Astrochronology of the Cenozoic Era: A Critical Review*

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Abstract

The global stratigraphic record of Milankovitch cyclicity within oceanic sediments has been compiled for almost 100% of the Cenozoic Era. This cycle stratigraphy record provides a continuous “Astronomical Time Scale (ATS)” for the Era that includes integration with magnetic stratigraphy, biostratigraphy, and geochronology from formations in the western Equatorial Atlantic Ocean and Mediterranean Sea. This ATS has been correlated to a high-precision model of the Earth’s astronomical parameters, the nominal La2004 astronomical model (Laskar et al., 2004), thereby placing numerical ages on each major cycle and calibrated event. The building of this ATS took place over many years, including the landmark “Astronomically Tuned Neogene Time Scale (ATNTS)” with a resolving power finer than ~20,000 years through the majority of the Neogene Period that was implemented in the Geologic Time Scale 2004 (GTS2004) (Lourens et al., 2004). Since 2004, additional astrochronologic scales developed from extended cyclic sedimentary sequences drilled by the Ocean Drilling Program have closed gaps in the early Neogene and extended the scaling to the base of the Paleogene Period. The only significant remaining gap is an 11 million year interval spanning the Early Eocene Climatic Optimum (42 to 53 Ma), which is the focus of IODP Expeditions 320-321 in the equatorial Pacific (during the time of this AAPG meeting). Despite this gap, the early Paleogene ATS is anchored in absolute time by using recalibrated Ar-Ar ages for the base-Cenozoic that are tied to longer-term 405-kyr astronomical cycles. In early 2008, the pan-European Earthtime-EU Project initiated activities to further improve the Cenozoic ATS. This involves, among other things, fine-scale ATS inter-calibration with high-precision radioisotope dating, and advanced modeling of geodynamic variables (e.g., tidal dissipation) that are used in the astronomical solution. The community goal of a robust ATS with calibrated ages for all biologic, magnetic, and geochemical events through the entire Cenozoic is nearing fruition.
Earth’s Orbital Parameters

\[ \Pi = \Omega + \omega \]
Earth’s orbital parameters and insolation

- 65°N summer insolation
- Precession index
- Obliquity
- Eccentricity

Time (Ma)

Watts/m²

Opening remarks
Cenozoic overview
Eocene Green River
K/T boundary
BREAK
Cretaceous ATS
Jurassic ATS
Solar System Roadmap
Late Paleozoic ATS
Mars Cyclostratigraphy
ATS and the GTS

Methods used in GTS 2004:
- Composite standard
- Subzone scaling
- Spline fitting
- Seafloor spreading
- Direct dating
- Orbital tuning

- Cenozoic
- Cretaceous
- Jurassic
- Triassic
- Permian
- Carboniferous
- Devonian
- Silurian
- Ordovician
- Cambrian

Absolute and Floating Time Scales:

- Absolute
- Floating

Timeline:
- 2010
- 2011
- 2012
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INTRODUCTION

La2004
cyclostratigraphy

NEogene
Pleistocene
Pliocene
Miocene

PALEogene
Oligocene
Eocene
Paleocene

CONCLUSIONS

Late Miocene, Gibliscemi, Sicily

Late Pliocene, ODP Leg 160
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INSOLATION: \[ W = S_0 \rho^2 (\sin \theta \sin \delta + \cos \theta \cos \delta \cos H) \]
- cyclostratigraphy

Cenozoic coverage

The data
- stable isotopes (O and C) (forams)
- CaCO3, Fe, Ti/Al, Si (marine seds.)
- magnetic susceptibility
- lithofacies (e.g., sapropels)
Age model based on sapropel tuning to summer insolation with 3-kyr lag between maximum summer insolation and sapropel midpoint—based on radiocarbon age of Sapropel S1.  

Lourens et al. 2004
NEOGENE
• Pleistocene

Age model from a stack of 57 globally distributed benthic δ18O records tuned to a nonlinear (5 to 15 kyr lagged) ice model driven by 21 June insolation at 65ºN, based on La93(1,1), except 0-135 Ka which is calibrated to GRIP and U/Th dating of Termination II.

