Study Guide # 2 - Spring, 2000
Geology 230 - Evolution of the Earth

THE EVOLUTION OF LIFE

Lynn S. Fichter
James Madison University

Topics to be covered and general objectives:

During this period, we will cover the following topics in lecture:

☺ The record of life on earth. *Are there recognizable patterns, or is it all just random and unpredictable?*

- ◊ An introduction to non-equilibrium thermodynamics (chaos/complexity theories).
- ◊ Evolution of Moneran biochemical pathways.
- ◊ Symbiosis and the origin of the Protist kingdom.
- ◊ The Origin of multicellularity.
- ◊ The Phanerozoic record of multicellular life.

☺ A sampling of the significant scientific problems in the history of life on earth. *Just how much do we know and understand after more than a century of study?*

- ◊ The principles of non-equilibrium thermodynamics [Prigogine's **Dissipative Structures** and Bronowski's **Stratified Stabilities**]. *How can life get more complex when the second law of thermodynamics says everything in the universe should be running down?*
- ◊ Evolutionary Theory. Many problems exist in science which are very difficult to solve, and which do not have simple solutions. *Evolutionary theory is much more than Darwin's theory of natural selection.*
- ◊ The Gaia hypothesis for the coevolution of life and the earth. *To what degree are the Earth and life related?*

PROCESS

#1 "Any phenomenon which shows continuous change in time";

#2 "A series of actions or operations definitely conducing to an end."

Theory-free science makes about as much sense as value-free politics. Both terms are oxymoronic. All thinking about the natural world must be informed by theory, whether or not we articulate our preferred structure of explanation to ourselves. Stephen Jay Gould, Natural History, 4/93, p 17.

GENERAL INTRODUCTION TO EVOLUTIONARY PROCESSES

Nothing is more fundamental about planet Earth than that it is characterized by processes. This is because the Earth is an open system. That is, it continuously receives and dissipates energy, not only from the sun, but also from its own molten iron core.

Because the earth is an open system, it is evolutionary, and we observe that both the earth's lithosphere and biosphere have evolved [just meaning changed; "improvement" is much more difficult to ascertain] with time. Although Chaos and Complexity theory argue it is axiomatic that open systems evolve and become more complex, the actual evolutionary events are exceedingly complex and controlled by specific proximal causes which we still do not understand well.

Throughout history many theories have been proposed to explain the evolution of life, and the earth. Even today new theories continue to be proposed because we are only partially able to explain or understand the world around us. Many of the new theories are very powerful, and controversial. Often when first proposed these new theories are viewed skeptically, and sometimes just dismissed out of hand. The skepticism often exists for philosophical reasons. Because of ideology, or training, or other beliefs, people are reluctant to seriously consider new, unfamiliar ideas. But at other times people are skeptical just because the evidence is not easy to gather, analyze, or understand.

Nonetheless, ideas which at first seem far fetched often turn out to be profound. They explain things that can be explained in no other way. Of course, other ideas turn out to be inconsequential. It is a delicate balance between refusing to accept a new idea, and accepting an idea too uncritically. There is no right way to think in these situations. What is important is for you to have a rich imagination, and the training to know when and how to discipline it. Still, through a life time, you will probably be wrong about new ideas more times than right. Remember Hardin's Law: "Once you have all the facts necessary to change your mind, it takes you five years to do it."

During the last half of the semester I want you to gain an appreciation for the nature and significance of two of the most important evolutionary processes on the earth and the theories which purport to explain them. These processes and theories are absolutely fundamental to understanding the Earth's history. These two processes are not alike, however.

The Evolution of Life belongs to the process definition #1 above, the Evolution of Mountain Ranges to the process definition #2.

From all we have learned about the evolution of life, there is continuous change with time but it is not cyclical, or "conducing to an end." Thus life has had a continuously profound and changing influence on the planet [and our interpretation of it] and it is necessary to know its origin, evolution, and influence.

The evolution of mountain ranges is "conducing to an end," however, for studies of the past and present demonstrate that mountains and mountain building processes have a beginning, and a middle, as well as an end. After studying processes of the Evolution of Life and their effects, our next study will be of the Evolution of Mountain Ranges.

On an exam, you should be able to demonstrate your knowledge of the Evolution of Life by specifically answering the following:

I seem to be always in the process of reworking parts of the evolution of life section of the course. This study guide is based on my thoughts at the moment, but there will probably be changes as the semester progresses. The history of life is just too complex to summarize in the time available. There are more subjects I would like to cover than we have time for, so I will just pick and choose my way through them, and when we run out of time, I will stop. Therefore, everything in this study guide will probably not be covered.

