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 sclerochronological 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 Foredam drill.
- Carbon and oxygen isotope values were measured using a Thermo Scientific Delta V Plus isotope ratio 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.
- $\delta^{18}O$ and $\delta^{13}C$ data with apparent sinusoidal patterns were normalized to a mean of 0 by subtracting the mean of the sample data as required by MATLAB.
- Seasonal temperature differentials were calculated by assuming a constant $\delta^{18}O$ for seawater and multiplying the peak-to-peak amplitude of the $\delta^{18}O$ sine function by 4.69 as defined by Grossman and Ku (1986).
- All specimens preserve primary aragonite as indicated by their iridescence.
- 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).

Table 1		$\delta^{18}O$			$\delta^{13}C$		
Specimen Name	Specimen Length (mm)	Period of Best Fit (mm)	Amplitude of Best Fit (‰ VPBD)	R^2	Period of Best Fit (mm)	Amplitude of Best Fit (‰ VPBD)	R^2
Fatheree	320	367 ± 27	1.671 ± 0.156	0.94	334 ± 73	0.8314 ± 0.340	0.44
CC-1	393	373 ± 47	0.225 ± 0.066	0.42	331 ± 54	0.3100 ± 0.108	0.33
CC-2	332	No Sine Fit	No Sine Fit	0.34	339 ± 69	1.2204 ± 0.224	0.52
WY-1	107	No Sine Fit	No Sine Fit	0.73	No Sine Fit	No Sine Fit	0.43
MT-1	185	No Sine Fit	No Sine Fit	0.02	No Sine Fit	No Sine Fit	0.07

Figure 1
The locations represented by the ammonites studied during this investigation are projected onto a reconstruction of the WIS.

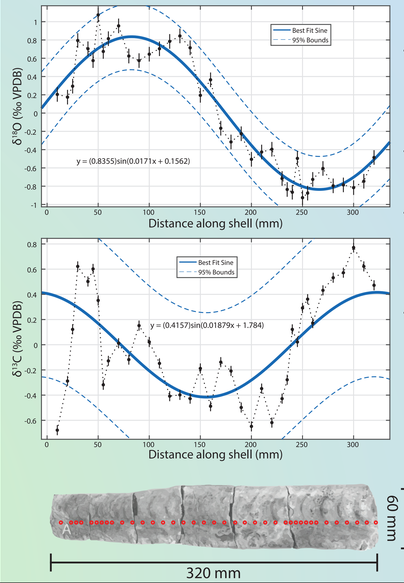
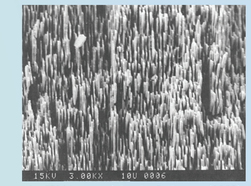


Figure 2

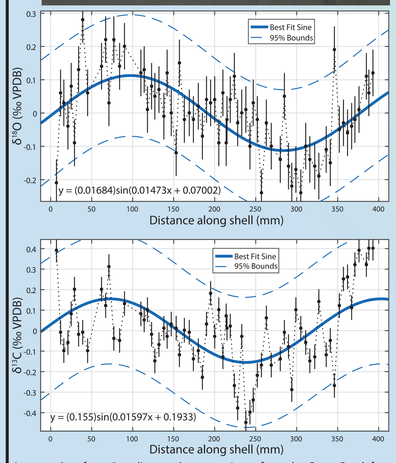
- Fatherree et al. (1998) measured $\delta^{18}O$ and $\delta^{13}C$ in an ontogenetic sequence on a single *Baculites compressus* collected from the Pierre Shale in Northern Wyoming (43.9333 °N, 102.8167 °W).
- A sinusoidal $\delta^{18}O$ trend over the length of the shell (320 mm) was recognized to be approximately one seasonal cycle.
- We reanalyzed their data for sinusoidal fits with MATLAB using the same methods by which our data was processed (see Methods) to produce functions for their $\delta^{18}O$ and $\delta^{13}C$ signals.
- 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).



