genetic code helps understand evolution of life

Instructional Features of Living Systems: Genetic Code (cont’d)
- Genetic code and “triplets”
  - 4 different nucleotides (base pairs)
  - 20 different amino acids
  - How does 1 nucleotide specify 1 amino acid? (N=4)
- Options
  - 2 letter code sequence (e.g., T-A) for 1 amino acid (N= 16)
  - 3 letter code sequence (e.g., T-A-G) for 1 amino acid (N=64)...more than adequate since there are only 20
- “Triplet Code”
  - CCG calls for proline
  - AGT calls for serine
Amino Acid Codons

<table>
<thead>
<tr>
<th>First Letter</th>
<th>Second Letter</th>
<th>Third Letter</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>U</td>
<td>A</td>
<td>G</td>
</tr>
<tr>
<td>C</td>
<td>A</td>
<td>G</td>
</tr>
<tr>
<td>C</td>
<td>G</td>
<td>C</td>
</tr>
<tr>
<td>A</td>
<td>U</td>
<td>C</td>
</tr>
<tr>
<td>A</td>
<td>C</td>
<td>U</td>
</tr>
<tr>
<td>C</td>
<td>U</td>
<td>A</td>
</tr>
<tr>
<td>C</td>
<td>G</td>
<td>A</td>
</tr>
<tr>
<td>A</td>
<td>C</td>
<td>U</td>
</tr>
<tr>
<td>A</td>
<td>G</td>
<td>C</td>
</tr>
</tbody>
</table>

Instructional Features of Living Systems: Genetic Code (cont’d)

- Redundancy in code
  - CAA calls for glutamine
  - CAG calls for ______?
- Prominence of first two bases in code
  - GC__ calls for alanine
  - AC__ calls for threonine
- Stop signal (UAA or UAG or UGA)
- Start Signal (AUG)
- Evidence that code evolved very early in life on Earth?

Mutations and Evolution

- Mutation at the molecular level
  - Define
  - Causes
    - Environment (examples)
    - Endogenous (e.g., replication)
- Fitness of mutation
  - Negative fitness (extreme is lethal)
  - Positive fitness
  - Neutral fitness
- Role in evolution

EXTREMOPHILES
NATURE’S ULTIMATE SURVIVORS

Adapted from
HOUSSEIN A. ZORKOT, ROBERT WILLIAMS, and ALI AHMAD
UNIVERSITY OF MICHIGAN-DEARBORN

What are Extremophiles?

- Extremophiles are microorganisms
  - Viruses, prokaryotes, or eukaryotes
- Extremophiles live under unusual environmental conditions
  - Atypical temperature, pH, salinity, pressure, nutrient, oxic, water, and radiation levels

Types of Extremophiles

1. Psychrophiles
   - Microbes that live in cold environments like the Arctic and Antarctic or icy oceans
2. Thermophiles
   - Microbes that live in very hot environments like deep geysers and volcanic lakes
3. Alkaliphiles
   - Microbes that live in basic environments like soda lakes
4. Halophiles
   - Microbes that live in very salty environments like salt lakes and salt marshes
5. Acidophiles
   - Microbes that live in acidic environments like sulfur springs
More Types of Extremophiles

- **Barophiles** - survive under high pressure levels, especially in deep sea vents
- **Osmophiles** - survive in high sugar environments
- **Xerophiles** - survive in hot deserts where water is scarce
- **Anaerobes** - survive in habitats lacking oxygen
- **Microaerophiles** - thrive under low-oxygen conditions
- **Endoliths** - dwell in rocks and caves
- **Toxitolerants** - organisms able to withstand high levels of damaging agents. For example, living in water saturated with benzene, or in the water-core of a nuclear reactor

### Environmental Requirements

**EXTREME PROKARYOTES**

- Members of domains Bacteria and Archaea
- Possibly the earliest organisms
- Early earth was excessively hot, so these organisms would have been able to survive

#### Hyperthermophiles

- Members of the base of the tree of Life: Bacteria
- Possibly the earliest organisms
- Early earth was excessively hot, so these organisms would have been able to survive

#### Morphology of Hyperthermophiles

- Heat stable proteins that have more hydrophobic interiors
- Prevents unfolding or denaturation at higher temperatures
- Chaperonin proteins
  - Maintain folding
- Monolayer membranes of dibiphytanyl tetraethers
  - Saturated fatty acids which confer rigidity, prevent degradation in high temperatures
- A variety of DNA-preserving substances that reduce mutations and damage to nucleic acids
  - E.g., reverse DNA gyrase and Sac7d
- Can live without sunlight or organic carbon as food
- Survive on sulfur, hydrogen, and other materials that other organisms cannot metabolize

