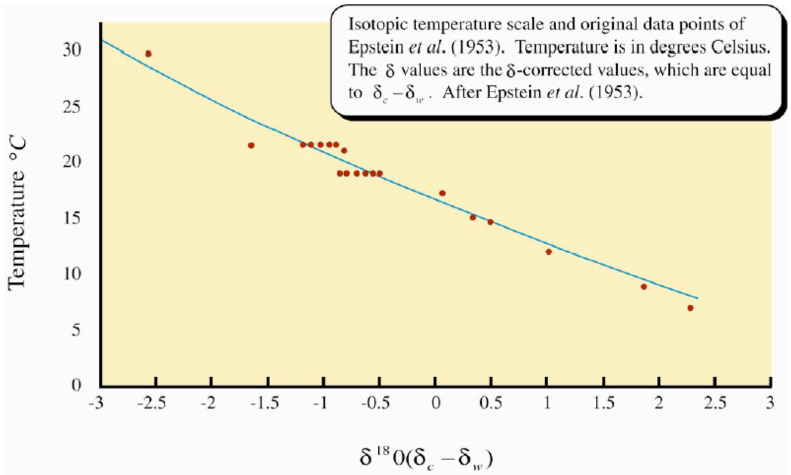
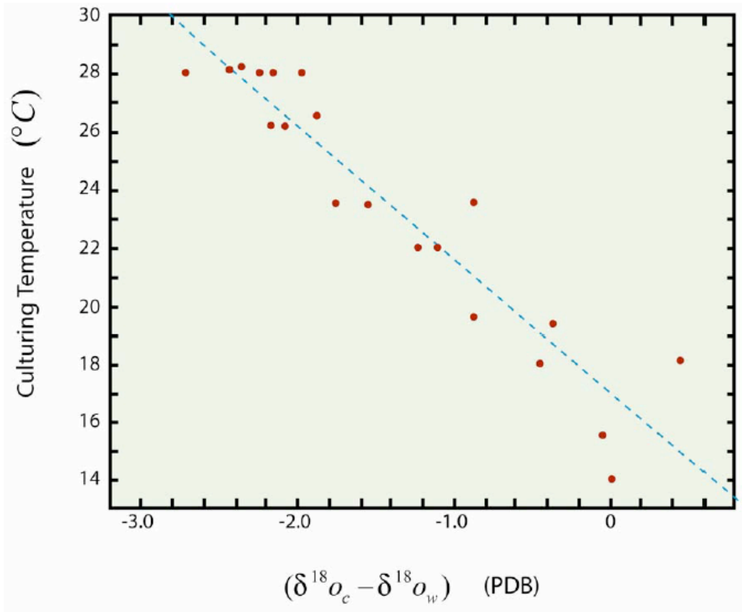
Epstein’s mollusk growth experiment

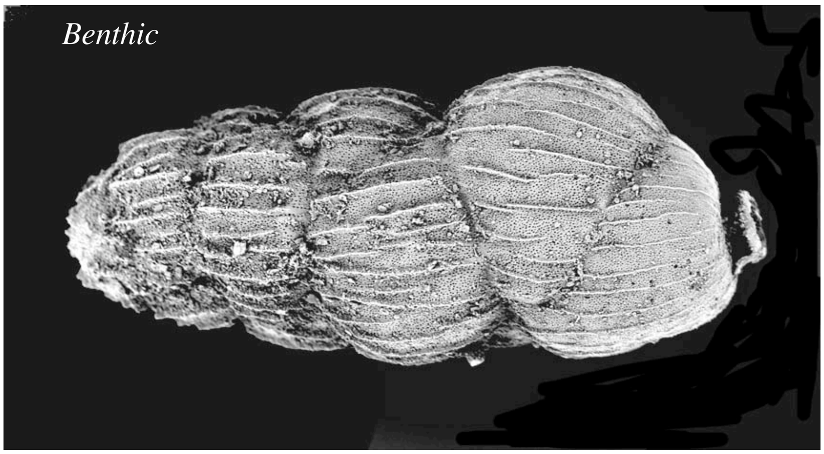


Epstein’s data

Erez et al. (1983) (planktonic G. sacculifer laboratory experiment)

