MILANKOVITCH TUNING AND A TIME SCALE FOR THE QUATERNARY

THE QUATERNARY AND ITS LESSONS

OUTLINE OF TOPICS DISCUSSED

Section Q1

- Ice Ages: a brief overview
- Ice Ages: important discoveries
- The question of cyclicity
- The Albatross Expedition and its pioneers
- Emiliani: laying the foundations

Section Q2

- It is getting warmer
- Possible responses of the ocean
- Responses within the ice ages

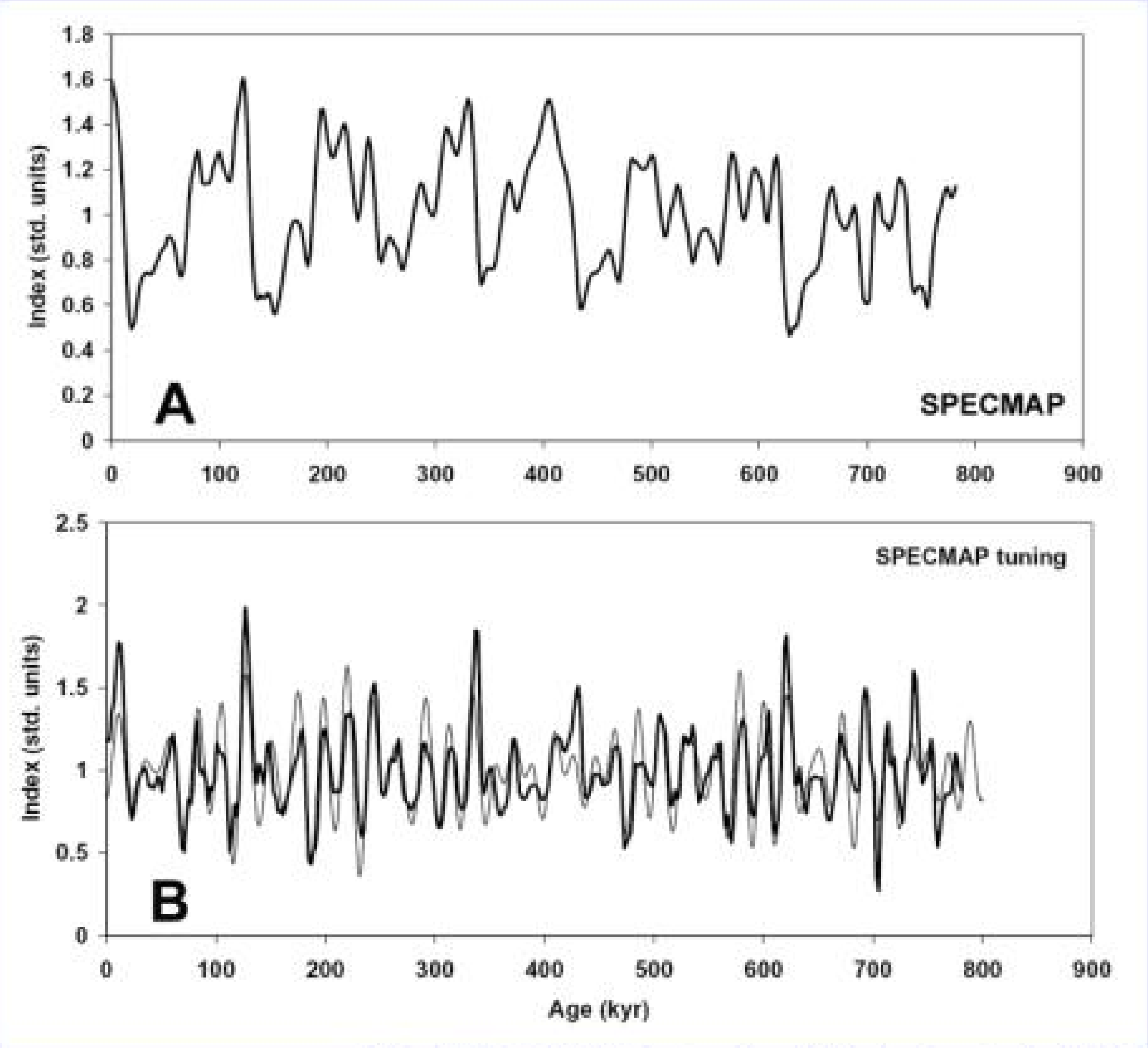
Section Q3

Milankovitch and the Time Scale

Section Q4

- Deglaciation and potential rates of sea-level rise

