Did sea level change influence carbon isotopic trends in the Late Permian Delaware Basin?

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Abstract

Previous studies have argued that stable carbon isotopic trends can be influenced by changes in relative sea level. As sea level rises, the oceanic basin becomes well mixed, organic carbon burial increases, and the influence of freshwater is diminished. This results in increasing carbon isotopic values in the rocks. When sea level falls, these processes work in reverse and carbon isotopic values progressively decrease. While previous studies have argued for a systematic relationship between sea level and carbon isotopes, those interpretations have not been tested quantitatively. For this project we aimed to propose a statistical test for correlating sea level and carbon isotopes. We focused our efforts on rocks exposed in Guadalupe Mountains National Park and Carlsbad Caverns National Park. By pairing carbon isotopic records with the rock record, we performed a series of statistical tests to correlate sea level change and stable carbon isotopic trends.

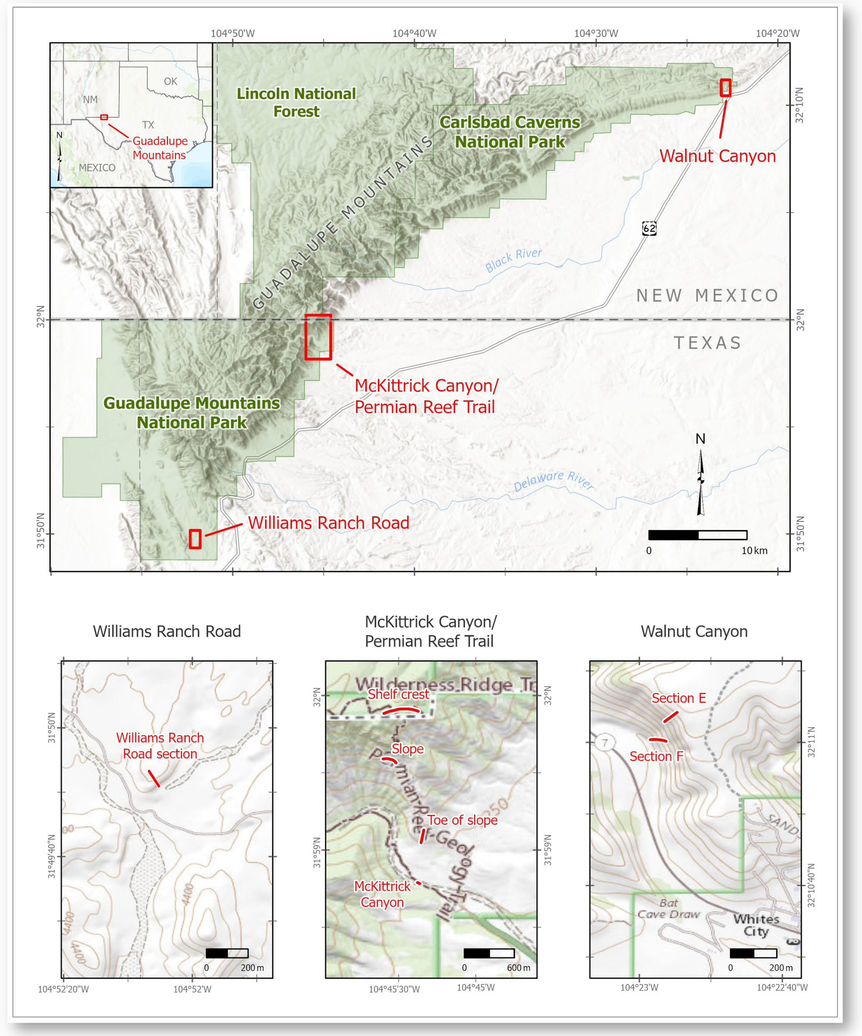


Figure 1: Map showing the study areas in Guadalupe Mountain National Park and Carlsbad Caverns National Park. The approximate extent of measured sections in this and related studies are shown as red lines on the detailed location maps. Note that this study focused on the Walnut Canyon Section E & F and Permian Reef Trail – Toe of Slope (TOS) sections.

