Uncertainties of Extracting Amplitude and Frequency of Orbitally Driven Sea-Level Fluctuations from Shallow-Water Carbonate Cycles*

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Abstract

In the absence of an accurate age model, high-resolution chronostratigraphy of carbonate successions often relies on spectral analyses of cycle-stacking patterns and the comparison to the frequencies of orbital-forcing mechanisms. There is, however, overwhelming evidence in the modern and the Pleistocene of Great Bahama Bank that carbonate depositional cycles are unreliable recorders of both the frequency and the amplitude of orbitally driven sea-level fluctuations. This unreliability causes large uncertainties for forward modeling of reservoir units in shallow-water carbonates.

Uncertainties in the assessment of the amplitude are caused by unfilled accommodation space and the inability to measure the amount of sea-level fall in platform-top sediments. Unfilled accommodation space is not recorded in the strata. Likewise, the amount to which sea level drops below an exposure surface is not recorded in the stacked shallow-water cycles. As a consequence, carbonate cycles record only a fraction of the amplitude of a sea-level cycle: a portion of the rise and nothing of the fall.

Uncertainties in the frequencies are caused by the variable amplitude of sea-level change, producing "missed beats" on the platform, and meter-scale oscillations of sea level within highstands that potentially produce cycles of very short durations. "Missed beats", where a sea-level fluctuation is not recorded because the subsequent sea-level rise does not create accommodation space and a new cycle, occur preferentially during times of long-term sea-level fall but are also produced by the depositional topography that is created by the irregularly filled accommodation space. Furthermore, sea-level amplitudes based on the isotope record document random amplitude variability during the last 57 glacio-eustatic changes, complicating a model-based solution for capturing missed beats. In addition, suborbital oscillation of the sea level during highstands with amplitudes of up to 15 m produce cycles of short durations. Suborbital, intermittent sea-level oscillations during the last interglacial (MIS 5e) are documented in the Bahamas in stacked reefs, in repetitions of beach-eolian successions, and by subaerial exposure surfaces on subtidal facies.

The combined effects of missed beats and oscillations within highstands are difficult to extract from the rock record. Consequently, establishing a chronostratigraphic framework in carbonates based on astrochronology is full of uncertainty.

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UNCERTAINTIES OF EXTRACTING AMPLITUDE AND FREQUENCY OF ORBITALLY DRIVEN SEA-LEVEL FLUCTUATIONS FROM SHALLOW-WATER CARBONATE CYCLES

Gregor P. Eberli

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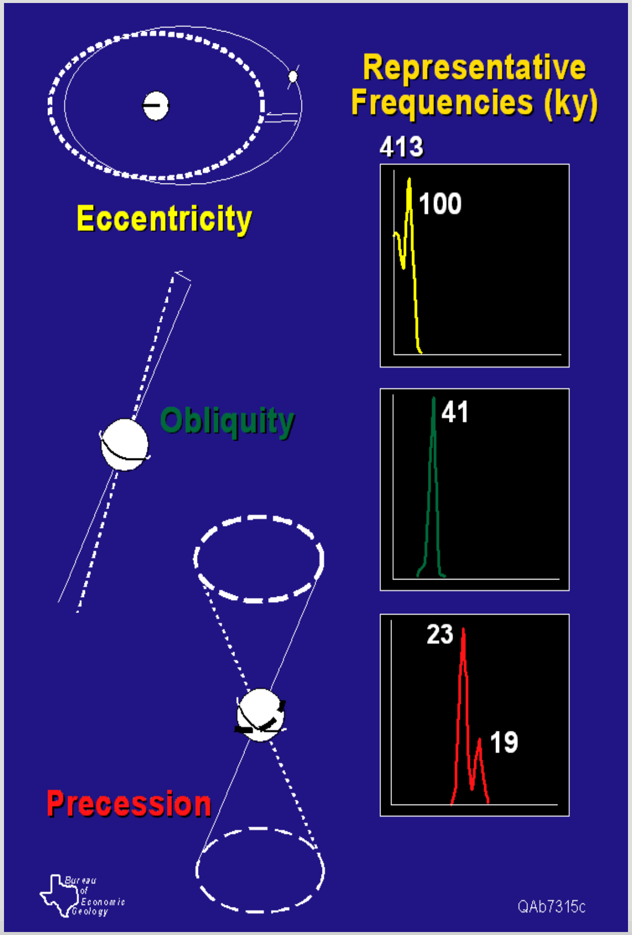
CARBONATE CYCLES AND ORBITAL FORCING



Assumption:

Precession (19 – 21 kyrs) is the highest recorded frequency

CARBONATE CYCLES AND ASTROCHRONOLOGY

Astrochronology is the dating of sedimentary units with calibration of astronomically tuned times scales, such as Milankovitch cycles.

“Some orbital eccentricity modes can be used for orbital-stratal calibrations to several hundred million years ago”

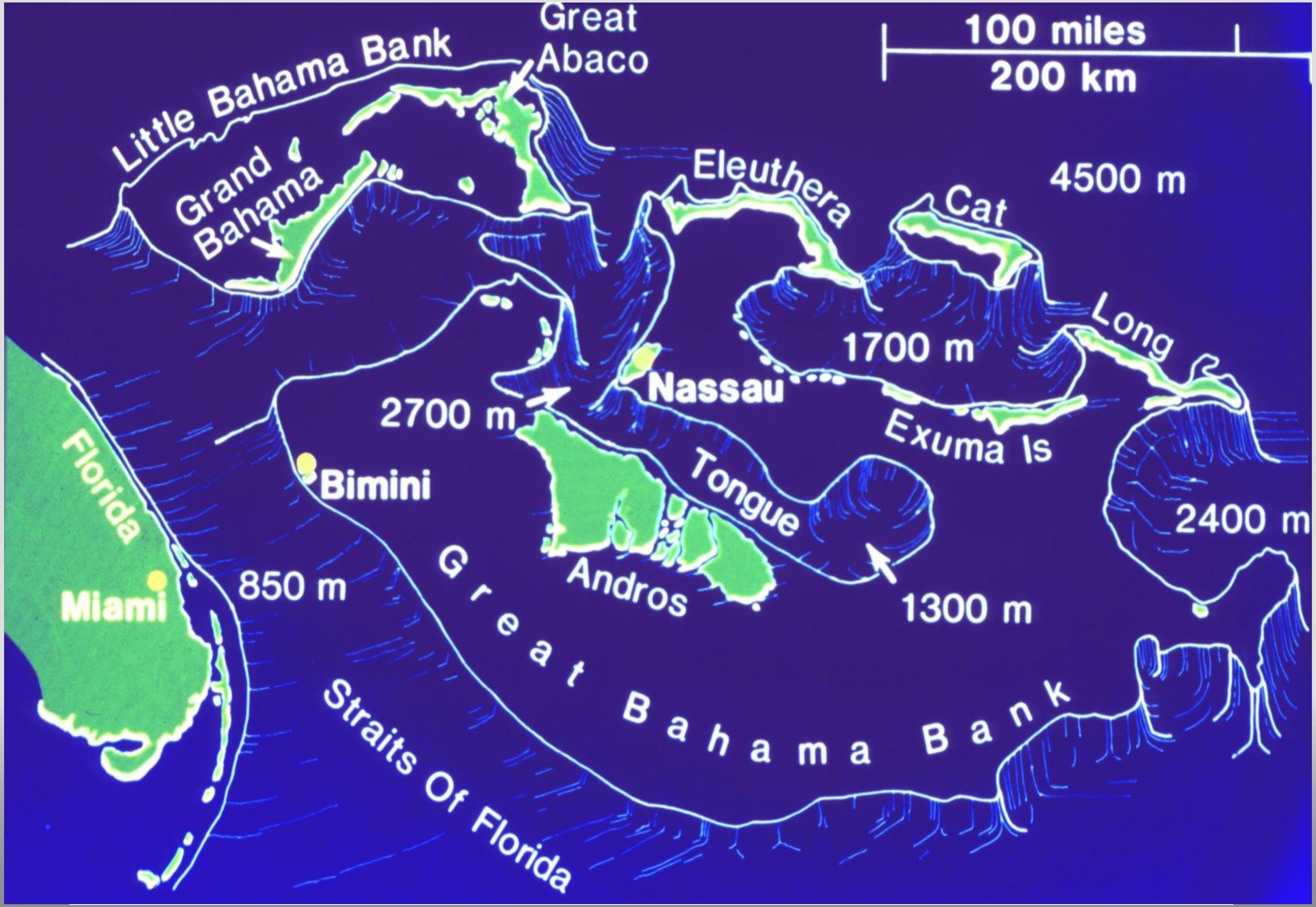
Hinnov 2000

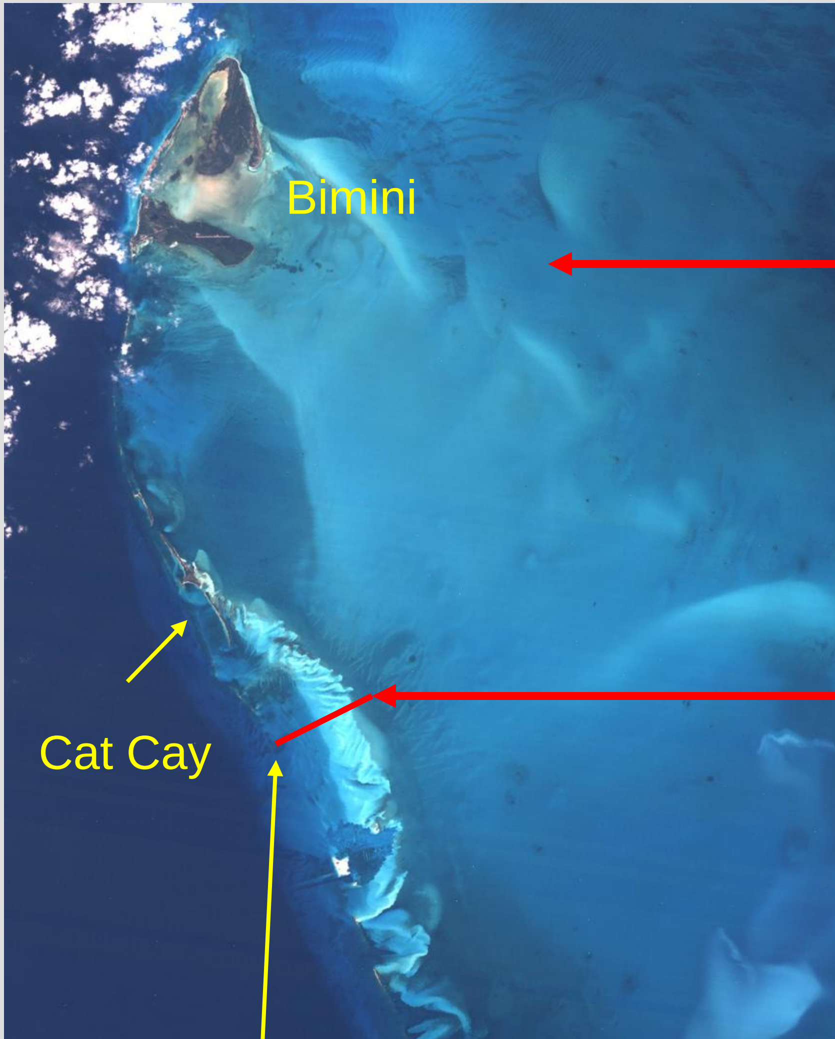
Key Points

Depositional cycles are unreliable recorders of amplitude and frequency of orbitally driven sea-level fluctuations because:

