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Age differences between Atlantic and Pacific benthic $\delta^{18}O$ at terminations

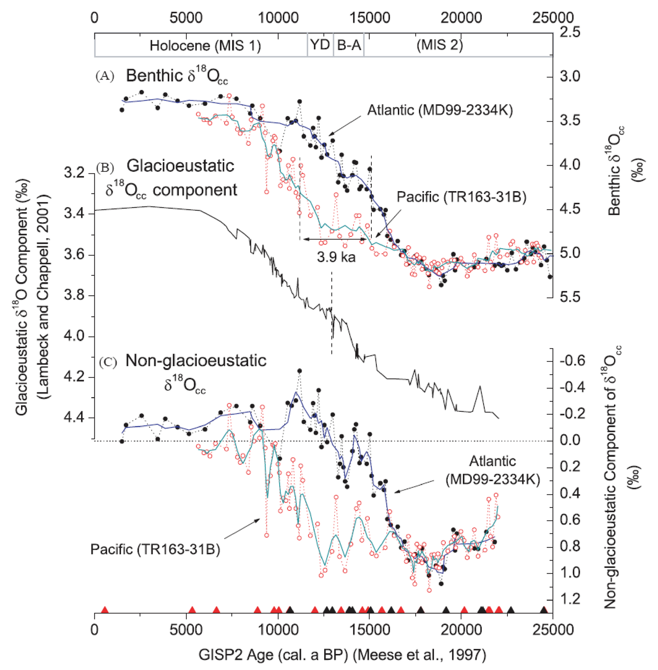
Lorraine Lisiecki & Maureen Raymo
Boston University

Abstract

Benthic $\delta^{18}O$ is often used as a stratigraphic tool to place marine records on a common age model and as a proxy for the timing of ice volume/sea level change. However, *Skinner & Shackleton* [2005] found that the timing of benthic $\delta^{18}O$ change at the last termination differed by 4000 years between two sites in the Atlantic and Pacific. Do these results imply that benthic $\delta^{18}O$ change may not accurately record the timing of terminations? We compare benthic $\delta^{18}O$ records from 34 sites in the Atlantic and Pacific to evaluate differences in the timing of terminations as recorded by benthic $\delta^{18}O$. Statistical analysis of sedimentation rates derived from the alignment of benthic $\delta^{18}O$ suggests an Atlantic lead over Pacific benthic $\delta^{18}O$ change during the last 6 terminations. We estimate an average termination age difference of 1300 years between the Atlantic and Pacific, approximately consistent with the delay expected due to ocean mixing rates, given that most glacial meltwater probably enters the North Atlantic. However, we also find evidence of brief 4000 yr lags during the middle of several terminations, suggesting that termination mid-points may make poor $\delta^{18}O$ tie points.

Introduction

A



Skinner & Shackleton [2005]

Because a large fraction of benthic $\delta^{18}O$ change is due to global ice volume change, benthic $\delta^{18}O$ is often used as a stratigraphic tool to place marine records on a common age model and as a proxy for the timing of ice volume/sea level change. These applications require the assumptions that $\delta^{18}O$ change is rapidly transmitted throughout the deep ocean and that the effects of hydrographic changes are in phase with ice volume.

