Charting Climate Change and Ocean Dynamics During the Mid-Cretaceous Supergreenhouse: Chemical Evidence from Tanzanian Foraminifera

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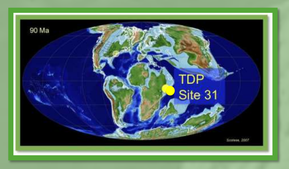
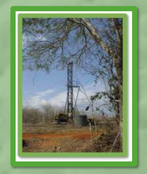
Introduction

As the causes and consequences of global climate change gain an ever-increasing presence in our social conscience, the construction of accurate models concerning past, present, and future climactic fluctuations has urgent significance. Of particular interest in climactic modeling are historical periods of "Supergreenhouse" climate, which are characterized by exceedingly high ambient temperatures, a carbon-dioxide-rich atmosphere, and acidic seas.



Site TDP 31 during the mid-Turonian Period(90 millennia ago)



Drilling rig at TDP Site 31

The most extreme warmth of the Cretaceous Period occurred during the Turonian Stage, roughly 89-93.5 million years ago; it caused periods of oceanic anoxia and vast changes in faunal diversity. In this project, chemical analysis of the exquisitely preserved fossil remains of Tanzanian Drilling-Project Foraminifera gives an intimate look into the climate of this unusual period.

Central Questions

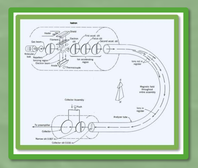
1. How warm was the ocean's surface and bottom water temperatures at the Tanzanian latitude during this time of extreme warmth? How well does this data correlate with that from other drilling sites?

2. What was the variability of the ocean's temperature on short and long time-scales?

3. Is there evidence, as some authors have suggested, for continental ice sheet growth and decay during this time?

Methods

- Identification of 8 distinct, remarkably well-preserved planktonic and benthic foraminifer species from 31 different sample levels of the drilling site TDP 31 was made for samples deemed large enough for stable isotopic analysis; species were selected based both on reliability of their stable isotopic signals based on past study and the abundance of well-preserved specimens.



Mass Spectrometer Schematic Diagram

-Scanning electron/light microscope imagery and cathodoluminescence were used to establish a reproducible standard of ideal preservation.

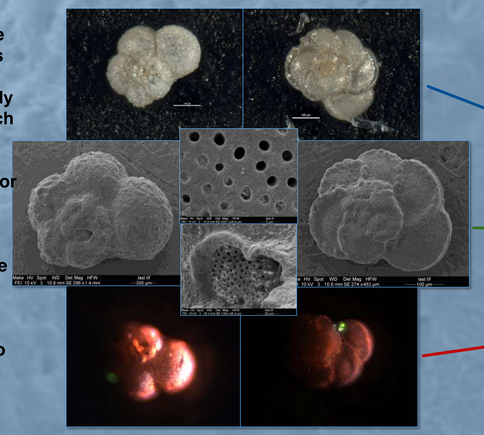
-Shell chemistry was analyzed through the technique of mass spectrometry, which sought the stable isotope ratios of oxygen (^{18}O /^{16}O) and carbon (^{13}C/^{12}C) extant within the calcium-carbonate-based microfossils.

-Oxygen isotope ratios of planktonic and benthic foraminifera enabled comparison of changes in surface and bottom temperatures through time, while a carbon isotope stratigraphy was developed to enable regional and global correlation and to infer changes in productivity in the water column.

Light Microscope, aka "The Argentinosaurus"

Foraminifera

Foraminifera are unicellular, aquatic organisms that produce single or multi-chambered tests (shells). Upon perishing, their empty shells "rain" continuously upon the ocean floor to form rich layers of carbonate-rich sediment.
These organisms are valuable for paleoenvironmental studies because of their vast fossil record (over 500 million years) and remarkably high abundance in various levels of the water column. Though they boast a diverse taxonomy, foraminifera are most easily classified in two main groups: planktonic (surface-dwelling) and benthic (bottom-dwelling).

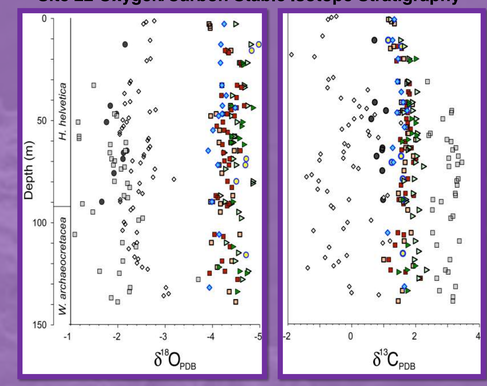


Shell Preservation

Standards of ideal preservation in TDP 31 samples were established through the analysis of well-preserved representative specimens using three imaging techniques:
Light Microscope photography: Qualitative analysis of shell texture and translucence; well-preserved foraminifera appear "glassy" to the eye and show no signs of infilling or diagenesis.
Scanning Electron Microscopy: Offers more detailed geological analysis; pores and chambers should be minimally in-filled by recrystallized calcite and other contaminants.
Cathodoluminescence: Many minerals glow characteristically when exposed to an electron beam. well-preserved specimens shine either orange-red (calcitic) or dim green (aragonitic) when electronically excited.

