Auxiliary Materials
for Meyers et al. (2012)

INTRODUCTION: This auxiliary material submission contains tables, figures and supplementary text for Meyers et al. (2012), pertaining to the astrochronologic testing and astronomical time scale construction at each study site (DSDP Site 603B, Tarfaya S13, Demerara Rise ODP Site 1261B).

Table S1. Theoretical target periods used in the ASM analyses, based on the time domain astronomical model of Laskar et al. (2004, 2011) and the frequency domain astronomical model of Berger et al. (1992).

Term	Mean LA04/LA11 frequency (cycles/ka)	N^{δ}	Corresponding Laskar04/ Laskar11 period (ka)	2σ uncertainty (cycles/ka)	% Uncertainty in frequency	Berger et al. (1992) period (ka)
E1	2.466250×10^{-3}	4	405.47	5.737305×10^{-5}	2.3 %	*
E2	7.875000×10^{-3}	8	126.98	3.585686×10^{-4}	4.6 %	*
E3	1.031875×10^{-2}	8	96.91	4.307386×10^{-4}	4.2 %	*
O1	2.060000×10^{-2}	4	48.54	3.265986×10^{-4}	1.6 %	50.43
O2	2.655000×10^{-2}	4	37.66	2.000000×10^{-4}	0.8 %	38.93
P1	4.460000×10^{-2}	4	22.42	1.566312×10^{-3}	3.5 %	22.34
P2	5.455000×10^{-2}	4	18.33	2.000000×10^{-4}	0.4 %	18.54

δ = number of estimates used for determination of mean frequency and standard deviation.
** = Berger et al. (1992) do not provide Cretaceous eccentricity period estimates. The eccentricity periods of Laskar et al. (2011) are used.*

Table S2. ASM-derived astronomical periods for the DSDP Site 603B wt.% OC data series, using the astronomical target of Laskar et al. (2004, 2011; see Table S1).

Observed frequency (cycles/m)	MTM harmonic probability (%)	Observed period (ka)	Resolution bandwidth (ka)	Laskar04/ Laskar11 target period (ka)	Misfit (cycles/ka)
0.3750	99.48	331.87	398.24 - 284.46	E1: 405.47 (415.13-396.26)	0
0.7875	96.41	158.03	171.66 - 146.41	E2: 126.98 (133.04-121.45)	6.827771×10^{-4}
1.3250	97.60	93.93	98.58 - 89.69	E3: 96.91 (101.13-93.03)	0
2.4500	93.90	50.80	52.13 - 49.53	O1: 48.54 (49.33-47.79)	8.179869×10^{-5}
3.3875	91.37	36.74	37.43 - 36.07	O2: 37.66 (37.95-37.38)	0
5.6625	93.53	21.98	22.22 – 21.74	P1: 22.42 (23.24-21.66)	0
6.8375	99.21	18.20	18.37 - 18.04	P2: 18.33 (18.40-18.26)	0

Note: MTM—multitaper method. Observed temporal periods were determined using an optimal sedimentation rate of ~0.80 cm/ka.

Table S3. ASM-derived astronomical periods for the DSDP Site 603B wt.% OC data series, using the astronomical target of Berger et al. (1992; see Table S1).

Observed frequency (cycles/m)	MTM harmonic probability (%)	Observed period (ka)	Resolution bandwidth (ka)	Berger1992 target period (ka)	Misfit (cycles/ka)
0.3750	99.48	339.64	407.57 – 291.12	E1: 405.47	0
0.7875	96.41	161.73	175.68 – 149.84	E2: 126.98	1.201269×10^{-3}
1.3250	97.60	96.12	100.88 – 91.79	E3: 96.91	0
2.4500	93.90	51.99	53.35 – 50.69	O1: 50.43	1.034833×10^{-4}
3.3875	91.37	37.60	38.31 - 36.92	O2: 38.93	4.202622×10^{-4}
5.6625	93.53	22.49	22.74 – 22.25	P1: 22.34	0
6.8375	99.21	18.63	18.80 - 18.46	P2: 18.54	0

Note: MTM—multitaper method. Observed temporal periods were determined using an optimal sedimentation rate of ~0.79 cm/ka.

Table S4. ASM-derived astronomical periods for the Tarfaya S13 density series (112.5-137.5 m), using the astronomical target of Laskar et al. (2004, 2011; see Table S1).