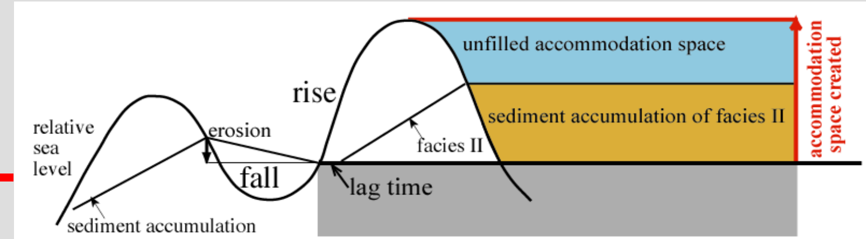
1. Amplitude is impossible to measure
2. Shallow-water carbonates have an incomplete record of sea-level changes
3. Sea level oscillates within highstands to produce sub-Milankovitch cycles

AMPLITUDE OF SEA-LEVEL FLUCTUATIONS

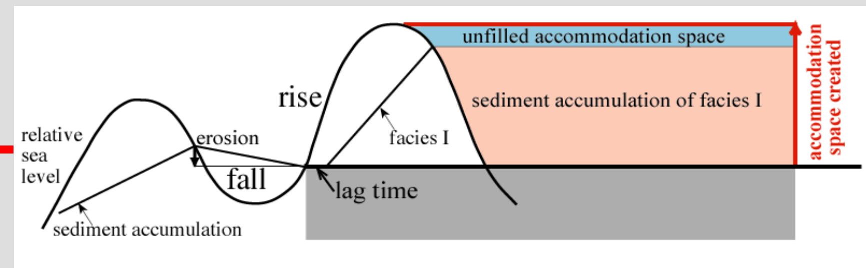


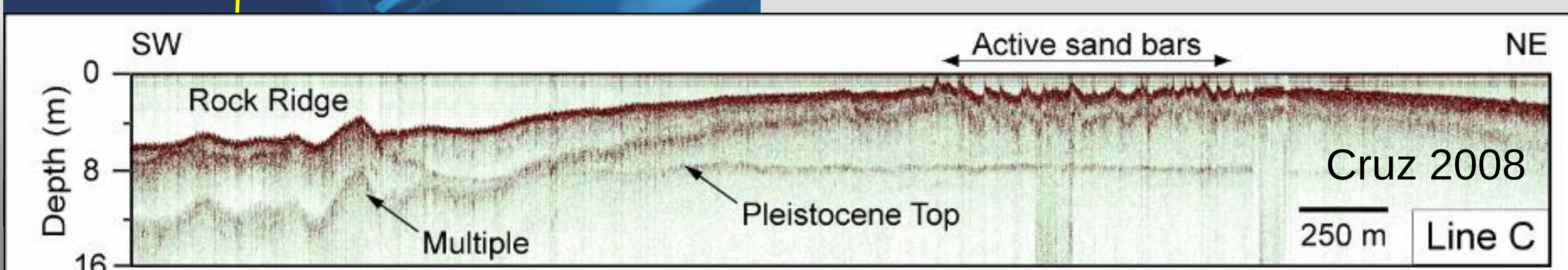


Accommodation Filling Platform Interior

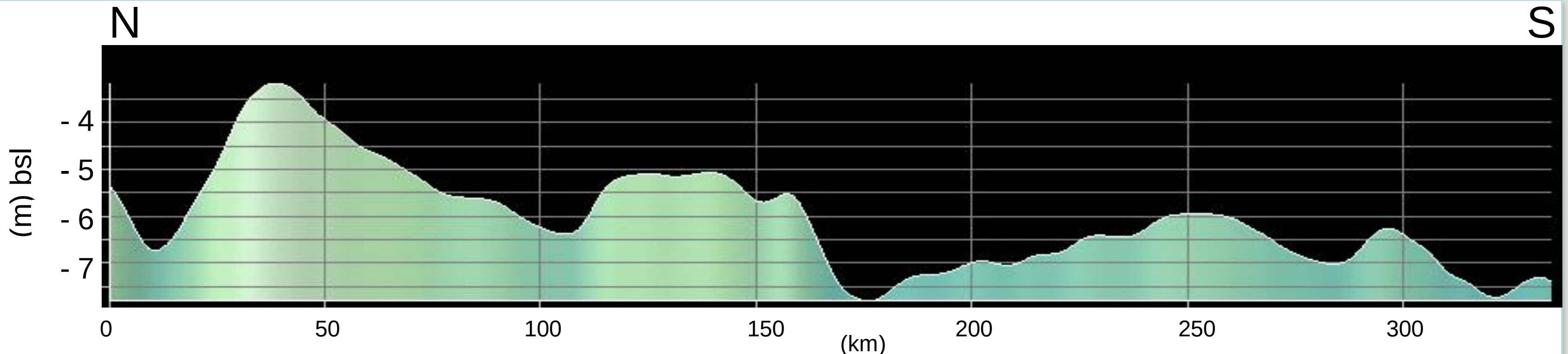


Accommodation Filling Ooid Shoal

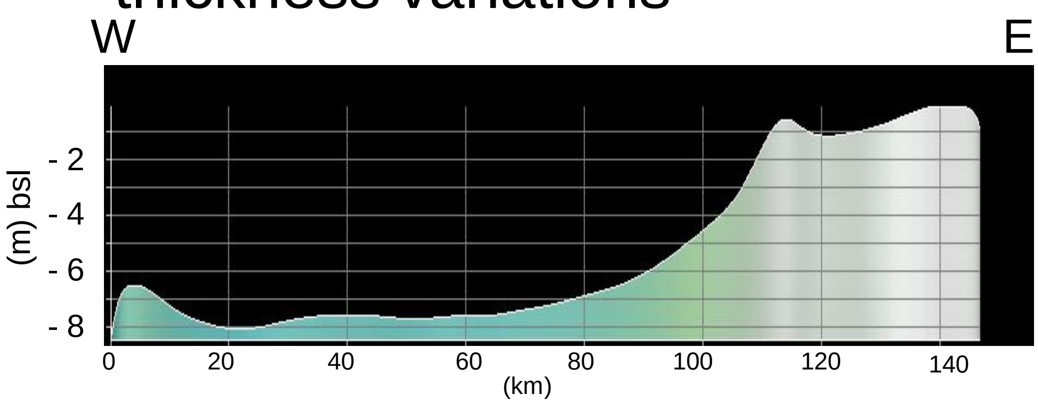


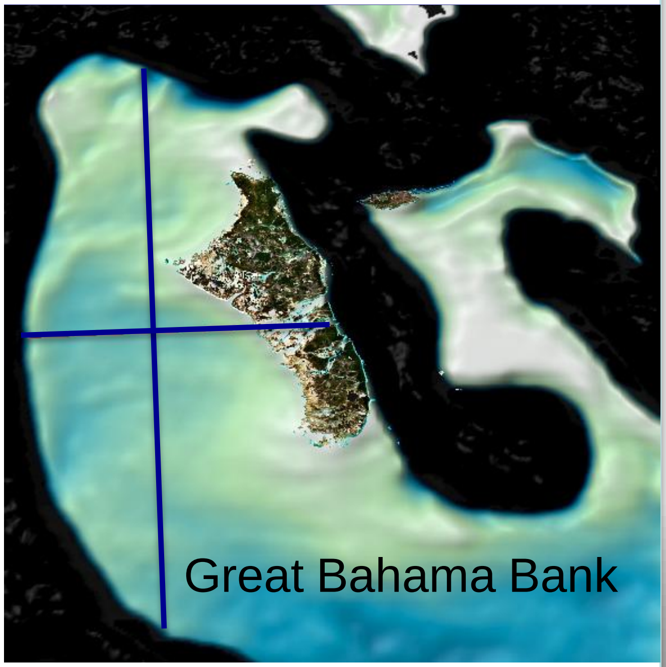


Depositional Topography GBB

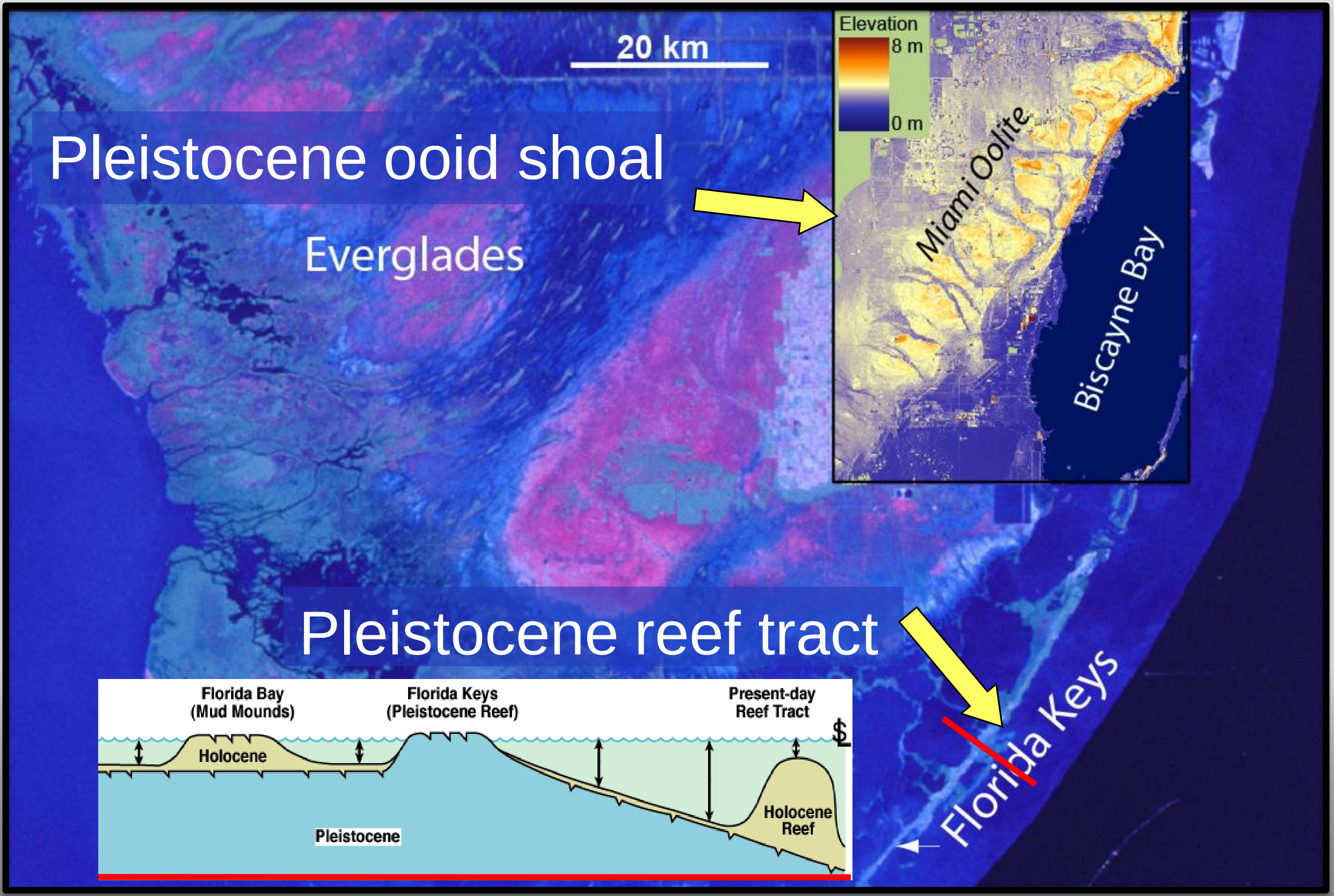


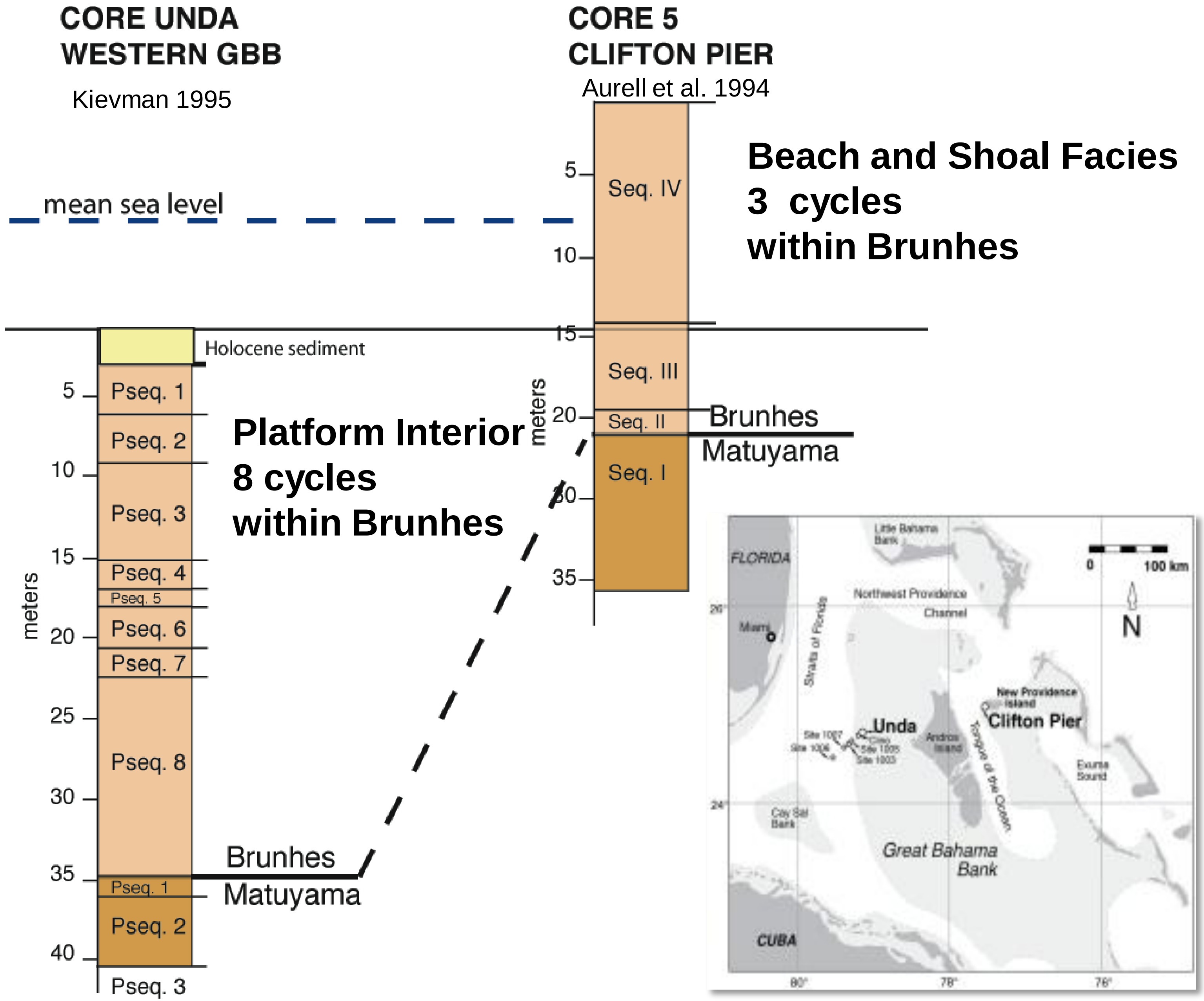
Variable filling of accommodation space creates depositional topography and thickness variations





PRESERVATION OF DEPOSITIONAL TOPOGRAPHY




CORE UNDA