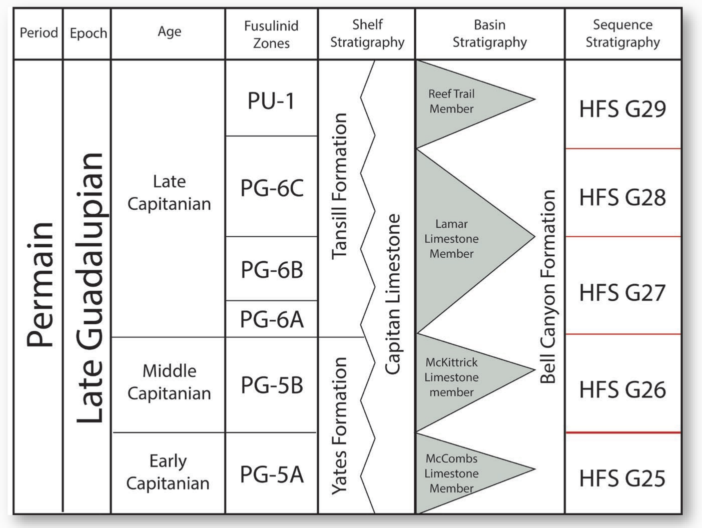


Figure 2: Lithostratigraphy, biostratigraphy, and sequence stratigraphy for the Delaware Basin modified from Rush and Kerans (2010), which builds upon Tyrrell (1969), Esteban and Pray (1977), Tinker (1998), Kerans and Tinker (1999), Wilde et al. (1999), and Lambert et al. (2002). Fusilinid zone abbreviations are: PG-5A - *Polydiexodina, Codonofusiella paradoxica, Leella bellula*; PG-5B - *Codonofusiella extensa*; PG-6A - *Yabeina texana*; PG-6B - *Paradoxiella pratti*; PG-6C - *Reichelina lamarensis*; PU-1 - *Paraboultonia-Lantschichites, Cordonofusiella, Reichelina.*

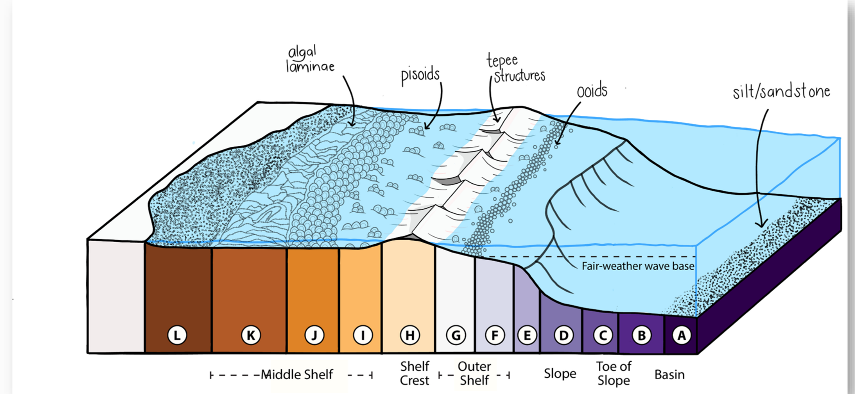


Figure 3: Depositional environments for the Delaware Basin modified from Tinker (1998) and Rush and Kerans (2010). Facies associations used in this study (identified by color and letter) are modified from those used in Rush and Kerans (2010) and Bebout and Kerans (1993).