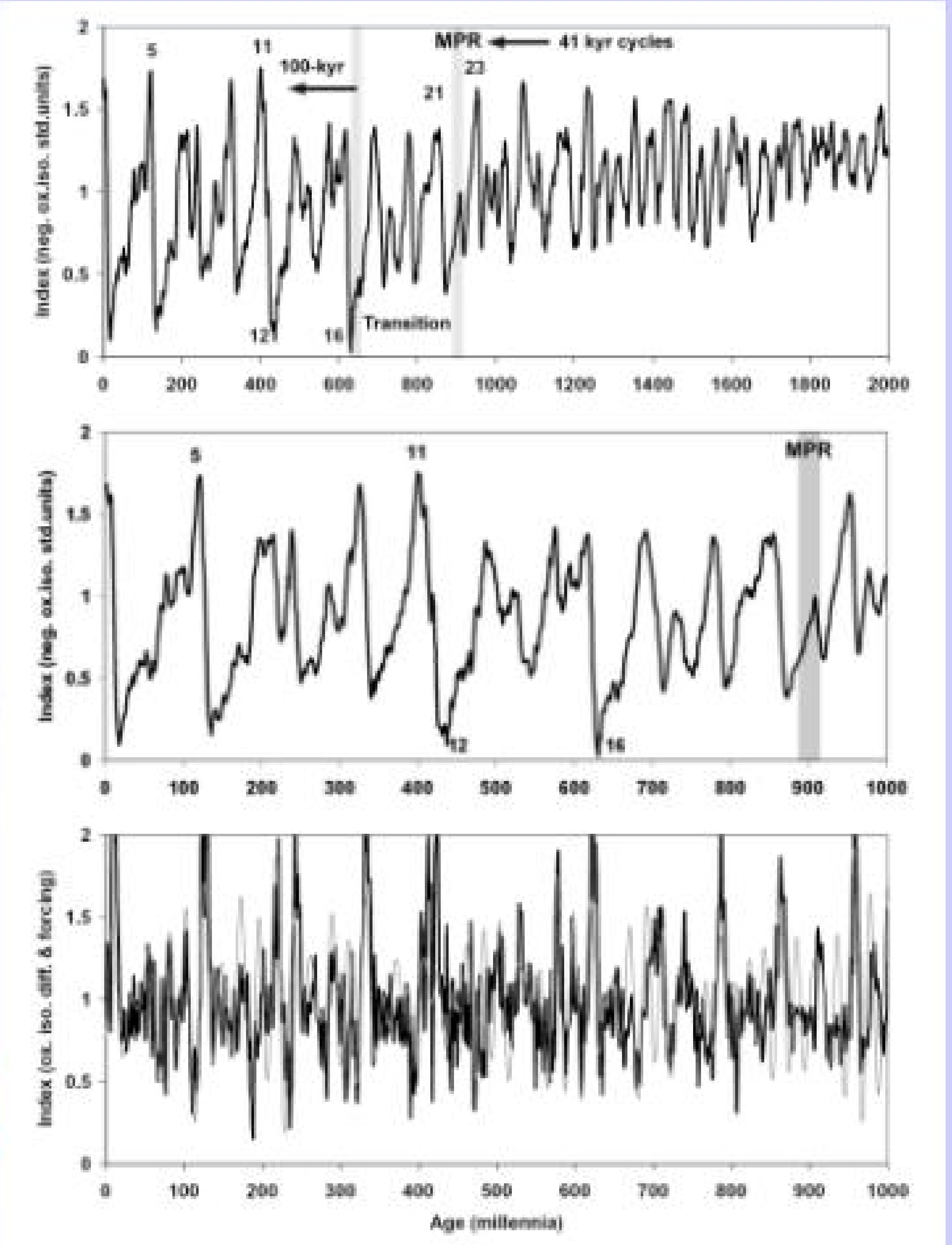
Tuning of the deep-sea record is pervasive. A simple way to check on its presence is to compare the first derivative of the record with the series of the forcing function (summer insolation, high northern latitudes).



The SPECMAP standard (Imbrie et al. 1984, **A**) and its derivative (**B,** heavy black line), which closely matches Milankovitch forcing (thin gray line). All series were converted to standard units, with mean=1 and standard deviation equal to 0.25. Milankovitch forcing from A. Berger.

