Examining deglacial circulation changes in the North Atlantic

Approximate word counts are given as guidelines. These do not have to be obeyed strictly, however marks will be awarded for a concise, scientific, writing style. Be brief and to the point and make good use of appropriate referencing.

Exercise 1 – Mid-depth temperature and δ^{18}Osw reconstruction **(40 marks total)**

The aim of this exercise of for you to process and interpret unpublished Mg/Ca-δ^{18}O data from marine sediment core RAPiD-10-1P, ~63^{o}N, 17^{o}W, 1.2 km water depth, south of Iceland, which has been previously used in studies such as Thornalley et al 2011, GPC, and Thornalley et al 2011, Science. This data spans the last 20 ka and can be used to examine paleoceanographic changes in the northern North Atlantic during the deglaciation.

You have been provided with δ^{18}O (corrected for a vital effect of 0.24‰) and Mg/Ca, Fe/Ca, Mn/Ca ratios obtained from the oxidatively cleaned benthic foraminifera *Melonis barleeanuum* (size fraction 212-500 μm). See Barker et al 2003, G^3, for details on cleaning methods and procedures.

The temperature equation for the precipitation/calcification of calcite depends on both temperature and the δ^{18}O of the water it precipitated from. Mg/Ca has been used as an independent proxy for temperature. In this practical we will use the temperature equation of Shackleton (1974) that you were given in an earlier practical exercise:

$$T\ (^oC) = 16.9 - 4.38\ (\delta^{18}Oc - \delta^{18}Osw) + 0.1\ (\delta^{18}Oc - \delta^{18}Osw)^2$$

We also need to account for converting d18O from VSMOW to VPDB scales:

$$\delta^{18}O_{PDB} = \delta^{18}O_{VSMOW} - 0.27‰$$

This yields a solution of the temperature equation:

$$\delta^{18}Osw = (\delta^{18}Oc + 0.27) - [4.38 - (4.38^2 - 4 \times 0.1(16.9 - T))^{0.5}]/(2 \times 0.1)$$

The temperature of calcification can be obtained independently using Mg/Ca. An equation of the following form has been developed for the Mg/Ca calibration of temperature in *M. barleeanuum*:

$$Mg/Ca = 0.12 \times T + 0.96$$

You have also been provided with a sea level curve scaled for the whole ocean shift in δ^{18}O that resulted from the growth and decay of continental ice-sheets, which are enriched in ^{16}O compared to the ocean.

Q1. Provided with these equations and data for δ^{18}O and Mg/Ca for *M. barleeanuum*, calculate bottom water δ^{18}Osw values for the past 20 ka at site RAPiD-10-1P. Make a plot of T and δ^{18}Osw. Have you rejected any of the Mg/Ca measurements? If so, why? **(~100 words; 10 marks)**

Q2. Describe the results. What are the possible controls on δ^{18}Osw? How would you interpret the changes in your record during HS1 (~14.7-17 ka)? How does these results compare with published hypotheses regarding the cause of mid-depth δ^{18}O and temperature change in the North Atlantic during HS1? **(~300 words; 30 marks)**

Exercise 2: Tracers of deep ocean circulation change **(60 marks total)**

Next you are going to use some unpublished radiocarbon data to interpret changes in the circulation of the deglacial North Atlantic. The data comes from a core OCE-326-GGC14 (43°N, 56°W) taken at 3.5 km depth on the Laurentian Fan, within the core of modern NADW, which flows southward at depth as a deep western boundary current along the eastern continental margin of North America. The data is provided in tab 'deglacial 14C data'.

Q1. We need to construct an age model for the core based on the planktic foram ^{14}C dates. To convert the ^{14}C dates from radiocarbon years to calendar years we need to use the calibration curve IntCal 13. This is mainly based on tree ring, varved lake sediments and coral data, in which calendar age has been obtained independently (in effect by counting annual layers or using U/Th dating of corals), allowing a plot to be made of the ^{14}C content versus calendar age, which is then interpolated and smoothed.

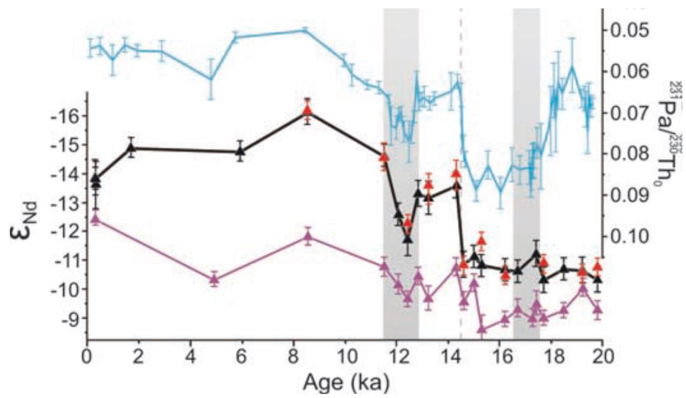
Preferably use an online program such as Calib (http://calib.qub.ac.uk/calib/) or OxCal (https://c14.arch.ox.ac.uk/embed.php?File=oxcal.html) to convert your radiocarbon ages to calendar ages. If you are unable to do this you can use the IntCal table in the spreadsheet. Assume the surface ocean reservoir age at our site is 400 years (this is assumed in the MarineCal option of IntCal). Input the upper and lower age estimates in the labelled columns and calculate the mid-point estimate. Use the mid-point as your calibrated age.

Next, construct the age model. You simply have to fill in the core depth in column A and the corresponding calibrated ages you have just calculated into column B. The first two entries have been completed as an example. Plot your calibrated ages versus depth **(5 marks).**

Q2. We have counted the % abundance of *Neogloboquadrina pachyderma* sinistral (Nps) in the core. This species of planktic foram lives in cold polar and subpolar water, and is associated with the presence of sea-ice. Plot % Nps versus age for your core. How does it compare to the Greenland ice core records of climate? (I have provided you with NGRIP $\delta^{18}O$ – more negative values indicate colder climate.) Are there any differences in timing? Why might this occur? (Hint - What assumption did we use in constructing the age model and why that might have changed in the past?) **(~100 words; 10 marks)**

Q3. Next, calculate the offset between the planktic and benthic 14C ages, and input them in column B-P age. (Benthic forams live on the seafloor, ie at 3.5 km depth in this case, planktics near the sea surface.) Plot your B-P ages. What do these suggest about the radiocarbon age of the deep water through the deglacial? How would you interpret this in terms of circulation change? – think about modern ^{14}C ages NADW and AABW and surface reservoir ages. **(~200 words; 15 marks)**

Q4. Interpret your changes with respect to published εNd and Pa/Th data from the deep NW Atlantic (4.5 km depth), shown in the figure below (data provided in spreadsheet; see Roberts et al 2010, McManus et al 2004). How would you interpret the Pa/Th data? Is this consistent with your ^{14}C data? What relevant issues are there with Pa/Th? What does the εNd data suggest about water mass changes in the deep NW Atlantic during the deglacial? (Just use the black curve; the pink curve is not representative of seawater.) **(~200 words; 15 marks)**



Q5. Calculate and plot what % of water came from northern versus southern sources (use the literature to estimate end member values and assume a similar concentration of Nd in the water masses)? Sometimes this calculation doesn't work; why? What might this imply about the assumption behind εNd as a water mass tracer? **(~100 words; 15 marks)**

END