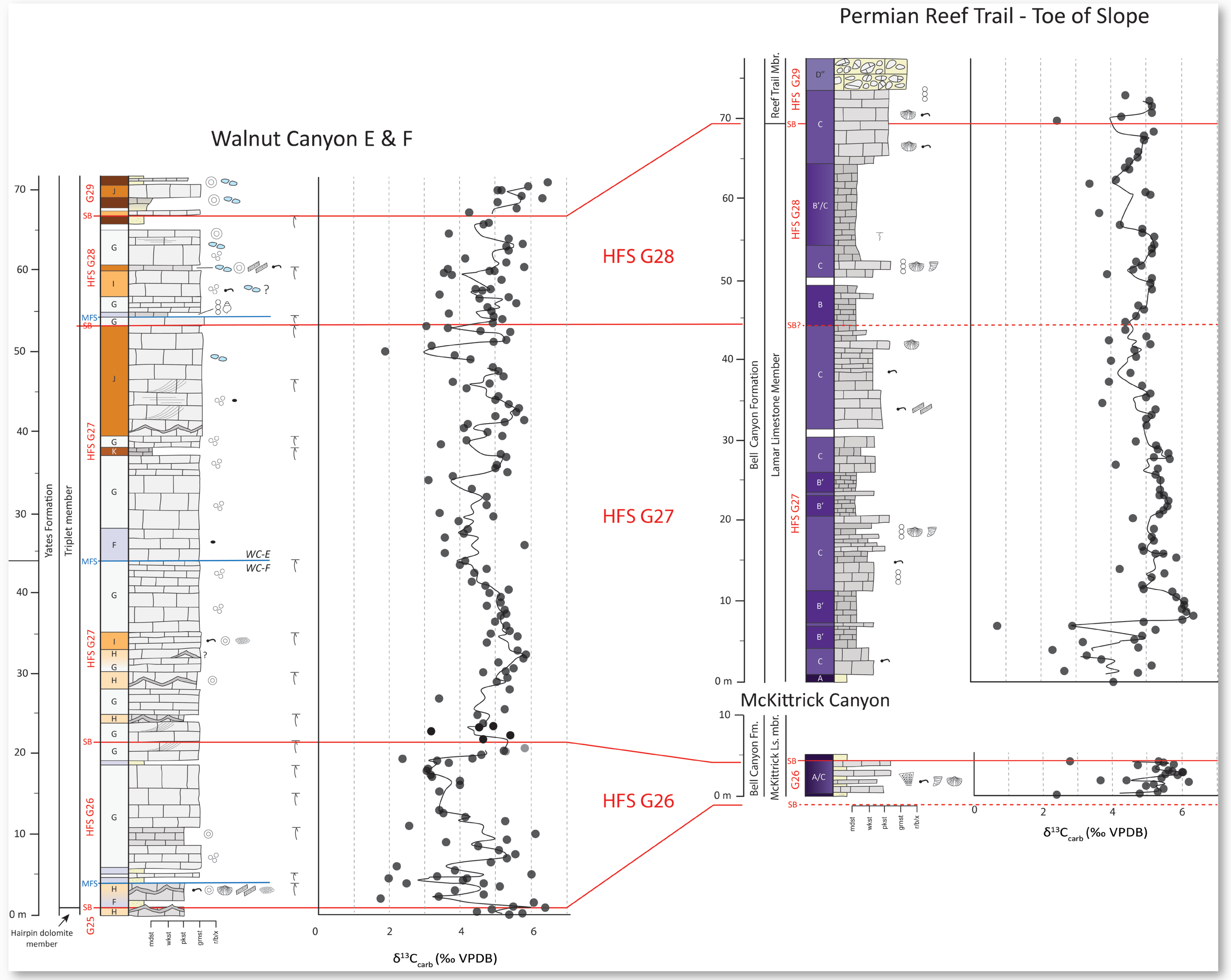


Figure 4: Summary graphic logs and carbon isotopic records for the Walnut Canyon E & F and Permian Reef Trail - Toe of Slope study sections. Correlation is based on the position of sequence boundaries in each section. For Toe of Slope, sequence boundary placement is based on Bebout and Kerans (1993) and for Walnut Canyon, sequence boundary placement is based on approximate position in Rush and Kerans (1993). Sedimentology, facies association interpretations, and geochemical records are from this study.

Methods

We tested the relationship between carbon isotopic trends and relative sea level by assigning estimated water depths and performing a serious of statistical tests on a bivariate data set of $\delta^{13}C$ values and water depth.

Paleobathymetry was estimated from Tinker (1998) to assign a water depth range for each facies association. Five statistical tests were conducted, using Python, to test the relationship between $\delta^{13}C$ values and water depth for Walnut Canyon and Permian Reef Trail – Toe of Slope. First, we conducted an Ordinary Least Squares (OLS) linear regression test. Then we conducted four, common, time series analyses, Arima (0,1,0), Arima (0,0,1), Arima (1,0,1), and Arima (1,1,0). A p-value less than 0.05 was used to statistical significance.

