

This homework covers materials presented in lectures 4,5 and 6, as well as the accompanying reading assignments for those lectures (see syllabus). These are primarily short answer questions. In most cases, a few sentences should suffice. Please try to answer all questions in the space provided, use the back of the page if you have to. Be careful to answer each part of multi-part questions. **Note:** Homeworks will be graded on the basis of a *random subset* of these questions – so your best strategy will be to answer all the questions to the best of your ability.

1) Describe Stanley Miller's origin of life experiment (ie. what was the nature of his experiment, and what were the results?) With regard to explaining how prebiotic protein synthesis might have occurred, what was one problem with the results of Miller's experiment?

Miller combined CH_4 , NH_3 , H_2 and water in a sealed apparatus, with no O_2 . He heated the water to form water vapor, and exposed the "atmosphere" to continuous electrical discharge. After a period of time a number of simple amino acids formed, indicating that some of the building blocks of life could be created by simple inorganic reactions. One problem with the results of the experiment with respect to pre-biotic protein synthesis was that the products of the reactions were a 50/50 mixture of D/L isomers. These products are not likely to lead to something like modern proteins, which use predominantly the L form of each amino acid. Another issue is that the Earth's early atmosphere may not have been as reducing as the model atmosphere used in Miller's experiment, although how reducing the early atmosphere really was is still being debated.

2) Describe *two* different ways in which minerals might have played a role in the very early development of life.

Various roles that minerals could have played in pre-biotic synthesis:

Templates for molecular arrangement, sorting and synthesis

Containers to shelter organic molecules and bring them together for reactions

Catalysts for biologically significant reactions

Scaffolds to arrange molecules in close proximity

Reactants with organic molecules

3) Briefly explain how and why carbon isotopic measurements from organic carbon preserved in ancient rocks provides evidence for widespread biological methane production about 2.7 billion years ago.

Methanogenic bacteria produce methane (CH_4) which is greatly depleted in ^{13}C relative to ^{12}C , ie. it is isotopically light with a very negative $\delta^{13}\text{C}$ signature. Due to widespread methane production 2.7 bya, the isotopic signature of this methane worked its way into the biosphere and was preserved in ancient organic carbon deposits in rocks. The isotopic signature of ancient organic carbon from 2.7 billion year old rocks thus has a very negative $\delta^{13}\text{C}$ signature which is thought to be due to the widespread methanogenesis occurring in the biosphere at that time.

4) Circle the "fixed" forms of nitrogen among the following 5 forms of nitrogen:

NH_3

N_2

N_2O

NO_3^-

amino acid

ALL of the above are fixed, EXCEPT N_2 .

5) When did cyanobacteria evolve? How do we know this?

Cyanobacteria are believed to have first evolved about 2.7 billion years ago, as determined by the presence of 2-methyl hopanes, biomarkers specific for cyanobacterial cell membranes, in oils from ancient rocks dated to be 2.7 billion years old.

6) What are banded iron formations, and how do these formations provide geological evidence for the rise of atmospheric O₂?

Banded iron formations are layered deposits of iron oxides and silicate material. Massive BIF deposits were all laid down prior to 1.9 billion years ago. In order for BIFs to form it is thought that the deep oceans had to be anoxic, containing vast inventories of soluble Fe²⁺. Periodic upwelling of deep seawater onto the shelf regions where locally high aqueous O₂ concentrations occurred (due to the presence of early photosynthetic cyanobacteria) caused large-scale oxidation and deposition of the Fe as insoluble Fe oxides. Thus, the atmosphere prior to 1.9 billion years ago had to have much lower O₂ concentrations because the deep ocean was still anoxic, but local zones of high O₂ existed in continental shelf environments.

7) a) True or false: The geologic record indicates that the rise in atmospheric oxygen coincided closely in time with the evolution of the first cyanobacteria. FALSE: There was a 400 million year delay between the appearance of the first cyanos in the record, and the rise of atmospheric O₂.

b) True or false: Biomarker evidence indicates that eukaryotes had evolved by 2.7 billion years ago, therefore atmospheric O₂ must have been abundant by that time. FALSE: Eukaryotes were present by 2.7 bya, but O₂ was only high in local regions, not abundant in the atmosphere.

8) Why was the presence of ozone in the stratosphere important for the development of life on land? When did atmospheric ozone levels become significant?

The presence of ozone in the stratosphere provides an effective shield against high-energy UV radiation. This enabled life (especially eukaryotes which are most sensitive to UV) to colonize the surface ocean and eventually land. An effective atmospheric ozone shield is thought to have developed soon after O₂ levels in the atmosphere became abundant, so around 1.9 billion years ago.

9) How does the carbon isotopic composition of photosynthetically produced organic carbon compare to the isotopic composition of the CO₂ used during photosynthesis? (In terms of the stable carbon isotopes, ¹²C and ¹³C.) Consider the “plant in a box” model discussed in class: During photosynthesis, plants preferentially take up ¹²CO₂ relative to ¹³CO₂. This causes the biomass formed by the plant to be isotopically light (depleted in ¹³C relative to ¹²C, with a more negative δ¹³C) relative to the pool of CO₂ in the atmosphere. In a closed system, as more biomass is formed and CO₂ is depleted, the remaining CO₂ will become isotopically heavier (enriched in ¹³C, with a more positive δ¹³C).

10) Suppose you analyze an ancient carbonate deposit from the Cambrian period and find that the δ¹³C value is about -1 per mil. What does this imply about the atmospheric oxygen levels during the Cambrian, relative to modern times?

Modern carbonates have a δ¹³C signature of about 0. Therefore, the Cambrian carbonates at -1 per mil are significantly isotopically lighter. This implies that the inorganic carbonate (ie. CO₂) in the earth system during the Cambrian period was significantly depleted in ¹³C relative to modern times. Because of the connection between photosynthesis, plant biomass, and the δ¹³C of CO₂ as described above in question 17, isotopically light Cambrian carbonates relative to modern carbonates implies less plant biomass during the Cambrian period, less photosynthesis, and therefore lower atmospheric O₂ concentrations relative to modern times.

11) What does the record of charcoal preserved in rocks since the Devonian period tell us about atmospheric oxygen levels over that time?

The presence of charcoal in the geologic record implies burning of forests at various periods since the Devonian. Burning of forests implies that atmospheric O_2 concentrations must have been regulated over this period such that the O_2 concentration remained within the “fire window”: above 13% so that burning could occur, but below 35% so that burning of biomass could not get out of control and consume all of the terrestrial biomass.

12) How does burial of organic carbon tend to prevent loss of atmospheric O_2 ?

The production of organic matter through photosynthesis produces O_2 . The respiration and/or combustion of organic matter uses up O_2 . Therefore the presence of O_2 in the atmosphere today implies that a stoichiometrically equivalent amount of reduced organic carbon has been buried (sequestered) in the earth system so that it cannot react with, and consume, all the atmospheric O_2 . Thus, burial and sequestration of organic carbon, which mostly happens in marine sediments, is effectively a “source” of atmospheric O_2 .

In class we discussed a negative feedback loop involving the burial of organic carbon in marine systems as a control on atmospheric O_2 : if atmospheric O_2 rises, so does the O_2 content of the deep ocean. This will tend to decrease the amount of organic carbon that gets buried and sequestered in marine sediments before being respired, so that will tend to decrease atmospheric O_2 concentrations, acting to bring the system back into balance.