SIO 40 Fall 2007 Homework 5 **Due Nov 16th**

This homework covers materials presented in lectures 14, 15, and 16 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) Explain what the "Faint Young Sun Paradox" refers to.

The Faint Young Sun Paradox refers to the fact that, although the sun was about 30% less bright during the very early history of the Earth, Earth's climate has evidently still remained warm enough to support liquid water the entire time. This apparent paradox is likely resolved by the variations in the concentration of greenhouse gases in the Earth's atmosphere.

2) Along with CO_2, methane produced by methanogens is thought to have been an important control on Earth's climate during the Archean (~3.8-2.5 billion years ago). Methane is a powerful greenhouse gas. What type of negative feedback loop is thought to have operated during that time to keep Earth's climate from getting too hot (or too cold)?

A negative feedback loop involving surface temperature, atmospheric CH_4 and CO_2 and the organic haze layer likely kept Earth cool: higher temperatures would have led to an increase in CH_4 due to increased methanogen growth, with a corresponding decrease in atmospheric CO_2 (due to silicate weathering). As CH_4 and CO_2 levels equalized, methane would begin to polymerize and form an organic haze, which would eventually get thick enough to block sunlight and cause cooling.

3) What types of geologic evidence are used to infer past glaciations?

Geological evidence for past glaciations includes tillites (heterogeneous deposits that have been compacted into rock), moraines (piles of glacial debris), glacial striations (scrapes along rock surfaces left by glaciers), and dropstones (chunks of rock which appear to have been dropped into laminated sediments).

4) What triggered the Huronian glaciations 2.3 billion years ago?

The Huronian glaciations are thought to have been triggered by the rise of atmospheric O_2 due to the evolution of oxygenic photosynthesis in cyanobacteria. The O_2 oxidized the methane in the atmosphere, thus reducing the greenhouse gas content of the atmosphere and initiating glaciations.

5) What role is albedo thought to have played in the development of Snowball Earth conditions?

The Snowball Earth cycle was initiated by decreasing atmospheric CO_2, which caused the polar ice sheets to expand into lower latitudes. Once the ice sheets got past 30° latitude, the positive feedback loop between ice cover and surface temperature took over (more ice = higher albedo = lower temperatures = more ice), making the climate sytem unstable. This resulted in a rapid expansion of the polar ice sheets all the way to the equator.

6) How does the Snowball Earth Model explain the re-occurrence of banded iron formation deposits ~6-700 million years ago?

It is thought that during the Snowball Earth episode the ice-covered oceans went largely anoxic due to the utilization of oxygen in the bacterial respiration of organic carbon combined with restricted exchange with the atmosphere. This caused a buildup of iron in the oceans in the reduced form, Fe^{2+}. When the ice sheets receded and oxygen was re-introduced to the oceans, banded iron formations were again laid down due to the rapid oxidation of Fe^{2+} to Fe^{3+}.

7) How did Earth get out of the Snowball Earth glaciation phase? What was climate like immediately following a Snowball Earth episode?

Eventually, with silicate weathering shut off due to the ice cover, CO_2 supplied by volcanism and plate spreading built up to relatively high concentrations in the atmosphere. The enhanced greenhouse effect eventually caused melting of the ice sheets. Climate immediately after the Snowball Earth episode is described as a "hothouse" due to the high concentrations of CO_2 as well as water vapor in the atmosphere.

8) Relative to today what was climate like during the Cretaceous period, around 100 million years ago? What factors are thought to be responsible for determining climate at this time?

Cretaceous climate was warmer than today's with a smaller temperature gradient between the equator and the poles. Primary factors in controlling climate were CO_2 levels in the atmosphere, and the geographical placement of the continental land masses.

9) How many major extinctions have taken place over the past 500 million years, according to fossil records of biodiversity? Which was the largest mass extinction?

Fossil records of biodiversity indicate that 5 major extinctions have occurred over the past 500 million years, with the end Permian event evidently being the largest.

10) Explain the greenhouse extinction theory recently advanced to explain the end Permian mass extinction event 250 million years ago.

The sequence starts with extensive volcanic activity associated with the Siberian Traps formation. The release of greenhouse gases CO_2 and methane from the volcanoes initiates a rapid global warming. This causes the ocean to warm, decreasing O_2 solubility. The lowered solubility of O_2 fosters the widespread development of anoxia at depth in the oceans, allowing anaerobic bacteria which produce H_2S to fluorish and increase concentrations of H_2S in the oceans. Eventually, destabilization of the oceanic chemocline brings anoxic water to the surface, suffocating oxygenic marine life and resulting in catastrophic release of H_2S from the surface ocean to the atmosphere, killing life on land. The H_2S also has a detrimental effect on the ozone layer, hastening the destruction of land organisms.

11) What are the main pieces of evidence in support of a meteorite impact as the cause of the Cretaceous-Tertiary mass extinction?

The best evidence is the existence of a worldwide sedimentary layer enriched in iridium from around that time, as iridium is generally very low in concentration in earth rocks, but enriched in some meteorites. The Chicxulub crater in the Yucatan has also been dated to the Cretaceous/Tertiary boundary. Impact debris like shocked minerals has also been detected. Finally, the geologic record of carbon isotope abundance (discussed in next question) shows evidence of a single abrupt catastrophe, such as a bolide impact.

12) What are the environmental consequences of the impact of a 10-km diameter meteorite with Earth?

The impact would likely have caused a degradation or elimination of the ozone layer, exposing Earth's surface to ultraviolet radiation for several years. Beyond the total devastation near the impact site, including giant tsunamis, dust and debris from the impact would have been spread throughout the atmosphere, reducing the amount of solar radiation that could get through for months to years. Sulfate aerosol layers may have been formed due to the vaporization of large amounts of calcium sulfate from the Chicxulub crater site, prolonging the cooling effect and causing acidic precipitation. Ultimately, CO_2 released from the impact would cause global warming following the initial cooling. Rapic temperature swings would have contributed to the mass extinction induced by the impact.