Results

The results for Walnut Canyon showed a weak correlation of -0.0907 between $\delta^{13}C$ and estimated water depth. The OLS linear regression was autocorrelated with a *p*-value of 0.310. Arima models had insignificant autocorrelation. Arima (0,1,0) and Arima (1,0,1) had p-values greater than 0.900. Arima (1,1,0) had a p-value of 0.606. Arima (0,0,1) had a *p*-value of 0.323. Kurtosis averaged 3.50 and Jarque-Bera (JB) averaged 15.0 across all models.

The results for Permian Reef Trail - Toe of Slope showed a weak correlation of 0.210 between $\delta^{13}C$ and estimated water depth. The OLS linear regression was autocorrelated with a *p*-value of 0.028. The time series analyses lacked autocorrelation. Arima (0,1,0) had a *p*-value of 0.783. Arima(1,0,1) and Arima (1,1,0) had *p*-values around 0.150. Arima (0,0,1) had a *p*-value of 0.0620. Kurtosis averaged 9.0 and JB averaged 200 across all models.

Water Depth vs. $\delta^{13}C$ for Toe of Slope

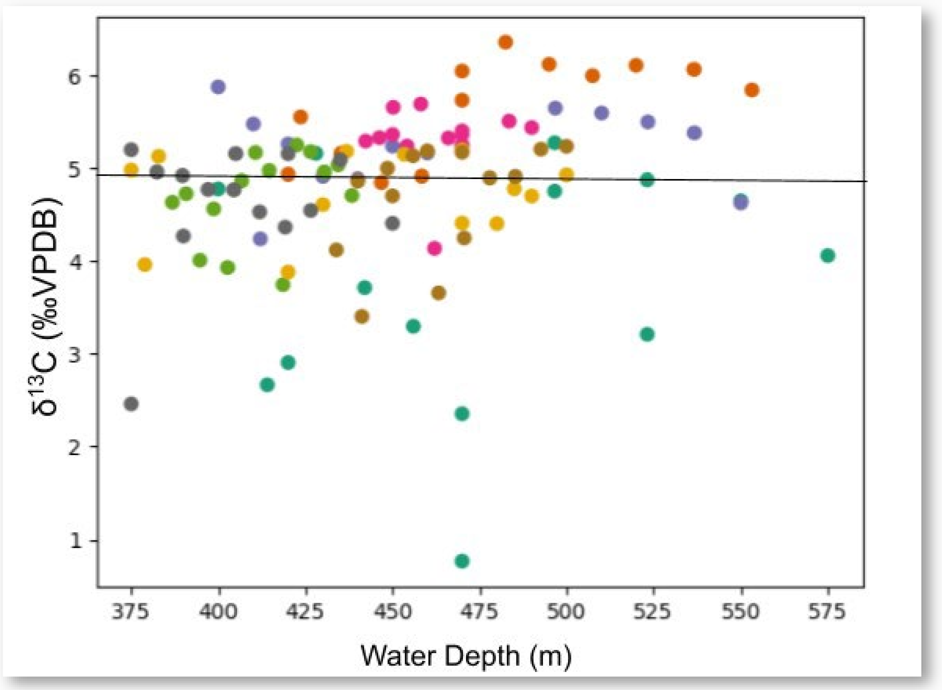


Figure 5: Plot of paleobathymetry vs. $\delta^{13}C$. The black line represents the line of best fit.