WESTERN GBB
Kievman 1995
CORE 5
CLIFTON PIER
Aurell et al. 1994
Beach and Shoal Facies
3 cycles
within Brunhes
mean sea level
Holocene sediment
Pseq. 1
Pseq. 2
Pseq. 3
Pseq. 4
Pseq. 5
Pseq. 6
Pseq. 7
Pseq. 8
Pseq. 1
Pseq. 2
Pseq. 3
meters
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Brunhes
Matuyama
Platform Interior
8 cycles
within Brunhes
Seq. IV
Seq. III
Seq. II
Seq. I
meters
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Brunhes
Matuyama
FLORIDA
Miami
Northwest Providence
Channel
New Providence
Island
Clifton Pier
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Andros
Island
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0
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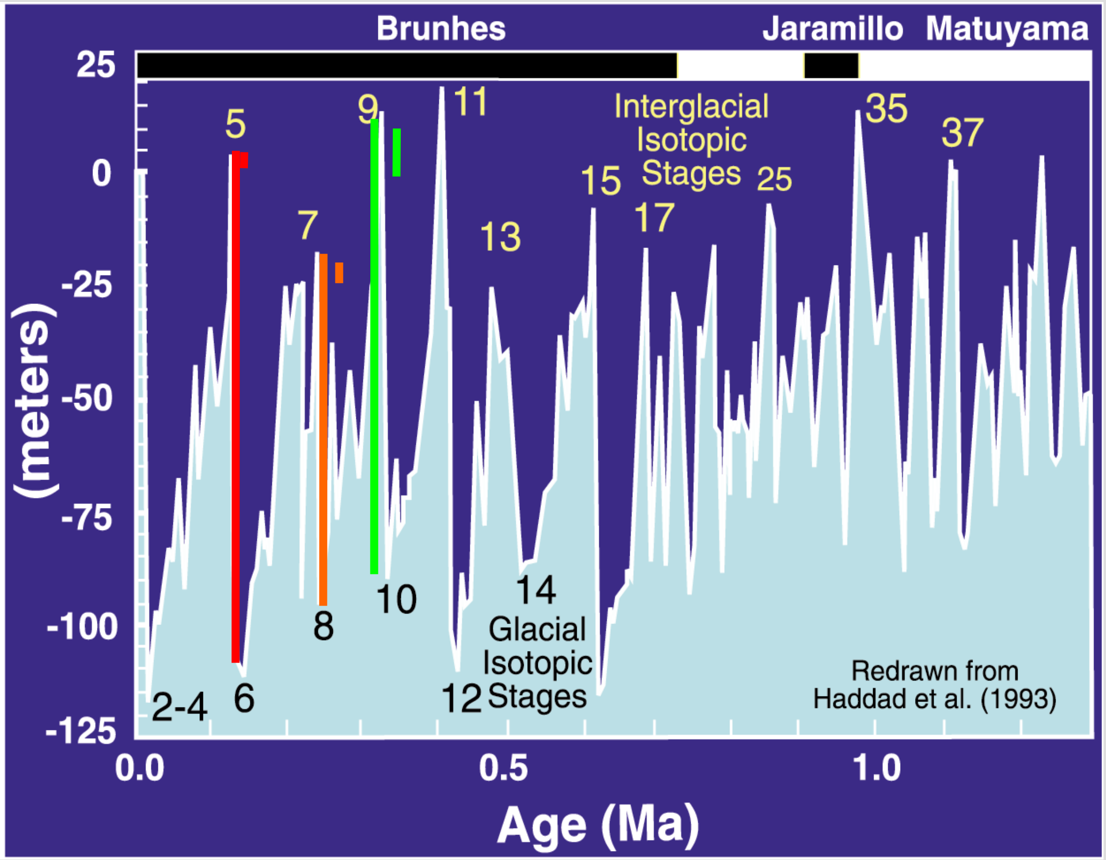
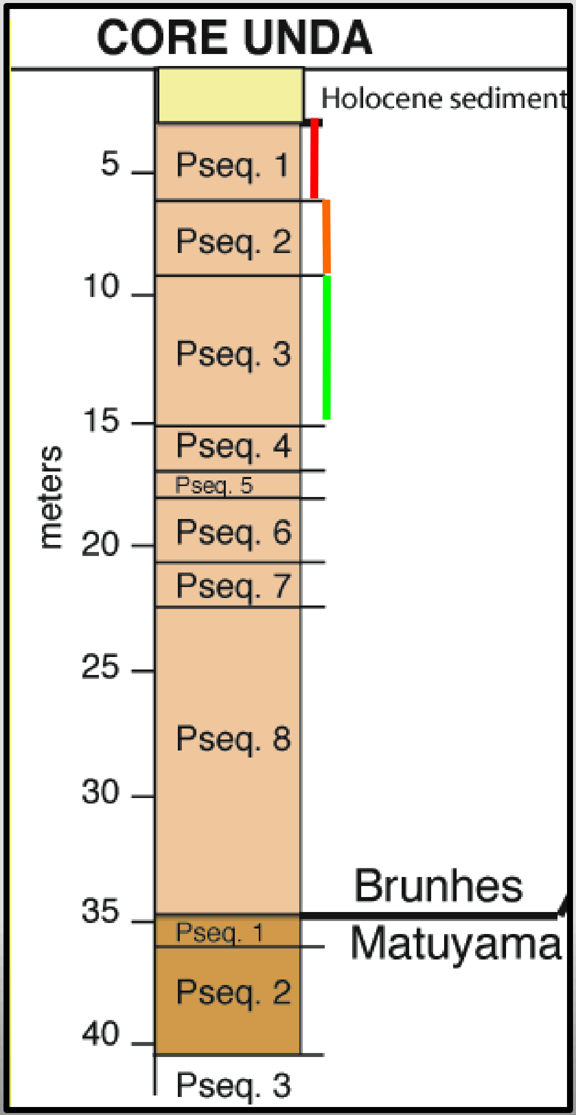
Cycle thickness and sea-level amplitude