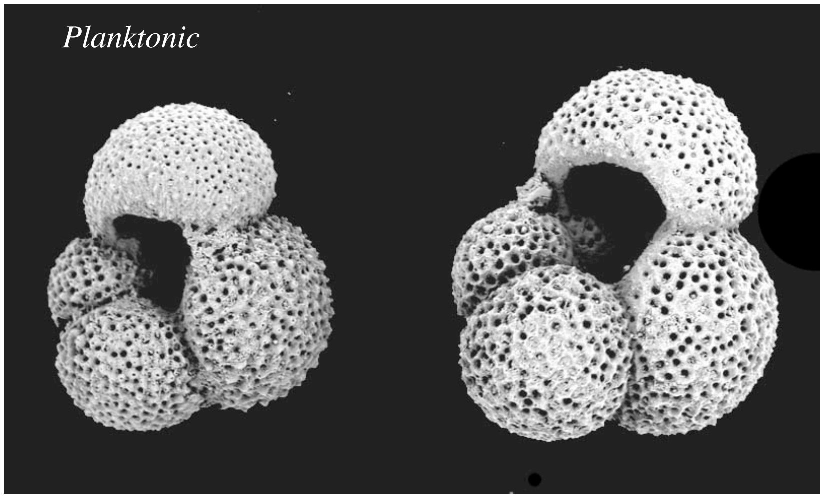


Uvigerina cushmani



An example of a benthic foram. Size is around 250 microns.

Globigerina bulloides



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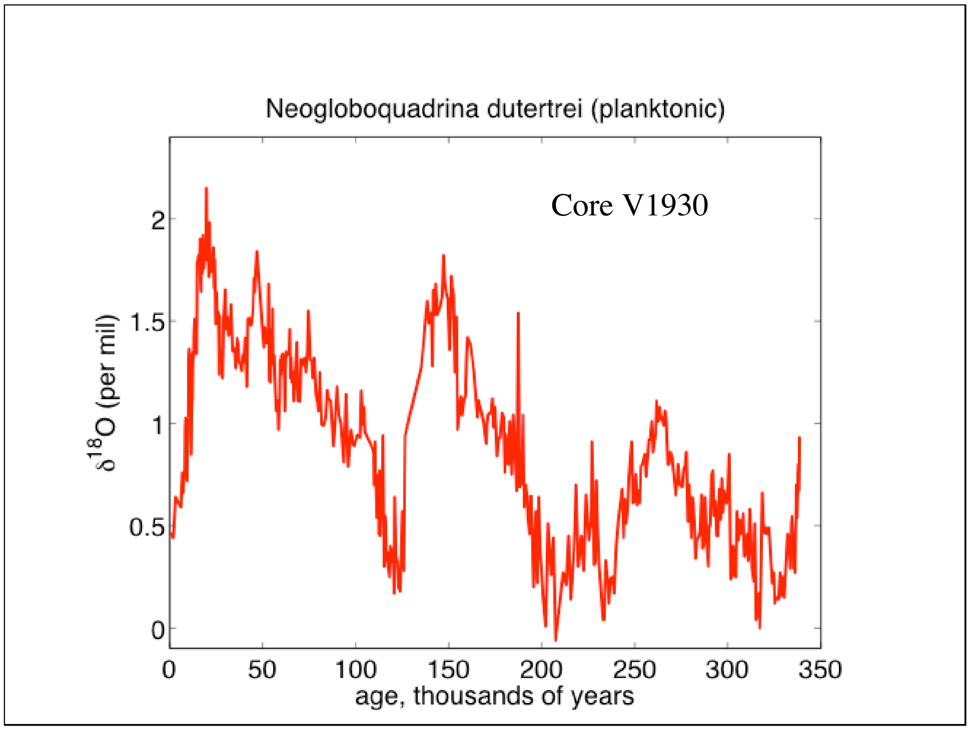
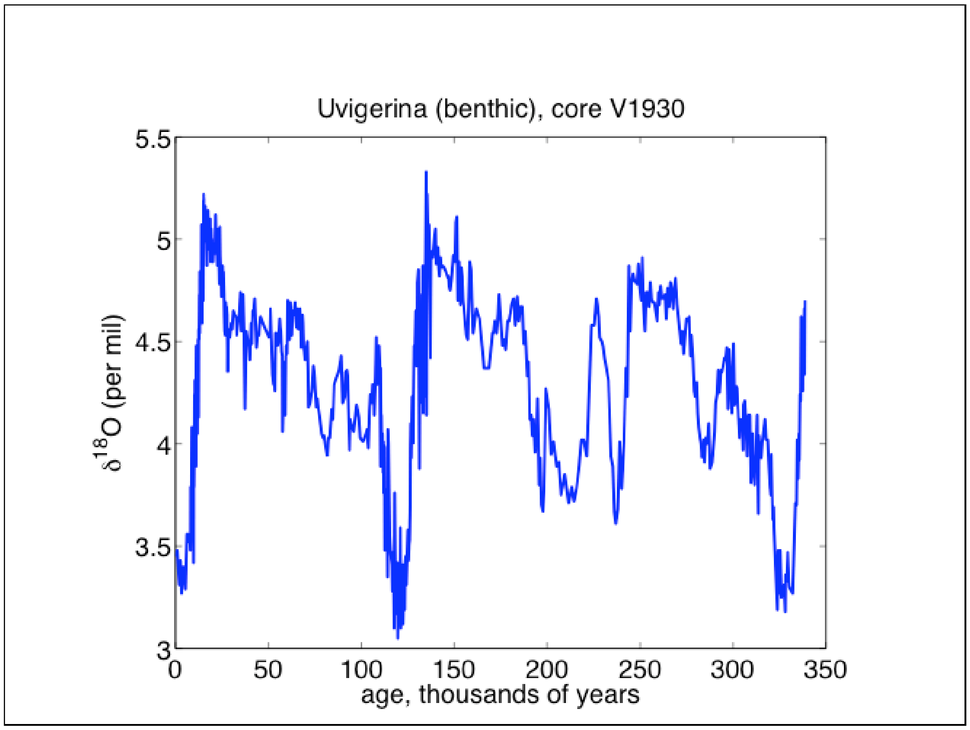