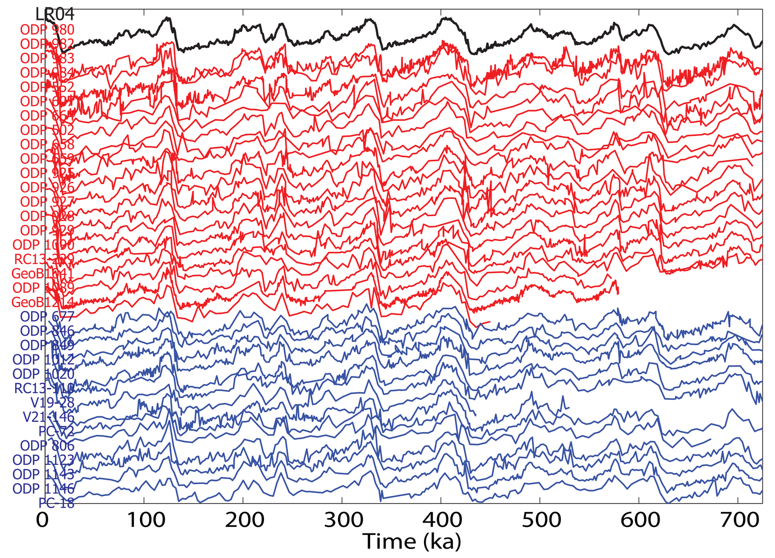
Recently, *Skinner & Shackleton* [2005] found that the timing of benthic $\delta^{18}O$ change at the last termination differed by ~4000 years between two sites in the Atlantic and Pacific (Figure A). Based on Mg/Ca paleothermometry, they argued that these age discrepancies resulted from a late temperature increase in the Pacific and millennial-scale circulation changes in the Atlantic. Such a large discrepancy in $\delta^{18}O$ change would produce significant age model errors when the alignment of $\delta^{18}O$ stratigraphy is based on termination mid-points. Additionally, this suggest that benthic $\delta^{18}O$ change may not always be a reliable indicator of the timing of sea level change.

Here we compare benthic $\delta^{18}O$ records from 34 sites in the Atlantic and Pacific to evaluate differences in the timing of terminations as recorded by benthic $\delta^{18}O$.

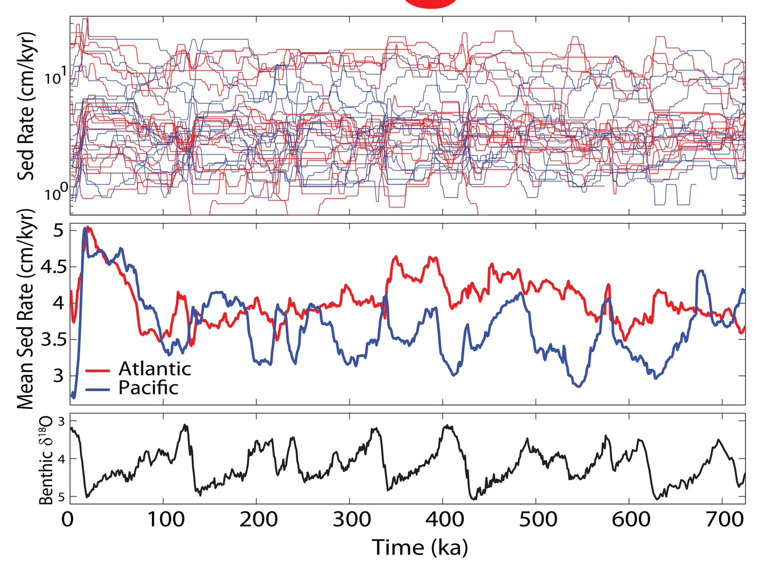
Methods

The age or duration of terminations (other than the most recent, T1) cannot be measured directly. Instead we compare sedimentation rates during terminations to examine whether the change in benthic $\delta^{18}O$ at terminations may be delayed or slower in the Pacific than the Atlantic. Aligning Pacific $\delta^{18}O$ to Atlantic $\delta^{18}O$ should produce a spike in Pacific sedimentation rates if slow Pacific terminations are compressed to fit faster Atlantic terminations. We align the benthic $\delta^{18}O$ records of 20 Atlantic and 14 Pacific sites to the LR04 benthic $\delta^{18}O$ stack [*Lisiecki & Raymo*, 2005] using an automated graphic correlation algorithm [*Lisiecki & Lisiecki*, 2002] (Figure B). Figure C shows the sedimentation rates of each site and their geometric mean. Because uncertainty in our age model affects absolute sedimentation rates, we focus on the ratio of Pacific to Atlantic sedimentation rates (Figure D), which is independent of age model.

