EOS 240: Lab Assignment 8

Cenozoic Climate

Due: 2:30 pm March 27, 2025 (Th section)
Due: 1:30 pm March 28, 2025 (F section)

You have one week to complete this assignment. You should submit your response to the course Brightspace page as a single PDF file. **Additionally, we ask that you upload a copy of the scripts, code, or spreadsheets you used to complete the assignment. These documents will help us track down mistakes.** Responses to questions should be typed, using complete sentences and standard grammar. If you choose to support your answers with hand-drawn illustrations or hand-written calculations, you should scan or photograph the written work and integrate it into your PDF file as a figure. Double check that your image resolution is high enough to read. A google search of 'PDF combiner' will return a number of webpages that allow you to upload individual images and combine them into a single .pdf file (example: combinepdf.com). There are also a number of good apps for mobile phones. If you write your response in a word processor, please export to .PDF before submitting your response.

You are not excluded from working with others (pairs are recommended), but each person will submit their own copy of the assignment. In your submission, include the names of anyone you worked with on the assignment.

To answer the questions, you can perform calculations and make figures using Excel (an open source alternative: www.libreoffice.com), or with a program or programming language of choice.

Name : ______________________________

Page:	2	3	4	5	**Total:**
Marks:	6	3	9	2	20
Score:					

Introduction

In this lab you will use $\delta^{18}O$ observations and sea-level records to constrain the history of land based ice during the early Cenozoic and the most recent glacial cycle.

Question 1 (20)

$\delta^{18}O$ and Past Climate

The table below describes the following properties of the three major ice sheets on Earth: the isotopic composition, mass, and amount of global mean sea-level change that would happen if the ice sheet were to melt entirely. The relationship between sea level change and ice mass loss is distinct for each ice sheet, as some sectors of ice sit below sea level and the glacial isostatic adjustment associated with mass loss from each ice sheet is unique. In the following calculations, you can assume that the relationship between mass loss and sea level rise is linear for each ice sheet.

	$\delta^{18}O$ (‰)	Mass (10^{18} kg)	Sea-level (m)
Ocean	0	1358	–
Greenland Ice Sheet	-35	2.66	7.3
West Antarctic Ice Sheet	-41	2.75	4.3
East Antarctic Ice Sheet	-56.5	21.55	53.3

(a) (1 point) Calculate how $\delta^{18}O$ of the ocean would change if the Greenland ice sheet melted. To answer this question, set up (and solve) two equations: one for the conservation of mass before and after ice melt, and one for the conservation of isotopic ratio before and after ice melt. *Hint: You can calculate the mass balance of isotopes the same way we calculated the mass balance of trace element concentrations in solid and liquid phases.*

(b) (2 points) Calculate how $\delta^{18}O$ would change if you melted enough of the East Antarctic ice sheet to get 7.3 meters of sea level rise (the sea level rise associated with melting the entire Greenland ice sheet).

(c) (1 point) Make a figure showing the relationship between ocean $\delta^{18}O$ change and sea level rise associated with the melt scenarios in parts (a) and (b). Your x-axis should be the sea-level rise contribution, and your y-axis should be the change in the $\delta^{18}O$ of sea water.

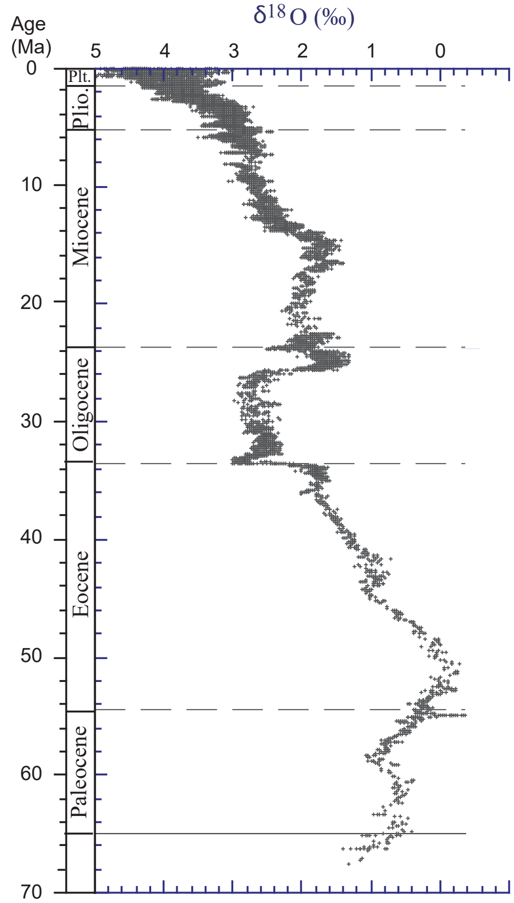
(d) (1 point) Based on your figure in part (c), is there unique relationship between the $\delta^{18}O$ of sea water and global mean sea-level change?

(e) (1 point) what is the $\delta^{18}O$ of an ice-free Earth?

There is a linear relationship between the δ^{18}O fractionation in benthic foraminifera shells and the temperature of the water that the organism is living in:

$$T = 16.5 - 4.8(\delta^{18}O_s - \delta^{18}O_w)$$

Where T is temperature, $\delta^{18}O_s$ is the isotopic composition of the foraminera shell, and $\delta^{18}O_w$ is the isotopic composition of sea water. The following figure shows a compilation of $\delta^{18}O_s$ values from benthic foraminera spanning the last 70 million years. Use this temperature fractionation and dataset to answer the following questions:



(f) (2 points) Discuss this dataset with at least one other student. Use your combined knowledge of ice sheet isotopic compositions and the temperature fractionation equation to describe at least two features of Cenozoic climate (the last 65 million years).