Observed frequency (cycles/m)	MTM harmonic probability (%)	Observed period (ka)	Resolution bandwidth (ka)	Laskar04/ Laskar11 target period (ka)	Misfit (cycles/ka)
Not detectable	-	-	-	E1: 405.47 (415.13-396.26)	Not detectable
0.1000	91.41%	105.57	131.95 – 87.98	E2: 126.98 (133.04-121.45)	0
0.1000	91.41%	105.57	131.95 – 87.98	E3: 96.91 (101.13-93.03)	0
0.1950	98.14%	54.14	60.32 – 49.11	O1: 48.54 (49.33-47.79)	0
0.2750	99.24%	38.39	41.40 – 35.79	O2: 37.66 (37.95-37.38)	0
0.4400	97.79%	23.99	25.14 – 22.95	P1: 22.42 (23.24-21.66)	0
0.5950	96.75%	17.74	18.36 - 17.17	P2: 18.33 (18.40-18.26)	0

Note: MTM—multitaper method. Observed temporal periods were determined using an optimal sedimentation rate of ~9.47 cm/ka.

Table S5. ASM-derived astronomical periods for the Tarfaya S13 density series (166.5-191.5 m), using the astronomical target of Laskar et al. (2004, 2011; see Table S1).

Observed frequency (cycles/m)	MTM harmonic probability (%)	Observed period (ka)	Resolution bandwidth (ka)	Laskar04/ Laskar11 target period (ka)	Misfit (cycles/ka)
0.0400	97.27%	411.79	823.24 – 274.56	E1: 405.47 (415.13-396.26)	0
0.1600	99.29%	102.95	117.65 – 92.51	E2: 126.98 (133.04-121.45)	2.627837×10^{-4}
0.1600	99.29%	102.95	117.65 – 92.51	E3: 96.91 (101.13-93.03)	0
0.3150	99.31%	52.29	55.83 – 49.17	O1: 48.54 (49.33-47.79)	0
0.4200	99.98%	39.22	41.18 – 37.44	O2: 37.66 (37.95-37.38)	0
0.7550	90.58%	21.82	22.41 – 21.25	P1: 22.42 (23.24-21.66)	0
0.9200	95.76%	17.90	18.30 - 17.52	P2: 18.33 (18.40-18.26)	0

Note: MTM—multitaper method. Observed temporal periods were determined using an optimal sedimentation rate of ~6.07 cm/ka.

Table S6. ASM-derived astronomical periods for the Tarfaya S13 density series (98.5-123.5 m), using the astronomical target of Berger et al. (1992; see Table S1).

Observed frequency (cycles/m)	MTM harmonic probability (%)	Observed period (ka)	Resolution bandwidth (ka)	Berger1992 target period (ka)	Misfit (cycles/ka)
Not detectable	-	-	-	E1: 405.47	Not detectable
0.1100	91.37	104.90	128.21 – 88.77	E2: 126.98	0
0.1100	91.37	104.90	128.21 – 88.77	E3: 96.91	0
0.2050	99.95	56.29	62.37 – 51.29	O1: 50.43	3.326552×10^{-4}
0.2950	99.08	39.12	41.96 - 36.63	O2: 38.93	0
0.5250	92.19	21.98	22.85 – 21.17	P1: 22.34	0
0.6450	90.36	17.89	18.46 - 17.35	P2: 18.54	2.135399×10^{-4}

Note: MTM—multitaper method. Observed temporal periods were determined using an optimal sedimentation rate of ~8.67 cm/ka.

Table S7. ASM-derived astronomical periods for the Tarfaya S13 density series (166.5-191.5 m), using the astronomical target of Berger et al. (1992; see Table S1).

Observed frequency (cycles/m)	MTM harmonic probability (%)	Observed period (ka)	Resolution bandwidth (ka)	Berger1992 target period (ka)	Misfit (cycles/ka)
0.0400	97.27%	418.50	836.67 – 279.04	E1: 405.47	0
0.1600	99.29%	104.63	119.57 – 93.00	E2: 126.98	4.886495×10^{-4}
0.1600	99.29%	104.63	119.57 – 93.00	E3: 96.91	0
0.3150	99.31%	53.14	56.74 – 49.97	O1: 50.43	0
0.4200	99.98%	39.86	41.85 – 38.05	O2: 38.93	0
0.7550	90.58%	22.17	22.78 – 21.60	P1: 22.34	0
0.9200	95.76%	18.20	18.60 – 17.81	P2: 18.54	0

Note: MTM—multitaper method. Observed temporal periods were determined using an optimal sedimentation rate of ~5.97 cm/ka.

