Milankovitch cyclicity and stable isotope time scale calibration in the Paleogene: Challenges and Results

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Abstract:

Significant progress has been made over the last decade in the extension of astronomically calibrated geological time scales for the Neogene (Hilgen et al., 1999, Shackleton et al., 1999). The validity of these time scales has been supported by comparison of data from different parts of the world's oceans, through the improvement of astronomical calculations, and independent dating methods and intercalibrations (Renne et al., 1994). While evidence of astronomical forcing has been found for intervals from most parts of the Cenozoic, extending astronomically calibrated time scales into the Paleogene faces some fundamental problems that require a different approach than the sophisticated "pattern matching" that worked so well for the Neogene. These challenges are related to uncertainties and limits of astronomical calculations, sparser data coverage, and a climate system that behaved quite differently to today's "ice-house" setting. This contribution reviews some of the challenges that will have to tackled, presents a new set of astronomically calibrated benthic isotope data from the late Eocene, and suggests a new approach to synthesise astronomically calibrated durations for magnetic reversals that arise from floating time scales, which are so far more common in the Paleogene.

Challenges and limits of astronomical calculations for time scale use:
One crucial challenge that is faced when tackling the astronomical calibration of the geological time scale is the fact that the Solar System is chaotic, limiting the age back to which one can compute astronomical solutions with confidence (Laskar, 1999). Thus, one has to constrain astronomical parameters from the rock record. Apart from tidal dissipation effects, which change the detailed interference of particularly obliquity and climatic precession cycles, a larger scale effect is more directly linked to the chaotic nature of the Solar System: amplitude variations of the obliquity and climatic precession cycles with periods of ~1.2 and ~2.4 million years can be affected by chaotic transitions in the planetary solutions. This contribution will review the effects these chaotic transitions can have on astronomical "target" curves, particularly during the Paleogene, and why astronomical time scale calibrations will have to take this into account.

Astronomically calibrated stable benthic isotopes from the Eocene:
High-resolution lithological proxy measurements from ODP 1052 in the western Atlantic (Pälike et al., 2001) have provided duration estimates for magnetochrons from the late middle Eocene. This contribution presents high-resolution benthic stable isotope measurements from the same location. The astronomically calibrated isotope measurements co-vary with the lithological measurements and the astronomy in the obliquity frequency band, documenting the interaction of astronomy and climate during this transition from the Paleogene "green-house" world to the Oligocene "ice-house" world (Figure 1), and significant events that were not recognised in previous, lower resolution studies.

Integration of floating time scales with magnetostratigraphy:
The geomagnetic polarity time scale (Cande & Kent, 1995) incorporates astronomically calibrated ages back to 5.23 Ma. Recent results have changed significantly the age of the Oligocene/ Miocene boundary (Shackleton et al. 1999, 2000). These changes, which we will show have now been corroborated by results from ODP 199, need to be incorporated into the astronomically calibrated polarity time scale. We present a new approach, using a combination of calibrated absolute ages, and constraints on sea-floor spreading rates obtained from astronomically calibrated magnetic reversals from floating time scales, to compute a consistent set of spline interpolated ages for sea-floor magnetic reversals. This approach allows us to incorporate durations of magnetic reversals that result from the floating time scales more common in the Paleogene so far. First results, constrained by results from ODP 1218 in the Oligocene, and ODP 1052 in the late middle Eocene, suggest that the Eocene/Oligocene boundary age could be slightly older than previously estimated. It is suggested that this approach might be a useful first step to integrate astronomically calibrated ages from the Cenozoic until a full coverage, with independent data from different ocean basins, becomes available.

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Figure 1: ODP 1052 stable isotope record from *Cibicidoides* spp. and *Nutallides truempyi*, and XRF Ca/Fe ratios, on the time scale of Pälike et al. (2001). All isotope data were corrected for sea-water disequilibrium using species specific adjustment factors. Also shown is the age adjusted data compilation of stable isotope data from Zachos et al. (2001).

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