The Shackleton planktonic foram d18O values from core V1930, off the coast of Peru.



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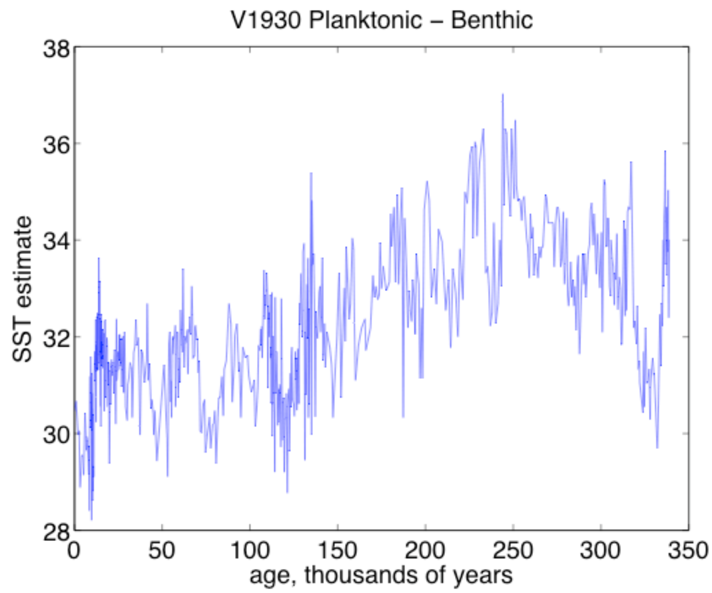
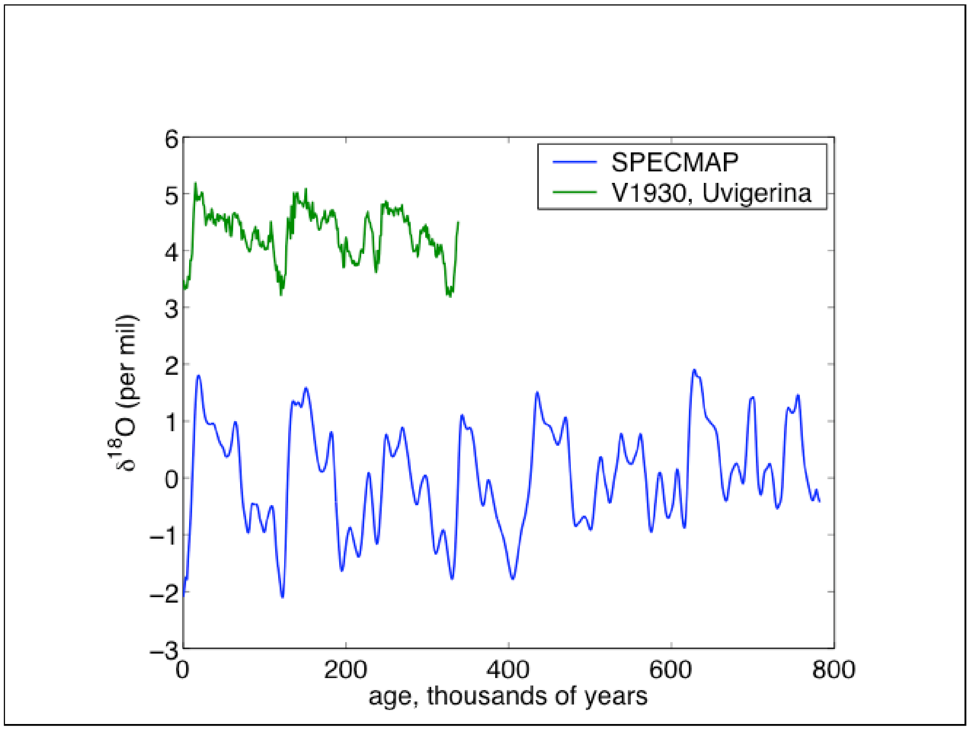


Assuming that the benthic foram d18O changes are due only to ice volume changes, then we can estimate the temperature change over time at the V1930 site by subtracting the two preceding curves and multiplying by -4. We obtain a temperature history that suggests ever-cooler temperatures throughout the last 250,000 years. Is this correct?