Table S8. ASM-derived astronomical periods for the ODP Site 1261B FMS data (609.8-615.8), using the astronomical target of Laskar et al. (2004, 2011; see Table S1).

Observed frequency (cycles/m)	MTM harmonic probability (%)	Observed period (ka)	Resolution bandwidth (ka)	Laskar04/ Laskar11 target period (ka)	Misfit (cycles/ka)
0.2362	97.30%	285.33	440.57 – 210.99	E1: 405.47 (415.13-396.26)	0
0.6142	90.08%	109.74	126.95 – 96.65	E2: 126.98 (133.04-121.45)	0
0.6142	90.08%	109.74	126.95 – 96.65	E3: 96.91 (101.13-93.03)	0
1.3858	91.80%	48.64	51.74 – 45.88	O1: 48.54 (49.33-47.79)	0
1.9528	93.08%	34.52	36.05 – 33.10	O2: 37.66 (37.95-37.38)	9.747694×10^{-4}
3.0079	90.89%	22.41	23.05 – 21.80	P1: 22.42 (23.24-21.66)	0
3.5748	96.80%	18.85	19.30 – 18.43	P2: 18.33 (18.40-18.26)	5.926254×10^{-5}

Note: MTM—multitaper method. Observed temporal periods were determined using an optimal sedimentation rate of ~1.48 cm/ka.

Table S9. ASM-derived astronomical periods for the ODP Site 1261B FMS data (632.4-638.4), using the astronomical target of Laskar et al. (2004, 2011; see Table S1).

Observed frequency (cycles/m)	MTM harmonic probability (%)	Observed period (ka)	Resolution bandwidth (ka)	Laskar04/ Laskar11 target period (ka)	Misfit (cycles/ka)
0.2520	99.39%	349.06	521.25 – 262.38	E1: 405.47 (415.13-396.26)	0
0.6457	96.56%	136.22	156.38 – 120.66	E2: 126.98 (133.04-121.45)	0
0.9764	91.82%	90.08	98.47 – 83.00	E3: 96.91 (101.13-93.03)	0
1.9843	92.63%	44.33	46.27 – 42.54	O1: 48.54 (49.33-47.79)	6.846395×10^{-4}
2.2992	96.71%	38.25	39.69 – 36.92	O2: 37.66 (37.95-37.38)	0
4.0787	95.65%	21.56	22.01 – 21.13	P1: 22.42 (23.24-21.66)	0
4.7244	96.08%	18.62	18.95 – 18.29	P2: 18.33 (18.40-18.26)	0

Note: MTM—multitaper method. Observed temporal periods were determined using an optimal sedimentation rate of ~1.14 cm/ka.

Table S10. ASM-derived astronomical periods for the ODP Site 1261B FMS data (609.8-615.8), using the astronomical target of Berger et al. (1992; see Table S1).

Observed frequency (cycles/m)	MTM harmonic probability (%)	Observed period (ka)	Resolution bandwidth (ka)	Berger1992 target period (ka)	Misfit (cycles/ka)
0.2362	97.30%	288.65	445.70 – 213.44	E1: 405.47	0
0.6142	90.08%	111.02	128.42 – 97.77	E2: 126.98	0
0.6142	90.08%	111.02	128.42 – 97.77	E3: 96.91	9.068120×10^{-5}
1.3858	91.80%	49.20	52.35 – 46.41	O1: 50.43	0
1.9528	93.08%	34.92	36.47 – 33.49	O2: 38.93	1.732270×10^{-3}
3.0079	90.89%	22.67	23.31 – 22.06	P1: 22.34	0
3.5748	96.80%	19.07	19.53 – 18.64	P2: 18.54	3.009037×10^{-4}

Note: MTM—multitaper method. Observed temporal periods were determined using an optimal sedimentation rate of ~1.47 cm/ka.

Table S11. ASM-derived astronomical periods for the ODP Site 1261B FMS data (632.4-638.4), using the astronomical target of Berger et al. (1992; see Table S1).

Observed frequency (cycles/m)	MTM harmonic probability (%)	Observed period (ka)	Resolution bandwidth (ka)	Berger1992 target period (ka)	Misfit (cycles/ka)
0.2520	99.39%	353.12	527.31 – 265.44	E1: 405.47	0
0.6457	96.56%	137.80	158.20 – 122.07	E2: 126.98	0
0.9764	91.82%	91.13	99.62 – 83.97	E3: 96.91	0
1.9843	92.63%	44.84	46.80 – 43.04	O1: 50.43	1.535334×10^{-3}
2.2992	96.71%	38.70	40.15 – 37.35	O2: 38.93	0
4.0787	95.65%	21.81	22.27 – 21.38	P1: 22.34	1.348272×10^{-4}
4.7244	96.08%	18.83	19.17 – 18.51	P2: 18.54	0

Note: MTM—multitaper method. Observed temporal periods were determined using an optimal sedimentation rate of ~1.12 cm/ka.