Comparison to Related Drill Site

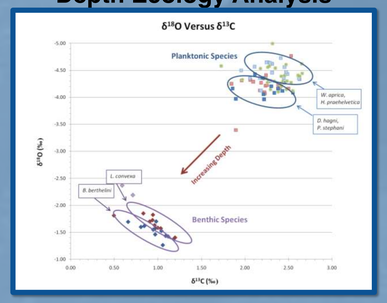
Site 22 Oxygen/Carbon Stable Isotope Stratigraphy



For the purpose of understanding to what extent the isotopic analysis of site TDP 31 can be correlated with other regional data, newly produced stratigraphic plots from Site 31 were placed against those of Site 22 (another site that contained samples measured from the same time period) The stratigraphies were compared by measuring the offsets between planktonic and benthic foraminifera in carbon and oxygen stratigraphies and the difference between estimated average temperatures. Both stratigraphies proved to be almost identical in offset and average values; thus there is strong evidence for correlation among regionally similar drilling sites in Tanzania.

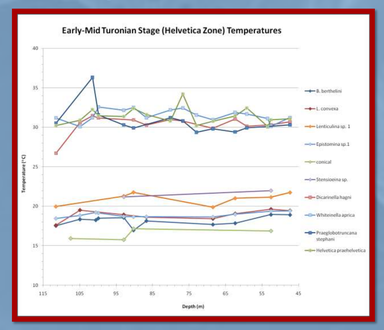
Results

Depth Ecology Analysis

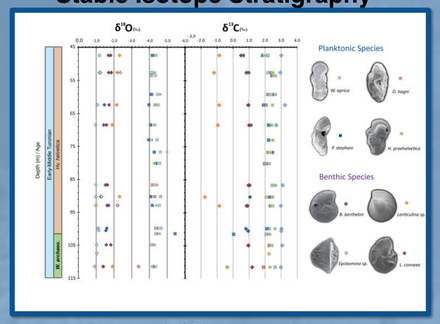


$\delta^{18}O$ vs. $\delta^{13}C$ cross-plots are useful for ascertaining depth ecology not only between benthic and planktonic species, but also between species within a single foraminiferal grouping. Thus, this plot allows for a higher-resolution look at preferred depth habitats of planktonic foraminifera within the ocean mixed layer.

Paleotemperature Reconstruction



Stable Isotope Stratigraphy



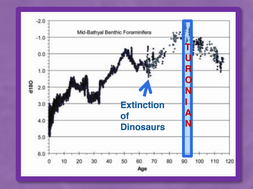
The oxygen isotope ratio ($\delta^{18}O$) stratigraphy above shows a marked distinction between planktonic (surface-dwelling) and benthic (bottom-dwelling) species, which are separated by a sizeable vertical gradient of almost 3‰. The carbon isotope ratio ($\delta^{13}C$) stratigraphy reveals a consistent 1.5‰ vertical gradient in $\delta^{13}C$ values, suggesting relatively little fluctuation in surface water productivity or supply of terrestrial organic matter.

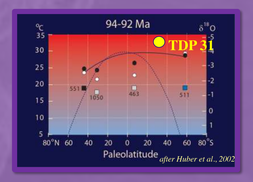
Carbon stable isotope ratio ($\delta^{13}C$) stratigraphy suggests moderate surface water productivity and high vertical stratification of the water column.

Differences in temperature between ocean levels is indicated by the vertical separation between benthic and planktonic species. As expected, the average planktonic water temperature is quite warm at ~32°C degrees, while the average benthic temperature is about 13°C lower (~19°C).

Background: The $\delta^{18}O$ of biogenic calcite and aragonite in foraminifera is primarily dependent on seawater temperature and salinity. We estimate surface and bottom water temperatures in the Turonian Period using empirically derived paleotemperature equations and assuming modern day ocean salinity and no polar ice caps (calcite: Erez and Luz, 1983; aragonite: Grossman and Ku, 1986). Surface-to-bottom water differences in temperature, derived from benthic and planktonic $\delta^{18}O$ values, average ~12°C.

Discussion





As the data from Site TDP 31 show, the *H. helvetica* Zone of the Turonian Stage was indeed a stable warm period of Supergreenhouse climate; the surface of the ocean averaged ~32 °C, and the sea floor was a balmy ~19 °C. However, these measurements have much more to say than simply a temperature reading. The lack of strong positive co-varying shifts in benthic and planktonic $\delta^{18}O$ values indicates no significant depletion of seawater ^{16}O due to polar ice-sheet growth. This, in combination with the relatively stable $\delta^{18}O$ and $\delta^{13}C$ values and high vertical gradients in $\delta^{18}O$ and $\delta^{13}C$ suggest (1) the water column in this region was well stratified, (2) little to no ice sheet growth, and (3) sea level remained relatively constant during this ~2.5 m.y. period of the Turonian.

Acknowledgments

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