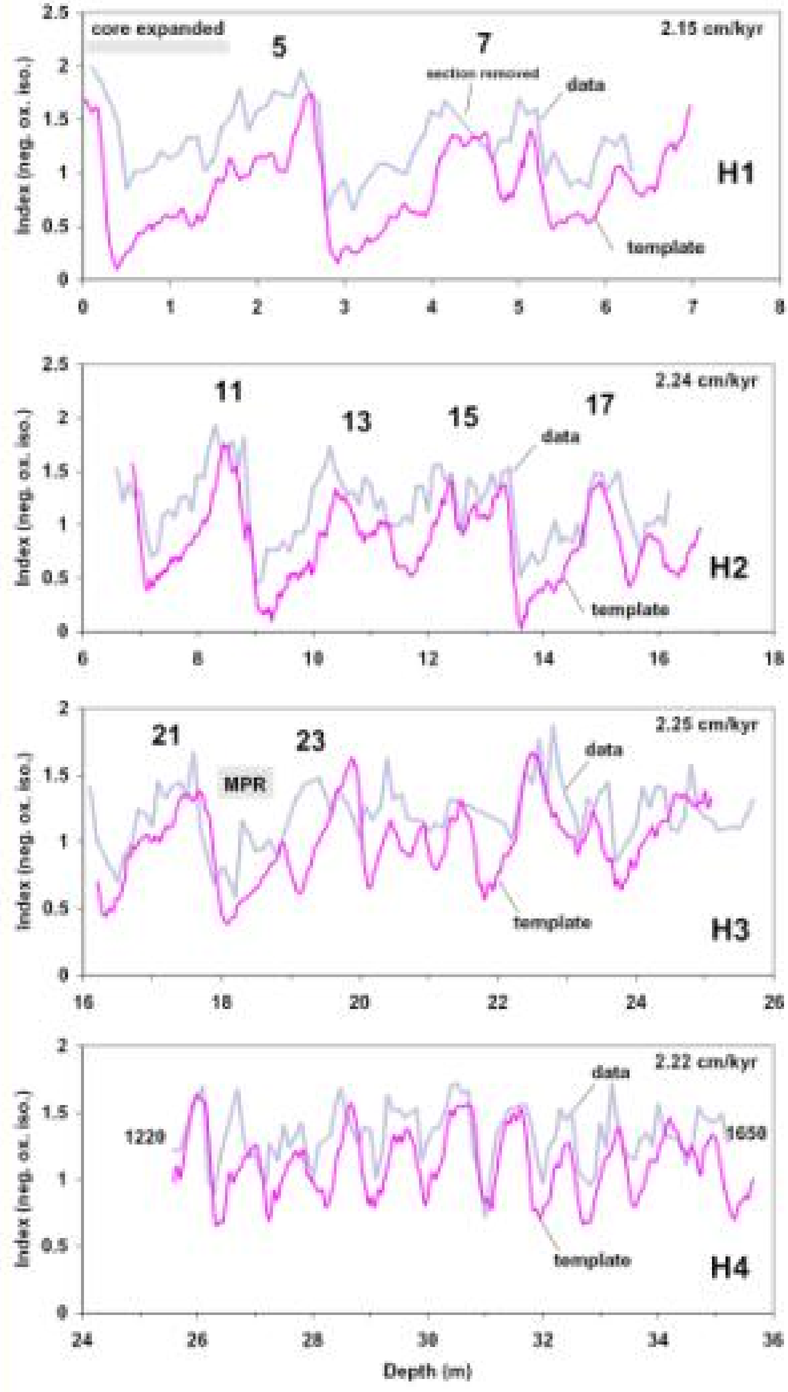
The most widely used standard is the one by Shackleton, A.Berger, and Peltier, 1990 (based on tuning the Site 677 record).

Recent compilations are by Zachos et al. (2001) and by Lisiecki and Raymo (2005). These are here combined to yield a general curve for the Quaternary.



Standard oxygen isotope record for the Quaternary, based on compilations by Zachos et al. (2001) and by Lisiecki and Raymo (2005). Upper panel, 2 million-year record, at steps of 1 kyr. Note the overall pattern; numbers refer to Marine Isotope Stages. Middle panel: same series, 1 million years only. Bottom panel: comparison of numerical differences (heavy line), and comparison with the presumed forcing function (July insolation, 65ºN, in A. Berger and Loutre, 1991; thin gray line), showing presence of tuning in the record. MPR, Mid-Pleistocene Revolution.

