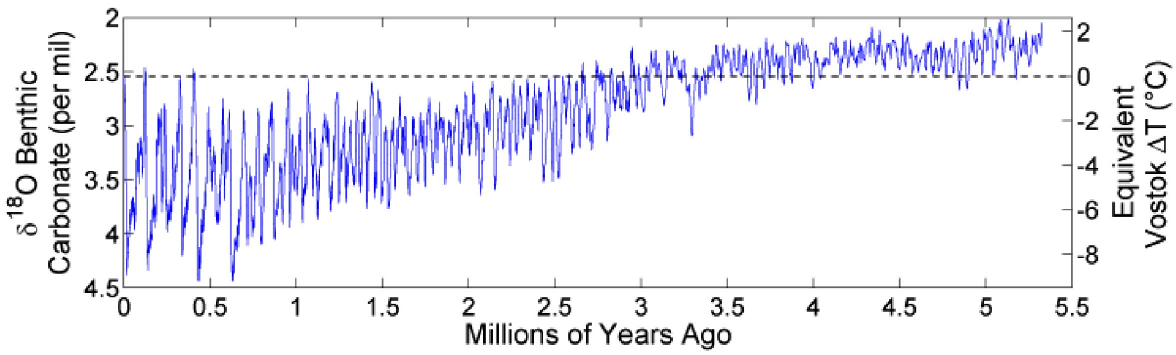
Deep Earth Academy
CONSORTIUM FOR OCEAN LEADERSHIP

Oxygen Isotopes, Milankovitch, and Climate

The figure below displays oxygen isotope data spanning the past 5 million years. These data are produced from the calcite shells of benthic foraminifers (single-celled protists that live on the seafloor). These microfossils are picked from deep-sea cores and analyzed on a mass spectrometer. The ratio of stable oxygen-18 to oxygen-16 ($^{18}O/^{16}O$) in the foram shells ($CaCO_3$) is used in ocean-climate research as proxies (indirect evidence) for changes in temperature and ice-volume. Such isotopic ratios are depicted using the “del” notation: $\delta^{18}O$. The ΔT in the plot below is equivalent to the change in temperature (°C) in the deep ocean. The data shown below represent a composite of 57 deep-sea cores (from Lisiecki and Raymo, 2005; *Paleoceanography*, 20, PA1003, doi:10.1029/2004PA001071.)

What changes, or trends in deep-sea benthic foraminifer $\delta^{18}O$ do you observe in these data?

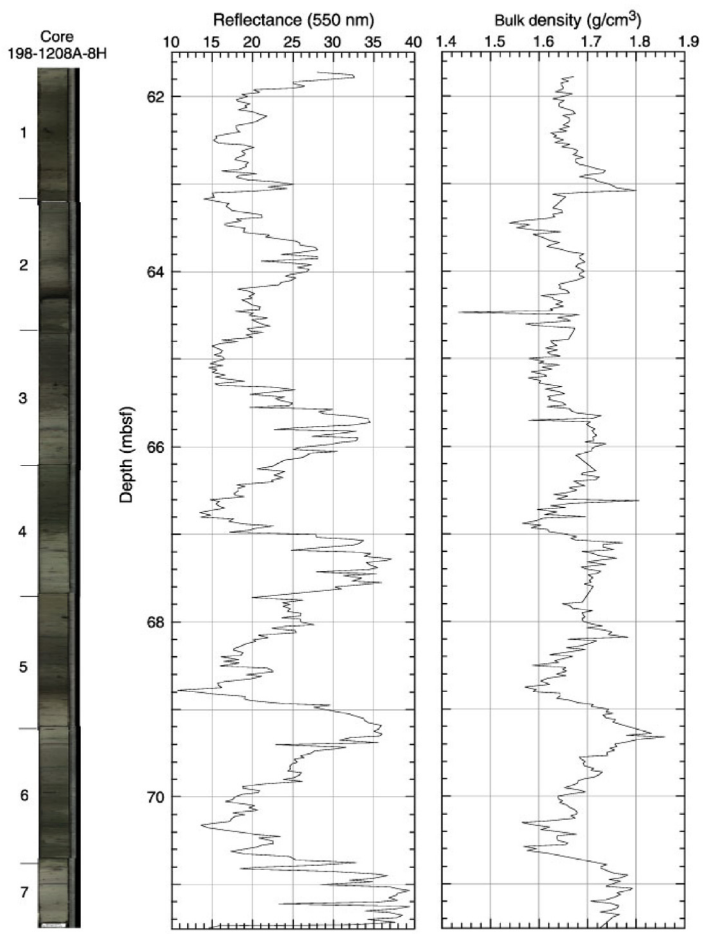
Focus on observations first, then create a list of hypotheses to explain the 5-million year trends.