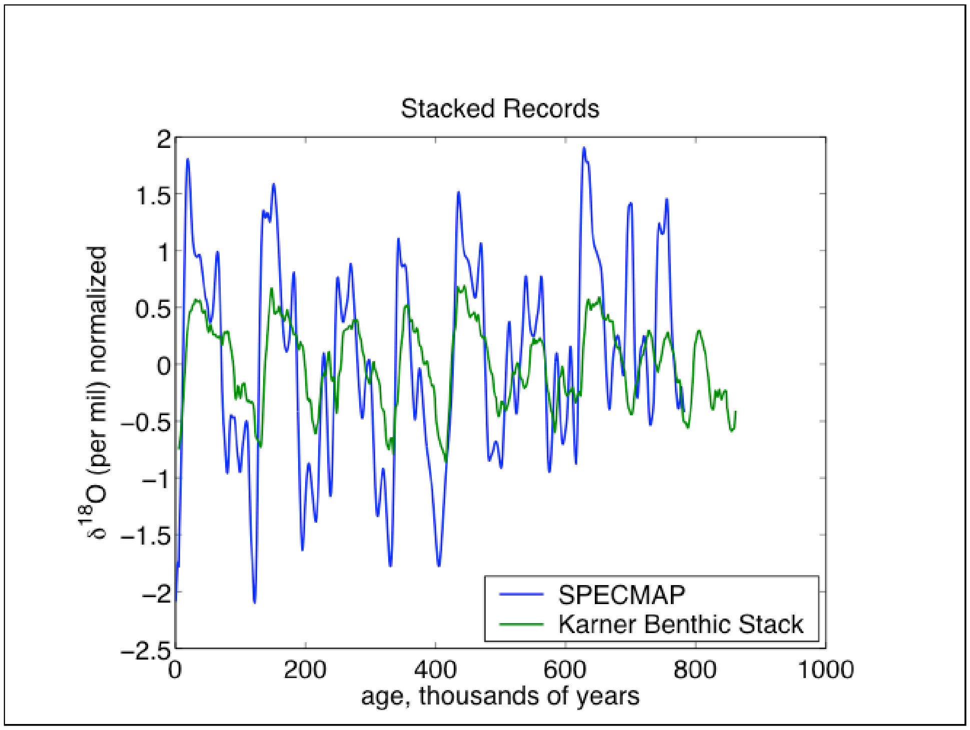
It might be, but if so it is probably only of local significance, since there is no reason to assume that SSTs changed uniformly throughout the globe.

Furthermore, local variations in surface water d18O unrelated either to temperature or ice volume can result from e.g. river runoff (meteoric waterr generally has much lower d18O than ocean water).

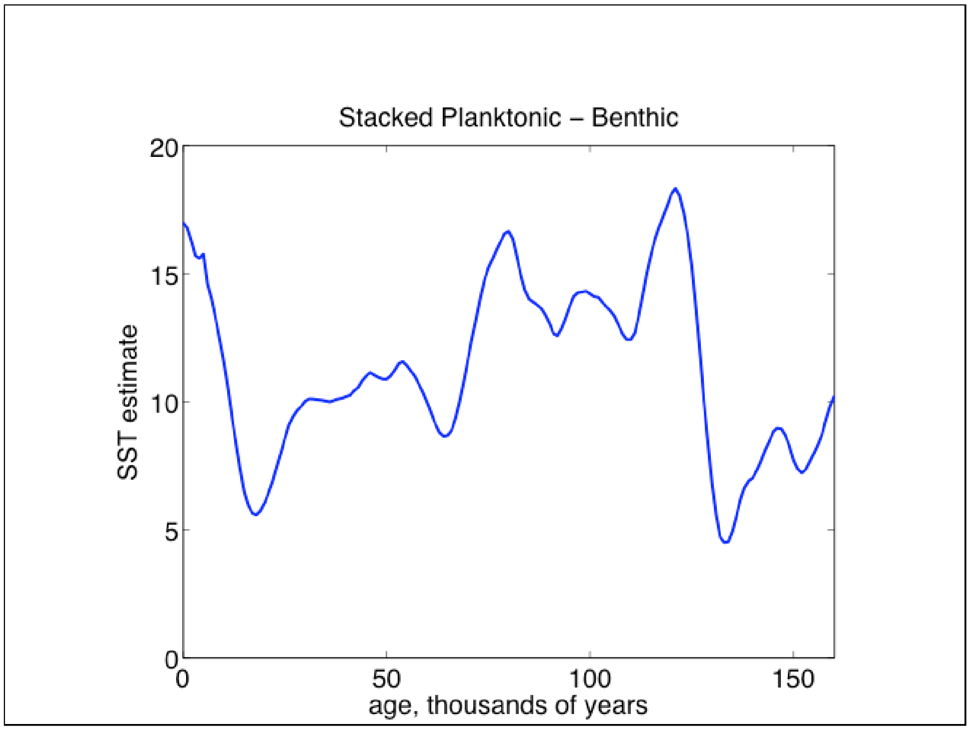
If we are interested in the global story, then it makes sense to combine or "stack" a large number of sediment cores to get a sense of the average temperature and ice volume change over time.