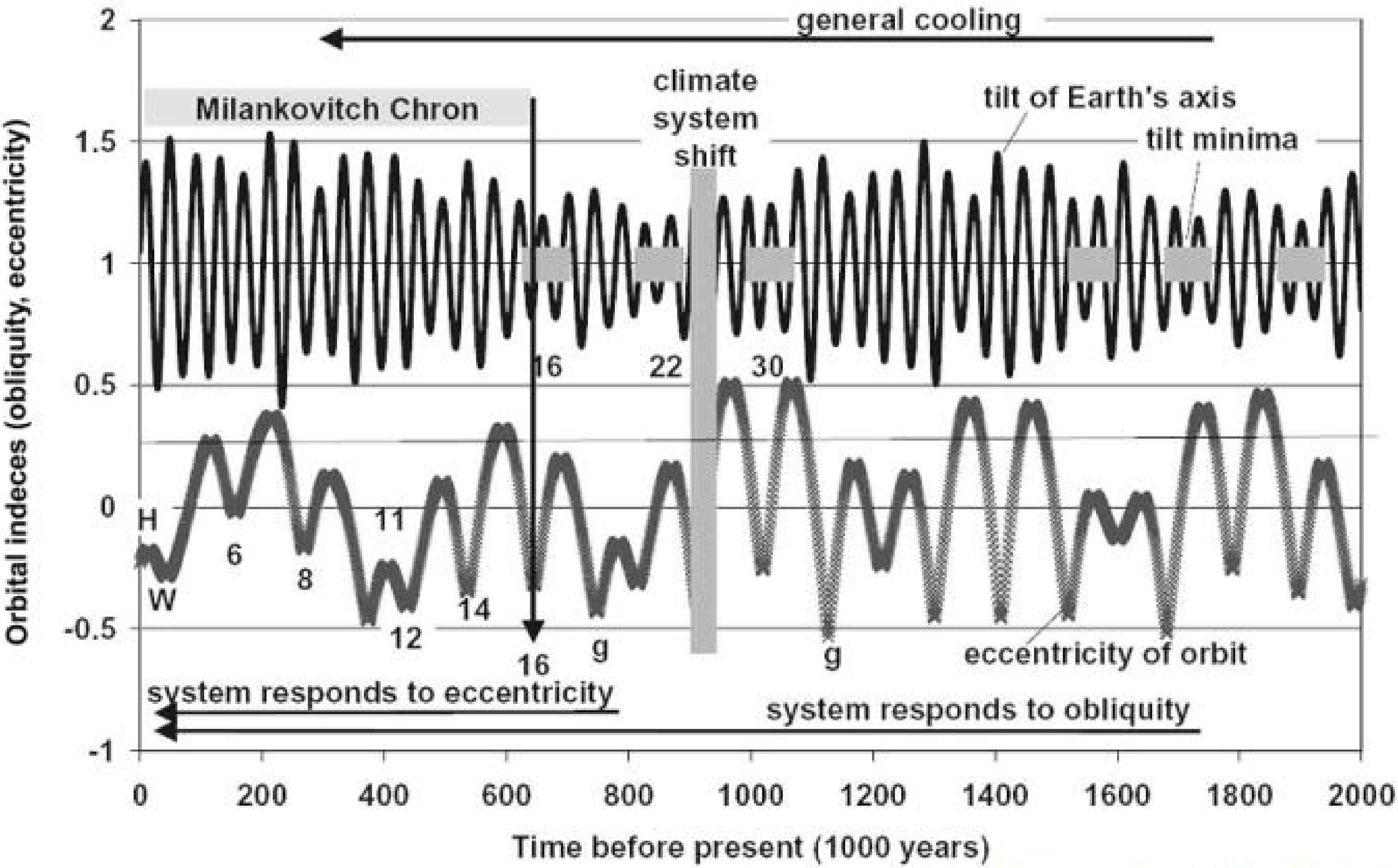
The worth of standards is in their usefulness in dating deep-sea records (whether they are tuned or not is a secondary issue). The tuned standard is indeed useful; thus, tuning is a valid approach to dating.



Evidence that the Zachos-Lisiecki-Raymo standard for Quaternary oxygen isotopes is useful: dating the record of Site 806B. H1, H2, H3, H4, successively deeper cores in the site; the deepest sample dates at 1650 kyr. Numbers are marine isotope stages. MPR, Mid-Pleistocene (climate) Revolution. The data from 806B are in Table 1 of Berger et al. (1993). The template is listed in the Appendix; it is based on compilations by Zachos et al. (2001) and by Lisiecki and Raymo (2005). The source of ages is in Milankovitch forcing (see A. Berger and Loutre, 1991).

