Lecture 16 - Stable isotopes

1. The fractionation of different isotopes of oxygen and their measurement in sediment cores has shown scientists that:

(a) ice ages are common and lasted for hundreds of millions of years
(b) temperatures like today have been common during most of the earths history
(c) there have been fairly rapid changes from interglacial periods to ice ages over the last million years
(d) climate has been very stable over the past million years

2. The only two copepod species inhabiting the same water have identical stable carbon isotope compositions, but the $\delta^{15}N$ of copepod H is 3‰ heavier (more ^{15}N-rich) than that of copepod L. Given these isotopic signatures, it is most likely that:

1. the two copepods are eating the same diet.
2. species H is a carnivore.
3. species L eats species H.
4. species L is a carnivore.
5. None of these.

3. If the land biomass in the last glacial period was significantly smaller than today every thing else held constant what to you expect CO_2 concentration and $\delta^{13}C$ to be?

1. concentration and isotopes lower than today
2. concentration higher but isotopes lower than today
3. both similar to the present
4. both concentration and isotopes higher
5. concentrations to be lower and isotopes higher

4. If oceanic gross and export production have been significantly higher in the last glacial (all else held constant) would you expect the $\delta^{13}C$ and concentration of surface water DIC to be:

1. concentration and isotopes lower than today
2. concentration higher but isotopes lower than today
3. both similar to the present
4. both concentration and isotopes higher
5. concentrations to be lower and isotopes higher

5. If the ocean's conveyer belt (deep sea circulation) has slowed down considerably would the dissolved phosphate and $\delta^{13}C$ in the deep waters of the South Atlantic be:

    1. Phosphate concentration and isotopes lower than today
    2. concentration higher but isotopes lower than today
    3. both similar to the present
    4. both concentration and isotopes higher
    5. concentrations to be lower and isotopes higher

6. You have observed high organic matter content in coastal sediments and want to relate this to high productivity in the area. Dr. Tringall indicated that this might be a faulty interpretation if a considerable fraction of the organic matter is of terrigenous origin; suggest what would you use as an indicator for the source of organic matter?

$\delta^{13}C$ of terrestrial plants (-28‰) is significantly different than marine plants (-20‰), analysis if the isotopic composition of the organic matter may reveal its origin.

7. At the LPTM (~55 million years ago) a negative excursion of ~2.5‰ in the $\delta^{13}C$ of both benthic and planktonic foraminifers is observed, this can be explained by:
    1. Input of light C to the ocean/atmosphere system by reduction in the ocean productivity
    2. Input of light C to the ocean/atmosphere system by reduction in the terrestrial biomass
    3. Input of light C to the system from dissociation of gas hydrates
    4. All of the above provided that the mass balance needed to explain the shift is reasonable.

8. Which of the following statements is **true** about the $\delta^{18}O$ paleotemperature method as applied to fossil carbonate shells?
    1. The $\delta^{18}O$ of the shell is affected by active isotope exchange with O_2 dissolved in the water
    2. Calcite is better to use than aragonite because calcite is thermodynamically more stable
    3. Calculated paleotemperaures are not affected by net transfer of seawater to continental glaciers
    4. The $\delta^{18}O$ of carbonate in benthic forams is unlikely to reflect changes in glacial volumes
    5. None of these

9. If the entire N in the surface water of a lake was derived from nitrogen fixation what do you expect the $\delta^{15}N$ of the NO_3^- dissolved in this system to be?

About +1‰ (close to atmospheric N_2)

10. Records of δD_{ice} and $\delta^{18}O_{ice}$ show large changes between glacial and interglacial time what caused the changes in these isotopes?

The temperature dependence δD and $\delta^{18}O$ of precipitation (colder = lighter isotopes) .

11. Fossil benthic and planktonic forams have been recovered from a 20 Ma core sample. The $\delta^{13}C$ of the benthics is 0‰ and of the palnktonics it is 4.0‰. If the photosynthetic fractionation factor and the C/P ratios in marine organisms were the same as today, by how much did the C/P ratios in the ancient deep sea differ from the C/P ratios in today's deep sea?

The mean difference between the $\delta^{13}C$ for benthics and planktonic forams in the recent marine sediments is about 2‰. Thus if the core sampled represents the mean value for the ocean at 20Ma then the $PO_4/\Sigma CO_2$ must have been about twice as high as today's and the productivity higher the difference between benthic and planktonic forms represents the export production that is regenerated at depth thus also PO_4 regeneration.

