Study Guide #3
Geology 230 - Evolution of the Earth

THE EVOLUTION OF MOUNTAIN RANGES AND THE ORIGIN AND EVOLUTION OF THE CONTINENTS
(Archean, Proterozoic, Phanerozoic)

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 geology of TRANSFORM, DIVERGENT and CONVERGENT plate tectonic boundaries and their bearing on the history and geology of mountain ranges.
- ☺ The various mechanisms of plate tectonic mountain building.
- ☺ The WILSON CYCLE.
- ☺ The question of the origin of the continents, the Archean and Proterozoic history of the continents, and the processes responsible for the origin of the North American craton.
- ☺ A plate tectonic rock cycle and a hypothesis for the origin of all rocks from a parent mafic magma.
- ☺ The principles used to interpret cratonic geologic records.
- ☺ The sequential evolution of the North American continent beginning with the latest Precambrian, and getting as far as we can before the semester runs out.

When we examine the oldest rocks on the earth we observe that most are not significantly different from rocks forming today. The implications are that the processes operating on this planet have not changed significantly since the earth's formation. This is the core of Charles Lyell's comment that the earth had *"no vestige of a beginning, no prospect of an end."* It was just the same processes cycling over and over endlessly, but getting nowhere in particular.

What has changed through the earth's history, however, and Lyell was not aware of, is the relative abundances of different rocks. Some rocks form in much greater abundance today than in the past, others have declined in importance, while a few have ceased forming altogether. The implication is that the frequency and intensity of the earth's processes have changed through time, leading to the conclusion that the earth has evolved. But, as we shall see, the earth's processes can interact in an almost unlimited variety of combinations, and the resulting evolution of the earth has been a continuously unique and changing scene. Thus what we observe in the Evolution of the Earth (the course title) are ***fundamental processes, but changing patterns of response.***

On an exam, you should be able to demonstrate your knowledge and comprehension of the principles and processes behind the Earth's evolution, and the ways they have interacted to create the Earth in general and North American in particular, by specifically answering the questions below:

THE EVOLUTION OF MOUNTAIN RANGES

Introduction and Background Knowledge

Plate Tectonic Theory is an integral part of this subject. In Geology 110 you have learned the basic concepts of plate tectonics, its historical development from continental drift theory, and the basic physical geology needed to understand it. I will not repeat this in this class. Yet that knowledge is essential to what we will discuss, and the importance of many ideas we discuss may be unclear or lost to you without this background knowledge.

Review the list of terms and concepts below. If any are unfamiliar to you look them up in your physical geology textbook or lab manual. Your historical textbook by Stanley, Exploring Earth and Life Through Time, also has a very good chapter on plate tectonic theory (chapter 6, p 130-155), although it will not cover all the concepts below. If you still have problems come see me.

Alfred Wegner and Continental Drift Theory	
♤ The Origin of Continents and Oceans	♤ Gondwana
♤ Pangaea	♤ Tethys sea
♤ Panthalassa	♤ Wegner's evidence for continental drift
♤ Laurasia	♤ Wegner's mechanism for continental drift

Plate Tectonic Theory

- When did the theory originate?
- How does the theory differ from continental drift?
- Nature of the evidence for the theory
  - Magnetic?
  - Seismic?
  - Gravitational?
  - Heat flow?
- Sea floor spreading
- Paleomagnetism
- Polar wandering
- Isostasy
- Earthquake mechanisms
- Earthquake distribution
  - Shallow
  - Intermediate
  - Deep
- A "plate"
- Subduction zone
- Hot spot
- Triple junction
- Island (volcanic) arc
- "Ring of fire"
- Oceanic trenches
- Crust
- Mantle
- Asthenosphere
- Continental crust
- Oceanic crust
- Moho

Igneous/Metamorphic/Structural Geology Concepts

IGNEOUS

- Composite volcano
- Shield volcano
- Fissure volcano
- Plateau (flood) basalts
- Pillow lava
- Fractional crystallization
- Fractional melting
- Solid solution phase diagrams
- Binary eutectic phase diagrams
- Bowen's theory for the evolution of igneous rocks

METAMORPHIC

- Metamorphic facies
- Metamorphic zones
- Index minerals (list)
- Isograds
- Blueschist
- Greenschist
- Amphibolite
- Granulite
- Regional metamorphism
- Hydrothermal metamorphism
- Serpentinite
- Soapstone
- Paired metamorphic belts

STRUCTURE

- Joints
- Normal faults
- Horsts
- Grabens
- Thrust faults
- Strike-slip faults
- Transform faults
- Reverse faults

In addition you should read "The Evolution of Igneous Rocks, and the Significance of Their Tectonic Associations, in the Lecture Notebook. It contains concepts I will develop in class, but it will certainly help to have read about them before I get to them.

