12.740 Paleoceanography
Spring 2008

PALEOCEANOGRAPHY 12.740 SPRING 2004 Lecture 1

MAJOR PALEOCEANOGRAPHIC AND PALEOCLIMATIC EVENTS OF THE PAST 2 MILLION YEARS

Although evidence for past climate is found on land as well, the longest relatively complete record of climate change is contained in deep-sea sediment cores. Although ice cores are short in duration and limited in geographic coverage, they are unparalleled in detail and in their ability to reconstruct past atmospheric composition. With sub-annual resolution, surface reef-building corals contain detailed information about tropical paleoclimate on times scale of decades to millennia..

Paleoceanography is a young science. For example, if you had been a respectable 'majoritarian' scientist of the year ____ you wouldn't have believed:

1850 Massive glaciers once covered the northern continents
1900 The earth is older than 20-40 m.y.
1950 There have been more than 4 major advances and retreats of massive continental glaciers in the last 2 m.y.
1965 Ice advances/retreats are paced by variations in the earth's orbit.

Most of the seafloor is <200 m.y. old; precious little is >100 m.y. This time scale sets the practical horizons of paleoceanography as most practitioners know it. Of course, oceans existed before then and some clues to them are preserved in rocks on the continent - but this is "geology" not paleoceanography; the tools and techniques available are completely different.

"Typical" oceanic sedimentation rates: 0.1 - 3 cm/10^3 yrs, so 500,000 years is represented by 0.5 m to 15 m (covered by piston cores); 100 my requires 100m - 3000m (covered by DSDP, especially hydraulic piston coring). Bioturbation of upper 3-15 cm reduces the time resolution obtainable from these sediments and induces artifacts of timing, precision, and magnitude.

PALEOCEANOGRAPHIC INDICATORS

I. Although paleoceanographers would like to be able to specify temperature, salinity, nutrient content, p_{CO_2}, etc., we can only know these indirectly through biological, chemical, and physical properties of sediments. How can we go about reconstructing these properties?

A. Physical paleotemperatures (e.g. oxygen isotopes) based on chemical/physical principles. Problems: assumption of equilibrium etc. may not be valid in low temperature and/or biological systems; isotopic composition of seawater must be known or assumed.

B. Bio-ecological paleotemperatures (e.g. Imbrie-Kipp method) based on modern-day correlations between temperature and the distribution of organisms in the ocean and in sediments. Problems: Correlation is observed, but causation is assumed but not proven (i.e. are population distributions really due to temperature tolerances of organisms?). How reliable is this assumption? Example: polar bears live quite well in the warm San Diego Zoo; the limit on their presence in temperate zones reflects not their temperature tolerances but rather their whiteness which aids their survival in the arctic. While it may be safe to assume that polar bears will not thrive naturally in warm climates, you have to be careful inferring temperature from their distribution. It is reasonable to expect that other factors are important to the distributions of organisms: light and nutrients (floral species); food availability and preferences (faunal species); ecological interactions (both).

C. Ocean paleochemistry: $\delta^{13}C$; Cd/Ca, Ba/Ca (tell us something about the distribution of nutrients and alkalinity in the ocean); carbonate dissolution indicators tell us about carbonate saturation in the deep ocean. Problem: reliability of tracers under certain conditions.

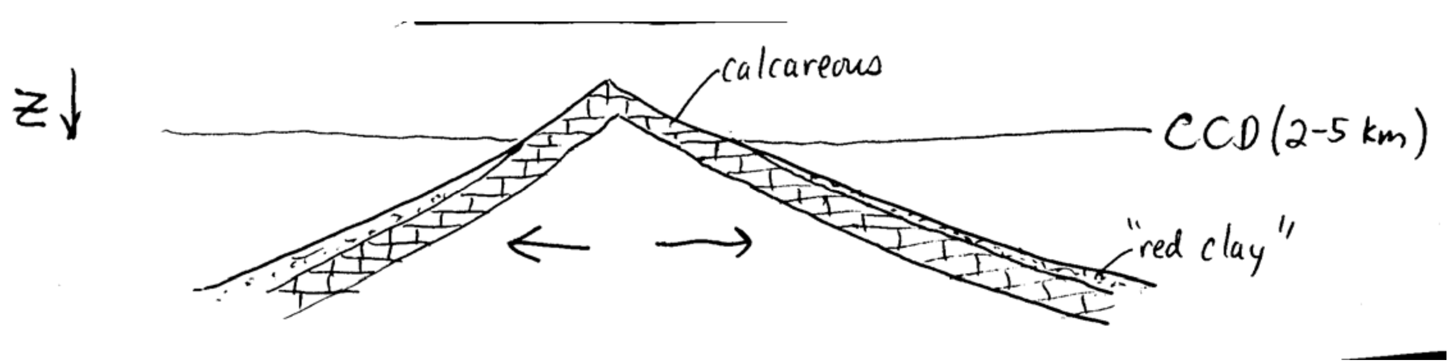
D. Terrigenous sediment sources: types of minerals; grain size; windblown materials vs. physical transport (water and turbidity currents); erosion.

