Paleoceanography Exam 2015

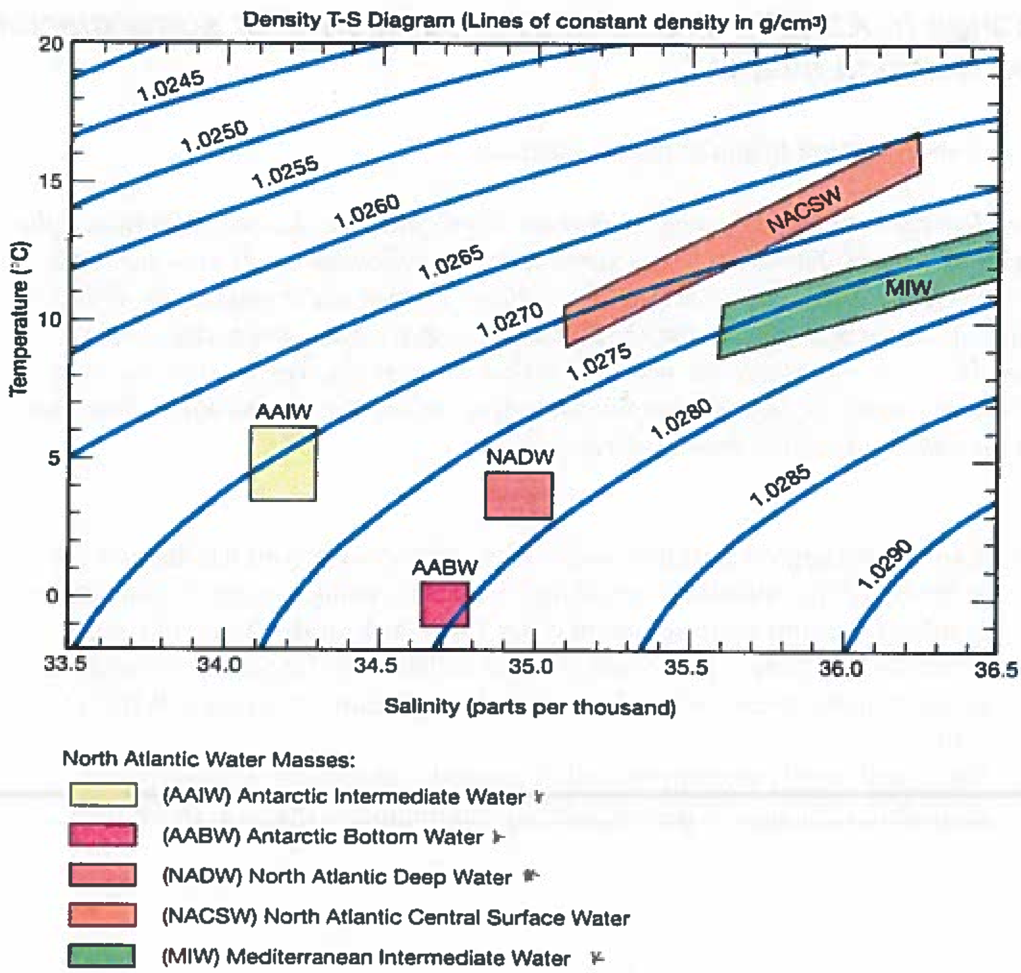
Please start each of the two parts on a new sheet of paper. Good luck!

Part I: Physical Oceanography (50 points)

Question 1.1 (12 Points)

Water masses in the oceans obtain their characteristic T and S values at the sea surface, only changing it through mixing with other water masses. Plotting these values against each other makes it possible to identify the different water masses and the processes involved in their formation. In the figure below the different water masses of the North Atlantic are shown in a T-S diagram.

a) Pick **four water masses** and briefly describe where and how they form. (8 Points)
b) Draw two T-S profiles (0-5000 meters) for the North Atlantic (30°N) and South Atlantic (50°S) and indicate the presence of different water masses. Explain briefly the main differences between the two profiles. (4 Points)



Question 1.2 (12 Points)

The North Atlantic has a subtropical gyre and a subpolar gyre.

a) Explain why the gyres form. What are the major differences between the two. (6 Points)
b) Why do both they flow faster on their western sides? (6 Points)

Use simple sketches to illustrate your answers.