Modified from http://en.wikipedia.org/wiki/Image:Five_Myr_Climate_Change.png

Cyclicity is very common in the geologic record of sediments and sedimentary rocks. For example, the upper photo below shows cyclic alternations of limestone and marlstone in rocks of Late Cretaceous age (west of Pueblo, Colorado; ~93.5 Ma; photo by R.M. Leckie). The lower photo shows cyclic alternations of nannofossil ooze and nannofossil clay in a deep-sea sediment core of Pleistocene age (Shatsky Rise, northwest Pacific; Core 198-1208A-8H; ~1.5 Ma; http://www-odp.tamu.edu/publications/198_IR/chap_04/c4_f9.htm#535728).

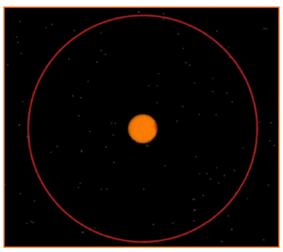
If the age at 62 meters below seafloor (mbsf) in Core 198-1208A-8H is 1.211 Ma, and the age at 85 mbsf is 1.770 Ma (ages based on magnetostratigraphy), and if we assume a constant sedimentation rate between these two age control points, *what is the likely periodicity of the cyclicity represented in this core?*

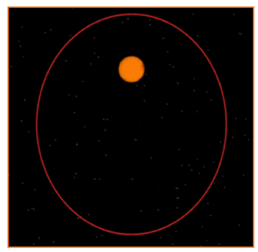


Milankovitch cycles are driven by Earth's natural orbital oscillations, which influence the amount of **in**coming **sol**ar radi**ation** (**insolation**) received. Periodic oscillations in insolation affect temperature and precipitation patterns, particularly in the high latitudes. Changes in insolation are the principle driver of glacial cycles at high latitudes, and wet-dry cycles at lower latitudes throughout geologic time. These oscillations are manifest in many different types of climate proxy data including lithology, sediment grain size, sediment color, magnetic susceptibility, gamma ray, stable isotopes, et cetera. Milankovitch cycles are pervasive through the geologic record, with many excellent examples preserved in deep-sea sediment cores.

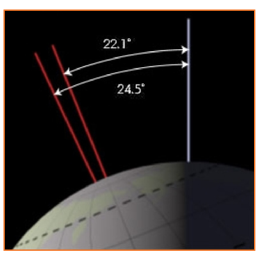
There are three major periodicities of Milankovitch cycles related to **eccentricity** of Earth's orbit around the Sun, **obliquity** in Earth's axial tilt relative to the plane of the ecliptic, and **precession** of the seasons. Each is briefly discussed below.

1. **Eccentricity** is a term to describe the degree of deviation from a perfect circle: the greater the eccentricity, the greater the elliptical deviation from a circle. A perfect circle has an eccentricity of 0 and a flattened circle (= straight line) has an eccentricity of 1. Earth's orbit around the Sun has an eccentricity that ranges from 0.005 to 0.058 with a mean of 0.028. The eccentricity today is 0.017. There is a range of periodicities (95 kyr to 136 kyr) with an average of ~100 kyr (100,000 years). There is also a long eccentricity cycle with a periodicity of ~413 kyr. The figure on the left is 0 eccentricity, while the figure on the right represents 0.5 eccentricity, which greatly exaggerates Earth's actual maximum. *http://en.wikipedia.org/wiki/Milankovitch_cycles*

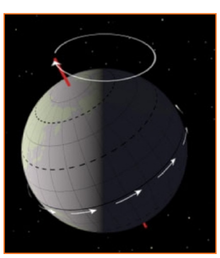




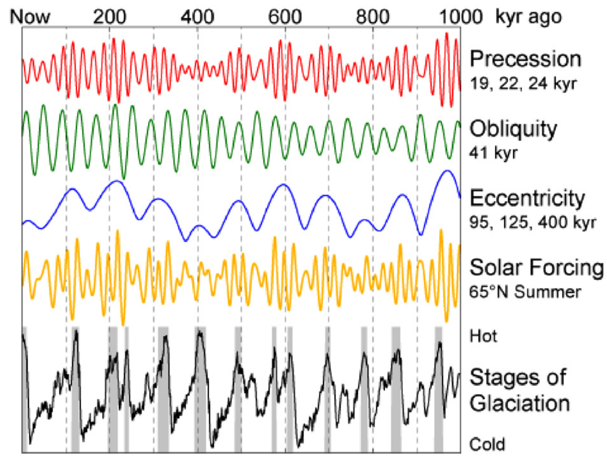
2. **Obliquity** describes the Earth's axial tilt, which ranges between 24.5° and 22.1°. Today the axial tilt is 23.5°. The periodicity of obliquity is ~41 kyr. Cooler summers in the high latitudes created by less tilt are more favorable for triggering an ice age compared with the warmer high latitude summers expected when the tilt is greater.