B



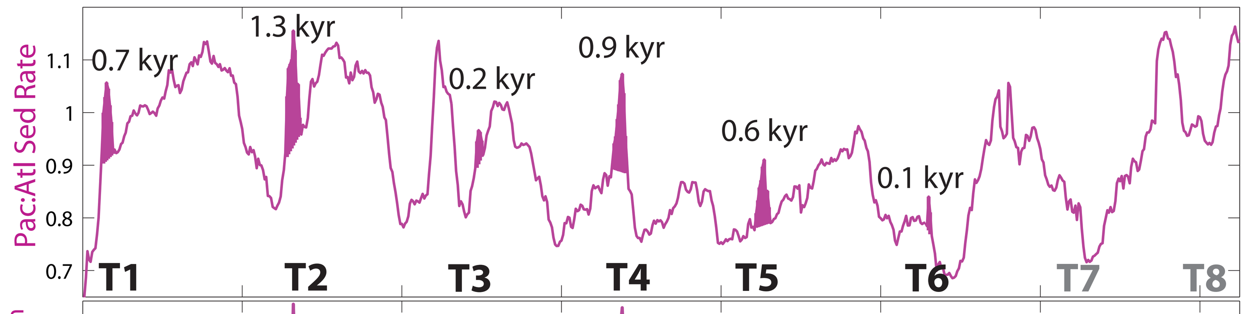
C



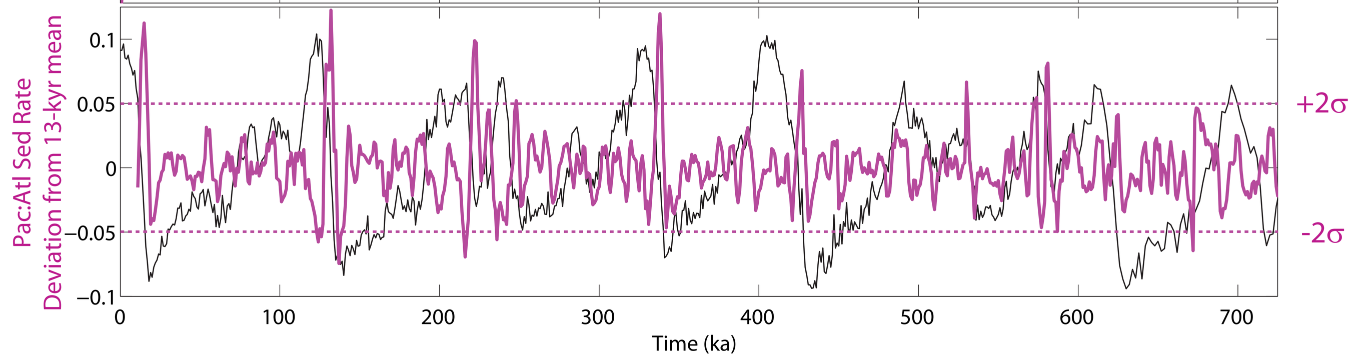
We must also address the fact that glacial cycles produce large sedimentation rate changes at many sites. This is partially compensated by averaging the sedimentation rates of many globally distributed sites. However, glacial cyclicity remains in the ratio of Pacific to Atlantic mean sedimentation rate (Figure D) due to basin-wide sedimentation changes. In addition to 100-kyr cyclicity, the sed rate ratio also clearly shows rapid, large changes at some terminations (T1, T2, T4, and T5).

To test the statistical significance of the termination changes, we calculate the deviation of the sed rate ratio relative its 13-kyr running mean (Figure E). Over the last 550 kyr, deviations in the sed rate ratio above the 2-σ limit are uniquely associated with terminations and the pseudo-termination preceding MIS 7c. Integrating the area under each termination spike relative to pre- and post-termination sed rates provides an estimate of the average duration difference between Atlantic and Pacific $\delta^{18}O$ change (Figure D).

D



E



Results

We create Atlantic and Pacific $\delta^{18}O$ stacks for the last 5 terminations using tie points only at the start and end of each termination and averaging data in 2-kyr intervals (Figure F). We also adjust the duration of Pacific $\delta^{18}O$ change by assuming that the duration differences calculated in Figure D result solely from lags in Pacific $\delta^{18}O$. Because the spikes in sed rate all occur mid-termination, $\delta^{18}O$ change appears to begin at nearly the same time in both oceans. Our sed rate results also suggest that Pacific $\delta^{18}O$ lags the Atlantic by less than 1.2 kyr at the end of terminations.