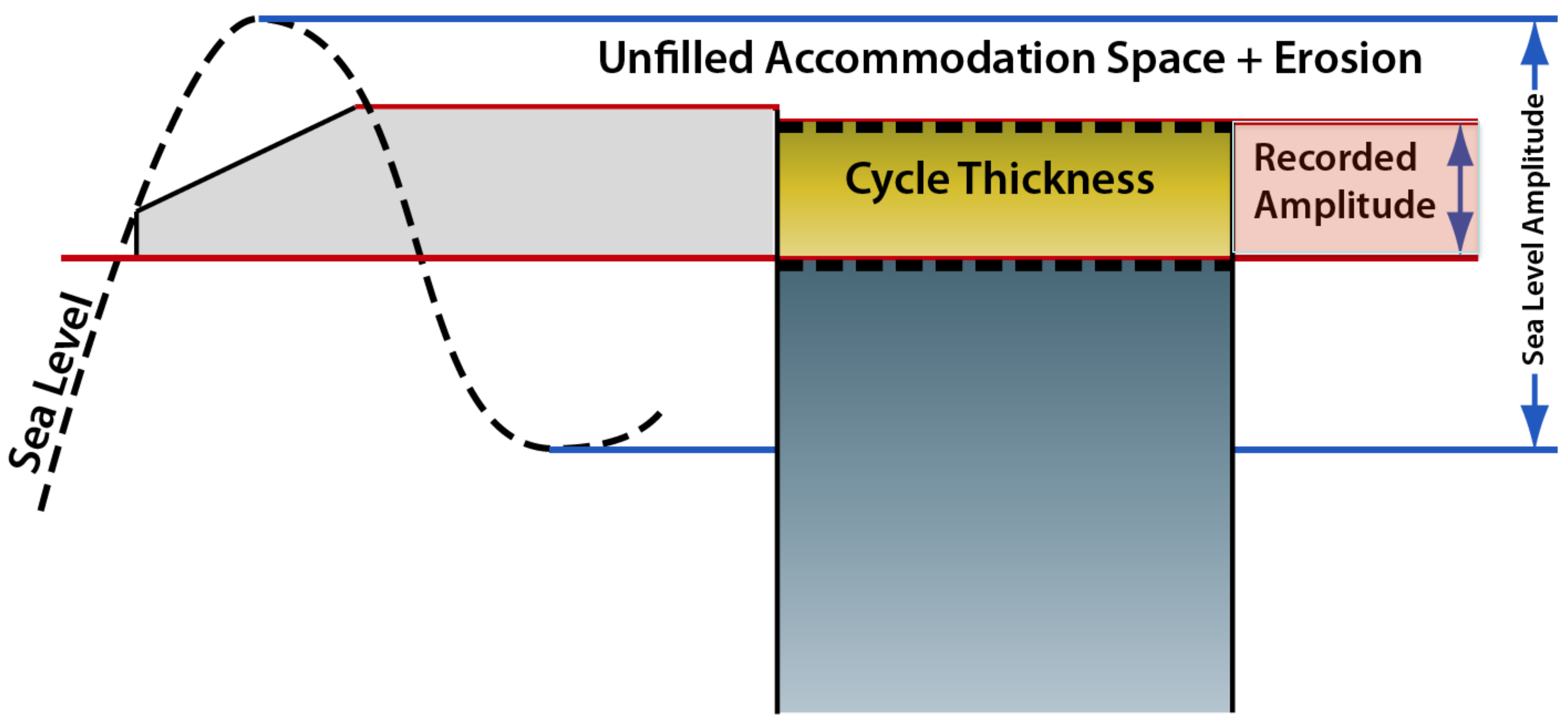




Only a fraction of the sea-level amplitude is recorded on the platform top

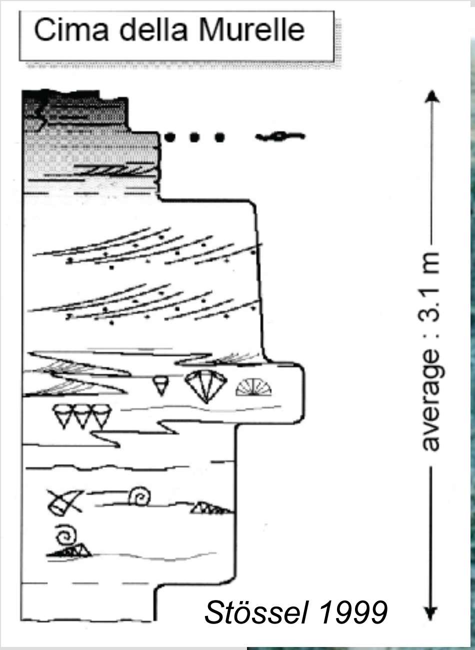
Kievman 1998

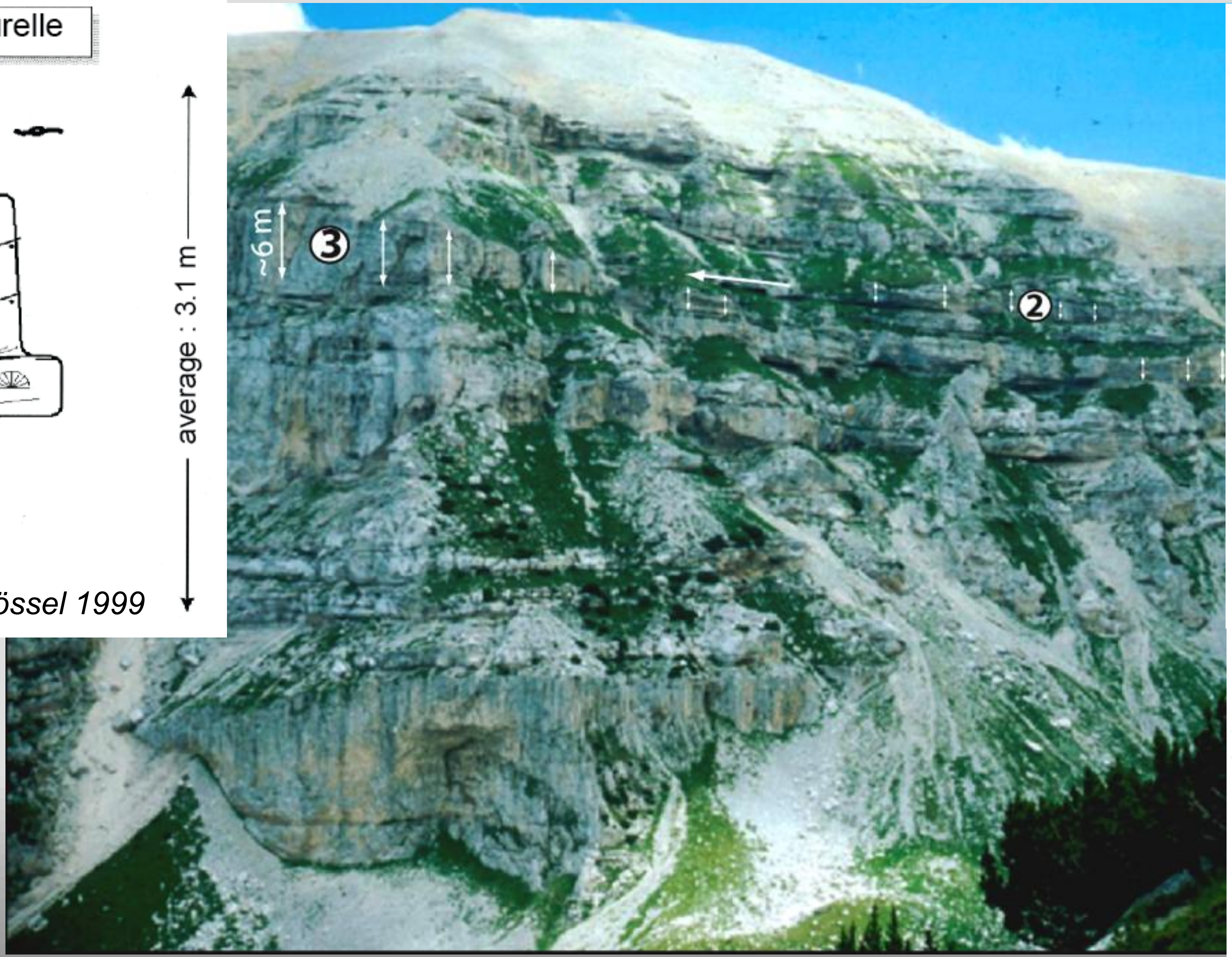
Uncertainty in Amplitude Estimates



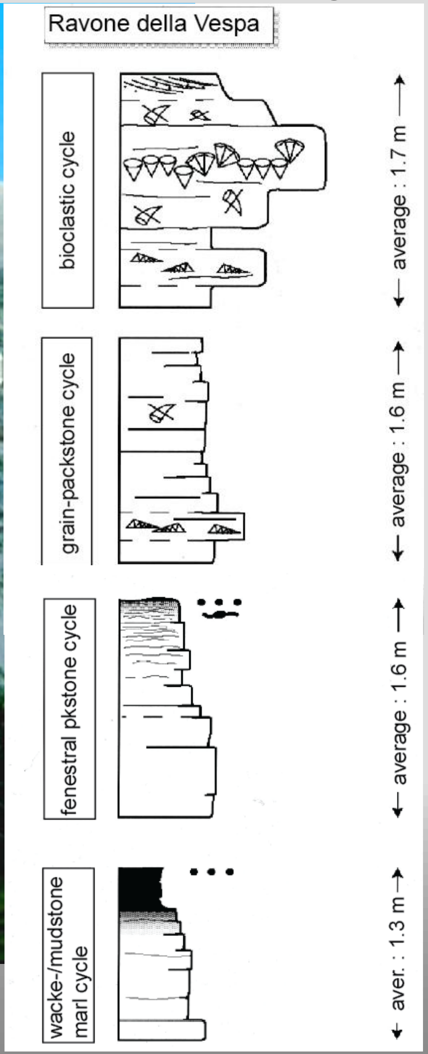
Cycle thickness variations: Cretaceous Maiella Platform Margin