E. Geological Time Scale: how do we determine time in geological systems? Most often, our direct information is spatial position: depth in ice or sediment core, etc.. Sometimes we have radioactive tracer information - e.g. ^{14}C, $^{230}Th/U$ - but these may need calibration or have accuracy problems. Most often, we determine time indirectly, via cross correlation. As the primary information on true time expands, the ages of our samples is altered as if it were written on a rubber band.

II. The "shifting paleotracer sand" problem: Paleo indicators rarely prove to be as simple as they are initially assumed to be, and sometimes their interpretation changes radically. In part, this arises from the indirect nature of the estimated properties relative to measured properties; in part, it arises out of the limited knowledge available at the time that a tracer is introduced. A certain measure of historical perspective is needed to understand the limits and capabilities of paleo tracers.

III. "50 Year Event" problem.

IV. Typical oceanic sedimentation pattern:



The study of paleoclimatology in deep sea cores requires stable indicators of past conditions and a reliable time scale. Carbonate fossils, esp. Foraminifera, provide most information - and are not found in deeper waters. This is a special case of a more general problem: the "paleoceanographic uncertainty principle": no record is left of some events.

A BRIEF REVIEW OF EVENTS OVER THE PAST TWO MILLION YEARS (AND THE EVIDENCE)

(1) The "Little Ice Age" (late second millennium); “Medieval Warm Period” (centered on end of first millenium

(2) 'Hypsithermal' ~8000 yrs b.p. - evidence: ^{14}C dates; sand dunes in Minnesota; oases and lakes in the Sahara; pollen in lakes and peat bogs

(2) Massive Continental Glaciation 18,000 years ago:

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Source: Imbrie and Imbrie (1979) Ice Ages: Solving the Mystery.

Evidence:

a) Glacial features on continents: moraines; scratches; drumlins; eskers; glacial rebound (link to earth's viscosity); viscous earth geodynamics. ^{14}C dating. But note: continental glaciation is self-erasing; very large glaciations tend to destroy evidence of previous smaller glaciation.

b) Oceanic faunal changes: T-correlated foraminifera and radiolaria: cooling of high-latitude North Atlantic; 5° latitude equatorward shift of Antarctic Circumpolar Front

c) Sea level evidence: ancient shore lines on stable and emergent islands

d) $\delta^{18}O$: in water vapor, a function of mean annual temperature - so ice deposited during glacials (still resident in Greenland and Antarctica) is isotopically depleted; annual cycles for exact and approximate dating; G/I variation.

e) Because of d), when there is a lot of ice, the oceans became isotopically heavier - this change is recorded in the $CaCO_3$ shells of forams: $\delta^{18}O_{foram} = \delta^{18}O_{water} + f(T) +$ species-dependent constant

f) Pollen - in peat bogs, lakes, and continental margin sediments

(3) Variations over the past 150,000 years:

a) Time scale: ^{230}Th ingrowth in corals, and interpolation between core top and Brunhes-Matayama magnetic reversal (780,000 years)

Major features:

b) Neither present nor glacial maximum are typical of last 135,000 years; climate has varied between these extremes in no simple pattern:

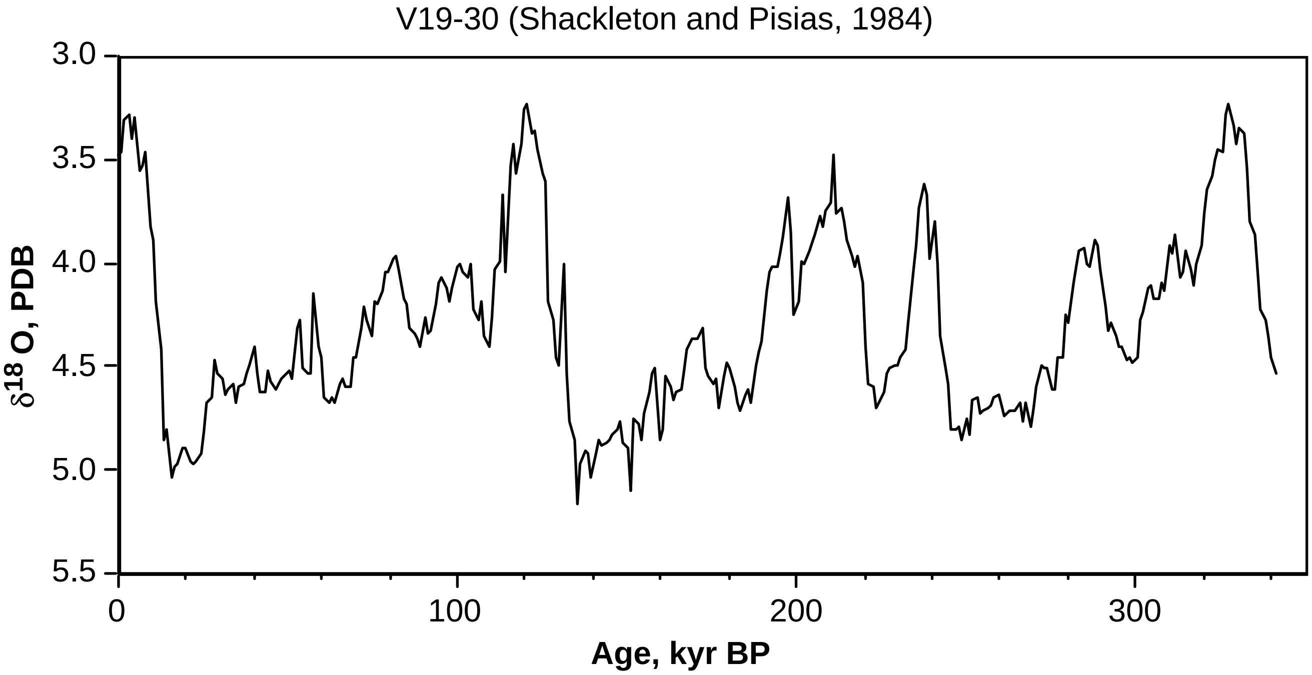
0 - 11 'Interglacial'
11 - 73 'Glacial' (with 28-62 somewhat warmer)
73 - 127 'Interglacial' (with three peaks, and only ~123k comparable to present)
127- 187 'Glacial'