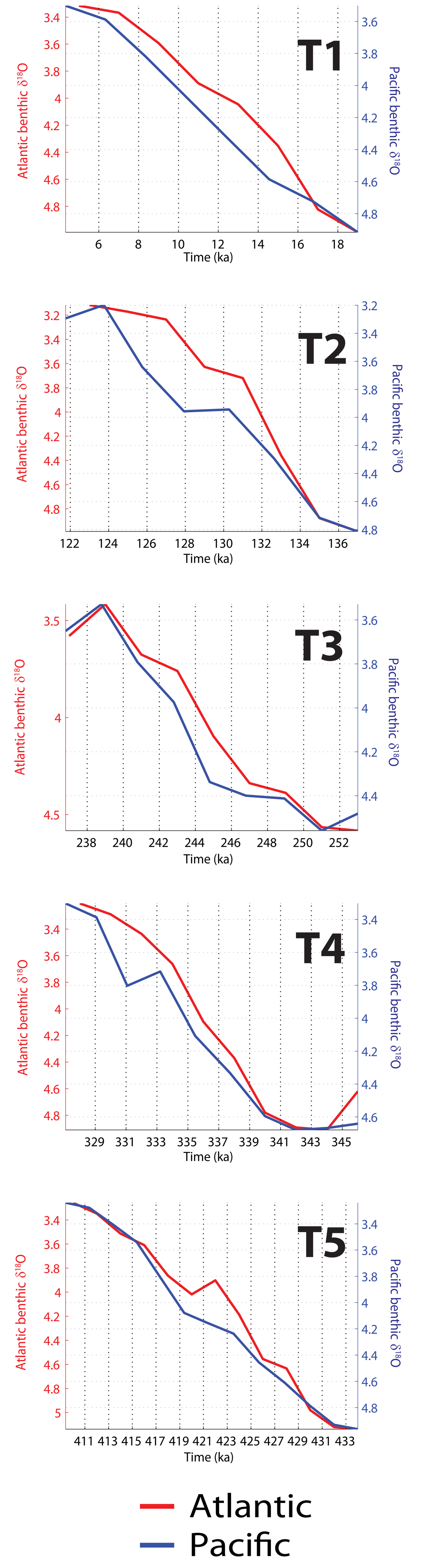
Figure F shows the maximum lag between mean Pacific and Atlantic $\delta^{18}O$ to be 2 kyr in T1, 5 kyr in T2, 2 kyr in T3, 4 kyr in T4, and 4 kyr in T5. The mean lag for all five terminations is only 1.3 kyr.

Discussion of Uncertainty

Age model uncertainty is ~4 kyr, but uncertainty in Pacific-Atlantic age differences should be only ~2 kyr. Our results describe average differences between ocean basins. Lags may vary depending on the specific hydrological setting of a particular site.

Our analysis is based on the assumption that sed rate changes during terminations are small or randomly distributed. This assumption clearly fails at some study sites. Widespread, termination-specific changes in sed rates (e.g., due to IRD deposition, abyssal currents, or carbonate dissolution) would produce errors in our results. For example, IRD would tend to lengthen termination stratigraphy in the North Atlantic and lead us to underestimate Pacific lags. Excluding the 5 North Atlantic sites with highly variable IRD content from our analyses results in changes in termination duration of only 0.2 kyr.

F



Conclusions

- For the last 5 terminations, Pacific benthic $\delta^{18}O$ change lags the Atlantic by an average of 1.3 kyr.
- During some terminations this lag briefly increase to ~4 kyr, perhaps due to the hydrographic changes described by *Skinner & Shackleton* [2005].
- Because we find no evidence for large age offsets at the beginning or end of terminations, these points make better $\delta^{18}O$ tie points than termination midpoints.
- The timing of $\delta^{18}O$ change at individual sites could vary significantly from the basin-wide averages presented here.

References

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Lisiecki, L. E., and M. E. Raymo (2005), A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$ records, *Paleoceanography, 20*, PA1003, doi:10.1029/2004PA001071.

Skinner, L. C., & N. J. Shackleton (2005), An Atlantic lead over Pacific deep-water change across Termination I: implications for the application of the marine isotope stage stratigraphy, *Quat. Sci. Rev., 24*, 571 - 580.

Original references for benthic $\delta^{18}O$ records can be found in Lisiecki & Raymo [2005].