Introductory Paleoclimatology Teaching Module

I.Objective: to learn theoretical and practical skills of reconstructing a paleoclimatic record.

Ancillary objectives:

- learn the theory behind stable and radioactive isotopes
- learn to access and use the National Oceanic and Atmospheric Association (NOAA) paleoclimatic database.
- learn how to use Pb-210 to establish geochronology
- learn how to isolate bulk total organic carbon (TOC) in sediments
- obtain a historical isotopic record from one's own sediments by obtaining isotopic ($\delta^{13}C_{TOC}$) values of bulk TOC downcore in the sedimentary record. Note, this specific portion of the teaching module may be augmented by substituting stratigraphic, organism test-based (e.g. $\delta^{18}O$), or organic geochemical proxies in place of $\delta^{13}C_{TOC}$.

II. Stable Isotope Chemistry Theory

Water, a key factor in climate, has the chemical formula, H_2O (e.g. H-H-O). This formula for water means that every molecule of water has two atoms of hydrogen for every atom of oxygen. You may recall from Freshmen Chemistry that the number of protons in an element is that element's unique identifier or "fingerprint". That unique identifier is called its atomic number. With respect to the elements in water, hydrogen has 1 proton. So, its atomic number is 1 (see periodic table). Oxygen has 8 protons. So, its atomic number is 8. Hydrogen will always have one proton and oxygen will always have 8 protons. However, the number of neutrons within an element can vary. For a specific element, the number of neutrons being unequal to its protons makes it an isotope.

Each element in nature can have many naturally occurring isotopes. For example, each of the elements in water hydrogen and oxygen, has several naturally-occurring isotopes. Oxygen in nature has the following stable isotopes: ^{16}O, ^{17}O, ^{18}O. Similarly, hydrogen in nature has the following isotopes: ^{1}H, ^{2}H. The number in the superscript on the left side of the element is the **sum of the number of protons plus the number of neutrons** in each element. So, if you know that oxygen will always have 8 protons. How many neutrons do ^{16}O, ^{17}O, ^{18}O each respectively have?

The most abundant of the isotopes of oxygen is ^{16}O; 99.76 % of all oxygen in nature is made up of the ^{16}O isotope, which has an atomic weight of 16. But, 0.2% of all oxygen is ^{18}O and 0.04% of all oxygen is ^{17}O. Similarly, most of the hydrogen on the Earth (99.98%) is made up of the ^{1}H isotope (having atomic weight of 1). A very small percentage of the naturally occurring hydrogen on Earth is ^{2}H (0.016%).

*Question 1: What are all the possible combinations of the isotopes of hydrogen and oxygen that can result in a water molecule? For example, one combination is ^{2}H-^{2}H-^{17}O. Normally, we think of water having a molecular weight of 18 but this water molecule by virtue of its isotopic arrangement has a molecular weight of 19. In a similar manner, write down **all** of the other combinations of the isotopes of hydrogen and oxygen in water.*

III. Paleoclimate example problems

III. A. Stable Isotopic Reconstructions and Graphing - It turns out that these small percentages of naturally-occurring isotopes matter!! Every time water evaporates, it prefers to evaporate the lighter combination of isotopes in the water molecule. Every time water vapor condenses and it rains, the heavier combination of isotopes preferentially rain out. We can use this to our advantage. Within a specific geographical region of the Earth, cloud formation from evaporation and precipitation from condensation are related to temperature. In fact, a scientist named Dansgaard figured out that there is a very strong correlation between the ^{18}O in rain water and the temperature of air (**$\delta^{18}O_{precip} = 0.7 * T_{air}$ (in units of ^{o}C) – 13.6).** Let's call this equation 1. To understand what $\delta^{18}O_{precip}$, please refer to the powerpoint slides given in class ("**Introductory Paleoclimatology Lecture**").

You have been given a data file listing $\delta^{18}O$ in ice from an ice core in Greenland. This core contains over 200,000 years of data - geologic time – way before the instrumental record!! Time is represented in years BP (years before present).

Tasks:

- Using a graphing program, please plot the years BP on the x-axis and $\delta^{18}O$ **on the** y-axis as a scatter plot. You should plot the years BP as getting older from left to right and the range should be 0 yBP to 200,000 yBP. The range for $\delta^{18}O$ should be -30 to -45 per mille ($^{o}/_{oo}$). Don't forget to label the axes on your graph.
- Now, using equation 1 above, solve for T_{air}.
- Using a spreadsheet program like Excel, please calculate the temperature of the air that existed when that ice was formed.
- Create another plot just like you did above. This time, plot years BP on the x-axis just like you did before but plot T_{air} in degrees Celsius on the y-axis.

Question 2: What do you think happened to air temperature about 12,000 yBP? What do you think caused it?

III.B. Alkenone Reconstructions and Graphing

In the same file as above, you have been given data on another proxy for climate from two stations in the Pacific, ODP Site . This proxy, the $U^{K'}_{37}$ index, comes from the lipids in an organism (see lecture notes). This organism resides in the ocean and eventually dies and settles out into ocean sediments. The calibration data for $U^{K'}_{37}$ suggests that sea surface temperature is related to this index via the following relationship: **$(U^{K'}_{37}) = 0.033 *$ [Sea Surface Temp] + 0.069**. Call this equation 2.

Tasks:

- Plot the $U^{K'}_{37}$ data for both stations on the same graph in different colors. The range for your $(U^{K'}_{37})$ should be 0.75 to 1.2 and the range for yBP should be from 0.5 to 1.5 Ma (millions of years BP).
- Now, use equation 2 and solve it for Sea Surface Temperature.
- Plot the sea surface temperature data for each site together on the same graph.
- The map below (McClymont and Rosell-Mele, Geology, 2005) shows the location of each site. Look at your temperature graph for each site as a function of time and look at the map.

