# AST 309L: Review Sheet for Exam 4

Exam 4 covers sections 4.1-4.5 in Chapter 4 (omit 4.6), and 6.1 (Searching for Life's Origins), 6.3 (The Evolution of Life) and 6.4 (Impacts and Extinctions) in Chapter 6. We are covering 6.5 as part of the last section of this course (for Exam 5). The three pages of 6.1 were not on the original list of readings because I didn't realize that ideas and evidence about "early life" had been moved into this short section of the new edition. It is mostly about the methods and difficulties in trying to learn when the first life appeared on Earth, and goes with the material in Ch.4 on the Hadean Eon.

Most of the material splits into "history of Earth," mostly geological topics, and "history of life," mostly on significant biological events. The textbook is heavy on the geology, and somewhat briefer on the history of life, but the exam should be balanced between the two areas. Hopefully you can see how these topics are all united by an underlying question: Is the type of development of life that occurred on Earth, from bacteria to large, physically complex creatures, maybe with intelligence like ours, likely to develop on other planets? In other words, is evolution, with respect to complexity, "convergent?" Or are the events that led us here so chancy, so improbable, that evolution elsewhere would almost certainly have gone in some unimaginably different direction that we can't even imagine? Ultimately this question can only be answered by searching for and finding (or not finding) signals from alien civilizations (topic of last section of this course), but we still want to be aware of the arguments surrounding it.

As an example, consider the idea of natural selection as a process that might lead to the same types of features wherever life arises, simply because a feature that is adaptive on one planet should be adaptive on other, similar, planets. This attitude toward convergence asserts that eyes like ours are so useful it is no wonder they have developed in creatures as different as mammals and squids; or that flying is so adaptive that there will surely be "birds" "bats" and other flying creatures of some sort on other planets. But this is too easy—almost any biological attribute can be seen as adaptive, a product of natural selection; the question is whether these attributes actually *arose* because of selection. And certainly some kinds of adaptation are not inevitable: For example, mass extinctions and other catastrophic events in the history of the Earth could be viewed as severe environmental chances that resulted in new adaptations to new conditions. But now we are talking about random events like a giant impact or a gamma-ray burst that happens to be pointed toward the Earth. Without these *same* "big events" on other planets, why would the adaptations be the same? This brings up all the less-severe environmental changes, like the persistent shift from ice age to "hothouse" and back—if features of the evolutionary record suggest that important consequences of natural selection are a response to such variations, we should be asking what the chances are that some other planet will have the same variations. Or whether there could be complex life on a planet without plate tectonics, etc.

In order to understand the last material in the handout on evolutionary genome-level processes, I suggest you go back to sec. 5.4 (DNA and Heredity) and read the two pages on "Mutations: The Molecular Basis of Evolution." This is the standard view of how life evolves that is taught in most non-majors courses, but it is a little simplistic. If we want to have a basis for our opinion about whether complex life is convergent, we need to at least see a little more of the story, most of which involves various amazing ways in which genes and genomes can rearrange themselves, sometimes for reasons that are completely obscure. The whole point of the list of processes on the handout is that, however evolution has occurred, it involves much more than mutation and natural selection.

There are a few topics covered in the lecture notes that are not covered in the textbook, so make sure you cover both. I also was compelled to update a few things in the textbook, like the new evidence concerning the first aerobically photosynthesizing bacteria—but you will see these in the lecture notes. In order to avoid any confusion about what the textbook says and the new evidence, I will not ask you about details on the exam; but you should be able to say what the conclusion is in a sentence.

Finally, there are a few dates that you are expected to know, only approximately, of course, since most of them aren't known accurately. A list of these might include the Cambrian explosion, the end of the era of heavy bombardment, the great oxidation event, the earliest evidence for eukaryotes, the time in the past that marked the rapid development of body plans, the extinction of the dinosaurs, the time in the past at which an extinction was almost certainly caused by a large bolide impact… This is not a complete list—some of the times are obvious enough that you should know them already, like the time of the origin of the Earth, or so important that I expect I don't have to remind you—an example is the implications of the oldest zircons. You should also know the approximate times of the four eons, and be able to say which events probably occurred in a given eon.

Here are some words that you should be able to talk about—it is of course not complete, but just a study guide.

radiometric ages half life carbon-14 dating global magnetism plate tectonics
mantle convection carbon isotope ratios stromatolites Proterozoic zircon crystals
era of heavy bombardment carbon dioxide cycle aerobic photosynthesis greenhouse gas
great oxidation event cyanobacteria purple and green sulfur bacteria eukaryotes
endosymbiosis Cambrian explosion neutral evolution (genetic drift) natural selection
gene duplication exaptation horizontal (lateral) transfer Snowball Earth episodes

Here are some **sample questions**. As usual, I've tried to make most of them more difficult than the average.

1. Which probably came SECOND (in time) in the following list?
a. Cambrian explosion. b. eukaryotic cells
c. photosynthesis d. meiotic sex
[So you should be able to put these in time order and comment on each. Which one may approximately coincide with the increase in the Earth's atmospheric oxygen content? So that you see that you should be careful, notice I did not write "aerobic photosynthesis."]

2. The ability of a planet to regulate its temperature, in particular to keep it within liquid water limits, is often claimed necessary for most life to survive. This temperature regulation might be difficult for an extraterrestrial planet
a. without any variations in its orbital parameters like eccentricity of orbit, tilt of spin axis.
b. without a sufficient supply of water vapor in its atmosphere.
c. without a sufficient supply of oxygen in its atmosphere.
d. if its mantle convection were too strong.
e. without some process like our ozone layer that shields the surface from ultraviolet radiation.

3. Assuming a "snowball Earth" episode occurred, why did the Earth ever unfreeze?
a. A change in the tilt of the Earth's rotational axis.
b. Because ice reflects less light than liquid water.
c. The resulting increase in geological activity.
d. There was no place for volcano- produced greenhouse gas to go besides the atmosphere.
e. Ice can dissolve carbon dioxide better than liquid water can.

4. Which component of Earth's geology is believed to have been largely responsible for the long-term climate stability that has allowed life to evolve?
a) global magnetism b) seismic activity c) plate tectonics d) erosion and weathering
[Careful! Think about it.]

6. Evidence from the analysis of zircon crystals suggests that the Earth
a. may have been habitable during its formation phase.

b. could only have been habitable after significant amounts of oxygen had built up in its atmosphere.
c. could only have been habitable after the end of the Hadean Eon 500 million years ago.
d. may have been habitable as little as 100 million years after its formation.

7. The first living organisms to develop photosynthesis were probably

a. purple and green sulfur bacteria
b. eukaryotes
c. cyanobacteria
d. stromatolites

8. Prior to the Cambrian Period, life consisted almost entirely of

a. eukaryotes only
b. prokaryotes only
c. multicellular organisms
d. single-celled organisms

9. Recent models of terrestrial-like extrasolar planets suggest that
a. Earth is just barely massive enough to have plate tectonics.
b. A planet with mass as small as Mars could have plate tectonics if it had an ocean and atmosphere.
c. Super-Earths, the lowest-mass planets that have been discovered so far, are unlikely to have plate tectonics.
d. The primary factor controlling whether or not plate tectonics occurs is whether or not the planet has a magnetic field.