By accepting Milankovitch forcing as the dominant element of controllling ice-age fluctuations, we obtain a precise dating tool, and also clues as to causes of climate shifts.

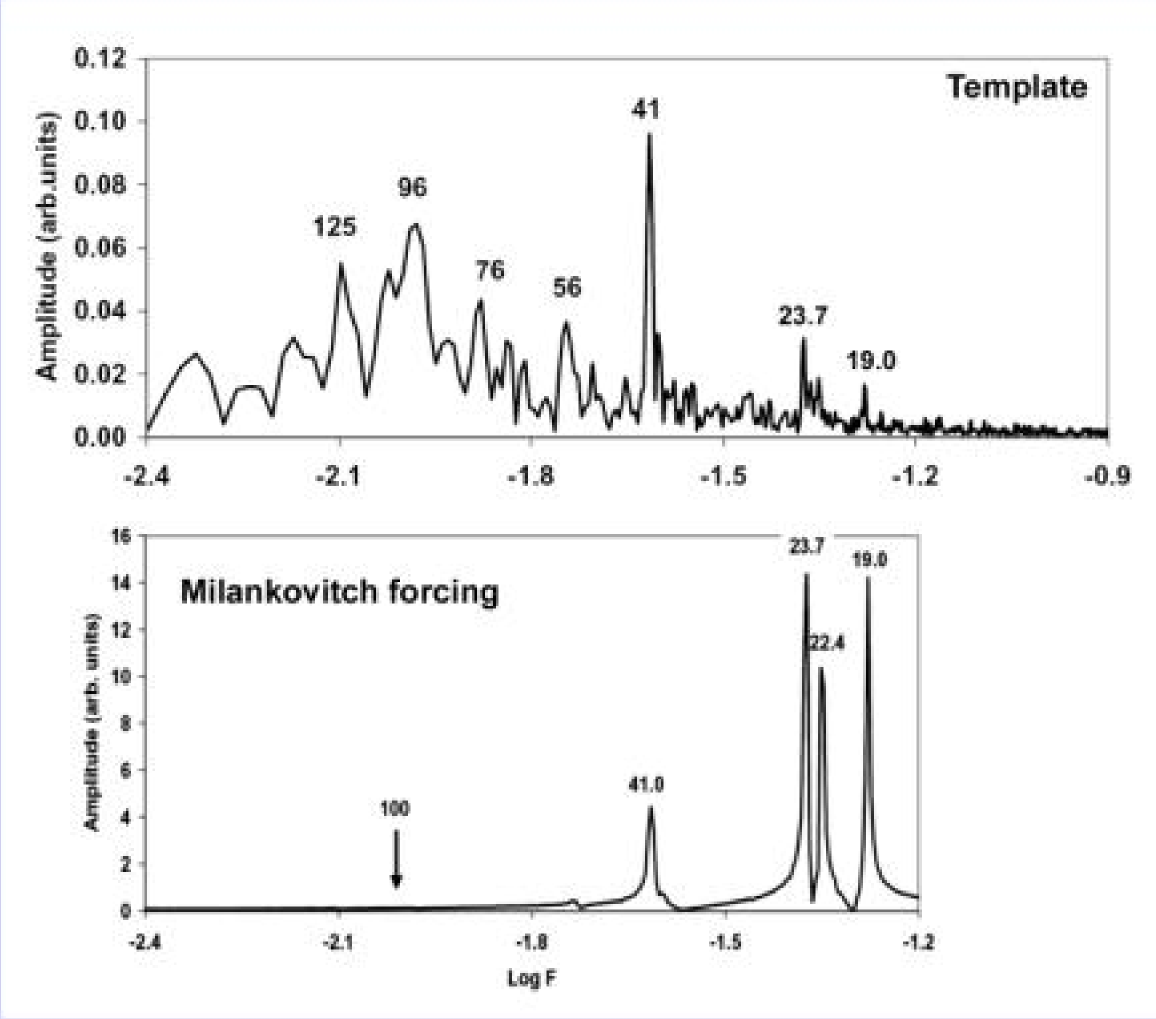
Not so incidentally, ice mass increase follows on minimum tilt and eccentricity