Platform margin

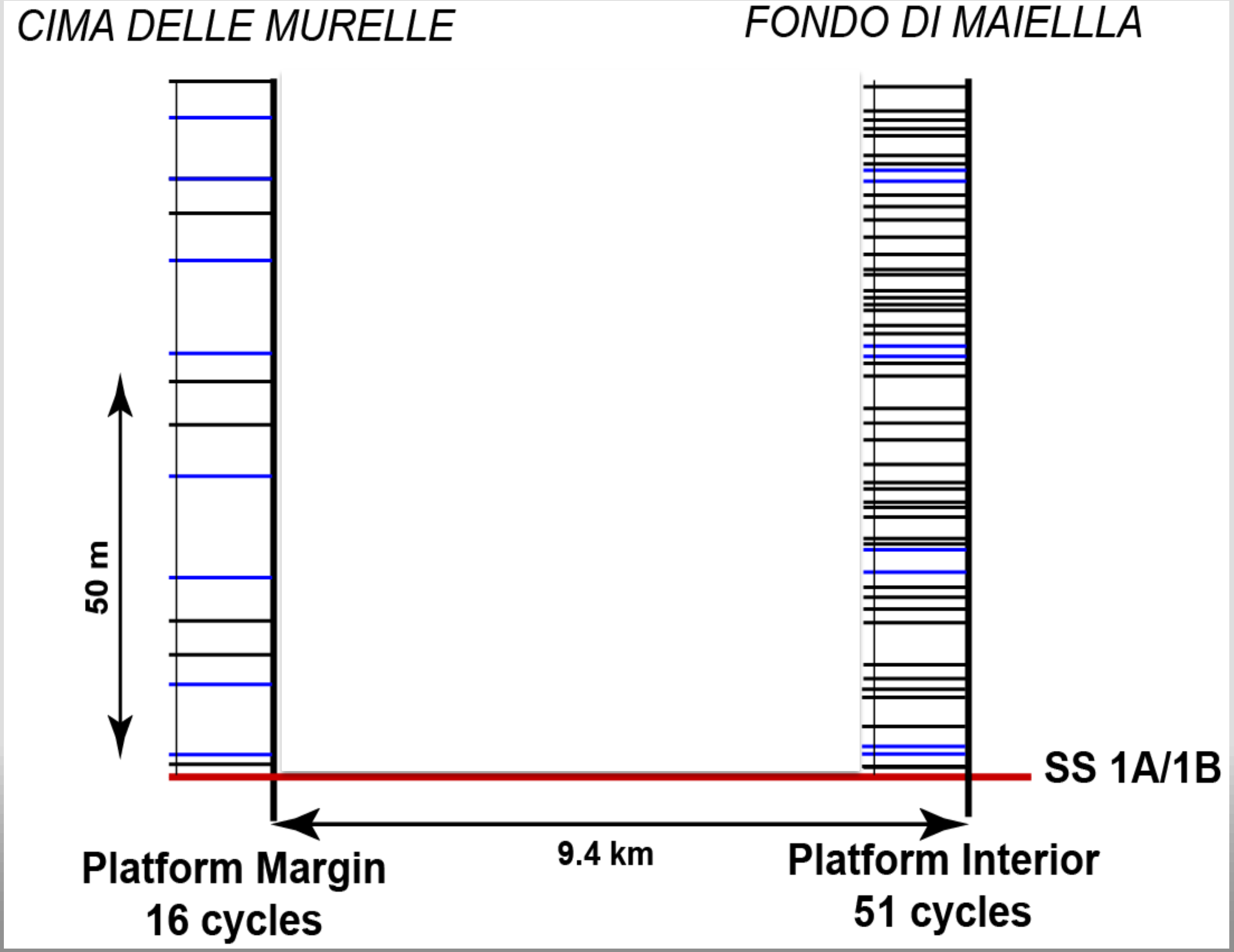




5 km from margin



Cycle thickness variations Maiella

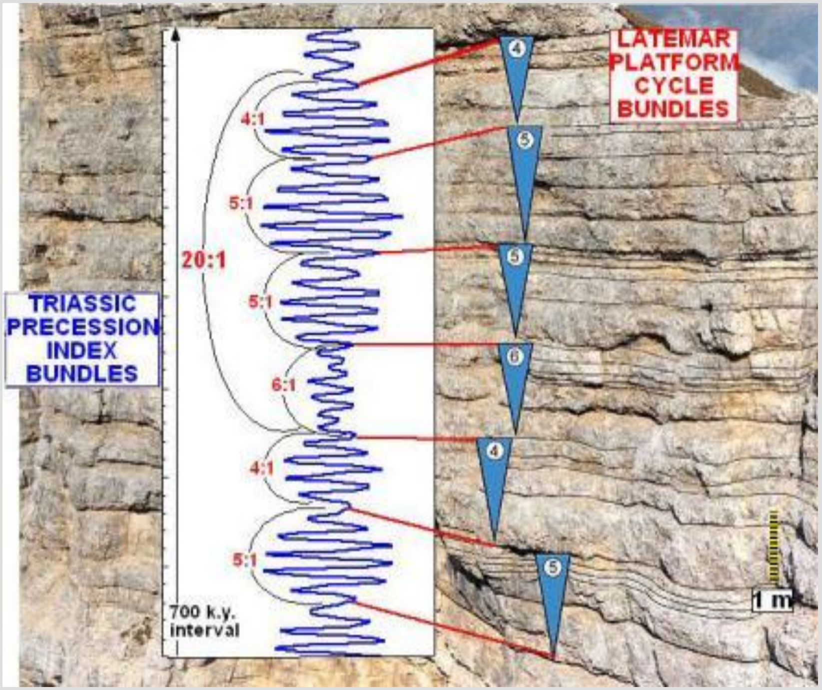


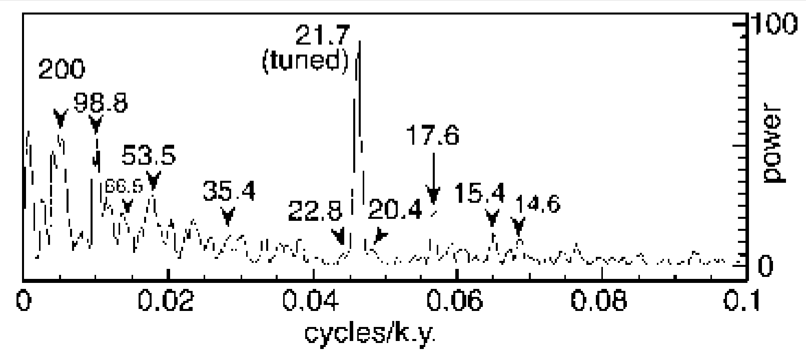
From Sanders 1996

Frequency of orbital driven sea-level changes

Latemar: ~ 600 shallow-water carbonate cycles

Goldhammer et al. 1987 ff.; Hinnov, Goldhammer 1991, 1997; Preto et al., 2000, 2004, Hinnov 2006





600 precession cycles at 20kyr = 12 my.

Biostratigraphic and radiometric age data question the Milankovitch characteristics of the Latemar cycles (Southern Alps, Italy)

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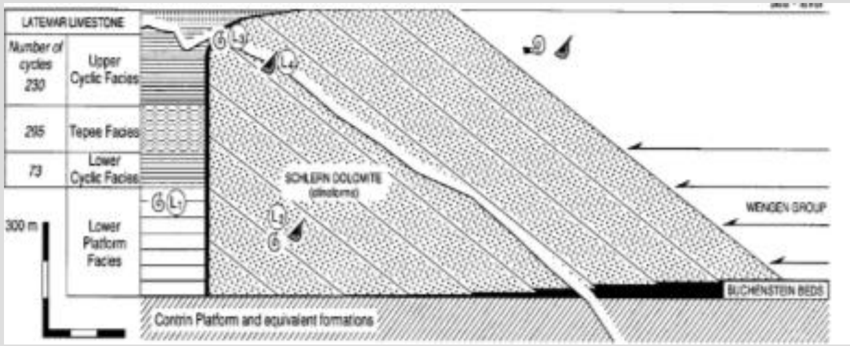
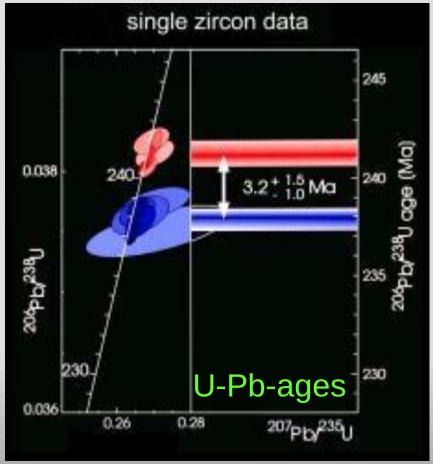


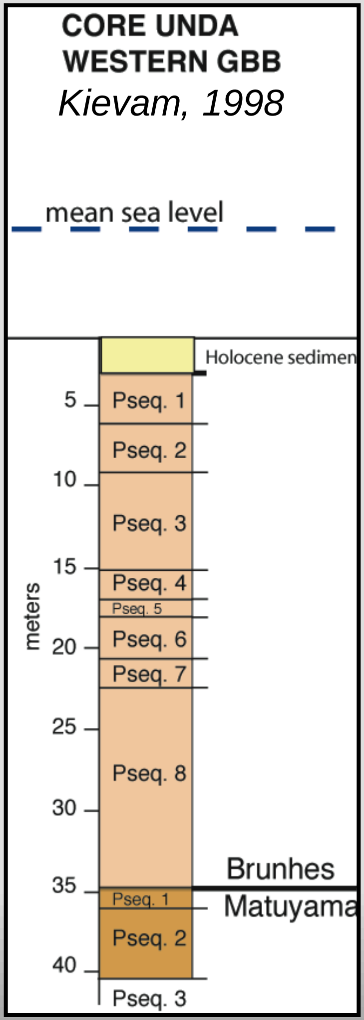
Mundil, Zühlke et al., 2003
Kent, Muttoni, Brack 2004, 2006