If I make changes I will announce them in class several times to insure everyone understands them. If some of these guidelines need to be rewritten, or new ones written, they will be handed out in new versions.

Introduction to the Fossil Record

Life on earth has existed for more than 3.5 billion years. During that time an enormous number of kinds of life have evolved, with very complex relationships. One of the dilemmas of trying to summarize this remarkable history is the fact that there is virtually no scale you can examine it where it simplifies. Viewed from afar, or very close, one is overwhelmed by the complexity and intricacy that life exhibits. This property of equal complexity and intricacy at all scales of observation is a characteristic of ***fractal geometry****, a subject we need to explore before we are done. But fractal geometry is a feature of chaos theory, and we may have to explore that to understand the record of life.*

The practical problem when confronting this record of life is that learning what kinds of organisms there are, and when they existed in earth history is daunting. There is an overwhelming number of organisms and relationships to learn. Personally, I find this disconcerting, and you will too. There is a lot of memorization involved, especially if you do not have much biology in your background, but I will try to keep it to the basic things you should learn in a course like this.

1. Just to keep things in perspective, what are the estimates of . . .
   - ❒ The number of living species that have been named and described?
   - ❒ The total number of species which may exist today?
   - ❒ The total number of species which may have existed throughout earth history?
   - ❒ The percentage of species which have become extinct?
   - ❒ The number of fossil species discovered and named?

2. Why and how is the fossil record so biased?

3. What special contributions does the fossil record make to our understanding of life on earth?

4. Did life arise more than once on this planet?

A. List the three points of cell theory.
B. Describe and explicate the evidence used to argue that all life on earth is related.

The Precambrian Record of Life

5. Describe ***Euclidean geometry***. Describe ***fractal geometry***. Explain in ways a layperson would understand the most salient distinguishing features between them.

6. Life is Fractal. Explain what this means in terms a layperson would understand. [See "Euclidian and Fractal Geometry" [1]].

7. "Life's Organization and Strategies": Distinguish among, define, or describe the most significant features of the following:

❒ Prokaryotes	❒ Protoctista	❒ Fungi
❒ Eukaryotes	❒ Animalia	
❒ Monera	❒ Plants	

8. "Major Stages in the Evolution of Life": This chart outlines the broad evolutionary relationships among the major life forms on the earth. Using it as a basis, be able to draw a phylogenetic tree summarizing the evolutionary relationships among the organisms on the chart.

*The evolution of this early life had a profound impact on the evolution of the earth, and we need to understand both. We used the chart "**Major Events in the Precambrian Evolution of Life**" to summarize and organize the events involved in the Archean and Proterozoic evolution. These questions explore some of the details of this history.*

9. Given a blank time chart "Major Events in the Precambrian Evolution of Life" be able to plot or give the timing of the following events.

EVENTS ASSOCIATED WITH THE PRECAMBRIAN EVOLUTION OF LIFE

First appearance of:	Evolutionary Events [2]:	♡ Anoxic atmosphere
♡ Prokaryotes	♡ Stage IA and IB	♡ Aerobic atmosphere
♡ Eukaryotes	♡ Stage II	♡ BIF range
♡ Protists	♡ Stage III	♡ Major BIF
♡ Animals		♡ Oldest rocks
		♡ Oldest fossils

10. The faunas/floras below are listed in alphabetical order. Be able to do the following:

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[1] Study Guide questions which refer to or use a chart, diagram, etc. from the Notebook of Lecture Illustrations are indicated by quote marks and this more ornate font style.

[2] Identify the major events each of these stages represents.

- ⇨ Arrange them in time sequence.
- ⇨ Give the absolute age of each.
- ⇨ Describe the representative organisms of each flora/fauna.
- ⇨ Identify the significant biological advances represented by each.

FLORA/FAUNA [3]

♡ Beck Springs	♡ Ediacara	♡ Onverwacht
♡ Bitter Springs	♡ Fig Tree	♡ Paradise Creek
♡ Chengjiang	♡ Gunflint	♡ Warawoona

Axiomatic Causes in Evolution

Non-Equilibrium Thermodynamic Principles, Dissipative Structures, and Stratified Stabilities

How the great complexity and intricateness of life came to be has wondered people for millennia. Without modern theories of dissipative structures, chaos, and complexity, rational explanation is virtually impossible.

