Using Carbonate Stable Isotopes to Identify Seasonal Trends in Late Cretaceous Ammonites

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Introduction
- Mollusks are typically thought to precipitate carbonate shell material in equilibrium with seawater.
- Little is known about the lifespan or habits of extinct ammonite species. Most postulations are made based on their modern analog - the Nautilus.

The uncoiled morphology of Baculites makes the genus an easy target for sclerocronological isotopic analysis.
- Seasonal temperature signals may be preserved in oxygen isotope content as shell material is deposited over time.
- Carbon isotope content may also preserve seasonal signals depending on organism behavior.

Methods
- Powdered shell samples were generated for isotopic analysis of ontogenetic sequences using a handheld foraminiferal drill.
- Carbon and oxygen isotope values were measured using a Thermo Scientific Delta V Plus mass spectrometer equipped with a gasBench II autosampler.
- Best fit sine functions (representing seasonal cyclicity) were found using the curve fitting toolbox in MATLAB. Datasets with insufficient data, such as unidirectional trends, were fit with linear functions.
- δ18O and δ13C data with apparent sinusoidal patterns were normalized to 0 by subtracting the mean of the sample data as required by MATLAB.
- Seasonal temperature differentials were calculated by assuming a constant δ18O for seawater and multiplying the peak-to-peak amplitude of the δ13C sine function by 4.69 as defined by Grossman and Ku (1986).
- All specimens preserve primary aragonite as indicated by their whiteness.
- Samples are currently being imaged with a scanning electron microscope to assess their preservation quality using the preservation index established by Cochran et al. (2010).

Carbon and oxygen isotope values were measured using a Thermo Scientific Delta V Plus using a handheld Foredam drill. Seasonal temperature differentials were calculated by assuming a constant δ18O for seawater and multiplying the peak-to-peak amplitude of the δ13C sine function by 4.69 as defined by Grossman and Ku (1986).

Results and Conclusions
- Baculites specimen CC-1 and the specimen described by Fatheree et al. (1998) show sinusoidal δ13C signals with similar periods around 370 mm and have overlapping error ranges (see Table 1).
- Baculites specimens CC-1, CC-2, and the specimen described by Fatheree et al. (1998) show sinusoidal δ18O signals with very similar periods around 355 mm. Error ranges overlap with each other and the period lengths produced from δ13C (see Table 1).
- The consistency in period length is suggestive of common cause, which could be explained by a seasonal trend since δ13C is temperature dependent and δ18O may reflect seasonal variation in organism behavior, metabolism, and/or activity.
- The lengths of these periods suggest that Baculites grew at extremely fast rates (>300 mm/yr).
- Baculites may be r-strategists that grow rapidly, live short lives, and produce large amounts of offspring, or they may simply reach their mature size quickly and stop growing.
- The amplitude of the δ13C signal from the specimen CC-1 is small which may indicate low magnitude seasonal cycles, agreeing with a shallow subtropical shelf environment.
- The amplitude of the Fatheree et al. specimen’s δ18O signal is several times greater than that of CC-1 as expected at a much higher paleolatitude.
- Seasonal amplitude could be reduced due to organism behavior, such as seasonal geographic migration or vertical migration in the water column.

Figure 1
The locations represented by the ammonites studied during this investigation are projected onto a reconstruction of the Western Interior Seaway (WIS). Middle Cretaceous Reconstruction Colorado Plateau Geosystems Inc.

Figure 2
Fatheree et al. (1998) measured δ13C and δ18O in an ontogenetic sequence on a single Baculites compressus collected from the Pierre Shale in Wyoming (43.9331°N, 102.815°W).
- A sinusoidal δ13C trend over the length of the shell (320 mm) was recognized to be approximately one seasonal cycle.
- We normalized their data for sinusoidal fits with MATLAB using the same methods by which our data was processed (see Methods) to produce functions for their δ13C and δ18O.
- The periods of these functions are similar to those we were able to fit to our specimens, CC-1 and CC-2 (see Table 1).

Table 1
<table>
<thead>
<tr>
<th>Specimen Name</th>
<th>Specimen Length (mm)</th>
<th>Period of Best Fit (mm)</th>
<th>Amplitude of Best Fit (% VPDB)</th>
<th>R²</th>
<th>Period of Best Fit (mm)</th>
<th>Amplitude of Best Fit (% VPDB)</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatheree</td>
<td>320</td>
<td>367 ± 27</td>
<td>1.671 ± 0.156</td>
<td>0.94</td>
<td>334 ± 73</td>
<td>0.831 ± 0.340</td>
<td>0.44</td>
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<tr>
<td>CC-1</td>
<td>393</td>
<td>373 ± 47</td>
<td>0.225 ± 0.066</td>
<td>0.42</td>
<td>331 ± 54</td>
<td>0.310 ± 0.108</td>
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<tr>
<td>CC-2</td>
<td>108</td>
<td>No Sin Fit</td>
<td>No Sin Fit</td>
<td>0.34</td>
<td>339 ± 69</td>
<td>1.220 ± 0.224</td>
<td>0.52</td>
</tr>
<tr>
<td>WY-1</td>
<td>107</td>
<td>No Sin Fit</td>
<td>No Sin Fit</td>
<td>0.73</td>
<td>No Sin Fit</td>
<td>No Sin Fit</td>
<td>0.43</td>
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<tr>
<td>MT-1</td>
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<td>No Sin Fit</td>
<td>No Sin Fit</td>
<td>0.02</td>
<td>No Sin Fit</td>
<td>No Sin Fit</td>
<td>0.07</td>
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Table 2
Calculated Annual ∆T (°C)
<table>
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<th>Specimen Name</th>
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<th>CC-2</th>
<th>WY-1</th>
<th>HC-1</th>
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<td></td>
<td>7.84</td>
<td>1.06</td>
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Acknowledgments
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Literature Cited