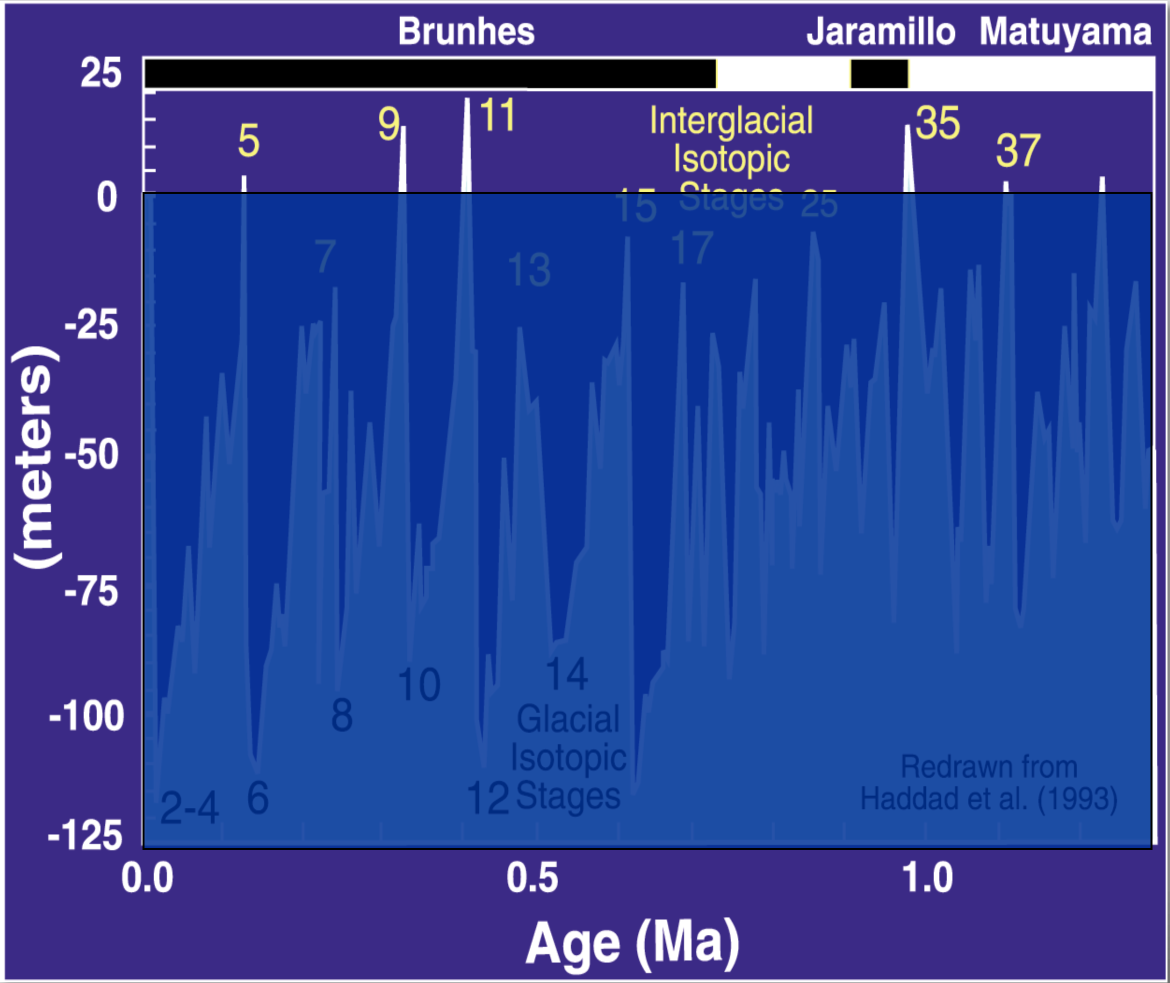
magmatic zircons



Latemar cycle interval = 2.5 my.
average duration of cycles: 1.5 - 2.5 kyrs

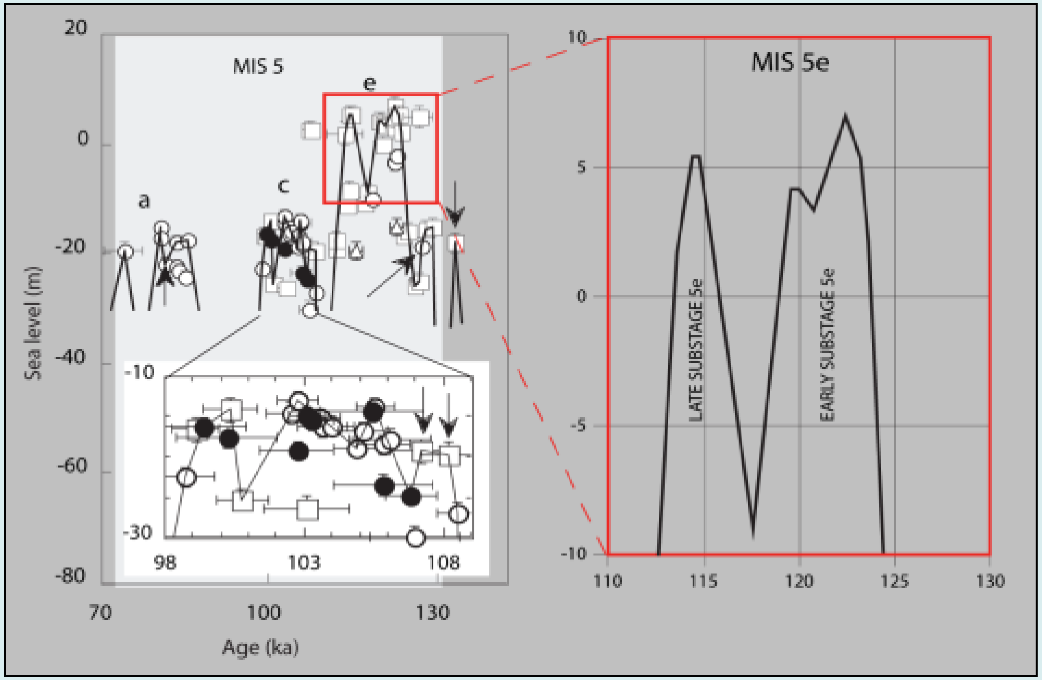
Pleistocene Cycles on Great Bahama Bank

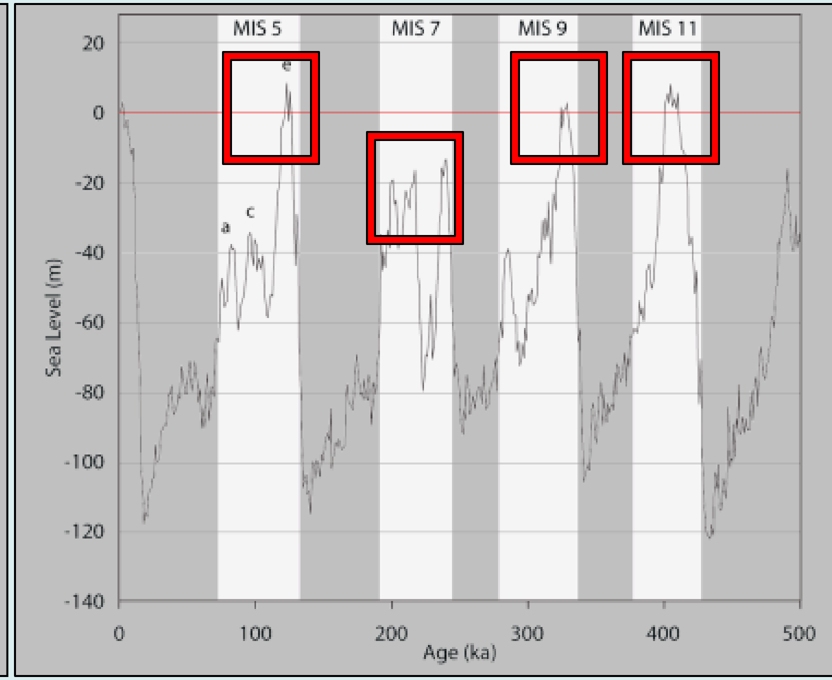




8 cycles but only 3 platform floodings

Sea-Level Oscillations within Highstands





Open-System Coral Ages Reveal Persistent Suborbital Sea-Level Cycles

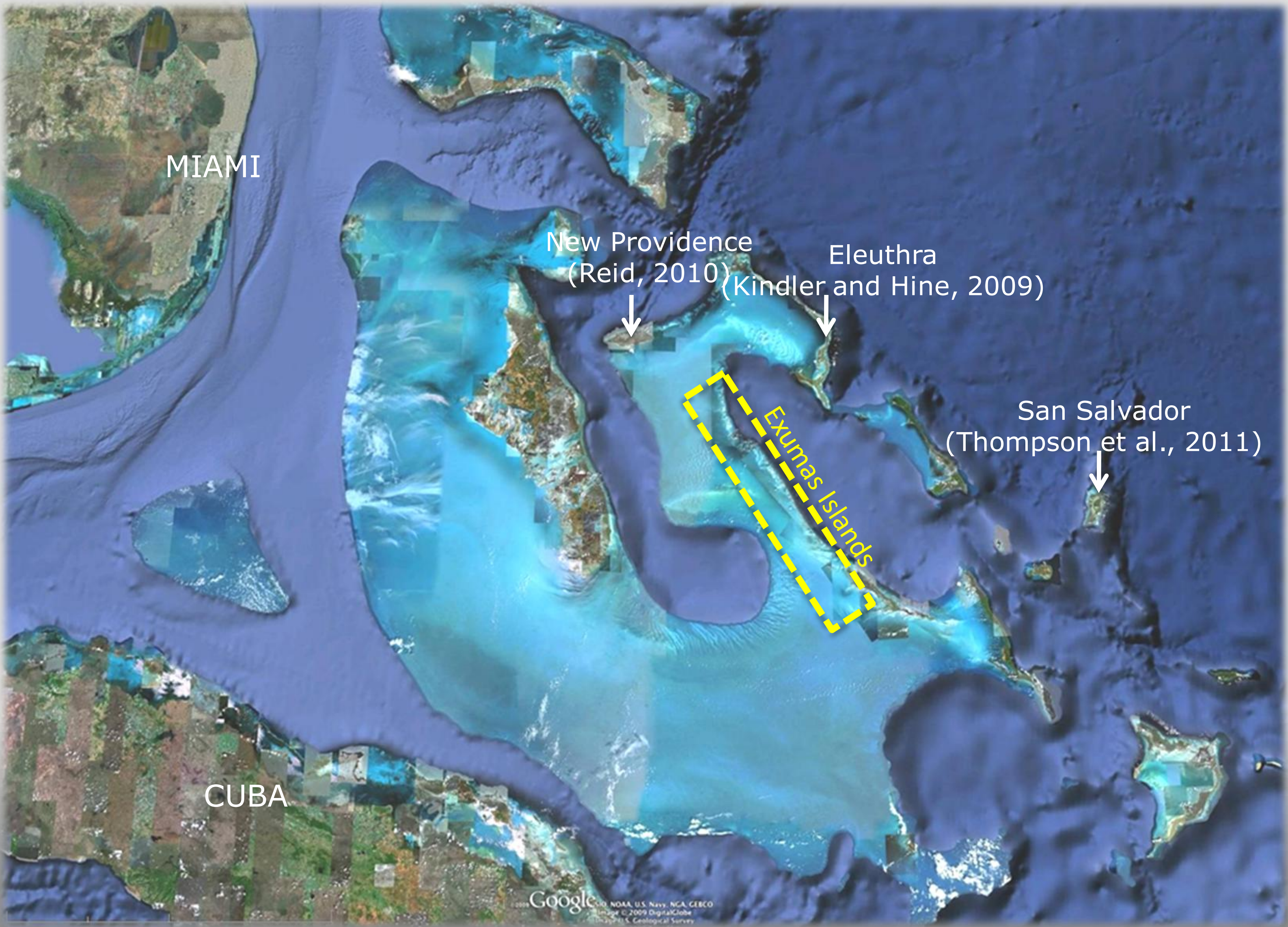
William G. Thompson*† and Steven L. Goldstein