This shows the SPECMAP stack (normalized), and the most famous benthic stack (not normalized).



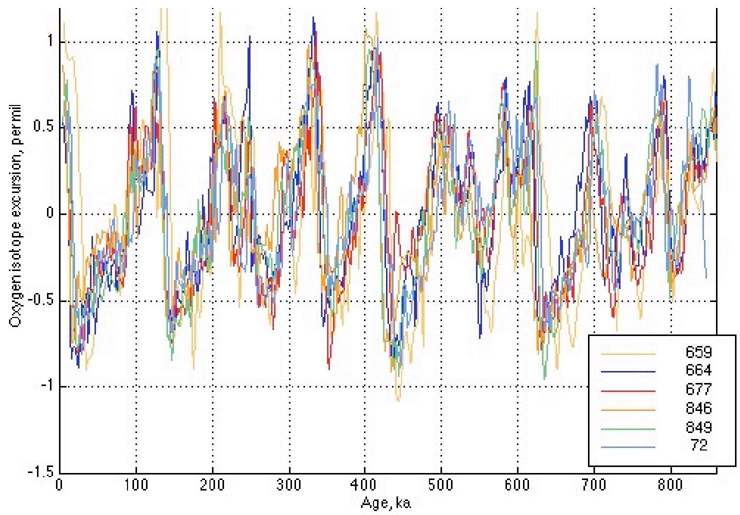
This shows the benthic and SPECMAP stacks together, normalized to an average value of 0. Note the much larger variations in SPECMAP, as excpected if most of the benthic data reflect sea level (ice volume) variations, while the planktonic reflect both temperature and sea level.



This shows the difference between the benthic and planktonic stacks, converted to SST. The last interglacial 125 kyr ago is obvoius, as is the last and next-to-last ice age (20 kyr and 140 kyr, approximately).

In the next class we will look quantitatively at the relationship between records like this one, and other paleoclimate data, and Milankovich forcing.

Benthic δ^{18}O from six equatorial records



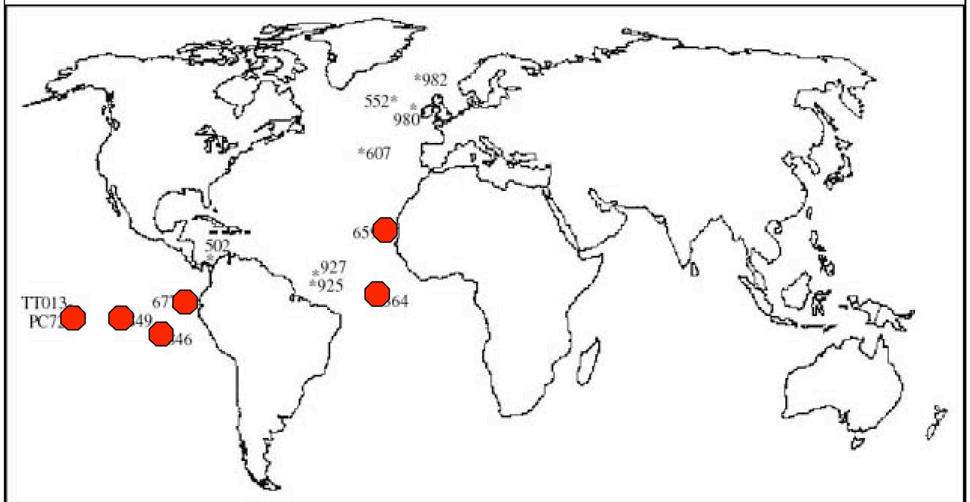
Globally, the observation is that one benthic core is generally like another, but one planktonic record can be quite different than another.

How similar are the benthic data? This graph shows a compilation of six equatorial records, locations shown on the next page.

