Milankovitch ice sheet and paleo-sea level models have been confronting the same sedimentary problem –

& the parallels don’t stop there

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Proposed 25-m water equivalent Cretaceous Ice Sheets

Present Volume ~ 57 meters (Lythe et al, JGR, v106(B6), 2001, p. 11335)
Phanerozoic CO2

Cenozoic CO2
Mean Annual Temperature: 17-19 °C
70° South Latitude

Howe (2003)
“....the climate was generally warm and humid to allow the growth of large conifers, with mosses and ferns in the undergrowth.”
Sequence stratigraphy hierarchy and the accommodation succession method

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Alternative Framework

• Insufficient or non-existent Cretaceous/Antarctic glaciation to explain coastal transgressive-regressive cycles.
• No equivalent eustatic mechanism with similar rates, amplitudes or frequency exists.
• Eustatic sea level did not rise and fall so rapidly.
• Sedimentary systems themselves are cycling with very weak or perhaps even no eustatic forcing.
• A complete set of parallels exist between this and the Milankovitch 100 Kyr Late Pleistocene ice sheet cycle – i.e. the “100 Kyr problem.”
Late Pleistocene 100 Kyr Ice Volume Cycles

Mass transport is nonlinear diffusion

Milankovitch theory showed that snowline forcing was insufficient by itself to cause cycle

Ice sheet models have indicated that such ‘passive’ sedimentary systems can auto-oscillate.

Cretaceous 1-2 Myr Relative Sea Level Cycles

Mass transport is nonlinear diffusion

Cretaceous climate theory showing that sea level forcing was insufficient by itself to cause cycle

In the absence of eustatic sea level changes, why couldn’t passive sedimentary basin systems auto-oscillate?
What constitutes a “sedimentary system”?


“... the sediments whose interpretation form the basis of earth history have been characteristically deposited with respect to a nearly horizontal controlling surface. This surface of control is baselevel ... sedimentation as well as erosion is controlled by baselevel and ...[it is] the surface at which neither erosion nor sedimentation takes place ... baselevel may be used as a wide and inclusive term, applying both to land and sea ...”
BASIC PROBLEM: Changes in all relative dimensions can be due to an *infinite combination of rates* for the two surfaces.
One cannot solve one equation for two unknowns …

$$A + B = 5$$

A second *independent* equation involving A or B or both is needed.
“A” type models provide reconstructions of the equilibrium line changes independent of the sedimentary surface.

“B” type models provide reconstructions of the sedimentary surface changes independent of the equilibrium surface.
CRETAUCEOUS “GREENHOUSE”

Ocean basin volume & water volume models

Palaeo-eustatic sea-level models “backstripping” models

Cretaceous “greenhouse” record for relative sea level changes

\[ A + B = C \]

Milankovitch theory & ice sheet models

Direct reconstructions of ice sheet elevation changes thru time from field data.

Late Pleistocene $\delta^{18}O$ record for ice volume

PLEISTOCENE “ICE HOUSE”
M. Milankovitch, “Canon of Insolation and The Ice Age Problem,” 1941, Preface, p. XV

“...The most important result concerned the question of whether the influence of the variability of the astronomical elements ... on the march of insolation was sufficient to fully explain the largest climatic fluctuations of the Quaternary... *I began by analyzing mathematically the connection between the altitude of the snowline and the radiant energy corresponding to the caloric summer halfyear. I found that shift of the snowline by one meter corresponded to a change of this energy by one canonic unit. With this result the most important climatic effect of the historic course of terrestrial radiation, i.e. the displacement of the snowline caused by...would be determined...”

Manifestly a Type-A Model!
Is this an A-type or B-type model? – DEFINITELY “A”
What is a B-type model for the Milankovitch problem?

- Direct reconstructions of ice sheet surface elevation changes through time.

- Many constraints on ice sheet geometry from field indicators, isostatic rebound, $\delta^{18}O$ etc but ...

- Hard to summarize the extent to which a time-series for surface geometry has been developed ...
Now I want to apply the same A-B framework to Cretaceous sea level problem
$WD(t) = SL(t) - S^*(t) + BD(t)$
\[ WD(t) = SL(t) - S^*(t) + BD(t) \]

If you were to use this equation to estimate SL => you must first estimate, WD, S* and BD.

If you are estimating S* and BD, \textit{then you are estimating sediment core-top (surface) elevations.}

\textbf{THIS IS A B-TYPE MODEL}
The “Backstripping” Equation:

\[ WD(t) = \Delta SL(t) \left[ \frac{\rho_a}{\rho_a - \rho_w} \right] - S^*(t) \left[ \frac{\rho_a - \rho_s}{\rho_a - \rho_w} \right] + TS(t) \]

\[ WD(t) = SL(t) - S^*(t) + BD(t) \]

In fact, \( BD = TS + \left( \frac{\rho_s - \rho_w}{\rho_a - \rho_w} \right) S^* \)
So ...

\[
WD(t) = \Delta SL(t) \left[ \frac{\rho_a}{\rho_a - \rho_w} \right] - S^*(t) \left[ \frac{\rho_a - \rho_s}{\rho_a - \rho_w} \right] + TS(t)
\]

\[
<=> \ WD(t) = SL(t) - S^*(t) + BD(t)
\]

Backstripping data can equivalently be used to construct WD, S* and BD to get sea level.

Since S* and BD give the sedimentary surface elevation.

This is a B-type model and approach to the relative WD attribution problem.
What are A-type sea level models?

• Direct reconstructions of ocean basin volume changes

• Direct reconstructions of water volume changes – eg $\delta^{18}O$

• The *absence* of ice sheets is an “A”-type reconstruction too!
In modelling, simplicity isn’t simple

CHRIS PAOLA
Sequence stratigraphy hierarchy and the accommodation succession method

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\( \kappa(RSL) \)

1. submerged, weakened transport
2. aerially exposed, vigorous transport

landward → basinward

RSL
constant upstream flux of terrigenous sediment

relative sea level (RSL)

$u$ (constant)

$\partial y / \partial x_o \cdot \kappa(RSL)$

basin subsidence sediment burial

$y_1(t)$

$y_2(t)$

$x_3(t)$

$10's - 100's$ of meters

$10's - 100's$ of kilometers

$u$ (constant)

sea level (constant)
CONCLUSIONS:

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