Emiliani's ^{18}O Stage notation

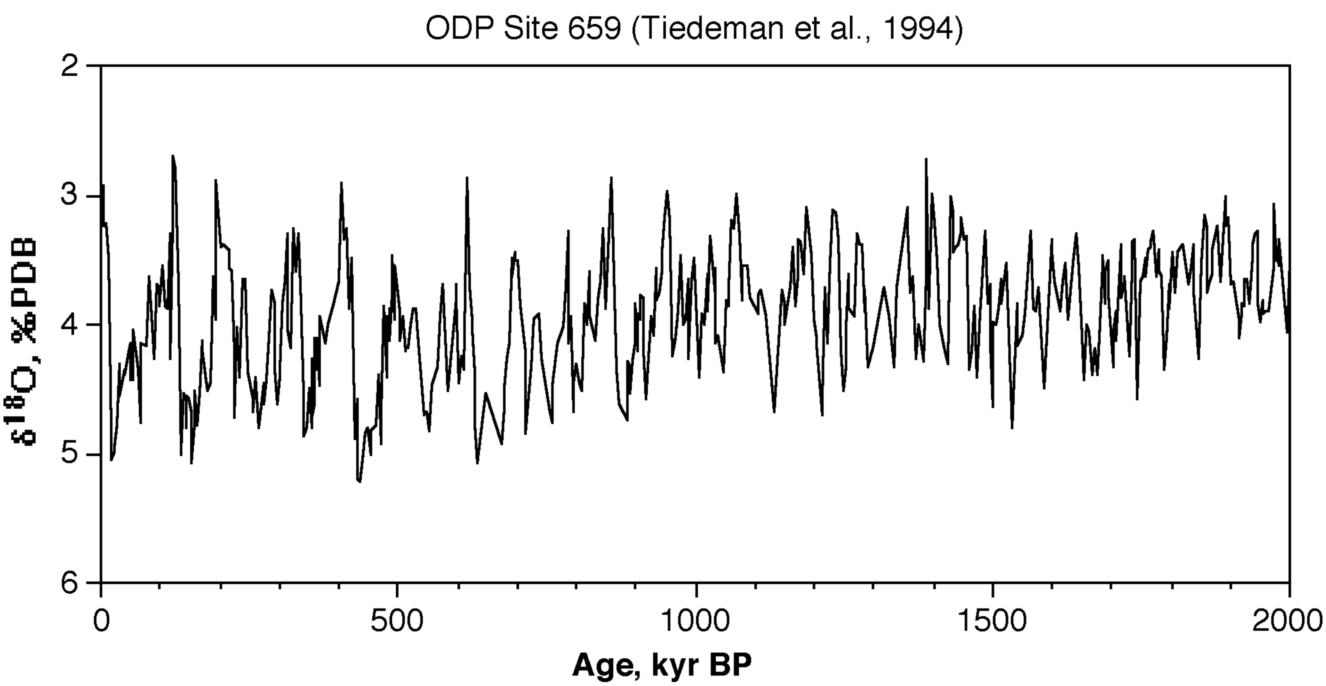
Seeming correlation with insolation record

c) Abrupt climate change during the past 110,000 years: Stadial/Interstadial transitions.

(3) Past 350,000 years: 3 major cycles



(4) Past 2 million years: several more cycles, then less variability, transitioning into the "40K world"



Cenezoic Benthic O18

Image removed due to copyright considerations. Please see:
Zachos, et al. *Science* 292 (2001): 688.