An SEM image of the the Fatherree (1998) *Baculites*' well-preserved microstructure

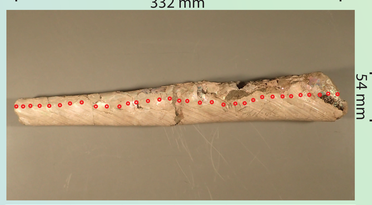
Table 2	Specimen Name	Fatherree	CC-1	CC-2	WY-1	HC-1
Calculated Annual ΔT (°C)		7.84	1.06	≥2.43	>3.33	n/a

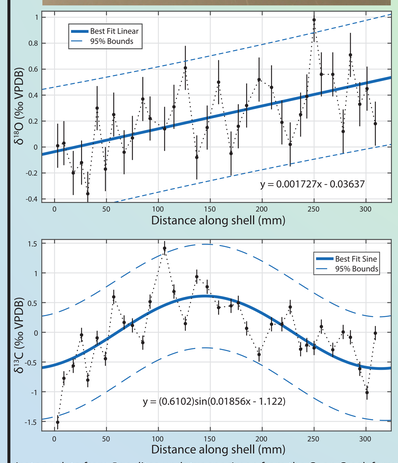
CC-1



Isotope data from *Baculites undatus* specimen from the Coon Creek formation (35.35218 °N, 88.42043 °W) is shown. Oxygen and carbon isotope data were normalized to 0 using means: $\delta^{18}O$ = 0.4294; $\delta^{13}C$ = 0.3979.

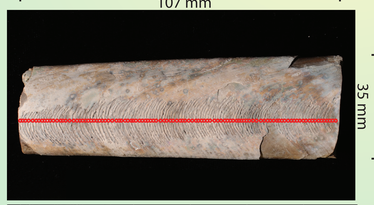
CC-2

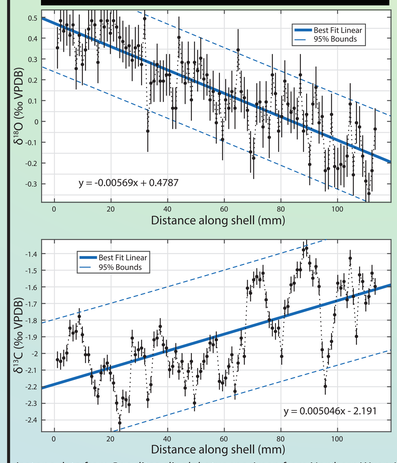




Isotope data from *Baculites undatus* specimen from the Coon Creek formation (35.35218 °N, 88.42043 °W) is shown. Carbon isotope data were normalized to 0 using mean: $\delta^{13}C$ = -0.1215. A sine curve could not be extrapolated from the oxygen data series, so a linear fit was used.

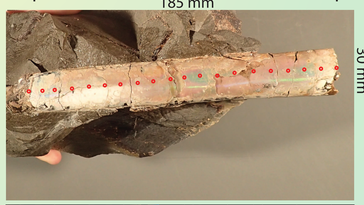
WY-1

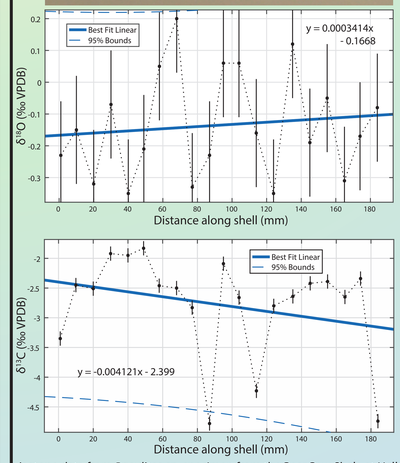




Isotope data from *Baculites clinolobatus* specimen from Northern Wyoming (44.75 °N, 108.5 °W) is shown. The unidirectional trends could represent a portion of the seasonal cycle given the shorter length of this specimen. Sine curves could not be extrapolated from the datasets, so linear fits were used.

MT-1





Isotope data from *Baculites sp.* specimen from the Bear Paw Shale at Hell Creek in Eastern Montana (47.6314 °N, -106.8688 °W) is shown. The signals in this specimen are rather noisy, and no meaningful or significant trends were identified.

Results and Conclusions

- *Baculites* specimen CC-1 and the specimen described by Fatherree et al. (1998) show sinusoidal $\delta^{18}O$ 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 Fatherree et al. (1998) show sinusoidal $\delta^{13}C$ signals with very similar periods around 335 mm. Error ranges overlap with each other and the period lengths produced from $\delta^{18}O$ (see Table 1).
- The consistency in period length is suggestive of common cause, which could be explained by a seasonal trend since $\delta^{18}O$ is temperature dependent and $\delta^{13}C$ may reflect seasonal variation in organism behavior, metabolism, and/or activity.
- The lengths of these periods suggest that *Baculites* grow 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 $\delta^{18}O$ 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. (2010) specimen's $\delta^{18}O$ 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.

Acknowledgments

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