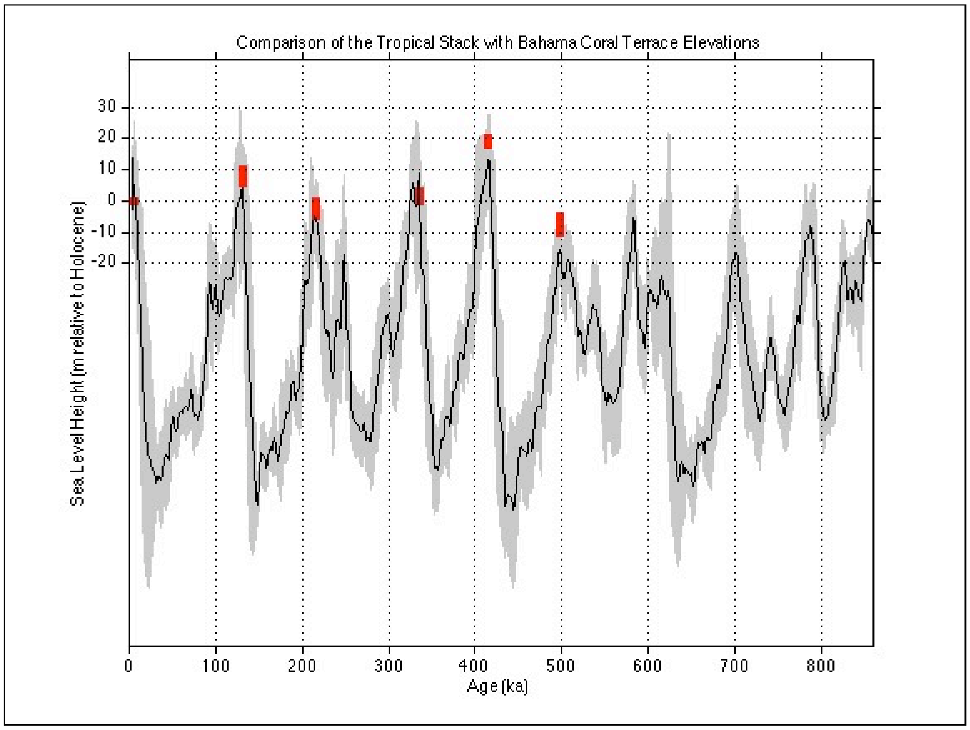
This is from Karner at Berkeley.

http://jlevine.lbl.gov/BenStackCompare.html

Locations of equatorial cores in Karner et al. benthic stack



This shows the locations used on the preceding slide. Note that cores shown but not marked with red were found to be “quite different” than the others. Nevertheless, that six cores from two different oceans give very similar results is strong support for the idea that the benthic records are “global” in what they represent.



How good is the assumption that the benthic data directly reflect ice volume (or sea level) rather than temperature change, as Shackleton suggested?

We'll make a calculation of this in our first problem set.

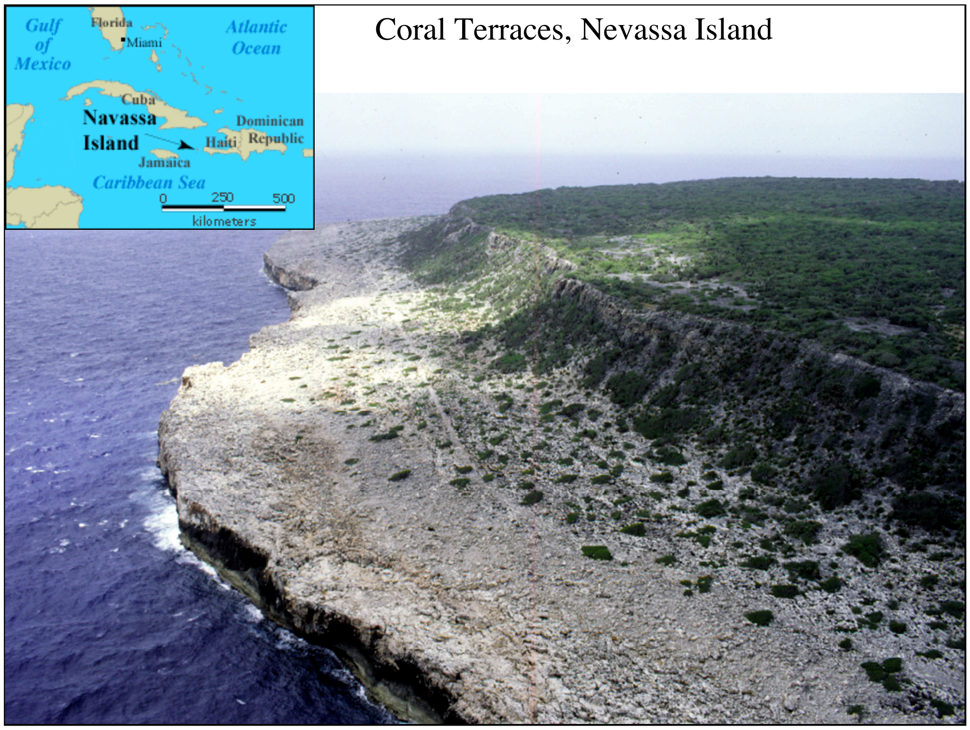
For now, note that independent measurements of sea level give a pretty consistent relationship with the benthic data.