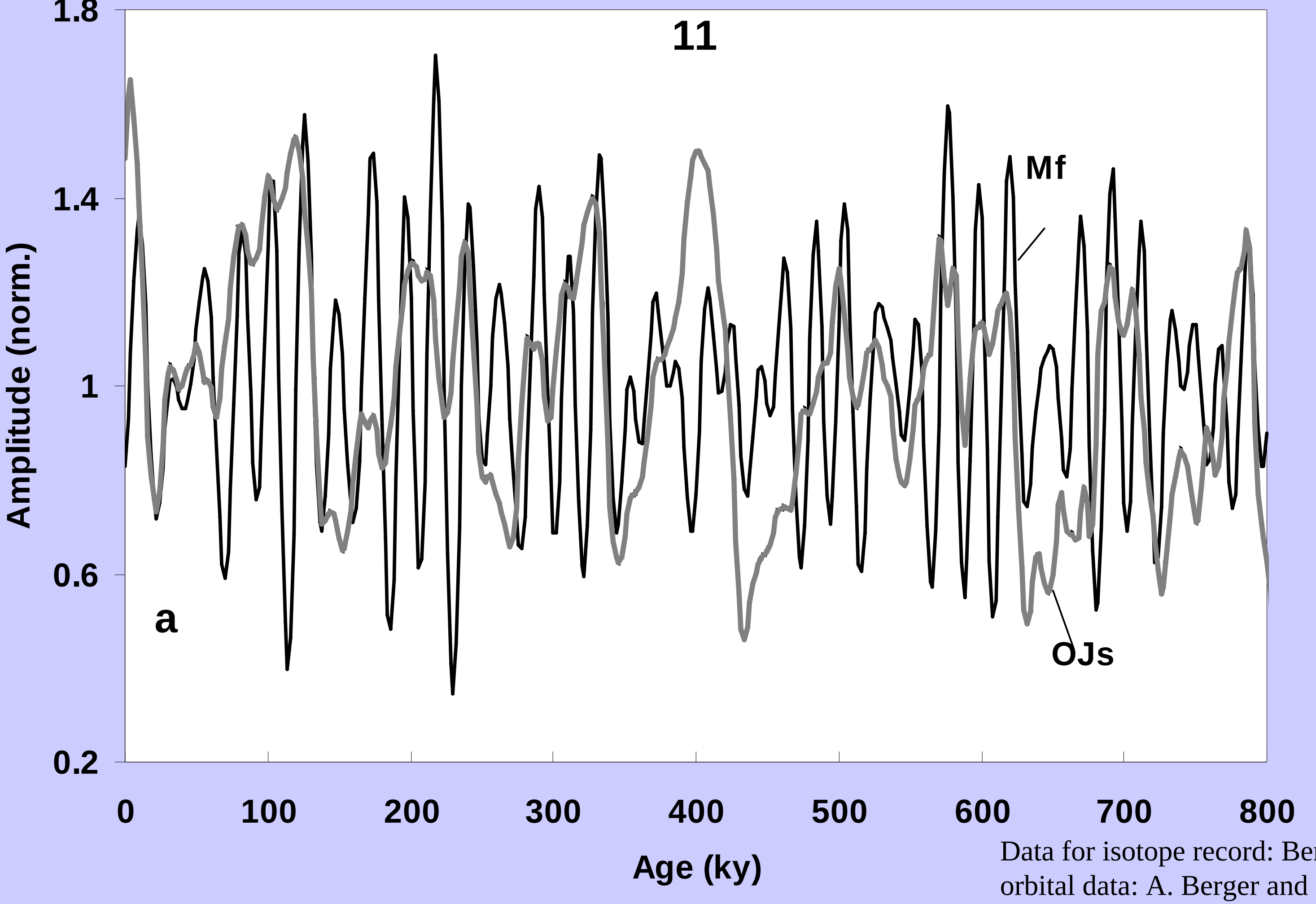
Orbital data from A. Berger & M.F. Loutre, 1991.

We have to be concerned about how to move energy from orbital forcing into the climate system. Obviously the process is complicated. It involves the suppression of high frequencies in favor of low ones.

Fourier spectra of the Quaternary isotope template (upper panel) and of the presumed Milankovitch forcing (lower panel; data in A. Berger and Loutre, 1991). Note the absence of forcing anywhere near 100 kyr.



When attempting to match oxygen isotope records to orbital forcing a la Milankovitch, it is soon discovered that there is something amiss: Stage 11 stands out like a sore thumb. Presumably the ice ages integrate the forcing and they oscillate while being forced (that is, there is lagged negative feedback in the system: big ice sheets promote further growth, but become unstable with time). Stage 11 reflects internal oscillation.