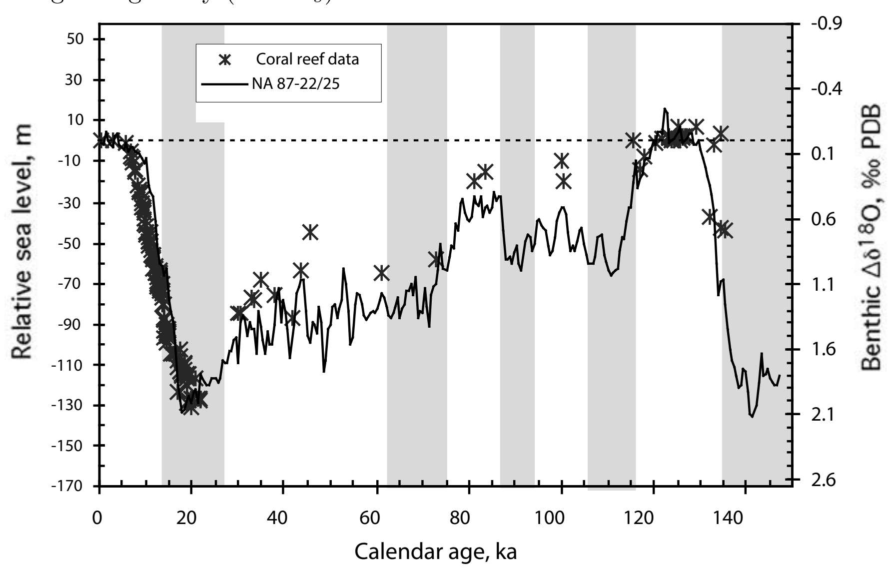
(g) (1 point) Roughly 50 million years ago there is a period known as the early Eocene climatic optimum. Geologic evidence suggests tropical plants and animals were living at the poles, and there is no evidence of terrestrial ice at this time. What was the temperature of the bottom waters where the analyzed benthic foraminera were living?

(h) (1 point) What is the maximum $\delta^{18}O_s$ you would expect to see in an ice-free world? Assume that bottom waters can not be reduced below $-1.8°$C.

(i) (1 point) Ice sheets have been on the surface of the earth for at least the last few million years. It has been suggested that when bottom water temperatures reach around 4°C that some ice sheets will start to appear. If this constraint is true, what the maximum $\delta^{18}O_s$ you would expect to see in an ice-free world?

(j) (2 points) Use your response to the previous two questions to describe climate change throughout the Cenozoic. Make specific arguments for periods of time where there *must* be ice on land and when there *may* be ice on land.

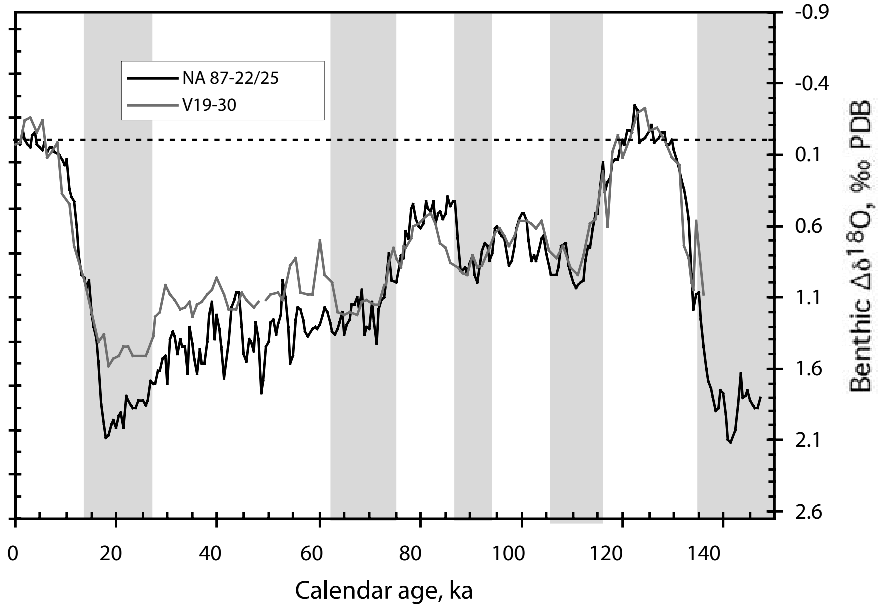
For at least the last few million years, ice sheets on land have expanded and contracted periodically in response to changes in Earth's orbit. The peak of the last ice expansion is known as the last glacial maximum (roughly 20 thousand years ago). The following figure shows the elevation of past sea level inferred from dated fossilized coral reef terraces as well as the change in the isotopic composition of benthic foraminifer from the value of organisms growing today ($\Delta\delta^{18}O_s$).



(k) (2 points) Describe the climate change recorded by the figure. When was Earth warm? When was it cold? Did climate warm and cool at similar rates?

(l) (3 points) What percent of the change in foraminifera isotopic value at the last glacial maximum is associated with ice sheet growth? Assume that the average isotopic composition of new ice sheets was -30 ‰ and that 2.4 meters of sea level fall correspond to a growth of 10^{18} kg of ice mass.

The following figure shows an additional benthic foraminifera isotopic dataset spanning the last glacial cycle. This dataset comes from the equatorial Pacific whereas the first dataset comes from the North Atlantic.



(m) (2 points) Why are these two records not identical? Interpret the difference in terms of climate and/or ocean dynamics.