This doesn't tell us what fraction of the d18O change is due to ice volume, but it suggests that they scale linearly with each other (when it gets cold in the deep ocean by some amount, there is a corresponding amount of ice on land).

The sea level estimates are from Hearty and Kaufman (QSR, 2000), who have measured the elevations of coral terraces from the Bahamas, each the remnant of a different sea level highstand. The terrace elevation data cover the last six interglacial periods, and are plotted in red. The benthic stack is plotted behind them. The largest disagreement between the two data sets is about 8 m.

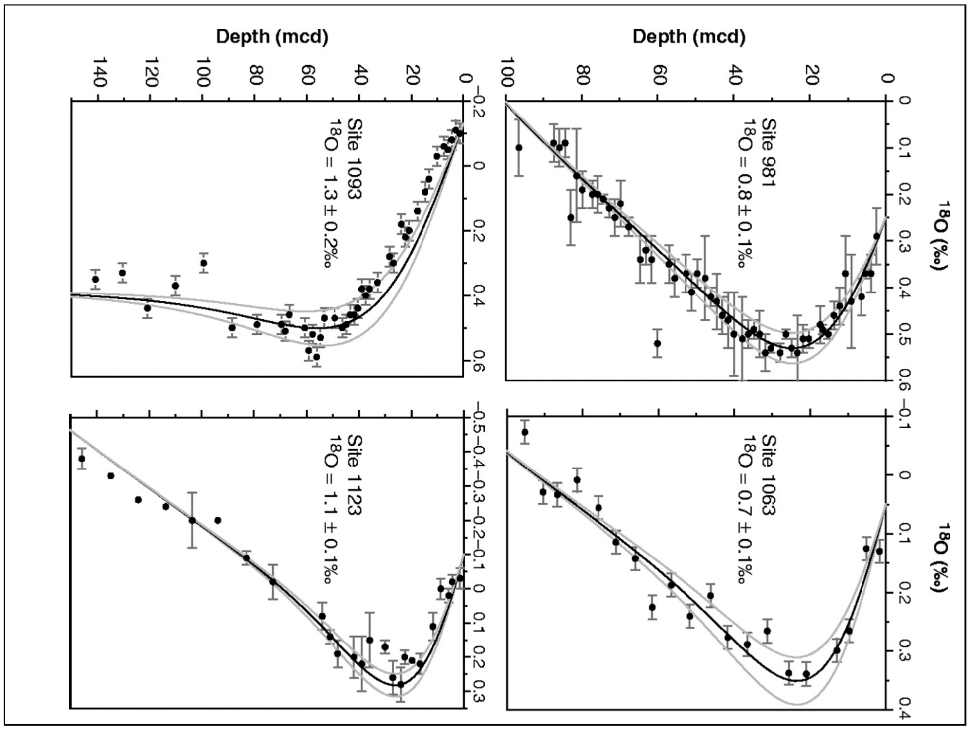
Note that the ages of the sea level high stands are NOT weel known except for the most recent on (~127,000 years ago). However, the assumpion that high sea level = either warm temperatures or little ice (or more likely both) is quite reasonably.

Coral Terraces, Nevassa Island



This is a photo of a coral terrace as an example -- note this one is quite a bit older (>3 Ma) than any we are discussing, but it shows the older sea level high stands (at least two of them) quite nicely.

Note that another way to form these terraces is to lift up the land, rather than lower sea level, so knowledge (e.g. from geodesy) of the tectonic uplift rate is important in estimates of sea level rise.