Lisiecki & Raymo, 2005

Agree to within 3 kyrs (Lisiecki older)

<table>
<thead>
<tr>
<th>REVERSAL</th>
<th>MIS</th>
<th>LOURENS ET AL.</th>
<th>LISIECKI &amp; RAYMO</th>
<th>Difference (myr)</th>
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<tbody>
<tr>
<td>Brunhes (b)</td>
<td>19</td>
<td>0.781</td>
<td>0.78</td>
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<td>28</td>
<td>0.988</td>
<td>0.991</td>
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<td>Jaramillo (b)</td>
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<td>1.072</td>
<td>1.075</td>
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<td>Olduvai (t)</td>
<td>63</td>
<td>1.778</td>
<td>1.781</td>
<td>-0.003</td>
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</table>
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- Pliocene
  Untuned Trubi Marls v. insolation

Window=250 kyr

Window=12 m (~270 kyr)


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Model comparison

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<tr>
<th>REVERSAL</th>
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<th>LISIECKI &amp; RAYMO</th>
<th>Difference (myr)</th>
</tr>
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<tr>
<td>Olduval (b)</td>
<td>74</td>
<td>1.945</td>
<td>1.968</td>
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<td>Matuyama/Gauss</td>
<td>G2</td>
<td>2.581</td>
<td>2.608</td>
<td>-0.027</td>
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<td>Kaena (t)</td>
<td>G22</td>
<td>3.032</td>
<td>3.045</td>
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<td>KM2</td>
<td>3.116</td>
<td>3.127</td>
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<td>Mammoth (t)</td>
<td>KM6</td>
<td>3.207</td>
<td>3.21</td>
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<td>Mammoth (b)</td>
<td>MG1</td>
<td>3.33</td>
<td>3.319</td>
<td>0.011</td>
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<tr>
<td>Gauss/Gilbert</td>
<td>MG12</td>
<td>3.596</td>
<td>3.588</td>
<td>0.008</td>
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<td>Cochiti (t)</td>
<td>GI27</td>
<td>4.187</td>
<td>4.184</td>
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<td>Cochiti (b)</td>
<td>Co4</td>
<td>4.3</td>
<td>4.306</td>
<td>-0.006</td>
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<td>Nunivak (t)</td>
<td>N1</td>
<td>4.493</td>
<td>4.478</td>
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<td>Nunivak (b)</td>
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<td>Sidufall (t)</td>
<td>Si2</td>
<td>4.799</td>
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<td>Sidufall (b)</td>
<td>Si6</td>
<td>4.896</td>
<td>4.898</td>
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<td>0.008</td>
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<td>Thvera (b)</td>
<td>TG2</td>
<td>5.235</td>
<td>5.254</td>
<td>-0.019</td>
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</table>

Avg. difference -5 kyr (Lisiecki older)
INTRODUCTION

Hilgen et al. 2007

- onset of MSC 5.96 Ma (not related to glacio-eustatic sealevel lowering)
- main desiccation phase coincides with twin peak glacials TG12-14
- evaporite cycles controlled by precession-forced climate.

CONCLUSIONS

Stronger obliquity forcing

Stronger precession forcing
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• Miocene

Calibration of sapropels to 65ºN summer insolation, Monte dei Corvi Beach, Italy.

Hüsing et al. 2009

The Tortonian section
at Monte dei Corvi.

Tortonian: 11.61-7.25 Ma
**Miocene**

Serravaillian: 13.65-11.61 Ma

*Hilgen et al. 2003*

- Individual sapropels are correlated to precession and 65°N insolation.
- Clusters correspond to short and long eccentricity.
- Interval with near-absence of sapropels corresponds to a 2.4-myr minimum in eccentricity (see green line).
- Tuned ages are 250-400 kyr older than argon-dated (in 1997) ash beds.

**NOTES:**

R=Respighi ash bed (Ar-dated: 12.85±0.15 Ma)
A=Ancona ash bed (Ar-dated: 11.4±0.25 Ma)
Circled numbers, letters = bioevents
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Green curve from Shackleton, 2001 (abstract), reported in Raffi et al. 2006.
Burgundy and orange curves from Holbourn et al., 2007

Raffi et al. 2006

ODP Site 1237
ODP Site 1146
ODP Site 925

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**Miocene**

Benthic stable isotope data from ODP Site 1090. *Billups et al. 2004*

Burdigalian: 20.43-15.97 Ma
Aquitanian: 23.03-20.43 Ma

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- Oligocene

Benthic stable isotope data from ODP Leg 199, Site 1218. *Pälike et al. 2006*
Late Eocene:

Leg 171B, Site 1052 (Blake Nose, Atlantic Margin, northern Florida).

High-resolution Ca/Fe chalk-rich series was tuned to ETP series with precession index reversed (to mimic Northern summer polarity).
But see M. Malchus, 2009
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独立的部分来自Zumaya (西班牙) — Dinares-Turell et al., 2007 and K. Kuiper, 2009
ONGOING WORK

Spring, 2009 -- IODP Expeditions 320/321: The Pacific Equatorial Age Transect (PEAT) targets the mid-Eocene from 42-53 Ma for astrochronology.
References