11. Describe the "problem of problems" and why it exists.

12. Define or describe the meaning of the following terms [listed alphabetically], giving pertinent examples [See "A Glossary of Terms and Concepts Associated with Non-Equilibrium Thermodynamic Systems"].

❒ Closed System	❒ Negative Feedback
❒ Determinism	❒ Open [dissipative] System
❒ Dissipative Structure	❒ Positive Feedback
❒ Entropy	❒ Stratified Stability

❒ 2nd Law of Thermodynamics, and its implications

A number of solutions to the classical, deterministic, everything heading toward entropy concept of the second law of thermodynamics have been developed in the past several decades. Most of these solutions have developed in isolation from each other, as specialists in different fields, investigating narrow problems, stumbled on the same phenomena. These lead to the development of theories known a non-equilibrium thermodynamics, chaos theory, complexity theory, and artificial life, among others. They are all pretty much describing the same phenomena, however. Chaos and artificial life studies provide us the easiest and quickest way to get to the essences of these ideas.

13. CHAOS THEORY #1: One definition of chaos theory we used was ***"The quantitative study of unstable aperiodic behavior in deterministic nonlinear dynamical systems."*** Be able to take this definition

[3] Fauna are all the animals living in a place. Flora are all the plants, including photosynthetic Monera and Protoctists [called microflora].

apart and describe the meaning of each component, and then put it back together again to explain what it all means to someone unfamiliar with it.

14. Describe what the ***computational viewpoint*** is, and why it is necessary.

15. CHAOS THEORY #2: A second definition of chaos theory we used was the equation **$X_{next} = r X (l-X)$**. Be able to describe, diagram, or interpret how this equation illustrates and defines chaos theory, or be able to answer questions about this equation using the following the terms and concepts [listed alphabetically] in the table below, or, where appropriate, those in the above table. [See "The Period Doubling Route to Chaos", and others.]

❒ Bifurcation [diagram]	❒ Period Doubling
❒ Edge of chaos	❒ Self Referencing
❒ Emergent property	❒ Sensitive dependence on initial conditions (butterfly effect)
❒ Iteration (Iterated)	

16. COMPLEXITY THEORY: like chaos theory, has many definitions or descriptions. We used two.
   ① Describe how complexity theory is related to chaos theory, including its relationships to the **$X_{next} = r X (l-X)$** equation and bifurcation diagrams.
   ② A second description compared chaos theory ("Simple laws can have very complicated, indeed unpredictable, consequences"; i.e. Local Rules/Global Behavior) with complexity theory ("Complex causes can produce simple effects.") Explain in terms a layperson would understand how this phrase ***"complex causes can produce simple effects"*** embodies complexity theory.

17. ATTRACTORS: Strange and Otherwise:
   ☞ In mathematical terms, describe what an attractor is, including a definition or drawing illustrating a phase space.
   ☞ Describe, define, illustrate, recognize, or give examples of Fixed Point, Limit Cycle, and Strange attractors.
   ☞ Describe in terms a lay person would understand what makes a Strange attractor strange.
   ☞ In vernacular (non-mathematical) terms, describe what an attractor is and give an example.

The Evolution of Precambrian Biochemical Pathways

The Monera Kingdom represents the first life forms, and are significant for having invented most of the biochemical systems, strategies, and pathways the rest of life relies on. They were also not only essential to creating our present atmosphere and retaining enough water to form the oceans, they are essential to maintaining modern ecosystems. But, the evolution of the bacteria is very complex and only understood in outline. And the fossil record provides very little evidence to help us. Most of the evidence comes from bacteriology, biochemistry, and cell physiology. The charts ***"The Extremophiles",*** *"****General Evolutionary Development of Biochemical Pathways****", "****The Evolution of ChemoOrganoAutotrophic Energy Producing Biochemical Pathways****" and* ***"Selected Geologically Important Prokaryote Biochemical Pathways****" summarize the* *broad evolutionary events in the Monera during the Archean and Proterozoic. The questions below explore some of the details of this history.*

18. What is life? List or explain the properties which characterize life.

19. Describe or explain the role and importance of ATP in living systems.

20. Distinguish between chemolithoautotrophy and chemoorganoautotrophy.

21. Describe or explain what an extremophile is, where they live, how they derive energy, and their place and importance in the history of life.

22. [A] The organisms in the table below are listed alphabetically. Arrange them in their evolutionary sequence.