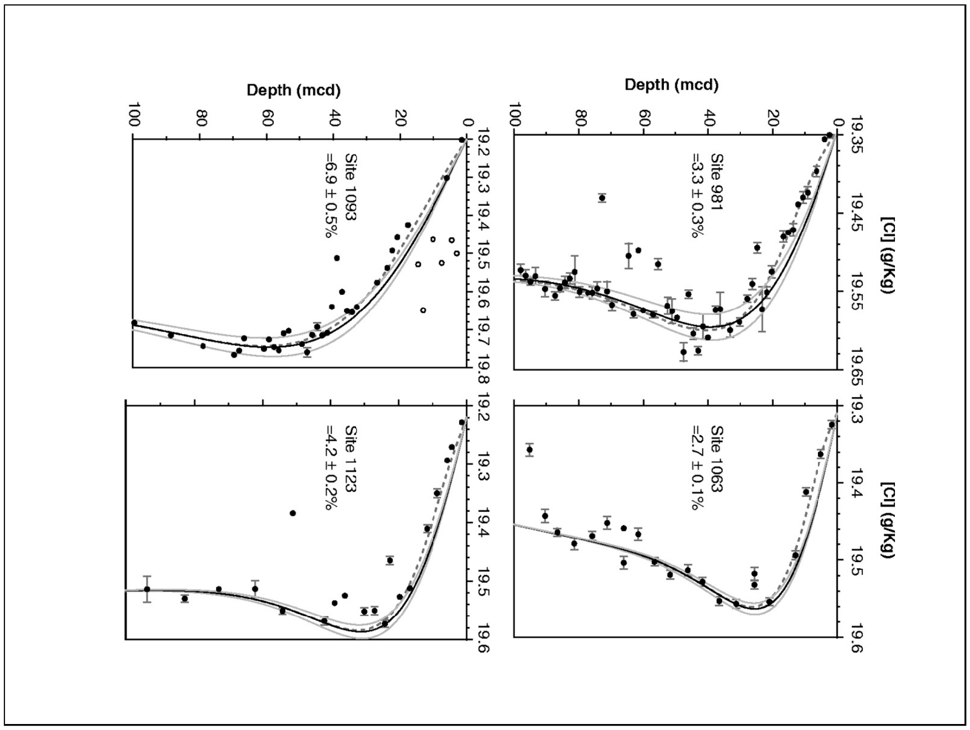


Another piece of evidence that supports the interpretation of benthic foram d18O in terms of ice volume is the del18O measurement of pore water, which is ancient sea water trapped in the sediment and cleverly retrieved without contamination. Because of diffusion the original d18O value of the sea water is not perfectly preserved, but there is memory of it, and if diffusion rates are known (or estimated), the original d18O of the ocean in the past can be deduced. The estimated last glacial maximum value is shown on each plot. It averages about 1 per mil.

Going back to figure (3), we can see that the total benthic d18O change from glacial to interglacial is about 1.5 per mil. Therefore, sea level change (or ice volume change) accounts for roughly 2/3 of the signal. The rest can be attributed to a cooling of about 2 degrees C, which is a satisfying number since deep ocean tempreatures are now about 2 degrees above the freezing point (and there is no evidence the deep ocean froze).

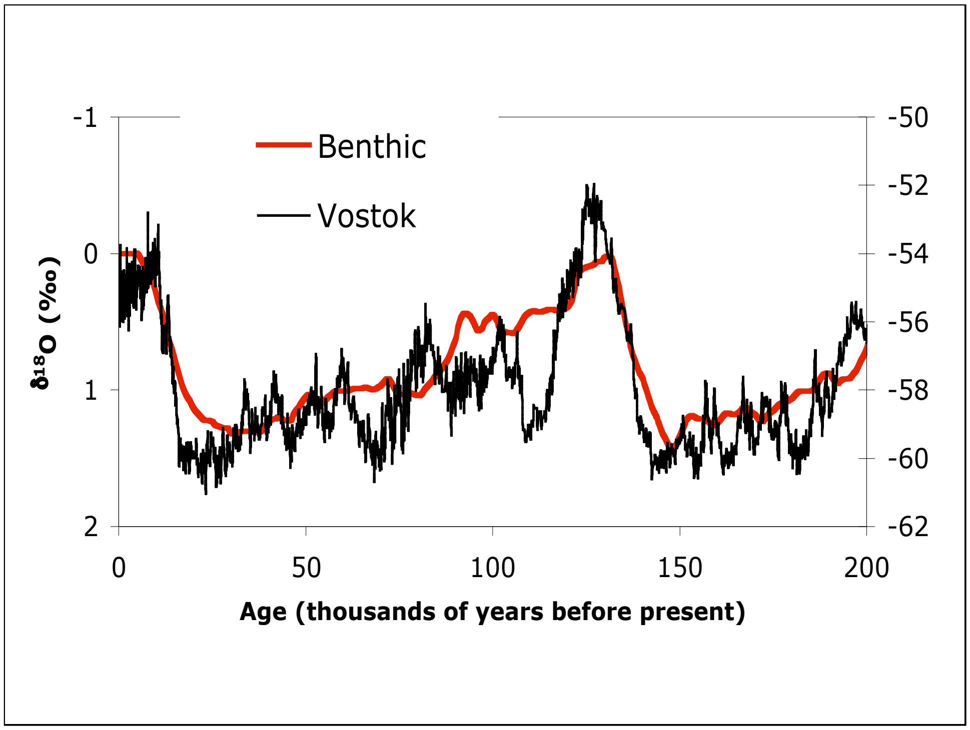
The four figures are from **The Salinity, Temperature, and 18O of the Glacial Deep Ocean Jess F. Adkins, Katherine McIntyre, Daniel P. Schrag** *Science*, Vol 298, Issue 5599, 1769-1773 , 29 November 2002.

The model fit to the data is a 1-D diffusion scheme that includes the effects of compaction advection but assumes there is no effect from



The estimates from the del18 measurements can be validated with salinity measurements, as shown here. The idea is simply that as sea level went down, salinity must have increased.

Also from Atkins et al., 2002.



The relationship between ice volume (from benthic del18O, left axis) and temperature (from Vostok ice core del18O) is remarkably good.