Residuals of OLS Linear Regression

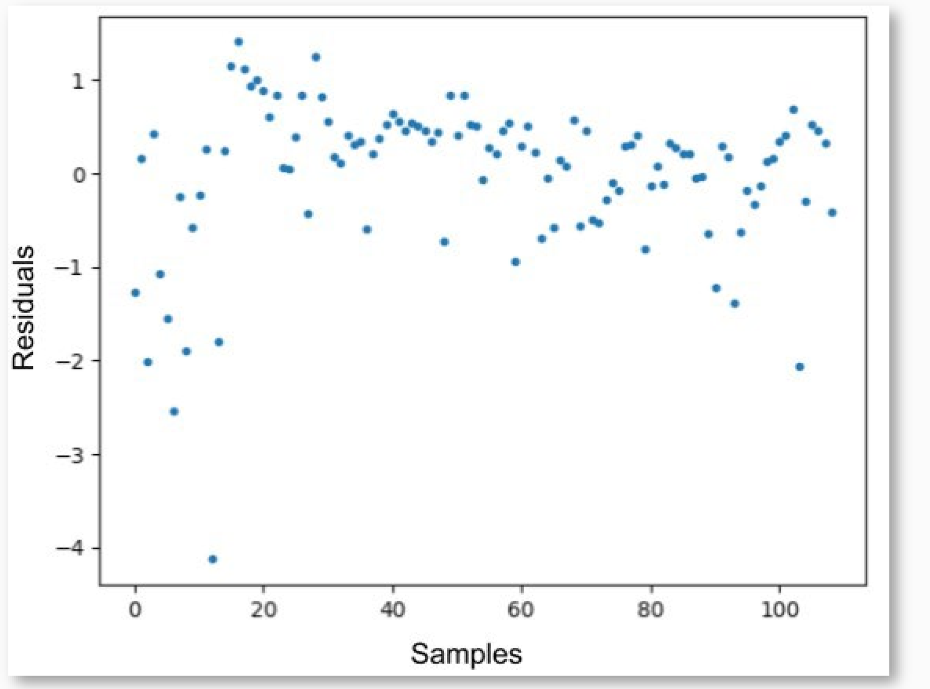


Figure 6: Plot of the residuals of Ordinary Least Squares (OLS) linear regression for Permian Reef Trail Toe of Slope. Sample is the sample number from 0 m to 75 m from the graphic log.

Autocorrelation for OLS Linear Regression

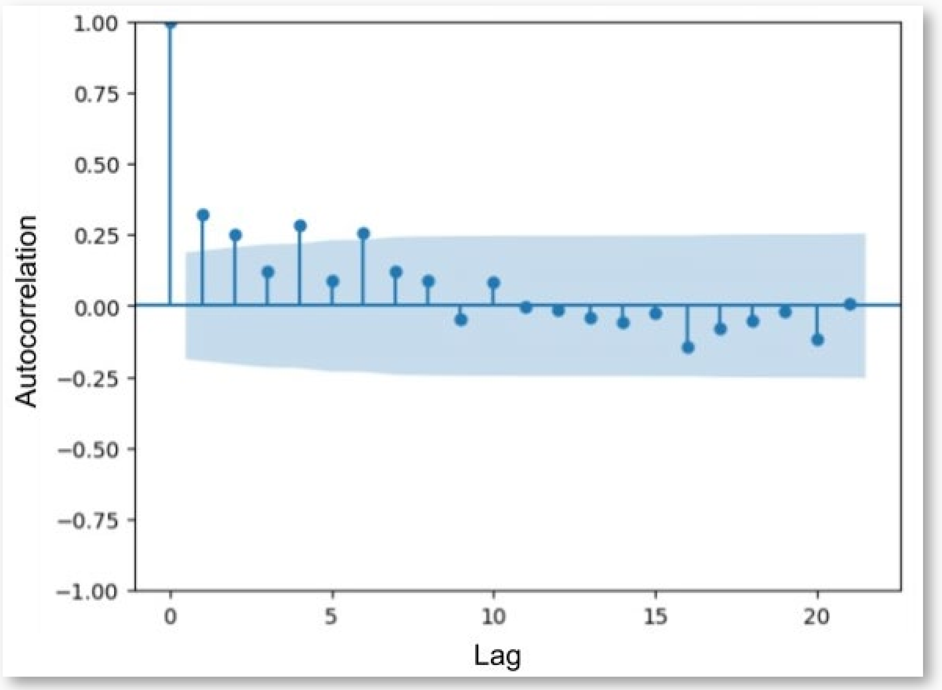
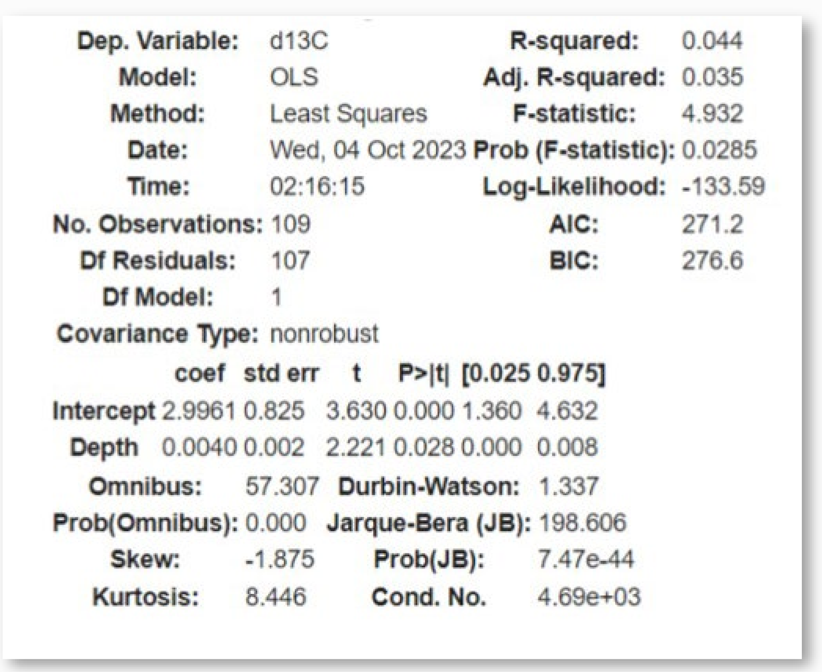