GROUPS OF MONERAN ORGANISMS

♤ Archaebacteria	♤ Green/Purple sulfur bacteria	♤ Precursor blue-green algae
♤ Blue-green algae	♤ Mitochondria	♤ Pyruvic fermenters
♤ Desulfovibrios	♤ Nitrogen fixers	♤ Urkaryotes

[B] For each organism in the table describe its basic ***adaptive strategies*** [way of making a living].

[C] Briefly list or discuss the evolutionary history of these organisms, including:

- ☞ The organisms involved at each step.
- ☞ The major crises at each step
- ☞ How the crises were solved at each step
- ☞ What, if any, affect each biological advance had on the earth.

[E] Reconstruct the arguments for the origin of oxygen in the Earth's atmosphere, including, and/or describing fully, any or all of the following concepts or ideas:

❐ Anaerobic photosynthesis	❐ Timing of the events
❐ Aerobic photosynthesis	❐ Description of BIFs
❐ Hydrogen crisis	❐ Formation of BIFs
❐ Oxygen crisis	

❐ The effects of formation of an oxygen rich atmosphere on the earth's geology and biology.

23. Describe the mechanisms by which the Protists [Eukaryotes] evolved, including the role of the following:

PROTIST ORIGINS [4]

❑ Beck Springs	❑ Host Cell	❑ Sexual reproduction
❑ Bitter Springs	❑ Mitochondria	❑ Spirochetes
❑ Blue-green bacteria	❑ Paradise Creek	❑ Symbiosis
❑ Fermentation	❑ Respiration	❑ Urkaryote

❑ The advantages of all these activities to the symbiont [the symbiotic organism] and its effects on the earth

❑ A listing of several typical phyla belonging to this kingdom.

The Gaia Hypothesis

One of the major issues in attempting to understand the Earth is the relationship between geochemical evolution and the biochemical evolution, or in terms of Gould's eternal metaphors, environment vs internalist arguments for evolution. Our focus here is to look at the earth as a system, where all components are interconnected in complex positive and negative feedback loops. The most inclusive theory dealing with this is the Gaia Hypothesis of James Lovelock and Lynn Margulis. It is a controversial theory, with vocal proponents and opponents. Our interest here, however, is to use the theory as an example of a systems approach to understanding the earth.

24. Be able to describe, or explain, or define . . .
    - [A] What the Gaia hypothesis is.
    - [B] The kinds of evidence which point to the existence of Gaia.
    - [C] The criticism level against the Gaia hypothesis.
    - [D] List some effects on earth history attributed to Gaia, or, conversely, some of the consequences for the earth's history the hypothesis' proponents argue would not exist if Gaia did not function.

25. Describe the function of the Daisyworld models.
    - [A] Be able to read, describe, and interpret any Daisyworld diagram discussed in class.
    - [B] Describe and explain the factors to which Lovelock attributes the ecological stability of Daisyworld models.
    - [C] Explain the birth and genesis of Gaia on earth by interpreting the Archean history as interpreted by Lovelock [see "Model of the Archean Before and After Life Following Daisyworld Models"]

26. Given a blank copy of Lovelock's Archean ⇨ Proterozoic Daisyworld model describe the events and cause ⇨ effect relationships described by the model.

[4] Fauna are all the animals living in a place. Flora are all the plants, including photosynthetic Monera and Protoctists [called microflora].

27. Compose a statement explaining to a layman the different ways earth and life have evolved together and influenced each other. Emphasize:
    - [A] The ways the earth is different in its history and character for having coevolved with life.
    - [B] The ways life is different because of the way the earth has changed.

The Origin of Multicellularity

Because we are multicellular we think being multicellular is the best and only way to be. But, the advantages of multicellularity are not obvious, and the problems encountered by the Protoctists attempting to become multicellular are formidable. Multicellularity must have its advantages, though, since it is estimated that it evolved independently at least 17 times, and probably many more. A vast literature, and large body of facts and theory exists on this issue. We just touched the subject.

28. List and describe some of the problems a multicellular animal must overcome.

29. Describe and/or indicate on a time chart the events associated with the origin of multicellularity, including the following.

ORIGIN OF MULTICELLULARITY

✪ Archaeocyathids	✪ Filmy phyla	✪ Revno horizon
✪ Changjiang	✪ Pancake/Ribbon phyla	✪ Round phyla
✪ Cnidaria	✪ Porifera	✪ Tommotian
✪ Ctenophores	✪ Porous phyla	✪ Trace fossil revolution
✪ Ediacara		

The Phanerozoic Record of Life

Despite the relatively short interval of time covered by the Phanerozoic [14%] compared to the Archean [40%] and Proterozoic [45%], its fossil record is the richest, most diverse, and abundant. It is also the fossil record studied the most. Your textbook is an excellent reference in preparing for the questions below .