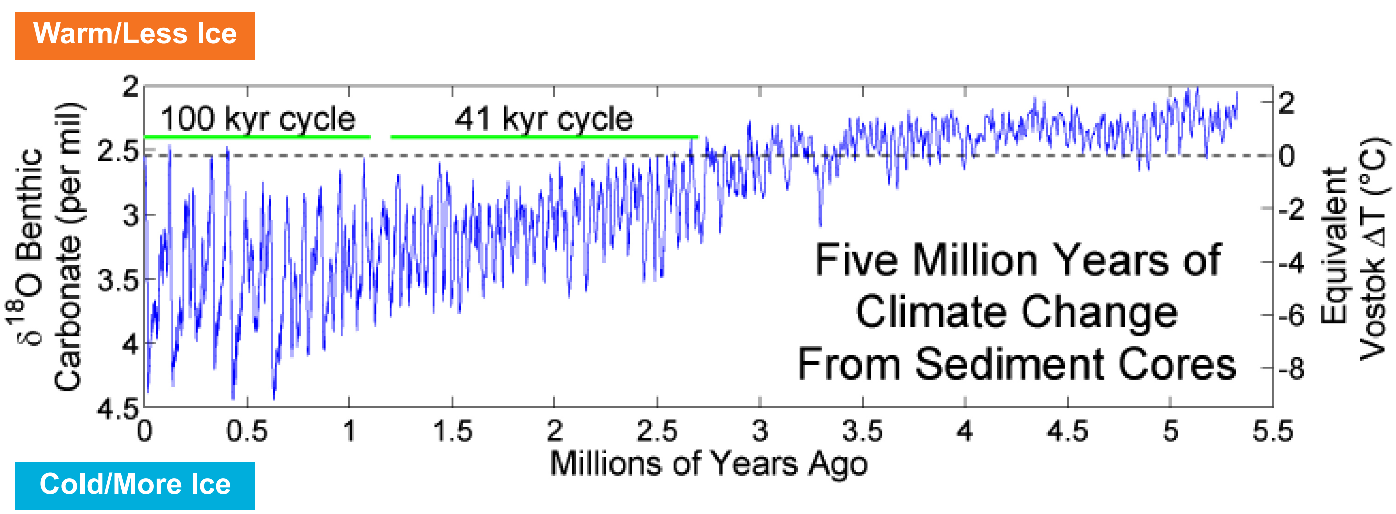
3. **Precession** of the equinoxes has a cyclicity of 19 kyr to 26 kyr. Because the spinning Earth wobbles like a top, this affects the time of year the Earth is closest to the Sun (owing to our slightly elliptical orbit around the Sun). Today, we are closest to the Sun (perihelion) about January 3 (Northern Hemisphere winter), and furthest from the Sun (aphelion) about July 4 (Northern Hemisphere summer). About 11,000 years ago, the Northern Hemisphere was at its closest distance from the Sun during the summer months.



The figure below shows the variations in Earth's orbital parameters (precession, obliquity, and eccentricity) and the resulting changes in solar energy flux (**insolation**) at 65°N over the past 1 million years. The observed glacial cycles are based on stable isotopes of oxygen ($\delta^{18}O$) from deep-sea benthic foraminifers (lower panel) and demonstrate a strong periodicity that fits well with the patterns of **orbital forcing** of eccentricity. **Interglacials** are shown with the gray bars. *http://en.wikipedia.org/wiki/Image:Milankovitch_Variations.png*



Below is an annotated version of the Lisiecki and Raymo (2005) composite benthic foram oxygen isotope curve shown above (p.1). Note the temporal changes in amplitude and frequency displayed in these data. In this record, **glaciation** was initially **orbitally-forced** by **obliquity**, but later changed to **eccentricity**. Also note the increase in amplitude of the glacial cycles and decrease in frequency over the past ~1 million years



In summary, **stable isotopes** of oxygen and carbon preserved in the calcite shells of fossils, including planktic and benthic foraminifers, are useful proxies for global environmental change. These types of analyses have revealed many fundamental processes of the coupled ocean-climate system, including the importance of **orbital forcing** of climate change, as well as the magnitude of ancient global environmental change. The exercises that follow will explore multi-proxy data, including stable isotopes, to address an example of abrupt global change 55 million years ago called the **Paleocene/Eocene Thermal Maximum**.