

Read the questions carefully; at the end, check that you have answered to all questions

**Question-1 Mediterranean circulation (16 pts).**

Water exchange between the Mediterranean Sea and the Atlantic Ocean takes place through the strait of Gibraltar.

- In which direction flows the surface water and in which direction the deep water? Please explain why.
- The deep Mediterranean water which forms in the Eastern Mediterranean, the so-called Levantine Deep Water, is the water with the highest density in the world. Why is this water not the deepest water of the oceans globally?
- When entering the Atlantic the Eastern Mediterranean deep water is directly on top of which water mass?

**Question-2 (14 pt)**

- Give a definition for export productivity and for burial efficiency in your own words
- what is the Redfield ratio (give ratio and explain origin)
- define lysocline and CCD, and indicate differences between them
- explain under what circumstances lysocline and CCD may nearly coincide

**Question-3 (16 pt)**

- Given potential explanations for the difference between observed  $\text{CaCO}_3$  preservation in the deep North Pacific and the deep North Atlantic. Explain briefly.
- Is there a difference in dissolution rate for biogenic opal for different water depths? Explain briefly
- Is there a difference in dissolution rate for biogenic opal between Pacific and Atlantic ocean? Motivate briefly

**Question-4 (20 pt)**

- What is the Global average formation rate ratio for organic-C versus inorganic-C
- What is the approximate average oceanic % of Organic Matter (OM) degradation for thermocline + deep ocean, compared to the OM formation rate (*primary production*) in the photic zone; give % and briefly discuss relevant factors
- What is the approximate average oceanic % of inorganic-C ( $\text{CaCO}_3$ ) dissolution for thermocline + deep ocean, compared to the  $\text{CaCO}_3$  formation rate (*primary production*) in the photic zone; give % and briefly discuss relevant factors
- What deep-ocean Corg/C-inorg ratio do you expect on the basis of Q-4-a,b,c
- If the Corg/C-inorg ratio measured from sediment trap fluxes appears to be two times that calculated now, can you give (a) reason(s) for that?

**Question Paleo.1. Early Earth (16 pts)**

Oxygenation of the deep ocean was more frequently punctuated by so-called ocean anoxic events early in Earth's history. There are several factors that together might have contributed to making the Earth more susceptible to such events.

- a) Which factors might have helped in making the deep sea more likely to become anoxic in deep geological time?
- b) What was the consequence of these ocean anoxic events on global carbon storage?
- c) Explain, using your answers at *a* and *b*, how such ocean anoxic events were (partly) controlled by a natural feedback similar to the weathering feedback you know from Ruddiman "Earth's Climate".

**Question Paleo.2. Millennial scale climate oscillations (18 pts.)**

The Gulfstream probably played an important role in the millennial time scale climate events known from the last Glacial. During the cold episodes temperatures on the continents bordering the North Atlantic were up to 15 degrees colder.

- a) What happened to the Gulfstream during these cold events and why?  
On the southern hemisphere it became warmer at the same time that temperatures dropped on the northern hemisphere.
- b) How do we know that these temperatures were anti-phased? (hint: explain proxies used and correlation between records)
- c) On longer time scales the Gulfstream has actually been suggested to have been instrumental in the build up of the northern hemisphere ice sheets. Explain when this might have played a role and what the suggested mechanism is.