Question 1.3 (4 Points)

Sea surface temperatures can be reconstructed using Mg/Ca ratios in the shells of Foraminifera. Name and very briefly explain two potential problems of this proxy method. (4 Points)

Question 1.4 (22 Points)

Recently, the journal Nature Geoscience published an article with the following title:

“Change in Atlantic overturning circulation over some glacial-aged Heinrich events”

Here is a short section from the papers abstract:

Heinrich events—surges of icebergs into the North Atlantic Ocean—punctuated the last glacial period. The events are associated with millennial-scale cooling in the Northern Hemisphere. ……… a northward flow of warm water passes through the Florida Straits and is reflected in the distribution of seawater properties in this region. Here we investigate the northward flow through this region over the past 40,000 years using oxygen isotope measurements of benthic foraminifera from two cores on either side of the Florida Straits.

10 a) Explain the approach of this study. How and why can you reconstruct the intensity of the Atlantic overturning circulation using oxygen isotope ratios in benthic foraminifera in sediment cores from the Florida Strait? (11 Points)
5 b) What do you think, did the authors find in their data (in terms of the intensity of the Atlantic overturning circulation during Heinrich events)? Why? (5 Points)
4 c) Name and briefly explain two other methods, which can also be used to reconstruct changes in the overturning circulation in the past. (6 Points)

Part II: Chemical Oceanography (50 points)

Question 2.1 Marine silicon cycle (16 points)

a. List two possible advantages a frustule may have for a diatom (2 points).
b. Explain in detail what a "deep chlorofyll-maximum" is (DCM; Hint: make a sketch) (3 points).
c. Describe why diatoms flourish in a DCM and how this typically changes in fall (3 points).
d. Explain in detail why rates of diatom production are very low between 40 degrees S and the equator in the Southern Hemisphere (4 points).
e. Explain why biogenic Si contents in sediments are not a direct measure for diatom production (4 points).

Quesetion 2.2. Carbon, oxygen and nutrient cycles (16 points)

During the Cretaceous, organic-rich deposits formed in deep sea settings in the Atlantic Ocean during so-called "oceanic anoxic events" (OAEs). Various explanations have been invoked to explain the formation of these organic-rich deposits in a low oxygen setting. Here, we will assume the following for the deep basin in the North Atlantic 94 Myrs ago:

Volume of the deep basin of the Atlantic: 40583 Tm^3
Average water depth: 2000 m
Influx of Pacific deep water: 22 Sv (where 1 Sv = 3.1536 Tm^3/yr)
Upwelling flux in Atlantic: 33 Sv
Downwelling flux in Atlantic: 11 Sv
Oxygen concentration in downwelling water: 200 μmol/l
Oxygen concentration in Pacific deep water: 50 μmol/l
Percentage of primary productivity that is degraded in deep basin waters: 8%
$C:O_2$ ratio during organic matter degradation: 106:132
1 mol of C = 12 gram

a. Draw a schematic of the water cycle for the deep basin of the Atlantic for the OAE (2 points)
b. Calculate the residence time of water in the deep basin of the Atlantic (2 points)
c. Calculate the downwelling flux of oxygen into the deep basin (2 points)
d. Calculate the influx of oxygen from the Pacific ocean (2 points)
e. Calculate what the minimum rate of primary productivity is (in g C m^{-2} yr^{-1}) to achieve fully anoxic bottom waters in the Atlantic during the Cretaceous (4 points).
f. Low oxygen leads to major changes in nutrient cycling in the ocean. Explain how this may impact the cycles of nitrogen and phosphorus and how this may impacted the productivity in the surface waters (Hint: indicate what key processes in each cycle may change). (4 points)

Question 2.3 Carbon pumps (12 points)

a. What is DIC, what is alkalinity (Hint: add all relevant species) (2 points)

a₂ Describe and explain the effect of the following processes on DIC and alkalinity in seawater (3 points)
- invasion of CO_2 from the atmosphere into seawater
- Organic matter production (photosynthesis)
- Calcium carbonate dissolution

b. Describe briefly how the three carbon pumps that operate in the ocean and that transport C against the gradient of DIC and total alkalinity work. Include reactions in your answer, where relevant (6 points).

c. Which pump is quantitatively most important in transporting carbon to the deep ocean in the present ocean? (1 point)

Question 2.4 Calcium carbonate in the ocean (6 points)

The figure below shows the modern steady state calcium carbonate cycle in the ocean and the carbonate concentration as a function of depth.

a. Explain what new steady state is expected to develop after a doubling of the river input of alkalinity. (2 points)

b. Describe the corresponding changes in the carbonate concentration as a function of water depth and the depth of the saturation horizon (Hint: draw the changes in the inset figure). (2 points)

c. An increase in alkalinity will lead to absorption of CO_2 by the ocean from the atmosphere. Give two reasons why a change in the river flux of alkalinity cannot explain the uptake of CO_2 from the atmosphere during glacial periods (2 points).