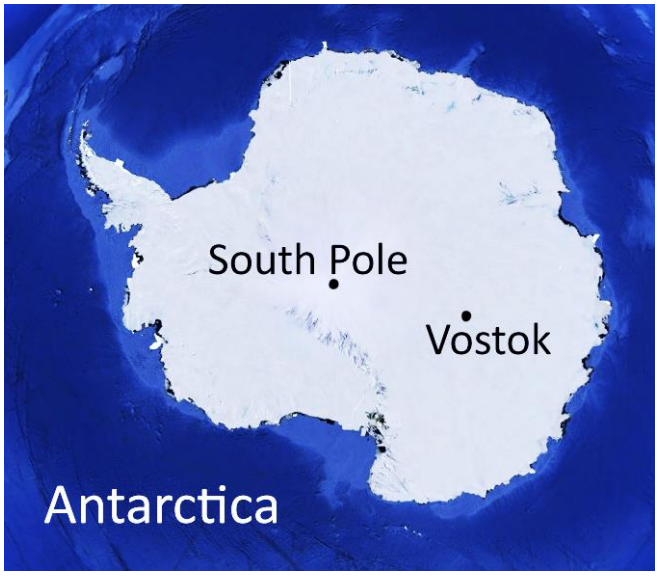
Paleoclimate proxies, Part II: Vostok ice core activity

Background information:

The Vostok ice core was drilled at a Russian research station high on a dome of glacial ice in Antarctica by an international team of researchers. It provides valuable paleoclimate data going back more than 400,000 years. One way of estimating temperature from the ice core data is to examine isotopic variations in hydrogen. Water, of course, is a molecule made of two atoms of hydrogen and one atom of oxygen. Like many other elements, hydrogen comes in neutron-heavy and neutron-light versions (isotopes). Normal hydrogen has one proton only, but some hydrogen has a neutron as well, making ^{2}H, also known as "deuterium," and usually abbreviated as "D."



C. Bentley annotations on Google Earth map

The signature of ancient temperature can be found in the ratio of heavier to lighter versions of hydrogen. When it is warmer out, there is more energy to power evaporation of heavy (D-containing) water molecules from the ocean. This means the ocean gets isotopically "lighter" during warm times, and the water that evaporates and later condenses into clouds and falls as precipitation (snow, in Vostok's case) gets isotopically "heavier." During cold times, the opposite is true: there is not enough energy to boost heavy water molecules out of the ocean as vapor, so the ocean gets isotopically heavier, and the snow (made from the water molecules that succeeded in evaporating) gets isotopically more "lightweight."

We measure the ratio of D to H using a machine called a mass spectrometer. We can then describe the "mix" of D and H in a sample of water (or ice) with a single number, called the **δD** (*pronounced "delta-deuterium"*).

The notation of δD is defined:

$$\delta D = (((D/H \text{ of a sample})/ (D/H \text{ of a standard})) - 1) \times 1000$$

(The "standard" is "Vienna Standard Mean Ocean Water" (vSMOW), which is not seawater that has salt in it, but rather water that evaporates from seawater, without any salt coming with it.)

The thing to remember about δD is that when δD decreases, it means that H is increasing in proportion to D – that the overall mix of the two isotopes is getting skewed toward the lightweight isotope. So: lower δDs mean more H and less D; this indicates a lower temperature (because there was less energy available to evaporate water molecules containing D atoms from the ocean). When δD is higher, it means there is more D and less H; this indicates a higher temperature (with more available energy to evaporate water molecules containing D atoms).

The unit we use to express δD is “per mil,” which basically means “out of a thousand,” in the same way that “per cent” means “out of a hundred.” Per mil is written ‰, which is just like the % symbol with one more “0,” just as a thousand (1000) has one more “0” than a hundred (100).

Instructions:

Open the spreadsheet distributed by your instructor.

The formula for calculating temperature from δD is:

$$\text{Temperature (° C)} = -55.5 + (\delta D + 440) / 6$$

Enter this formula into the final column of the spreadsheet (highlighted in yellow) to calculate the temperature. This will automatically draw a graph for you.

Examine the graph and use it and the graph from the previous activity to answer the following questions:

1. Which geological epochs are included in the sampled time period?

2. According to the coiling direction of the sampled forams, when was the temperature hotter? When was it colder?

3. What famous event was happening in Earth history during this interval of time?

4. According to this data set, when did that event end?

5. What is the total range (maximum minus minimum) of paleotemperatures recorded by the data set?

6. Would the temperatures during the warmer times at Vostok have felt “warm” by human standards?

7. How does this data set compare to the data set you examined for foram coiling direction? (Compare the two graphs) What do they have in common? How do they differ?

8. What might explain the differences you observed between the two data sets?