12. The stable isotopic composition of a mammalian bone can tell you:
    1. what time of year the individual died
    2. whether the individual was male or female
    3. whether the individual ate predominantly marine or terrestrial foods
    4. the average temperature of the environment during the life time of this individual
    5. how old the bone is

13. It is now believed that photosynthesis and sulfate reduction have existed on earth for more than 3 billion years. How could you confirm this using isotopes?

Measure $\delta^{13}C$ and $\delta^{34}S$ in old organic matter and sulfides and look for light isotope fractionation (or heavy isotopes in carbonate and sulfate).

14. How can you tell is a recently extinct animal was a browser or a grazer using isotopes?

Grazers typically eat grasses that are at least in low latitudes dominated by C_4 plants while browsers eat shrubs are trees that are C_3 plants. C_4 plants have $\delta^{13}C$ ratios of –12 while C_4 plants have $\delta^{13}C$ ratios of –25.

15. Compare the $\delta^{18}O$ curves of benthic forams and the water molecules in polar ice over the past 50,000 years, and explain.

$\delta^{18}O$ of forams is higher in the last galcial maximum (~ 1.2‰ difference) due to removal of ^{16}O to the ice caps while the ice $\delta^{18}O$ gets lighter (change from ~ -30 to -40‰) due to lower temperatures during glacial times.

16. The $\delta^{18}O$ in calcium carbonate is temperature dependent, but the $\delta^{18}O$ record of deep-sea sediments cannot be used to directly determine temperature of the oceans through the past. Why? What is needed to be able to estimate temperatures from $\delta^{18}O$ in carbonates?

The $\delta^{18}O$ of carbonates is also controlled by the $\delta^{18}O$ of seawater at the time of formation and this has changes with time. We need to know $\delta^{18}O$ seawater for estimating the temperatures.

17. A beautiful artifact made of a marine shell was found at a site in the Baja California desert. The archaeologist who found the artifact wanted to determine if the shell had been obtained from the Gulf of California or the Pacific coast side of Baja. The shell species is found at both localities. What geochemical measurements could be made on the shell to answer this question? Explain.

$\delta^{18}O$ of the carbonate would reveal the temperature of the water and there is a large difference between the temperature of the gulf and of the Pacific coasts.

18. Why is it that the $\delta^{13}C$ value of organic compounds in living organisms is always negative compared to $CaCO_3$? How would the organic matter and carbonate in meteorites differ?

Photosynthesis involves kinetic isotope fractionation (preferring the light isotope) thus the base of the food chain is negative (compared to the standard the PDB carbonate). The organic matter and CaCo3 in the meteorite are expected to have similar $\delta^{13}C$ values.

19. What controls the $\delta^{18}O$ of N. Atlantic Surface Water? What could this property be used for?

Evaporation, precipitation and ice melt. This could be used to trace the water mass like a conservative tracer.

20 Long-range plans of NASA include the exploration of other planets that have or had living organisms. If you were to advise an analytical experiment to ascertain the presence of life what would you look for and why?

21. List the following according to their $\delta^{13}C$ values starting with the most negative:

a. dissolved inorganic carbon in the deep ocean (0)
b. natural gas reserves (-50)
c. marine plants (-20)
d. carbonate sediments (+1)
e. terrestrial C4 plants (-13)
f. terrestrial C3 plants (-27)
g. atmospheric carbon dioxide (-8)
h. dissolved inorganic carbon in surface water (+0.5)

22. The $\delta^{13}C$ of CO_2 in the present atmosphere is about –8 per mil; the mean d13C for fossil fuels is about –25 per mil. Assume that over the next 100 years the CO2 content of the atmosphere doubles as a result of fossil fuel burning and that an equal amounts of C from this source is incorporated directly into the oceans (ignore C sinks to keep this simple). The total amount of CO_2 in the atmosphere is 5.5×10^{16} moles and the C in the ocean is about 320×10^{16} moles. What will be the $\delta^{13}C$ of CO_2 in the atmosphere in the year 2101? How big a change is expected in the $\delta^{13}C$ of marine carbonate rocks deposited a few thousand years after this (long enough for all the extra CO_2 to mix in)?

The $\delta^{13}C$ of the CO_2 in the atmosphere would be –16.5 per mil; For the ocean we assume that first the atmosphere gets mixed and is now at –16.5 per mil. The C dissolved in seawater id about 8 per mil higher e.g the newly incorporated C should be –8.5 and the mixture would be: -0.14 per mil. The planktonic forams may record the signal to a greater extend.