Reading Assignments: in Stanley:
Archean Life, p 201-208; Proterozoic Life, p 219-226; Early Paleozoic, 242-257; Mid Paleozoic, 264-289; Late Paleozoic, p 299-333; Early Mesozoic, 337-358; Cretaceous, 367-393; Paleogene, 403-418; Neogene, p 429-435.

30. Given a time scale with Periods indicated, mark the boundaries of the 6 major Phanerozoic stages in the evolution of life.
    - [A] What defines the boundaries among these stages?
    - [B] Which ones are more significant or profound than others?
    - [C] Why are they more significant?

The Phanerozoic record of the earth and of life are very complex and many attempts have been made to find cause ⇨ effect relationships between them. There are no doubt such relationships, but if there are *they are not straight forward. Nonetheless, the most significant events marking the evolution of life are the events which have done it the most damage.*

31. For each of the six stages of the Phanerozoic considered in class, be able to list:
    - ❒ The several significant groups of organisms, and
    - ❒ Geologic events which characterize and distinguish the stage.

32. For the Three Evolutionary Faunas of the Phanerozoic Marine Taxa:
    - ❒ List the taxa which most characterize each fauna.
    - ❒ Given the chart identify the major times of extinction.
    - ❒ Describe and explain the several conclusions that can be drawn about the Phanerozoic evolution of life from this data.

33. On the chart "The Phanerozoic Record of Life" we outlined and summarized the record of multicellular life. The chart no doubt seems very complex, but it is in fact a simple summary of life's Phanerozoic history [remember it is a fractal problem; blow the chart up and it would still look complicated]. It represents the most basic knowledge. Given a blank version of the chart, or any part of it, completely label it with the organisms and events as we discussed them in class.

Each stage in the Phanerozoic was a time during which unique or special events occurred in the history of life and the planet. Which stages are more important depends on your interests. Two stages I think important and interesting are the Lower Paleozoic and Upper Paleozoic. Prepare the following for each of them.[5]

If asked this question on the test you will be given the appropriate table below to work from on the test. You do not have to memorize what is on the table.

34. Be prepared to write an essay, approximately one page long, definitively and concisely describing the most important biological, geological, and climatological, events in the stage.

    If not asked to write the essay, you may be asked a critical reasoning question exploring the importance among some items in the tables below. For each of your essays [in addition to any other facts you deem important]:
    - ❒ Begin with a listing of the 2 or 3 most remarkable events taking place in the stage, and...
    - ❒ The facts, events, and/or concepts outlined on the tables below.

The Lower Paleozoic

[5] Your text book by Stanley is an excellent reference for this question and I highly recommend that you read the appropriate sections.

❒ Tommotian	❒ Cambrian extinctions
❒ Chengjiang fauna	❒ Trace fossil history
❒ Burgess shale fauna	❒ Nautiloids
❒ Trilobites	❒ Skeletons
❒ Echinoderms	❒ "Funny" phyla
❒ Archaeocyathids	❒ Nature of skeletal fossil record
❒ Cambrian Fauna	❒ Sauk sea
❒ Post Cambrian fauna	❒ Tippecanoe sea

The Upper Paleozoic

❒ Climatic changes	❒ Reptile history
❒ Topographic changes	❒ Plant history
❒ Crinoids	❒ Coals swamps
❒ Cryptostome bryozoans	❒ Uplands
❒ Blastoids	❒
❒ Alleghenian orogeny	
❒ Amphibian history	

Scientific Problems Concerning the History of Life

Life is so familiar to us that we take it for granted. But trying to explain life scientifically has proven to be extremely difficult. Life is such a complex phenomena, with so many facets, that there is little hope that we will soon understand it. Nonetheless, significant progress has been made in the last several decades at clarifying the problems we must solve. Of the many, many interesting problems available we examine only a few that have a direct bearing on understanding the earth's history.

Brooks and Wiley [Evolution as Entropy] are biologists who have applied the principles of non-equilibrium thermodynamics to evolutionary theory. Their theory is, in principle, a concise merging of traditional biological mechanisms of evolution with principles from non-equilibrium thermodynamics [including chaos and complexity] theory. They distinguish between axiomatic and proximal causes in evolutionary biology.