#### Sample Hyperthermophiles

- Frequent habitats include volcanic vents and hot springs, as in the image to the left

- *Sulfolobus solfataricus*, near Naples, Italy

- *Thermus aquaticus*
Deep Sea Extremophiles

- Deep-sea floor and hydrothermal vents involve the following conditions:
  - **low temperatures** (2-3°C) – where only psychrophiles are present
  - **low nutrient levels** – where only oligotrophs are present
  - **high pressures** – which increase at the rate of 1 atm for every 10 meters in depth (as we have learned, increased pressure leads to decreased enzyme-substrate binding)

- Barotolerant microorganisms live at 1000-4000 meters
- Barophilic microorganisms live at depths greater than 4000 meters

Extremophiles of Hydrothermal Vents

- Natural springs vent warm or hot water on the sea floor near mid-ocean ridges
- Associated with the spreading of the Earth’s crust. High temperatures and pressures

Psychrophiles

- Some microorganisms thrive in temperatures below the freezing point of water (this location in Antarctica)
- Some people believe that psychrophiles live in conditions mirroring those found on Mars – but is this true?

Characteristics of Psychrophiles

- Proteins rich in α-helices and polar groups
  - allow for greater flexibility
- “Antifreeze proteins”
  - maintain liquid intracellular conditions by lowering freezing points of other biomolecules
- Membranes that are more fluid
  - contain unsaturated cis-fatty acids which help to prevent freezing
- Active transport at lower temperatures

Halophiles

- Divided into classes
  - mild (1-6%NaCl)
  - moderate (6-15%NaCl)
  - extreme (15-30%NaCl)
- Mostly obligate aerobic archaea
- Survive high salt concentrations by
  - interacting more strongly with water such as using more negatively charged amino acids in key structures
  - making many small proteins inside the cell, and these, then, compete for the water
  - accumulating high levels of salt in the cell in order to outweigh the salt outside

Barophiles

- Survive under levels of pressure that are lethal to most organisms
- Found deep in the Earth, in deep sea, hydrothermal vents, etc.
**Xerophiles**

- Extremophiles which live in water-scarce habitats, such as deserts
- Produce desert varnish as seen in the image to the left
  - A thin coating of Mn, Fe, and clay on the surface of desert rocks, formed by colonies of bacteria living on the rock surface for thousands of years

**Deinococcus radiodurans**

- Possess extreme resistance to up to 4 million rad of radiation, genotoxic chemicals (those that harm DNA), oxidative damage from peroxides/superoxides, high levels of ionizing and ultraviolet radiation, and dehydration
- It has from four to ten DNA molecules compared to only one for most other bacteria
- Contain many DNA repair enzymes, such as RecA, which matches the shattered pieces of DNA and splices them back together. During these repairs, cell-building activities are shut off and the broken DNA pieces are kept in place

**Chroococcidiopsis**

- A cyanobacteria which can survive in a variety of harsh environments
  - Hot springs, hypersaline habitats, hot, arid deserts, and Antarctica
  - Possesses a variety of enzymes which assist in such adaptation

**Other Prokaryotic Extremophiles**

- Gallionella ferruginea and Anaerobic bacteria

Current efforts in microbial taxonomy are isolating more and more previously undiscovered extremophile species, in places where life was least expected

**EXTREME EUKARYOTES**

**THERMOPHILES/ACIDOPHILES**

- Cyanidium caldarium

Cyanidium is a genus of red algae. This species is acidophilic and thermophilic. Note that where the stream is cooler is the right, *Cyanidium* dominates.
These algae have successfully adapted to their harsh environment through the development of a number of adaptive features which include pigments to protect against high light, polyols (sugar alcohols, e.g. glycerine), sugars and lipids (oils), mucilage sheaths, motile stages and spore formation.

-Endoliths (also called hypoliths) are usually algae, but can also be prokaryotic cyanobacteria, that exist within rocks and caves. They are often exposed to anoxic (no oxygen) and anhydric (no water) environments.

Members of the Phylum Protozoa, which are regarded as the earliest eukaryotes to evolve, are mostly parasites. Parasitism is often a stressful relationship on both host and parasite, so they are considered extremophiles.

-Viruses are currently being isolated from habitats where temperatures exceed 200°F. Instead of the usual icosahedral or rod-shaped capsids that known viruses possess, researchers have found viruses with novel propeller-like structures. These extreme viruses often live in hyperthermophile prokaryotes such as Sulfolobus.