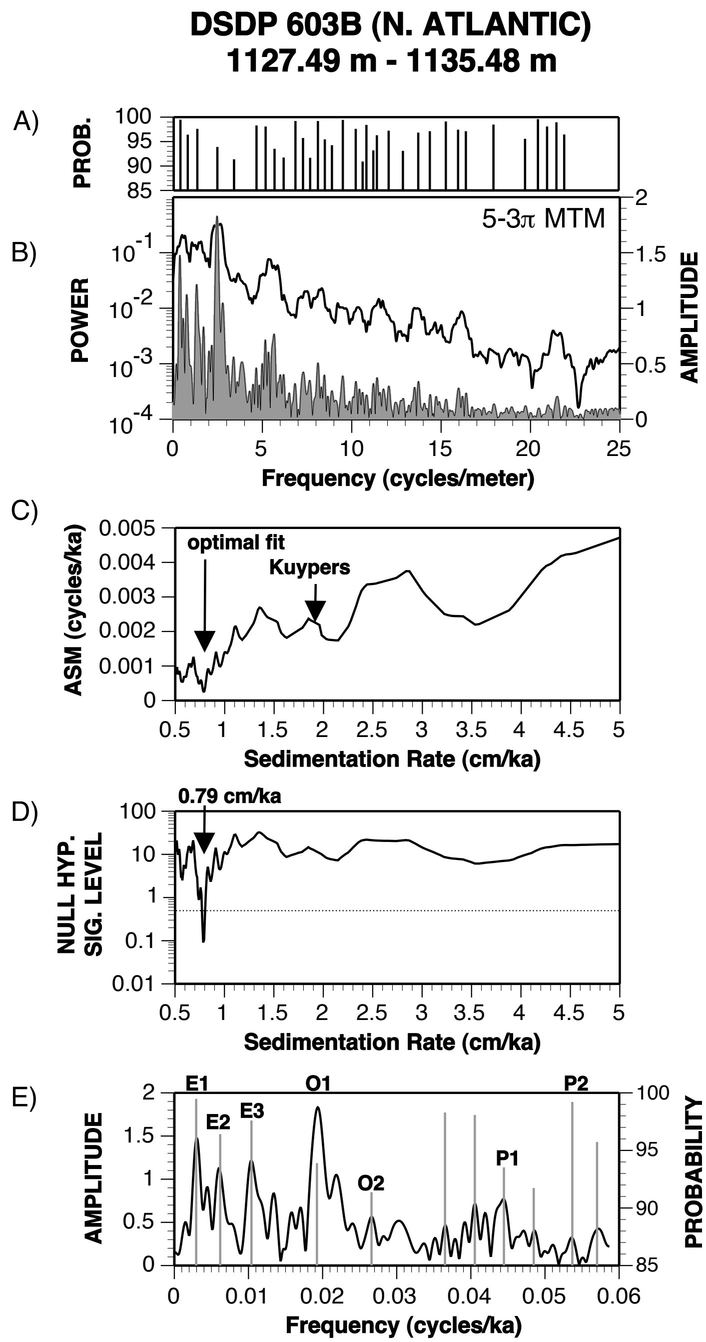

Figure S1. Multitaper method (MTM) spectral analysis and average spectral misfit (ASM) results for the DSDP 603B weight percent OC data series. MTM spectral analysis was conducted using five 3π tapers. ASM evaluates the astronomical model of Berger et al. (1992), and is calculated for 200 individual sedimentation rates spanning 0.5 to 5 cm/ka, with a log-scaling of the sedimentation rate grid. The null hypothesis Monte Carlo test utilizes 100,000 simulated spectra. A) MTM harmonic analysis probability results. B) Log MTM power spectrum estimate (bold line) and amplitude spectrum (gray). C) Average spectral misfit in cycles/ka. "Kuypers" indicates the sedimentation rate proposed by Kuypers et al. (2004). D) Null hypothesis significance levels. The dotted line indicates a critical significance level of 0.5%. E) Calibrated amplitude spectrum (black line) and harmonic analysis probability results (vertical lines), using a sedimentation rate of 0.79 cm/ka.