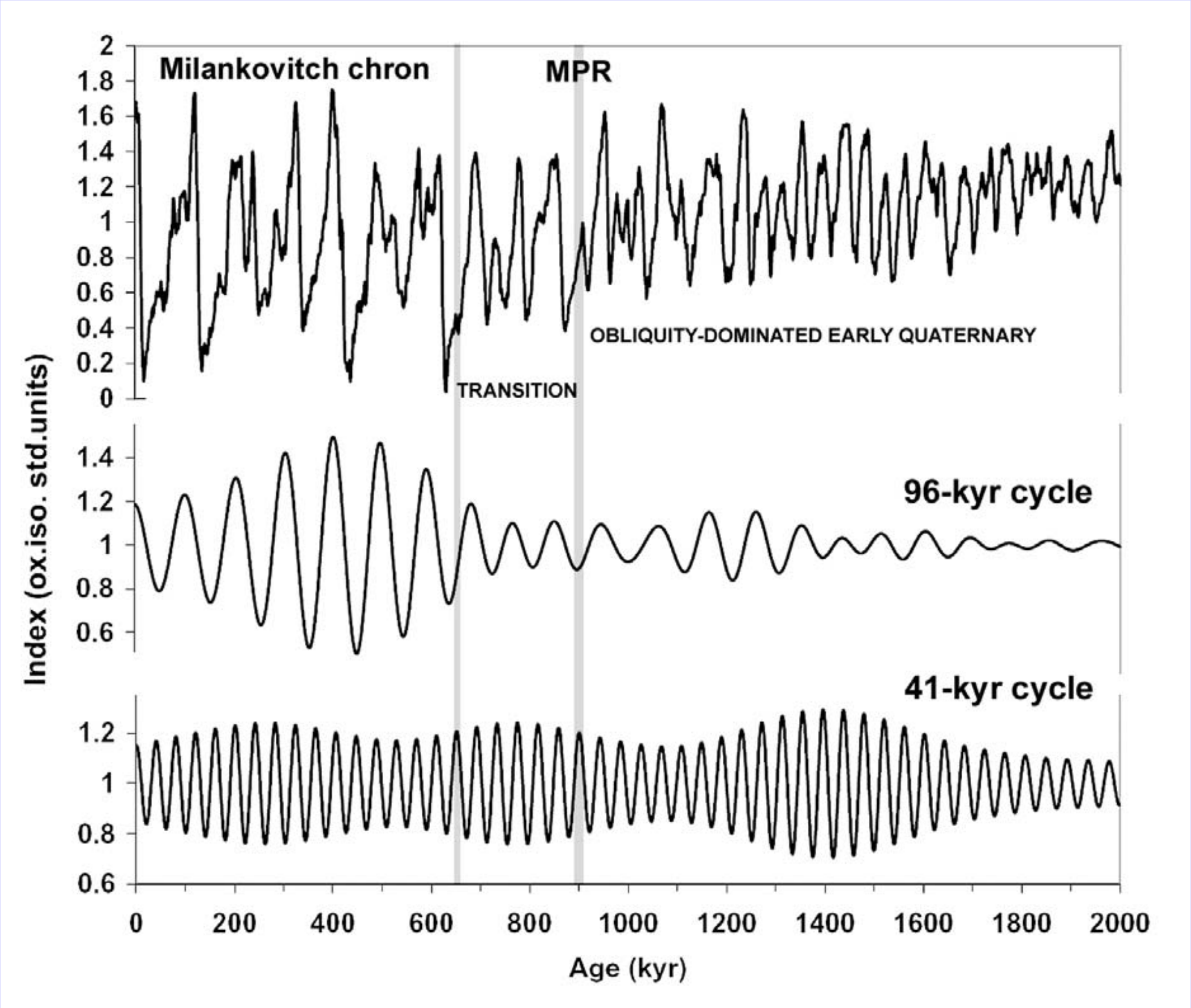


Comparison of tuned record and presumed forcing.

Note the glaring mismatch for Stage 11.

Data for isotope record: Berger et al. 1993, ODP Leg 130
orbital data: A. Berger and Loutre, 1991

The Stage 11 paradox flags a problem: the response to forcing, if any, is not as expected.