Figure 7: Plot of the autocorrelation of Ordinary Least Squares (OLS) linear regression for Permian Reef Trail – Toe of Slope. Lag is the delay between values.

OLS Linear Regression Results



Dep. Variable:	d13C	R-squared:	0.044
Model:	OLS	Adj. R-squared:	0.035
Method:	Least Squares	F-statistic:	4.932
Date:	Wed, 04 Oct 2023	Prob (F-statistic):	0.0285
Time:	02:16:15	Log-Likelihood:	-133.59
No. Observations:	109	AIC:	271.2
Df Residuals:	107	BIC:	276.6
Df Model:	1		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
Intercept	2.9961	0.825	3.630	0.000	1.360	4.632
Depth	0.0040	0.002	2.221	0.028	0.000	0.008

Omnibus:	57.307	Durbin-Watson:	1.337
Prob(Omnibus):	0.000	Jarque-Bera (JB):	198.606
Skew:	-1.875	Prob(JB):	7.47e-44
Kurtosis:	8.446	Cond. No.	4.69e+03

Figure 8: Results for the Ordinary Least Squares (OLS) linear regression for Permian Reef Trail – Toe of Slope. The *p*-value is 0.028 with high Kurtosis and Jarque-Bera.

Conclusions

Statistical tests showed no statistical significance between $\delta^{13}C$ and water depth in Walnut Canyon E & F and Permian Reef Trail – Toe of Slope sections.

- OLS linear regression was unsuitable to test $\delta^{13}C$ vs. water depth. The presence of autocorrelation, *p*-values greater than 0.05, and high Kurtosis implied that this test was insufficient. These results indicate that there are other variables influencing and concealing any possible relationship between $\delta^{13}C$ and water depth.
- Arima (1,1,0) might be useful for future analysis to study the relationship between $\delta^{13}C$ and relative sea level change. It had insignificant autocorrelation and *p*-values closer to 0.05. These results indicate that Arima (1,1,0) might be successful at identifying a relationship between $\delta^{13}C$ and water depth even when there are other variables influencing the data.

Further analysis between $\delta^{13}C$ and relative sea level change is needed. Paleobathymetry, missing geologic time within the stratigraphy, and depositional rates are variables that need to be further defined to conclude statistical relationships.

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