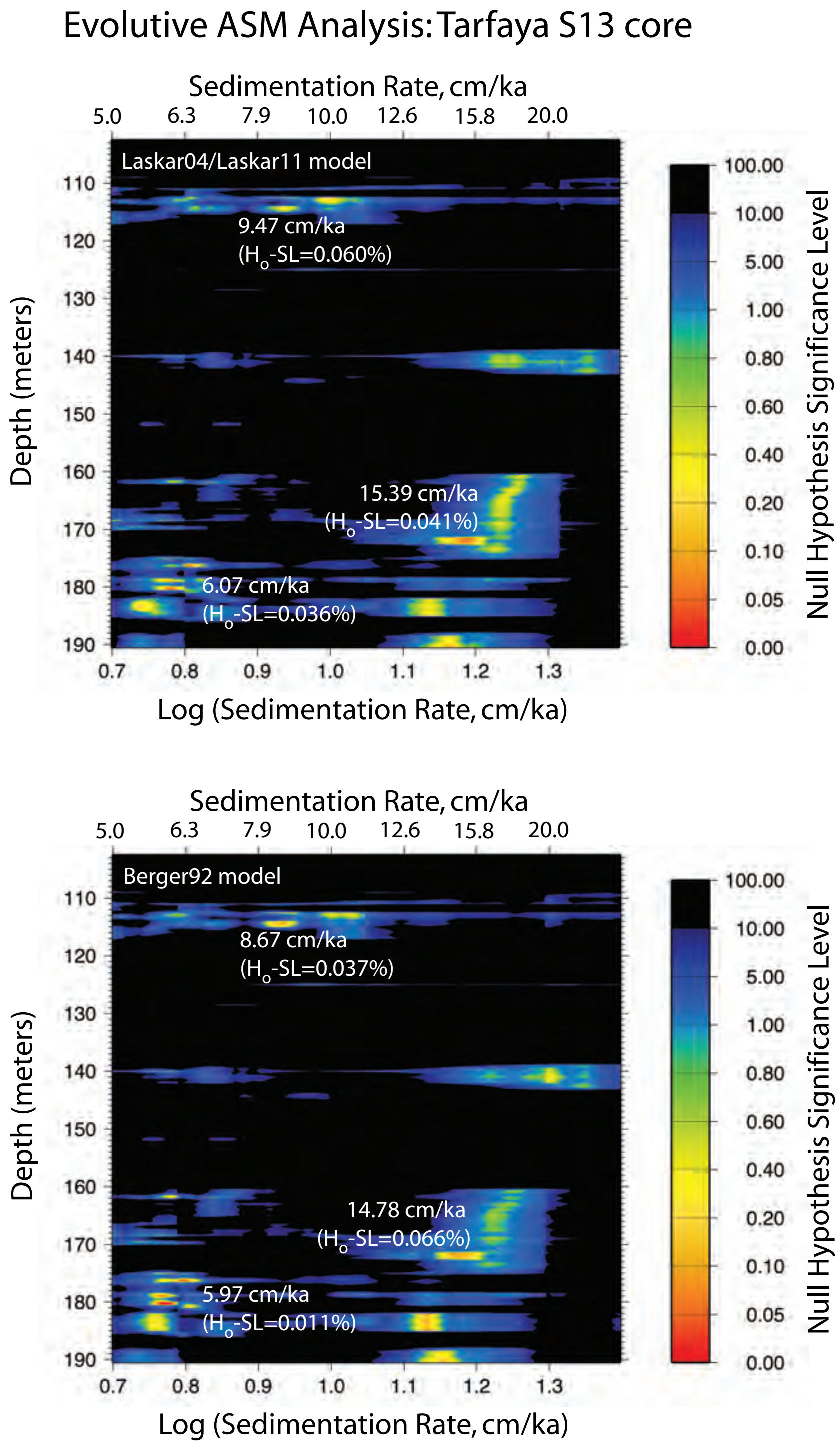

Figure S2. Evolutive ASM analysis for the Tarfaya S13 EHA results in Figure 5. ASM is calculated using 200 individual sedimentation rates spanning 5 to 25 cm/ka (log scaling). The upper plot evaluates the astronomical model of Laskar et al. (2004; 2011), and the lower plot evaluates the astronomical model of Berger et al. (1992). Representative sedimentation rates with null hypothesis significance levels ≤ 0.1% are indicated.

