Study Guide # 2

The Rock Cycle: Part One

The Center of Geology

(Minerals, Igneous Rocks, Science Principles)

GenSci 102A: Environment: Earth
Lynn S. Fichter
Department of Geology and Environmental Sciences
James Madison University

Topics to Be Covered and General Objectives:

Our earth, what we see, what we live on, what we have to study, is the result of cyclical transformations of MATTER by the dissipation of ENERGY. That is, the earth is an open system; energy continuously passes through the matter of which it is made and transforms that matter (it evolves) into the minerals and rocks we study.

As we have already explored in the first part of the semester, the chaos/complexity principles which underlie this evolution have three components:

(1) Processes of ***self-organization*** where adaptive systems (i.e. open systems) spontaneously arise out of disorder via the operation of local rules/global behavior in the complexity realm.

(2) ***(Natural) selection*** of the adaptive systems where they "compete" with each other on *adaptive landscapes* to find the optimum solution to the existing conditions.

- An adaptive landscape consists of a set of environmental conditions or variables toward which adaptive systems evolve. For us, these adaptive landscapes exist as phase diagrams. The positions these systems migrate to on these diagrams are attractors.

(3) ***Historical accident***, or contingency, where what has already evolved constrains what can evolve in the future.

- The converse side of this is that as evolution proceeds the number and diversity of adaptive landscapes increases leading to increasing overall complexity of the universe. On the earth this is seen as the increasing number and diversity of different rock types evolving out of the original simple composition of the planet.

This is our study and includes investigation of the following topics.

The Energy:

The energy is dissipated in four forms:

(Gravitational energy.
(Chemical energy - the transformation of matter into the most stable form it can possess under the conditions.
(Heat energy - escaping from the earth's interior. Expressed as volcanic activity and tectonism [earth deformation].
(Solar energy - coming from the sun, driving the atmosphere, and contributing to climate, deserts, tropical rain forests, land form development, etc.

The Matter:

Minerals: the central unit - virtually the whole earth is made up of minerals, at present 6000 kinds and counting [although only a couple dozen are most common and important]. Minerals are the most stable form, the lowest energy state, solid matter can have.

Rocks: mixtures of minerals, in three varieties igneous, sedimentary and metamorphic.

The Central Problems:

ƒ Discovering the exact conditions (attractors) under which each mineral and rock forms and is stable.
ƒ Discovering the processes by which minerals and rocks transform from one to the another as energy conditions change.

The Central Theory:

The ***Rock Cycle*** is the central theory in geology. It describes how all the earth's minerals and rocks are related and can be transformed from one to the other as the adaptive landscapes change. It also contains all environmental conditions and attractors which explain how all these transformations take place, and how all this has been demonstrated to be scientific truth.

Topics to Be Covered

k Organization of the elements into minerals, and the principles which underlie their abundances, chemical interactions, behavior, and crystalline structure.
k The systems humans has devised to classify and describe the great variety of materials which make up the earth.
k The processes responsible for the formation and evolution of the diverse rocks which compose the earth.
k The conditions and processes by which igneous, sedimentary, and metamorphic rocks transform into each other.

k The Rock Cycle as the central theory of geology.

I hope you gain an appreciation for the fundamental order of the universe and for the fact that the physical states of matter as we see them today are simply a response to the operation of fundamental physical and chemical energy on the basic "stuff" spread throughout the universe. I hope you also gain an appreciation for the human and scientific struggle to understand and make sense of this planet we live on.

On the exam you should be able to demonstrate your understanding of the Earth and the scientific processes by which we strive to understand it by intelligently providing answers to the questions below. Note that in a test question two or more of these may be combined in one question.

Note that these guides are often stated as if you should be able to do something, write something, explain something. This is in fact a good way to study. If you can understand these ideas well enough to explain them, as if to someone else if not yourself, then you will do ok. Also, remember that test questions commonly ask you to identify, recognize, or interpret diagrams and illustrations in the Lecture Notebook.

Specifically you should be able to:

The Architecture of Matter

1. Given a blank periodic table of elements identify the location of the alkali, alkaline earth, oxygen and halogen, boron, carbon, nitrogen, transition, and inert groups of elements. Name common examples in each group.
    - K Describe the chemical characteristics of common examples in each group [number of valence electrons, bonding characteristics, likelihood of forming anions or cations, stability].

2. Using the terms in the table below, describe the way the elements may bond to form compounds. Be able to identify or make sketches to illustrate the points. Be able to relate these concepts back to the periodic table.

