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12.740 Paleoceanography
Spring 2008

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INTRODUCTION TO CENOZOIC PALEOCEANOGRAPHY

I. Changing continental positions: given typical spreading rates:

$$(\sim 4 \text{ cm/yr})(10 \times 10^6 \text{ yr}) = 400 \text{ km}$$

A. Changing shape of ocean basins

B. So: ocean currents and property distributions must have been quite different in the distant past

1. e.g.: Antarctic Circumpolar current could not have been present prior to Australia-Antarctica separation (about 38 m.y.); Drake Passage. Isthmus of Panama open 10 m yr ago. Tethys (proto-Mediterranean) connected to open ocean.

2. Sites of bottom-water formation are likely to be different.

C. Paleocontinent reconstruction. Poles of rotation: Estimated from transform faults; magnetic anomalies; "hot spot" island chains; sedimentary paleomagnetism; paleoequators from sediment composition and deposition rate; continental climate indicators and igneous paleomagnetism.

D. Age-depth relation and paleo-depth backtracking

1. The depth of the seafloor (regionally averaged) is a function of the age of the ocean crust.

a. Relationship is due to conductive/advective loss of heat by lithosphere: thermal contraction results in density increase.

b. Until approximately ~70 my, depth of the seafloor increases linearly with respect to the square root of the age of the seafloor.

c. Beyond 70 m.y., underlying diffusion of geothermal heat in is balanced by heat diffusion out of the sea floor, so it does not get much deeper until it reaches a subduction zone.

2. Paleo-depth backtracking

a. In order to make oceanic reconstructions for the distant past, especially for properties such as calcium carbonate which are known to be depth-dependent, we must compute the paleo-depth

b. The age-depth relationship is for the regional topography; seamounts and other small-scale features do not conform to this relationship. Since real DSDP sites are going to be local, not regional, what is the best way to estimate the paleo-depth of that site?

(1) Assumption: local isostatic compensation (i.e. while the site may be above or below the regional average, the site will maintain its elevation difference relative to the regional average).

c. Also need to correct for sediment loading: as the site accumulates sediment, the seafloor is depressed isostatically by the additional loading.

- d. To a first approximation, all of these things can be handled reasonably well by simple approximations.
- e. Aseismic Ridge problem (e.g. Rio Grande rise; Walvis Ridge)
- 1. Although the origin of aseismic ridges may still be arguable, it is reasonable to assume that they originated on the ridge crest as hot-spots which reached the surface ocean. Normal weathering planed them down to the sea surface upon the termination of volcanic activity (as the site migrated away from the ridge crest), and as the seafloor subsides, the aseismic ridge subsides along with it.
- f. Originally, it was hoped that paleo-depth reconstructions would be useful in determining the age of opening of "oceanic portals" (i.e., the time at which ocean bathymetry in bottlenecks (e.g. Vema Channel; Antarctic-Australia) became appropriate for the passage of deep waters). It turns out that the timing is too sensitive to local topography to provide precise evidence; the geological data from DSDP sites is more informative than the paleobathymetric reconstructions. Nonetheless, the generalized paleobathymetry provides a useful backdrop for interpreting the geological evidence for changes in oceanic circulation.

II. Cenozoic Time Scale

A. Principal constraint: paleomagnetic time scale linked to radiometric dates

- 1. Radiometric dates come from K-Ar, Ar-Ar dating of lava flows, mainly (esp back to several million years ago).
- 2. Older dates were previously mainly based on extrapolation assuming constant spreading rates for a particular ridge (Hiertzler et al. time scale). This assumption can be modified by supplemental radiometric dates, but these are few and far between (LaBrequé et al; Kent et al; Berggren et al).
- 3. Main problems
 - a. Limited resolution: reversals typically occur every million years (on average; "Cretaceous Quiet Zone" has no reversals from from 90-120 m.y.)
 - b. Difficulty of recognizing reversals: all we can really say is that a given zone is normal or reversed; it can be difficult to know which normal or reversed zone it is, particularly in discontinuous sections (due to coring problems or hiatuses).
 - c. Some sediments are poor recorders of paleomagnetic records (e.g. high percent carbonate).

B. Biostratigraphy: first appearance and disappearance of species

- 1. Disadvantages: species appearance or disappearance may be time-transgressive; reworking of older fossils; selective preservation and "Lazarus species"
- 2. Advantages: unlike on-off paleomagnetic events, these are one-time only events, so they immediately place one in a specific time frame.

3. Appearance/disappearance events are typically one per million years, so resolution is comparable to paleomagnetic stratigraphy.
- C. There are almost no direct radiometric methods for dating DSDP sediments. People have tried K-Ar dating of ash layers (but these have proved unreliable due to diagenesis); ^{10}Be , ^{26}Al have some uses (e.g. accumulation rates of red clays), but are not precise chronometers because of their geochemical behavior. Basaltic basement can be dated by Rb-Sr in celadonites, but precision is limited.
 - D. Sr-isotope stratigraphy
 1. Sr isotopic composition of seawater is recorded in fossil carbonates. Since seawater composition changes from $\sim .7092$ today to $\sim .707$ at 45 m.y., Sr isotope curve can be used as a relative method of dating, with perhaps somewhat better than 1 m.y. time resolution. Problems: sedimentary diagenesis; linkage to absolute time scale; only works for carbonate phases (or others which incorporate only seawater Sr).
 - E. Carbonate stratigraphy: As in the Quaternary, there are systematic regional variations in the carbonate content of sediments; hence these can be used as a method of cross-correlating regional cores. Problems: the curve to be expected is not always well known; aliasing due to insufficient sampling frequency.
 - F. Orbital stratigraphy: evidence for Milankovitch cycles in older sediments is taken as "tree ring" chronometer to at least match the pacing of obliquity/precession cycles, sometimes using the envelope of precession and obliquity cycles. Orbital calculations are now "decent" back to perhaps 10-20 my, and beyond that at least the basic cycle lengths remain constant. Examples: Hilgen (1991), Pälike et al. (2001)
 - G. Others: fish-teeth (Sr isotopes; may be open system); trace fossils
 - H. At present, the most reliable stratigraphy is based on the combination of paleomagnetic and biostratigraphic information on several classes of organisms, with orbital tuning, preferably in continuous, multiple hole hydraulic piston core sites.
- ### III. Major features of the paleoclimate history of the Cenozoic
- A. Onset of Northern Hemisphere glaciation, 2.75 ma
 - B. "Climatic deterioration" over the last 65 m.yr.: High latitude, deep water temperatures were warmer in the past; shift to colder T both through slow, continuous change and through a number of major "events" of sudden change. Originally: Kennett and Shackleton (1977); updated by Zachos et al. (2001).

Cenezoic Benthic O18

Image removed due to copyright considerations.
Source: Zachos et al. (1991).

C. Problem: what is the history of Antarctic ice volume?

D. Some other interesting events:

Aptian “anoxic oceans” (high organic carbon sediments): was ocean anoxic?

Paleocene-Eocene Thermal Maximum (PETM, also known as LPTM): Methane hydrate “burp”?

Mediterranean desiccation ~ 6 ma

K-T impact 65 ma

IV. Paleocarbonate history of ocean basins: CCD reconstructions using paleo-depth backtracking.

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