Extremophiles are present among Bacteria, form the majority of Archaea, and also a few among the Eukarya.
**Chronology of Life**

- Early Earth largely inhospitable
  - High CO₂, H₂S, etc., low oxygen, and high temperatures
  - Life forms that could evolve in such an environment needed to adapt to these extreme conditions
  - H₂ was present in abundance in the early atmosphere
  - Many hyperthermophiles and archaia are H₂ oxidizers
  - Extremophiles may represent the earliest forms of life with non-extreme forms evolving after cyanobacteria had accumulated enough O₂ in the atmosphere
  - Results of rRNA and other molecular techniques have placed hyperthermophilic bacteria and archaia at the roots of the phylogenetic tree of life

**Evolutionary Theories**

- **Consortia:** Symbiotic relationships between microorganisms, allows more than one species to exist in extreme habitats because one species provides nutrients to the others and vice versa
- **Genetic drift:** Appears to have played a major role in how extremophiles evolved, with allele frequencies randomly changing in a microbial population. So alleles that conferred adaptation to harsh habitats increased in the population, giving rise to extremophile populations
- **Geographic isolation:** May also be a significant factor in extremophile evolution. Microorganisms that became isolated in more extreme areas may have evolved biochemical and morphological characteristics which enhanced survival as opposed to their relatives in more temperate areas. This involves genetic drift as well

**Mat Consortia**

- Microbial mats consist of an upper layer of photosynthetic bacteria, with a lower layer of nonphotosynthetic bacteria
- These consortia may explain some of the evolution that has taken place: extremophiles may have relied on other extremophiles and non-extremophiles for nutrients and shelter
- Hence, evolution could have been cooperative

**Use of Hyperthermophiles**

- **HYPERTHERMOPHILES (SOURCE):**
  - DNA polymerases
  - Alkaline phosphatase
  - Proteases and lipases
  - Amylases, α-glucosidase, pullulanase, and xyllose/glucose isomerases
  - Alcohol dehydrogenase
  - Xylanases
  - Lentinin
  - S-layer proteins and lipids
  - Oil degrading microorganisms
  - Sulfur oxidizing microorganisms
  - Hyperthermophilic consortia

- **USE:**
  - DNA amplification by PCR
  - Diagnostics
  - Dairy products
  - Detergents
  - Baking and brewing and amino acid production from keratin
  - Chemical synthesis
  - Paper bleaching
  - Pharmaceutical
  - Molecular sieves
  - Surfactants for oil recovery
  - Bioleaching, coal & waste gas desulfurization
  - Waste treatment and methane production
Use of Psychrophiles

**PSYCHROPHILES (SOURCE)**

- Alkaline phosphatase
- Proteases, lipases, cellulases and amylases
- Lipases and proteases (e.g., thermotolerant strains)
- Proteases (e.g., psychrotolerant strains)
- Polyunsaturated fatty acids
- Various enzymes (e.g., oligopeptidases)
- b-galactosidase
- Ice nucleating proteins
- Ice minus microorganisms
- Various enzymes (e.g., dehydrogenases)
- Various enzymes (e.g., oxidases)
- Methanogens

**USE**

- Molecular biology
- Cheese manufacture and dairy production
- Contact-tension cleaning solutions, protein tendering
- Food additives, dietary supplements, meat tenderizers
- Lactase hydrolysis in milk products
- Artificial snow, ice cream, other freezing applications in the food industry
- Frost protectants for sensitive plants
- Bioremediation, environmental bioprospecting
- Methane production

Use of Halophiles

**HALOPHILES (SOURCE)**

- Bacteriorhodopsin
- Polyydroxyalkanoates
- Rheological polymers
- Eukaryotic homologues (e.g., myc oncogene product)
- Lipids
- Various enzymes, e.g., nucleases, proteases
- Various industrial uses, e.g., flavoring agents
- g-linolenic acid, b-carotene and cell extracts, e.g., Spirulina and Dunaliella
- Various microorganisms
- Microorganisms
- Membranes

**USE**

- Optical switches and photocurrent generators in bioelectronics
- Medical plastics
- Oil recovery
- Cancer detection, screening anti-tumor drugs
- Liposomes for drug delivery and cosmetic packaging
- Heating oil
- Protein and cell protectants in variety of industrial uses, e.g., freezing, heating
- Various enzymes, e.g., amylases, proteases
- Various industrial uses, e.g., flavoring agents
- Various microorganismalties, e.g., Spirulina and Dunaliella
- Health foods, dietary supplements, food coloring and feedstocks
- Fermenting fish sauces and modifying food textures and flavors
- Various industrial uses, e.g., bioremediation
- Surfactants for pharmaceuticals