L atom	L element	L neutron
L compound	L ion	L proton
L covalent bonding	L ionic bonding	L shell
L electrical charge	L mixture	L valence electron
L electron		

3. States of Matter:
    1. List the states of matter and be able compare and contrast them for their properties and behaviors.
    2. Relate the various states of matter to their chaos/complexity theory behavior; i.e. energy flow, attractor state, and "r" value.
    3. Define/describe what a crystal is [as opposed to a frozen liquid like glass] and discuss the variables which control how different kinds of atoms bond together to form a crystal.
    4. Describe the relationship between crystal form and crystal structure by distinguishing among crystal form, cleavage, and fracture in minerals.
    5. Write the definition of a mineral and explain in writing the necessity of the internally orderly arrangement of atoms, restricted composition and a specific set of physical properties.

The Igneous Rock Forming Minerals

From this point on, and through most of the semester we are going to be talking about minerals and rocks. You cannot understand the earth without understanding minerals and rocks. But this class does not have a laboratory, and that is an enormous disadvantage since most of you are not familiar with minerals and rocks. To you, they will begin largely as disembodied names, which I will refer to over and over all semester, expecting you to understand what I am talking about. I know it is difficult to do, but you must make an effort to get to know these rocks beyond the level of isolated, unconnected words. I will bring rocks to class, and show them to you, and keep them around so you can look at them if you want, but if you do strive to develop visual memories that connect the names with the specimens then the course will be easier.

And of course, there are the web pages on minerals and rocks accessible through the course home page or

http://csmres.jmu.edu/geollab/Fichter/Fichter/websites.html.

4. Know the significance of, and characteristics and relationships among, the eight silicate ***rock forming minerals*** by doing the following:
    [a] Illustrate with drawings and describe the basic atomic structures of the silicon tetrahedron and aluminum tetrahedron [including geometry, types of bonding, and the rules which control how the bonds are organized].
    [b] Discuss in writing and with drawings the crystal structure and/or bonding relationships of each of the eight rock forming minerals and how those structures influence the relationships among and physical properties of those minerals.
    [c] Draw and completely label a sketch of Bowen's Reaction Series showing:
        [1] The position of the eight rock forming minerals,

[2] Those minerals whose crystal structures are composed of isolated silica tetrahedra, single and double chains, sheets of tetrahedra, mixed silica and aluminum tetrahedrons, and framework tetrahedrons,
[3] The discontinuous and continuous series [explaining what these mean], and . . .
[4] All the trends which occur from the top to the bottom of the reaction series.

Igneous Rocks

5. Demonstrate an understanding of the origins, classification, and variations in IGNEOUS ROCKS by doing the following:
   [a] Describe in writing the way in which magma composition and cooling history controls the diversity of igneous rocks we find. This includes a description or discussion of the different kinds of magmas [their chemical composition and resulting physical properties], and how all the kinds of texture are generated [aphanitic, phaneritic, porphyritic, glassy, cellular] .
   [b] List the two criteria on which igneous rock classification is based and briefly explain, in terms a layman would understand, the reason and significance of each in the classification procedure.
   [c] Given the chart "Percent Mineral Abundance by Volume" [without the underlying texture portion [see “Igneous Rock Classification on Texture and Mineral Composition”] be able to draw the boundaries for felsic, intermediate, mafic, and ultramafic magmas, and draw a chart outlining the classification of all the igneous rocks we studied.
   [d] Given outline drawings of Bowen's Reaction series illustrate the mineral composition of any of the igneous rocks discussed in class.

6. Demonstrate an understanding of the different ways igneous rocks form on and in the earth by doing the following:
   [a] Distinguish between intrusive and extrusive igneous rocks.
   [b] Write a definition or description of a volcano.
   [c] Sketch, recognize and/or describe typical examples of the following volcanos:

K Fissure	K Composite
K Shield	K Volcanic dome
K Cinder	K Calderas

   Name some typical examples and/or places where examples of each of these volcanoes can be found.
   [d] For each volcano type in [c] describe the typical magma/lava types, physical properties of those magmas/lavas, and/or geologic histories responsible for the volcanoes.

7. Recognize on a diagram, and define or draw the characteristics of the following intrusive igneous rock bodies: sill, dike, stock, batholith, laccolith, and volcanic pipe.

8. Given a blank cross section of a portion of the earth's crust [like, but not necessarily the same as the notebook drawing ***"The Geological Circumstances Under Which Various Kinds of Igneous Rocks are Found"***], identify the igneous rocks typically found in various locations.

The Nature of the Scientific Process

9. List the half dozen features or activities we discussed which are not by themselves science, and be able to explain what keeps each from being science (or conversely, explain what science is and how it incorporates parts of the list).

10. List and be able to explain the significance of or meaning behind the five guiding principles we explored as being necessary to any scientific hypothesis or theory: explainability [or causality], extensibility, logical fertility, falsifiability or testability, and simplicity.

Guiding Principles,
Science and the Study of Igneous Rocks

Where we explore a practical illustration of the guiding principles of science by analyzing the study of igneous rocks.