***Axiomatic causes** are those associated with any open, dissipative, self-evolving system. Axiomatic causes are driven by the positive feedback in the system, and it is axiomatic that such evolving systems will increase in complexity and diversity through a series of stratified stabilities.*

***Proximal causes** are the negative feedback which restrains the open system and keeps it from expanding into full blown chaos. The proximal causes are primarily biological constraints, including Darwinian natural selection.*

We explore these first, and then at the end look at the axiomatic principles, and will then bridge the gap between those principles and the proximal causes which constitute most of evolutionary theory.

Most of the significant debates among biologists and paleontologists over evolutionary theory come down to debates between micro- and macro- evolutionary processes. In the time scale biologists work at micro- is their main focus and so it looms large on their horizon. In the time scale paleontologists work at *macro- is their main focus. Micro- and Macro-, of course, cannot be separated. Macro evolutionary outcomes must be explainable in terms of micro evolutionary processes. That is what we try to do here.*

The Evolution of Evolutionary Theory

There is a common misconception that there is one evolutionary theory [Darwin's], and that evolution consists of natural selection and "survival of the fittest." Nothing could be farther from the truth. Evolutionary theory has not only evolved through time [and continues to evolve], but studies of evolutionary processes now involve, in addition to natural selection, population genetics, embryological studies, mathematical modeling, biochemical genetics, ecology, studies of the fossil record, etc., etc. It is highly sophisticated and technical, and requires knowledge of, if not expertise in, a wide variety of biological, geological, and mathematical disciplines.

Furthermore, the evolution of evolutionary theory strongly reflects Gould's three eternal metaphors. Many opinions and positions exist within evolutionary theory, sometimes held for scientific reasons and sometimes for philosophical reasons.

Darwin and the Origins of Modern Evolutionary Theory

35. Darwin and evolution by means of natural selection.
    - [A] Write a statement describing Darwin's theory of natural selection.
    - [B] Draw a diagram illustrating Darwin's evolutionary theory of natural selection. [See "Natural Selection and Gradualistic Evolutionary Models".
    - [C] Explain sympatric speciation.
    - [D] What was Darwin's dilemma?

36. Neo-Darwinism and the Modern Synthesis were the evolutionary theories of the 1940's, 50's, and 60's.
    - [A] What did they synthesize?
    - [B] Present a model explaining the evolutionary process according to the Modern Synthesis. Include the following concepts. [See "Founder Populations and the Allopatric Speciation Model"]

❒ Allopatric speciation	❒ Stasis
❒ Founder effect	❒ Genetic drift

37. What were the major misconceptions between advocates of the Modern Synthesis and P.E.?

Proximal Causes in Evolution

Darwinian Natural Selection, Ecological Opportunity, Extinction, the Role of History

The history of life is so complex and covers so much time that finding simple, universally true, generalizations has proven very difficult. On the balance scale of life there are, however, two great controlling weights. The first is the universal tendency for life to exploit each new evolutionary innovation, or each new environmental *opportunity, with an explosive evolutionary surge of adaptive radiation. The second great controlling weight are the extinctions. Over 99% of all species that have lived are extinct, so extinction is not a trivial matter. Nor does the phenomena have a simple explanation. Two excellent recent books by experts on extinction come to very different conclusions. The problem is involved enough we do not have time to pursue it in this class; Geology 250 looks at this is some detail.*

38. Describe, with examples, the major classes of proximal causes which influence evolution [see "The Relationships Between Proximal Causes and Positive and Negative Feedback Mechanisms"].
    - ❒ Explain whether they constitute positive or negative feedback.
    - ❒ Describe specific events in the history of life where these proximal causes are working.

39. What is the role and importance of extinction; what would the history of life be like if extinctions did not occur?

Theory is Crucial . . .

Positive and Negative Feedback And Information Flow in Evolution

The record of life is fractal. That is, now matter how much we enlarge the record, no matter how close we look at it, the degree of intricacy and detail remains the same - it never gets simpler. And if the record is fractal then the theory which explains it must be capable of generating those fractal patterns. These theories are Chaos and Complexity, and the first task of applying them to evolution is to see if they can explain the speciation process.

40. Relate positive and negative feedback mechanisms from chaos theory to biological processes by illustrating and explaining the meaning of positive and negative feedback in the following [you should be able to sketch and label these diagrams].
    - [A] The bifurcation diagram.
    - [B] The logistic equation $X_{next} = r\,X\,[1-X]$ and its relationship to biological positive and negative feedback [see "Relationship Between Positive and Negative Feedback . . ."].
    - [C] The flow of information in a reproducing species [see "Natural Selection and Gradualistic Evolutionary Models"]