More specifically you should be able to answer the following:

The WILSON CYCLE and TECTONIC ROCK CYCLE are our touchstone models for understanding and interpreting the earth. Detailed descriptions of each of these may be found at the following web sites. If you are lost or confused about any part of the models these web pages will help you.

http://geollab.jmu.edu/Fichter/Wilson/Wilson.html

http://geollab.jmu.edu/Fichter/Wilson/PTRC.html

Plate Tectonic Cycle

1. Either draw, or label a cross section, of the earth's lithosphere (similar to the one in your notebook of lecture illustrations) illustrating the following features. Note that many terms in this table refer to the same thing. Sometimes they are synonymous, other times the terms reflect different views of the feature.

❑ Back arc basin	❑ Divergent boundary	❑ Ocean basin
❑ Collision orogeny	❑ Divergent continental margin	❑ Plate
❑ Continent	❑ Island arc	❑ Remnant ocean basin
❑ Convergent boundary	❑ Magmatic arc	❑ Terrane
❑ Cordilleran orogeny	❑ Microcontinent	❑ Transform fault
❑ Craton		❑ Volcanic arc

2. Describe or explain what the Wilson Cycle is, in terms a lay person could understand, accompanied by a series of labeled sketches illustrating the steps in a typical cycle.
   A. Be able to describe, explain, or understand any processes in any stage of the cycle.

3. We took the nine stages of the Wilson Cycle and exploded them to look at their details. The questions below explore those details. For **PLATE RIFTING AND DIVERGENCE.**
   A. Explain how **HOT SPOTS** are related to ocean rifting by doing the following:
      1 Define or describe what is meant by a Hot Spot, including their general distribution today, and hypothesized cause.

2 Explain the processes by which Hot Spots are responsible for the bimodal igneous suite associated with them.

3 Describe and illustrate what is meant by a **TRIPLE JUNCTION,**
- ♢ Explain how they form,
- ♢ The processes and rocks formed in them, and
- ♢ Give a modern example.

4 Define what an **AULACOGEN** is (i.e., how they are recognized), . . .
- ♢ List a few examples, and . . .
- ♢ Explain their relationships to triple junctions, rifting events, continents, and the conditions under which they form.

B. Describe how **PLATE ACCRETION** creates new oceanic crust by doing the following:

1 Describe what an **OPHIOLITE SUITE** is.

2 Draw a fully labeled cross section of a typical oceanic rift where plate accretion is occurring: include:
- ♢ The location, composition, and/or characteristics of Layers 1-4,
- ♢ Positions of the Moho, crust, mantle, asthenosphere, and
- ♢ The origin, composition and position of all rocks associated with rifting processes.

C. Describe the characteristics of a **DIVERGENT** (Atlantic-type, passive, or trailing edge) **CONTINENTAL MARGIN** by doing the following:

1 Draw a sequence of fully labeled cross-sections showing the timing and development of a typical divergent continental margin including:

♧ Axial rift	♧ Listric faults	♧ Transgressive quartz arenite
♧ Continental terrace	♧ Plateau (flood) basalts	♧ Axial graben
♧ Continental crust	♧ Slope/rise	♧ Ophiolite suite
♧ Transition crust	♧ Rift graben clastics	♧ Aulacogen
♧ Oceanic crust	♧ Continental margin deposits	♧ Lateral graben
♧ Bimodal association		

4. For the closing stages of the Wilson cycle, **PLATE CONVERGENCE, SUBDUCTION, EARLY MOUNTAIN BUILDING:**

A Understand the complex geology of Subduction Zones and associated Mobile Belts, by doing the following:

1 List the variety of **CORDILLERAN TYPE** and **COLLISION TYPE** mobile belts including a simple cross section of each, a modern example, and how they are driven (i.e., their major sources of energy).

2 Draw a detailed, fully labeled cross section of a typical Cordilleran Mobile Belt of the **ISLAND ARC TRENCH** type, including the location of the following:

- ☺ Alkaline suite
- ☺ Backarc
- ☺ Blueschist metamorphism
- ☺ Calc-alkaline suite
- ☺ Flysch
- ☺ Forearc
- ☺ Island (volcanic, magmatic) arc
- ☺ Marginal (backarc) spreading center
- ☺ Mobile core
- ☺ Outer arc trough
- ☺ Outerarc ridge
- ☺ Regional metamorphism
- ☺ Subduction zone
- ☺ Tholeiite suite
- ☺ Trench
- ☺ Volcanic front
- ☺ Zone of fractionation

3 Describe and/or clearly explain the formation of the following:

- ✪ Alkaline suite
- ✪ Blueschist metamorphism
- ✪ Calc-alkaline suite
- ✪ Flysch
- ✪ Marginal (backarc) spreading
- ✪ Melange
- ✪ Subduction zone
- ✪ Tholeiite suite

5. For **PLATE COLLISION AND MOUNTAIN BUILDING**:

A Draw fully labeled, simplified cross sections illustrating the plate relationships in an "Island Arc Trench type" collision and a "Continental Trench type" collision, (show the position of major lithologic units).