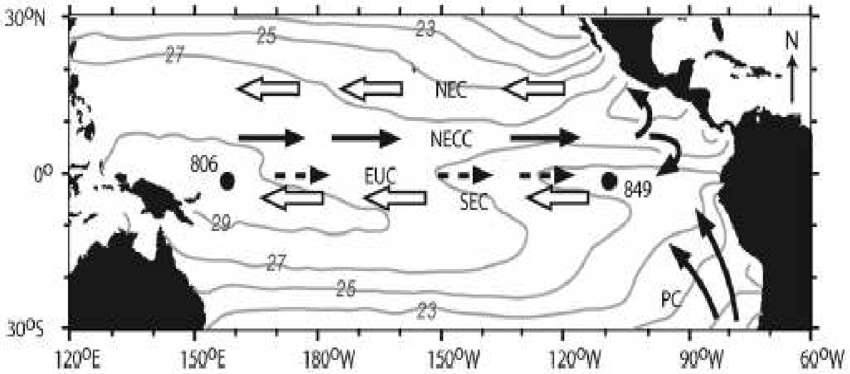

Figure 1. Map of surface and subsurface currents in surface ocean of tropical Pacific (adapted from Pisias et al., 1995). Surface currents: SEC—South-East Current, NECC—North-East Counter Current, NEC—North Equatorial Current, PC—Peru Current. Eastward flow of subsurface Equatorial Undercurrent (EUC) is also marked. Positions of SEC and NEC systems are closely related to position and strength of south-east and north-east trade winds. Ocean Drilling Program (ODP) Site 849 (0°11′N, 110°31′W) was collected from water depth of 3839 m. ODP Site 806 (0°19′N, 159°21′E) was collected from water depth of 2520 m on Ontong Java Plateau.

Question 3. Why do you think each site shows a different trend beginning at approximately 0.8 million years ago (Ma) and continuing until about 1.2 Ma? Could this have something to do with the changes in Walker Cells?

IV. Geochronology application using Pb-210 data (data provided by Dr. Reide Corbett)

For this section of your module, you will need to refer to your notes on "**Geochronology using Radioactive Tracers**", provided in class. The following table contains ^{210}Pb data from a core collected in a marsh next to Crystal River, Florida.

Tasks:

- Plot these data with Pb-210 and Ra-226 on the x-axis and depth (or midpoint of depth interval) on the y-axis.
- Using what you were shown in class about linear regressions, calculate an average rate of sediment accumulation based on the data in the table.

Depth (cm)	*Pb-210 (dpm/g)*	*Ra-226 (dpm/g)*
0-1	11.74	4.84
5-6	13.48	4.66
10-11	10.19	4.64
15-16	7.66	4.59
20-22	7.45	4.98
24-26	6.46	4.91
30-32	6.24	5.51
34-36	6.34	5.95
38-40	6.12	6.42

Question 4. What does the profile of each isotope look like?

Question 5. How would you go about assigning a calendar age to each depth interval using what you have calculated so far?

V. Practicum in Preparatory Steps for Stable Isotope Ratio Mass Spectrometer

Objectives:

- to learn the preparatory steps to obtaining your own $\delta^{13}C_{TOC}$ proxy information from an archived sediment core.
- to interpret trends in$\delta^{13}C_{TOC}$ profiles

Note – the core should be at least 2 m in length, 4" diameter and should already have been split into halves lengthwise.

Procedure:

1) Take a picture of your core half-section with the camera provided (be sure to label the top and bottom of the core). Obtain the geographical location of your core.
2) Measure the length of your sediment core.
3) Divide the total length by 10 – these are your designated core intervals. Each interval should be ~ 8 inches.
4) Take a 2 cm subsection out from the middle of each core interval. If the sediment is cohesive, this subsection should resemble a semi-circle, which you can spoon out with a spatula.
5) Place each subsection into a separate clean Quorpak jar and label the jar properly.
6) Using your spatula, homogenize each sample well. Be sure to clean the spatula in between samples.
7) Using the microbalance, tare a pre-ashed silver capsule.
8) Using the Fisons microspatula (looks like a golf club), scoop a small amount of sample into a silver capsule and record the weight of the sample in micrograms. Repeat for each sample.
9) Acidify the sample with the 0.2N HCl provided. If there is no bubbling, add the 2N HCl.
10) Place each sample in a sample tray and place the tray in an oven to dry.
11) After the sample is dry, reweigh. Record the difference in weight as a %. This will be your carbonate weight.
12) Crimp each foil sample into a small round tightly-packed sphere and place the sphere in a sample tray.
13) Load the tray on the elemental analyzer to obtain % TOC and $\delta^{13}C_{TOC}$ for each sample. Note, you will need to consult with a trained individual to learn how to create a batch file and method for your samples.

Tasks:

- After obtaining data, plot the % TOC (x-axis) of each sample versus depth (y-axis) at which each interval was subsampled (see step 4 above).
- Now, plot the $\delta^{13}C_{TOC}$ on the x-axis of each sample versus depth (y-axis) at which each interval was subsampled (see step 4 above).

Question 6. What is the range in the % TOC?

Question 7. What is the range in $\delta^{13}C_{TOC}$*?*

Question 8. Do you see any trends in the data with depth in the core? For example, are there any excursions in the isotope profiles?

Question 9. What are the factors that would cause the %TOC and $\delta^{13}C_{TOC}$ *to vary downcore? In other words, what are the possible reasons for any observed trends in either %TOC or* $\delta^{13}C_{TOC}$*?*

Question 10. How do your data compare to those of your classmates?