Use of Alkaliphiles

**ALKALIPHILES (SOURCE)**

- Proteases, cellulases, xylanases, lipases and pullulanases
- Proteases
- Elastases, keratinases
- Cyclodextrins
- Xylanases and proteases
- Pectinases
- Alkaliphilic halophiles
- Various microorganisms

**USES**

- Detergents
- Gelatin removal on X-ray film
- Hide dehairing
- Foodstuffs, chemicals and pharmaceuticals
- Pulp bleaching
- Fine papers, waste treatment and degumming
- Oil recovery
- Antibiotics

**ACIDOPHILES (SOURCE)**

- Sulfur oxidizing microorganisms
- Microorganisms

**USES**

- Recovery of metals and desulfurization of coal
- Organic acids and solvents

Use of Alkaliphiles

**ALKALIPHILES (SOURCE)**

- Proteases, cellulases, xylanases, lipases and pullulanases
- Proteases
- Elastases, keratinases
- Cyclodextrins
- Xylanases and proteases
- Pectinases
- Alkaliphilic halophiles
- Various microorganisms

**USES**

- Detergents
- Gelatin removal on X-ray film
- Hide dehairing
- Foodstuffs, chemicals and pharmaceuticals
- Pulp bleaching
- Fine papers, waste treatment and degumming
- Oil recovery
- Antibiotics

**ACIDOPHILES (SOURCE)**

- Sulfur oxidizing microorganisms
- Microorganisms

**USES**

- Recovery of metals and desulfurization of coal
- Organic acids and solvents

**Ta**q**Polymerase**

- Isolated from the hyperthermophile *Thermus aquaticus*
- Much more heat stable
- Used as the DNA polymerase in Polymerase Chain Reaction (PCR) technique which amplifies DNA samples

**Alcohol Dehydrogenase**

- Alcohol dehydrogenase (ADH), is derived from a member of the archaea called *Sulfolobus solfataricus*
- It can survive to 88°C (190°F) - nearly boiling - and corrosive acid conditions (pH=3.5) approaching the sulfuric acid found in a car battery (pH=2)
- ADH catalyzes the conversion of alcohols and has considerable potential for biotechnology applications due to its stability under these extreme conditions

**Bacteriorhodopsin**

- Bacteriorhodopsin is a trans-membrane protein found in the cellular membrane of *Halobacterium salinarium*, which functions as a light-driven proton pump
- Can be used for generation of electricity
Bioremediation

- Bioremediation is the branch of biotechnology that uses biological processes to overcome environmental problems
- Bioremediation is often used to degrade xenobiotics introduced into the environment through human error or negligence
- Part of the cleanup effort after the 1989 Exxon Valdez oil spill included microorganisms induced to grow via nitrogen enrichment of the contaminated soil

Psychrophiles as Bioremediators

- Bioremediation applications with cold-adapted enzymes are being considered for the degradation of diesel oil and polychlorinated biphenyls (PCBs)
- Health effects associated with exposure to PCBs include:
  - acne-like skin conditions in adults
  - neurobehavioral and immunological changes in children
  - cancer in animals

Life in Outer Space?

- Major requirements for life:
  - water
  - energy
  - carbon
- Astrobiologists are looking for signs of life on Mars, Jupiter’s moon Europa, and Saturn’s moon Titan
- Such life is believed to consist of extremophiles that can withstand the cold and pressure differences of these worlds

Life in Outer Space?

- Europa is may have an ice crust shielding a 30-mile deep ocean.
  - Reddish cracks (left) are visible in the ice – what are they?
- Titan is enveloped with hazy nitrogen (left)
  - Contains organic molecules
  - May provide sustenance for life?

Life in Outer Space?

- Some discovered meteorites contain amino acids and simple sugars
  - Maybe serve to spread life throughout the universe
- A sample of stratospheric air
  - myriad of bacterial diversity 41 km above the earth’s surface
  (Lloyd, Harris, & Narlikar, 2001)
CONCLUSIONS

How are extremophiles important to astrobiology?
- reveal much about the earth’s history and origins of life
- possess amazing capabilities to survive in extreme environments
- are beneficial to both humans and the environment
- may exist beyond earth

Homework #2 – Due 3/1/07

On the World Wide Web, look for recently published information (< 1 year old) about the discovery of a previously unknown type of extremophile. Describe the organism and the environment in which it lives, and discuss any implications of the findings for the search for life beyond Earth. Summarize your findings in a (minimum) 2-page report. Include the links to the web pages and papers used in your report.