SCIENCE VOL 308 15 APRIL 2005

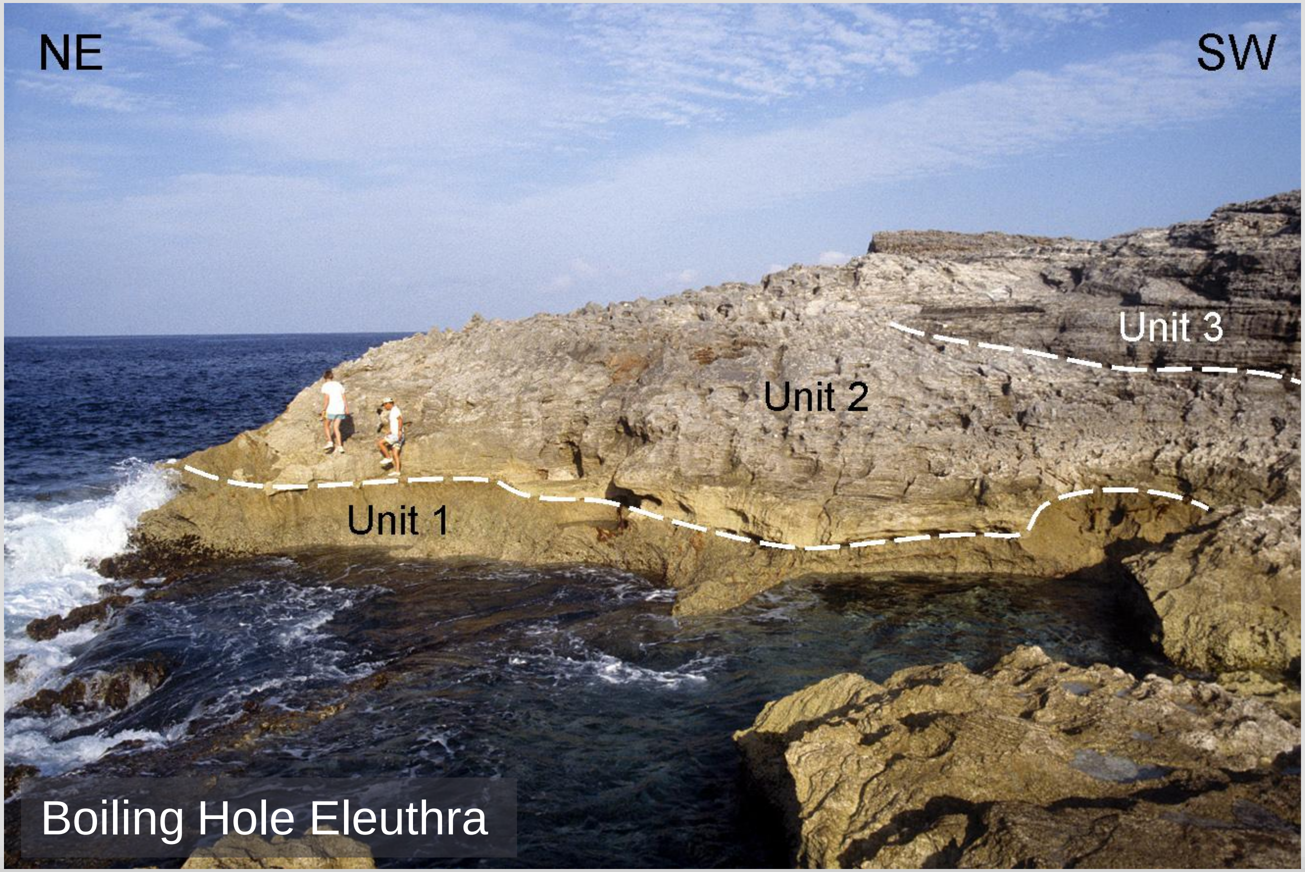
~ 15m sea level fall last interglacial highstand

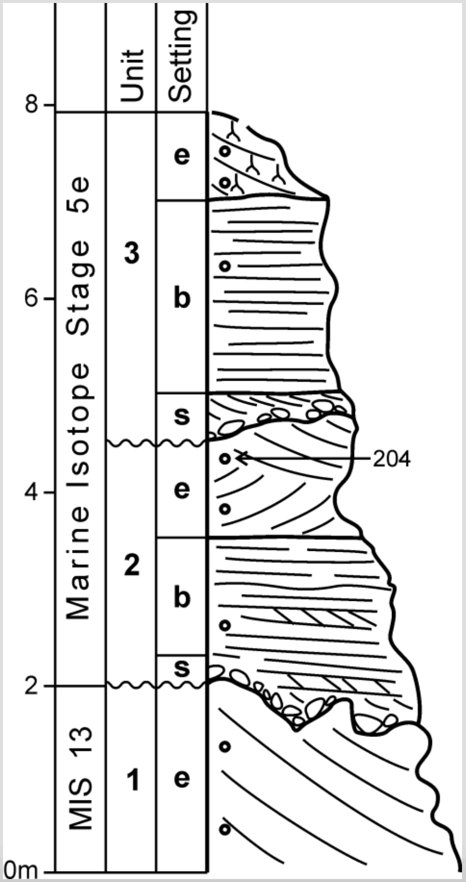
Pleistocene interglacials display oscillations of several meters

Sedimentary Record of Highstand Oscillations



Sedimentary Record of Highstand Oscillations





Kindler and Hine, 2009

2 Successions of Beach-Eolianites within MIS 5E

LETTERS
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nature geoscience

Sea-level oscillations during the last interglacial highstand recorded by Bahamas corals

William G. Thompson[1]*, H. Allen Curran[2], Mark A. Wilson[3] and Brian White[2]

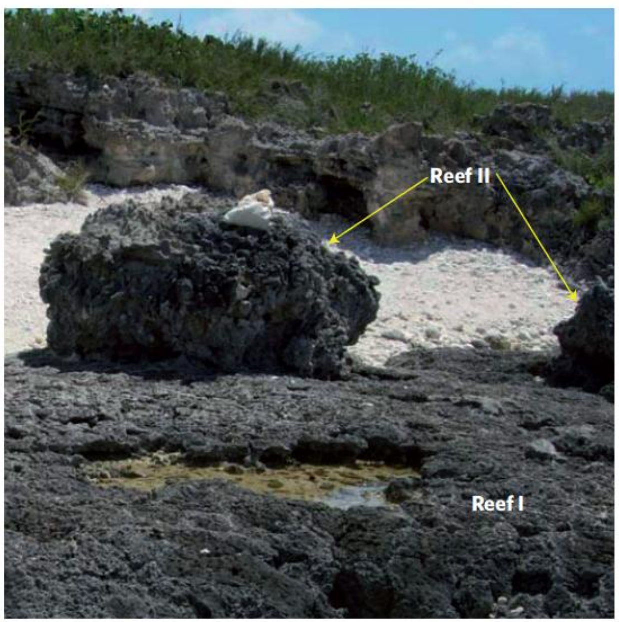
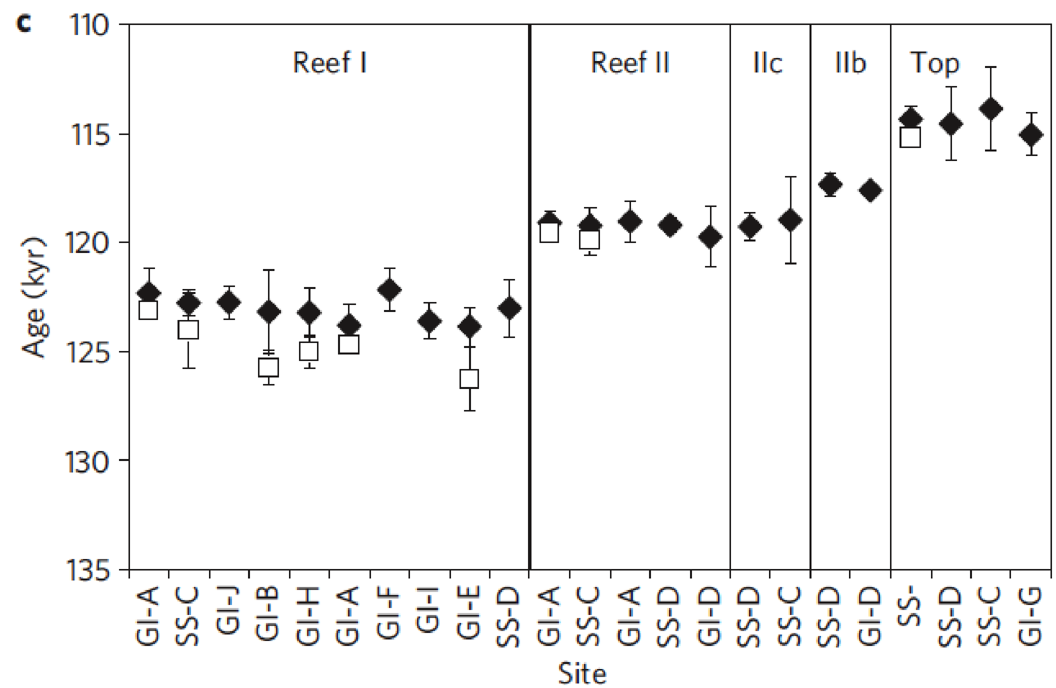
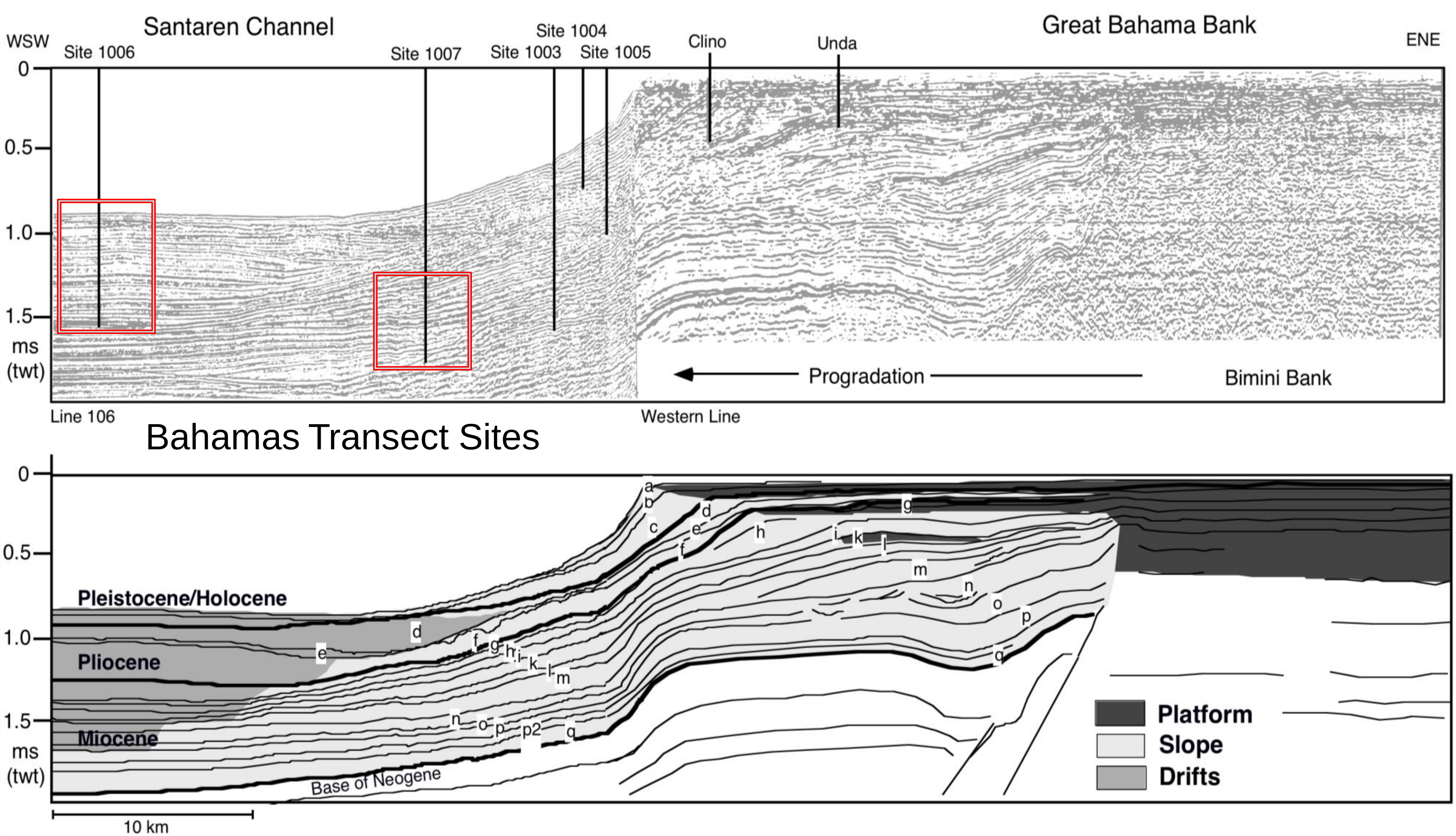