11. **EXPLAINABILITY** - explore how and why the minerals in Bowen's reaction series are related and behave as they do by using phase diagrams (i.e. adaptive landscapes) to illustrate why magmas do not behave like a cake mix, and by doing the following:
    - [a] Explain what is meant by Bowen's ***reaction principle***.
    - [b] Explain how the differences between rapid and slow cooling affect the stability of crystals forming in a cooling magma.
    - [c] Given an outline drawing of either a solid solution phase diagram or a binary eutectic phase diagram explain the processes which are occurring. For this you should EITHER:
        - K Be able to begin with a blank phase diagram and an initial melt composition and explain in writing and by filling out the diagram step by step the transformations taking place to complete cooling, OR
        - K Begin with a phase diagram already filled out with an example and answer questions about it. You should be able to do this for either case below, concisely contrasting why and how they are different.
            - S The dynamics occurring in a slow cooling [or heating] melt ***without fractionation***.
            - S The dynamics occurring in a slow cooling [or heating] melt ***with fractionation***.
    - [d] Explain the practical difficulties which limit the things which we can learn from laboratory experimental phase diagrams.

12. Explain the principle of igneous rock ***fractionation*** in terms of chaos/complexity theory by applying these concepts to any of the phase diagrams we studied (e.g. "r" from X_{next}, phase space, attractors, complexity, etc.).

13. **EXTENSIBILITY** - explore how the principles elucidated by the study of phase diagrams can explain the observation of zoned crystals such as feldspars [perthites and antiperthites] and olivine zoned with pyroxene.

14. **LOGICAL FERTILITY** - explore ***Bowen's Hypothesis*** for the origin of all igneous rocks from a single parent rock by doing the following:
    Diagram the Simple Ideal Model for the evolution of igneous rocks.
    [a] Explain in terms a layman would understand the theory behind the Simple Ideal Model, include concise explanations of what is meant by the parent magma, fractionation, and reaction.
    [b] Present the same arguments for A and B using a set of reaction series diagrams which illustrate how the melts and resulting rocks change in mineral content.

15. Distinguish between ***local*** and ***evolutionary attractors***, and between ***fractionating evolutionary attractors***, and ***elaborating evolutionary attractors***, and explain igneous rock evolution in these terms.

16. **TESTABILITY** - Karl Popper persuasively argued that what was important about a [scientific] theory was not whether it was truthful but whether it satisfied the criteria of being "scientific". Discuss Popper's criteria of falsifiability [or testability] for the scientific status of a theory by doing the following:
    [a] Explain in a statement a layman would understand what, in science, testability means or consists of, in particular why the major criteria of testability is falsifiable predictions.
    [b] One early test of Bowen's Hypothesis was study of the Palisades sill. You should be able to analyze the textural and compositional variations through the sill. In particular, you should be able to answer the following questions.
        1. Olivine is concentrated in a thin layer near (but not at) the bottom of the sill. What hypothesis and explanation can you offer for this observation?
        2. Where would you look to find a mineral assemblage that was most representative of the composition of the original magma that was intruded?
        3. Observe that from bottom to top in the main body of the sill pyroxene decreases (40% to 30%) while plagioclase increases (53% to 65%). Why?
        4. In general, the largest mineral grains are found in a zone just above the center of the sill. What hypothesis and explanation of processes can you offer for this?

[c] List and describe some of the other early tests Bowen's Hypothesis failed [for example the predicted vs. found volumes of various igneous rocks generated by fractionation processes.]

17. Despite the early tests Bowen's hypothesis failed, the hypothesis is alive and well.
    1. What assumption lay behind Bowen's hypothesis which led to its early difficulties?
    2. What current knowledge and theory overcomes these difficulties? Briefly explain with the help of an illustration the current model for the evolution of igneous rocks.

18. Describe or explain with the help of geologic cross sections how the principles laid out by Bowen’s Hypothesis are used to explain the origin and evolution of the Archaean earth from a moon-like composition (mafic parent rock and anorthosite) to ocean basins, island arcs, and continents.

19. **SIMPLICITY** [parsimony] -
    [a] Briefly describe what is meant by the complex subject of simplicity in philosophy and science.
    [b] Compose a statement exploring the degree to which you think Bowen's hypothesis fits the principle of simplicity.

20. And finally, note that in addition you may also be asked to identify from a picture any of the 8 rock forming minerals, or any igneous rock we examined, or identify any volcano or intrusive igneous body (e.g. sill, dike, etc.). Most of the test illustrations will come from the ones on the web pages, but there may be one or two that you have not seen before, but they will be typical examples of the specimen.

    These illustrations may show up as an overhead projected onto the screen, or I may put them into a PowerPoint presentation and just have the computer cycle through the images endlessly during the test time.