B List and illustrate several ways in which mobile belt mountain building may become more complex than that presented in the simple models.

6. Draw a detailed, fully labeled cross section of a **CONTINENT-CONTINENT** collision mountain building episode including the location of the following:

- ♢ Allochthons
- ♢ Backarc (marginal) basin
- ♢ Divergent margin sedimentary wedges
- ♢ Foreland
- ♢ Foreland basin
- ♢ Flysch
- ♢ Hinterland
- ♢ Klippe
- ♢ Melange belt
- ♢ Molasse
- ♢ Obduction
- ♢ Oceanic crust
- ♢ Paired metamorphic belts
- ♢ Remnant ocean basin
- ♢ Subduction zone
- ♢ Suture zone
- ♢ Volcanic front
- ♢ Wildflysch

7. For **STAGE I,** the last stage, of the Wilson Cycle:
   ◊ Take the last stage and be able to deconstruct it, identifying the processes or stages in the cycle where each rock unit formed, and/or identifying each rock type in the cross section and the processes by which it formed (see http://geollab.jmu.edu/Fichter/Wilson/StageI.html#How Much

8. List the complications of mountain building models, and explain each of their effects.

THE ORIGIN AND EVOLUTION OF THE CONTINENTS

Fundamental Processes But Changing Patterns of Response

Historical Background

9. Draw a time line of earth history showing the timing of the Archean, Proterozoic, and Phanerozoic Eras. For each Era give a succinct description of the significant rock record or geological processes occurring.

10. Given a chart showing the distribution of major rock types through time (see "Major Divisions in Earth History" in notebook) be able to explain or answer questions about why the abundances of rock types are changing with time. These explanations may include tectonic evolution of the earth, changing processes in earth history, the influence of life processes, or any others responsible for the generation of specific rock types.

For the Archean Geological Record

11. Describe the nature of the Archean rock record, including a listing of the major rock complexes, groups, or associations and their characteristics for both granulite-gneiss belts and greenstone belts.
    ☞ With the use of fully labeled diagrams, charts, or cross sections completely explain, describe, or understand the processes by which each of the complexes or rocks are formed.

☞ Be able to explain each rock unit alone, or illustrate how they are connected by a series of related crustal processes, including the interpretation of any diagrams and cross sections we used.

12. For the **ARCHEAN TECTONIC ROCK CYCLE:**
    A Beginning with an original ultramafic parent rock draw a diagram illustrating the sequence by which we were able to evolve the rocks listed below (see http://geollab.jmu.edu/Fichter/Wilson/PTRC.html)

✪ Anorthosite	✪ Intermediate igneous	✪ Quartz arenites
✪ Arkoses	✪ Lithics	✪ Metamorphism (all facies)
✪ Blueschist	✪ Mafic igneous	✪ Shales
✪ Carbonates	✪ Melange	✪ Ultramafic igneous
✪ Eclogites	✪ Migmatites	✪ Wacke
✪ Felsic igneous		

    B Explain in writing the tectonic conditions under which, and rock cycle processes by which, each rock listed in A is evolved.

    C Relate any of the rocks in the above table to a stage and location in the Wilson cycle.

THE GEOLOGICAL EVOLUTION OF NORTH AMERICA

For the Proterozoic Geological Record

13. List and briefly describe the significant changes which took place from the Archean to the Proterozoic. Briefly describe the nature of the transition, (distinct, transitional, large overlap, etc.) and provide some explanation for your description.

For the Phanerozoic Geological Record

14. Understand the principles which govern the interpretation of cratonic stratigraphy by doing the following:
    A Define or describe what an epicontinental (epeiric) sea is.
    B List the characteristics of the basic Cratonic stratigraphic record.
    C Explain or define what a sequence is and how it is recognized.

15. For NORTH AMERICAN CRATONIC SEQUENCES:
    A List in order from oldest to youngest the six North American sequences: **SAUK, TIPPECANOE, KASKASKIA, ABSAROKA, ZUNI, TEJAS** [1].
    B For each sequence describe in a few phrases the significant geological events which were added to North American cratonic geology **OR** which characterize that sequence.

16. For **NORTH AMERICAN OROGENIES:**
    A For each of the APPALACHIAN, OUACHITA, and CORDILLERAN mobile belts list in sequential order and give the basic timing of the orogenies and rifting events which affected the mobile belt [2].
    B For each orogeny explain the basic plate tectonic processes by which it occurred.

17. Given a blank outline of the chart, or any portion of the chart, for the Phanerozoic Geologic Evolution of North America be able to fill it out with all the significant events discussed in class.

18. At first the geology of the North American craton and of the mobile belts had little influence on each other. With time there was continuing interaction. Describe with the use of specific examples how the geology of the craton and mobile belts increased their interaction through the Phanerozoic.

---

[1] I will give you an outline chart like the one used in lecture and you will be able to label the sequences and orogenies on that chart.

[2] I will give you an outline chart like the one used in lecture and you will be able to label the sequences and orogenies on that chart.