Figure 1 | Great Inagua site A: two successive fossil reefs directly



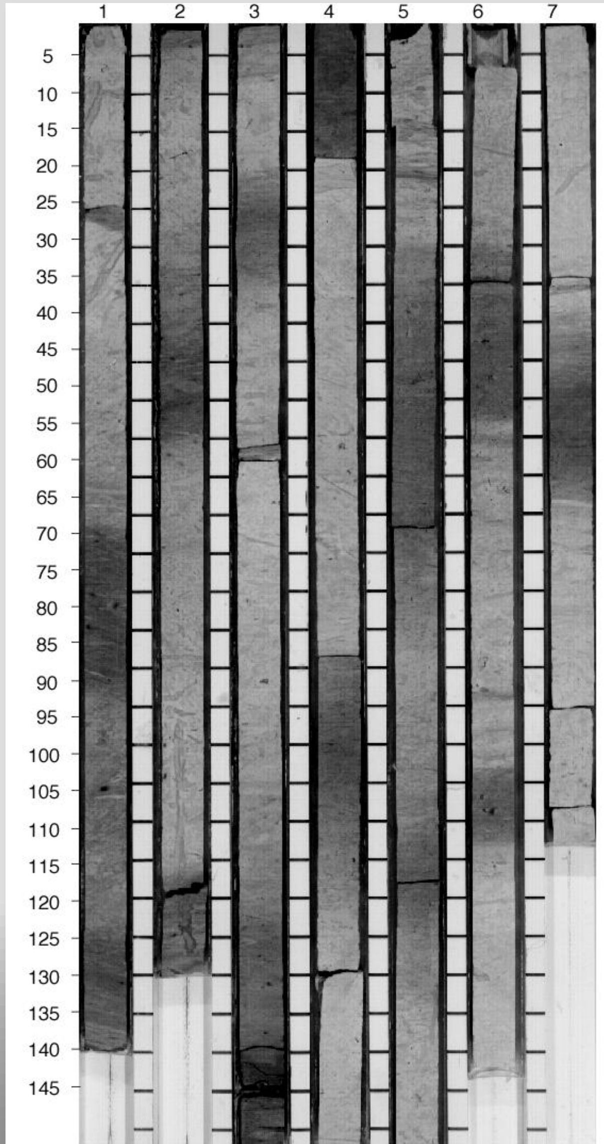
Basinal Cycles in the Straits of Florida

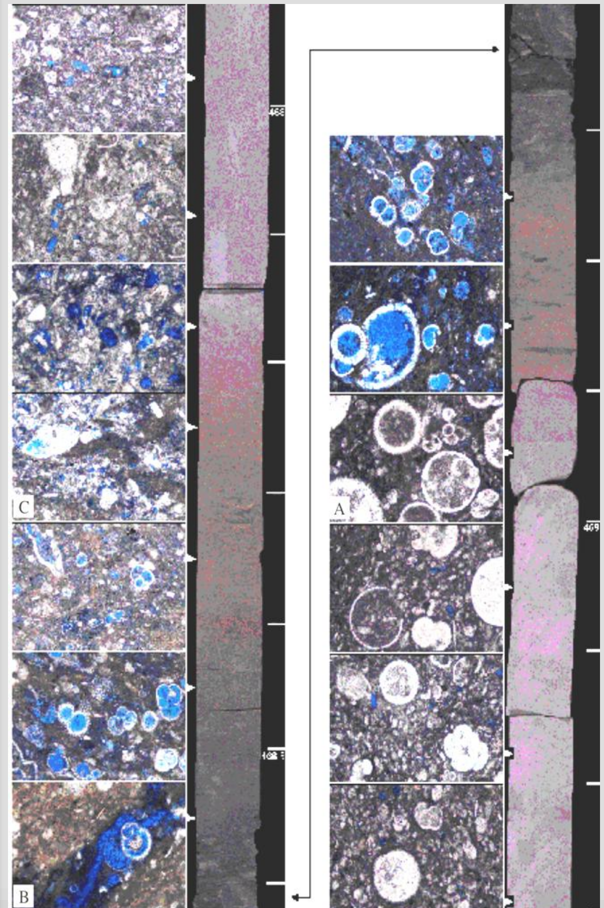


Red boxes indicate sites with marl-limestone alternations

Marl-Limestone Alternations

Core 1007, 84R



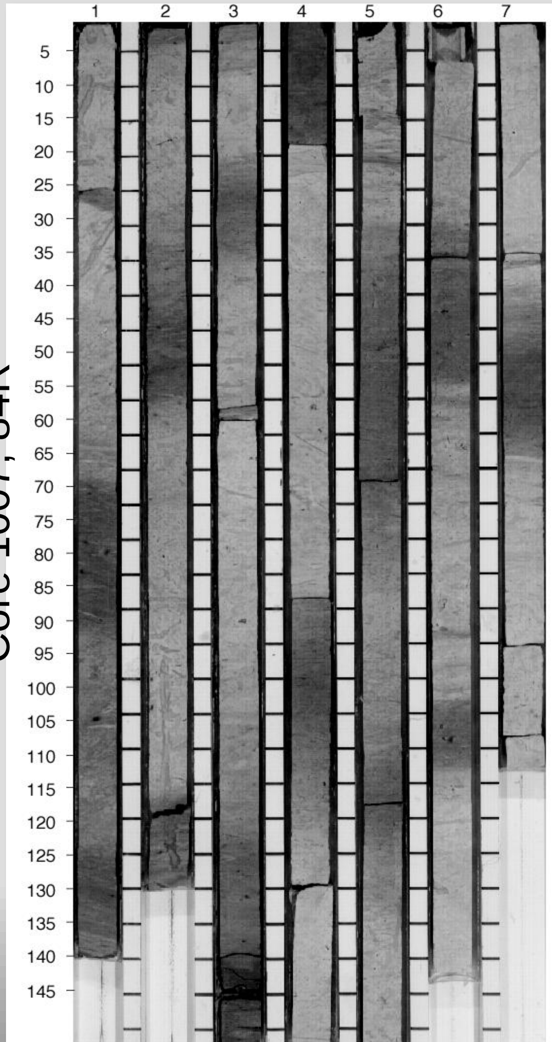


Dark, clay-rich intervals
= sea level lowstand

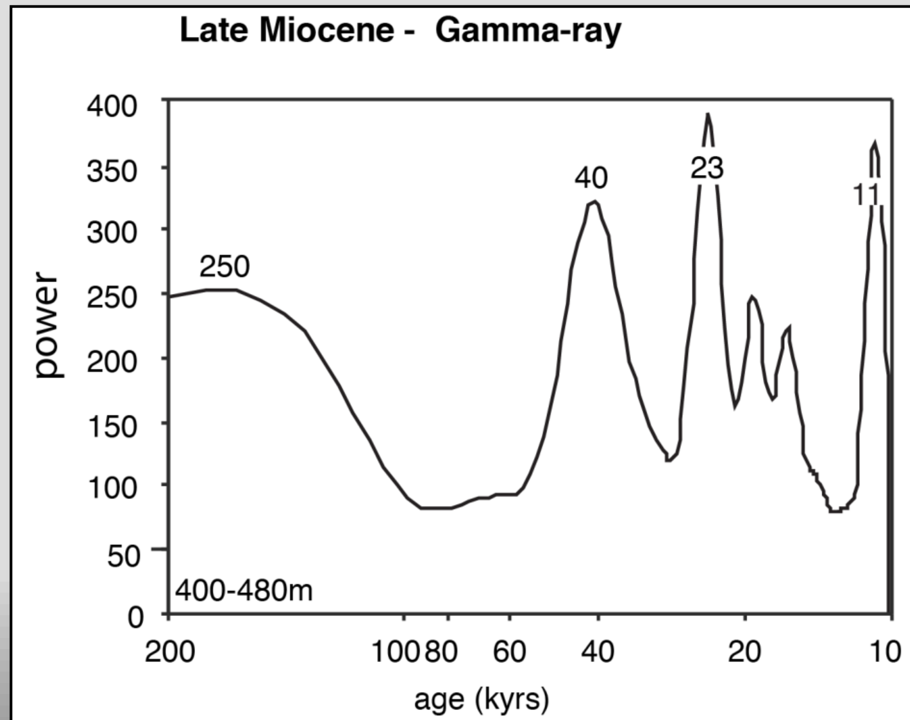
Light, carbonate-rich intervals
= sea level highstand

Half-Precession Signal in the Alternations

Core 1007, 84R

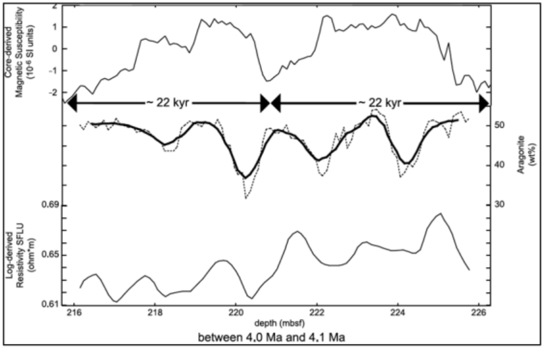


ODP Site 1006,
802 – 910 mbsf = 12.7 -13.6 myrs
81 alternations in 900 kyrs
cycle duration of 11,1 kyrs



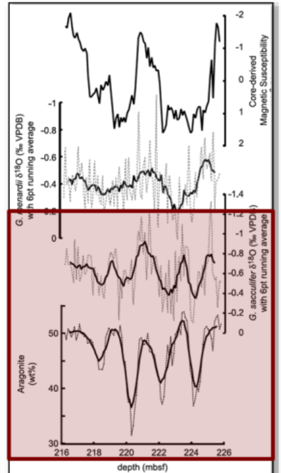
Bernet, 2000

Half-Precession Signal in Periplatform Ooze



$\delta^{18}O$ record of *G.sacculifer*, aragonite content and resistivity display sub-Milankovitch cyclicity.

$\delta^{18}O$ record of *G.menardii* and magnetic susceptibility display precession cyclicity.



Reuning et al., 2006

Eberli, 2012

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Presenter's notes: Top--Core-derived magnetic susceptibility and log-derived resistivity (SFLU) log of parts of sequence f. The core-derived magnetic susceptibility log is dominated by a precession signal; log-derived SFLU in contrast, by a semi-precessional signal (Kroon et al., 2000). The age of the examined interval was established by counting core-derived magnetic susceptibility cycles from the nearest foraminifer/ algae datum. Owing to the uncertainty of this floating stratigraphy, age between 4.0 and 4.1 Ma was assigned to the two precessional cycles.
Bottom—Sampled interval. The aragonite content shows a semi-precessional frequency and seems to dominate the SFLU signal. FO is first occurrence; LO is last occurrence.

Conclusions

1. Depositional cycles are unreliable recorders of the amplitude and frequency of sea level changes
2. Their frequency is not in concert with orbitally controlled climate cycles
3. Sea-level oscillations within highstands are of sufficient magnitude to add complexity to the stratigraphic record