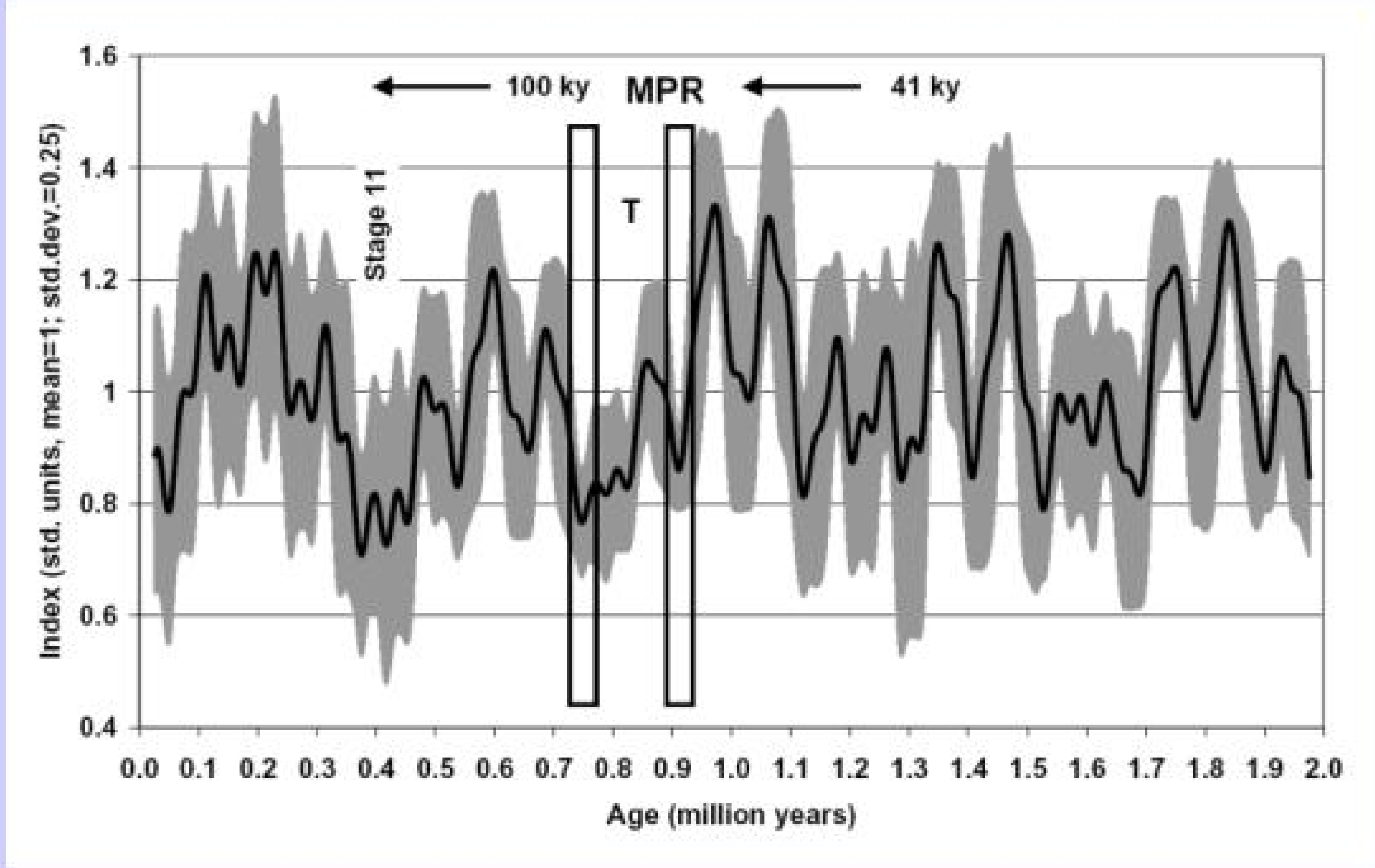


In addition, there is a major change in response at the MPR near 900,000 years ago: long cycles become dominant over 41-kyr cycles (although the latter persist).

Nature of the Mid-Pleistocene Revolution (MPR) in the ZLR template (standardized units of oxygen isotopes for the last 2 million years). Upper panel, template. Middle panel, 96-kyr cycle synthesized from Fourier elements (bandwidth 83.3 to 114.3). Lower panel, similarly synthesized 41-kyr cycle (38.1 to 44.9).

Isotope data Zachos et al. 2001, Lisiecki and Raymo, 2005, combined.

The cause for the MPR is not obvious. Apparently it is linked to a buildup of maximum ice mass at the time, presumably in response to a lack of strong forcing for summer warming (as seen in the orbital calculations).



Exploration of orbital forcing environment in the Quaternary, with emphasis on the MPR and its sequel. Heavy line: July insolation average for 50 kyr. Shaded: standard deviation about the average. Data from A. Berger and Loutre, 1991. The MPR coincides with the start of a time lacking strong forcing for summer warming.