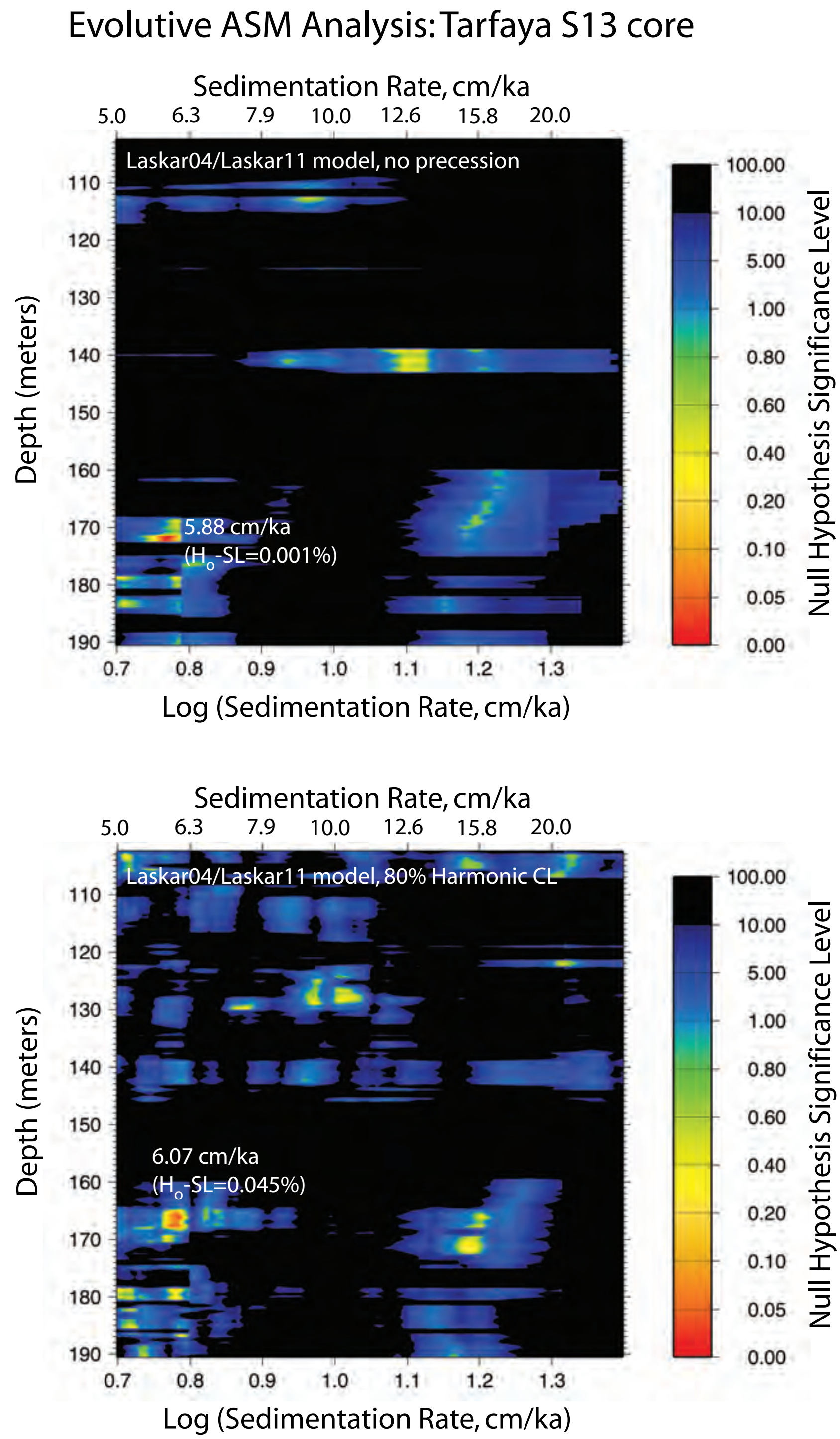

Figure S3. Evolutive ASM analysis for the Tarfaya S13 EHA results in Figure 5. ASM is calculated using 200 individual sedimentation rates spanning 5 to 25 cm/ka (log scaling). The upper plot evaluates the astronomical model of Laskar et al. (2004; 2011), excluding the precession terms. The lower plot evaluates the astronomical model of Laskar et al. (2004; 2011), using all frequencies with harmonic confidence levels ≥ 80%. Representative sedimentation rates with null hypothesis significance levels ≤ 0.1% are indicated.

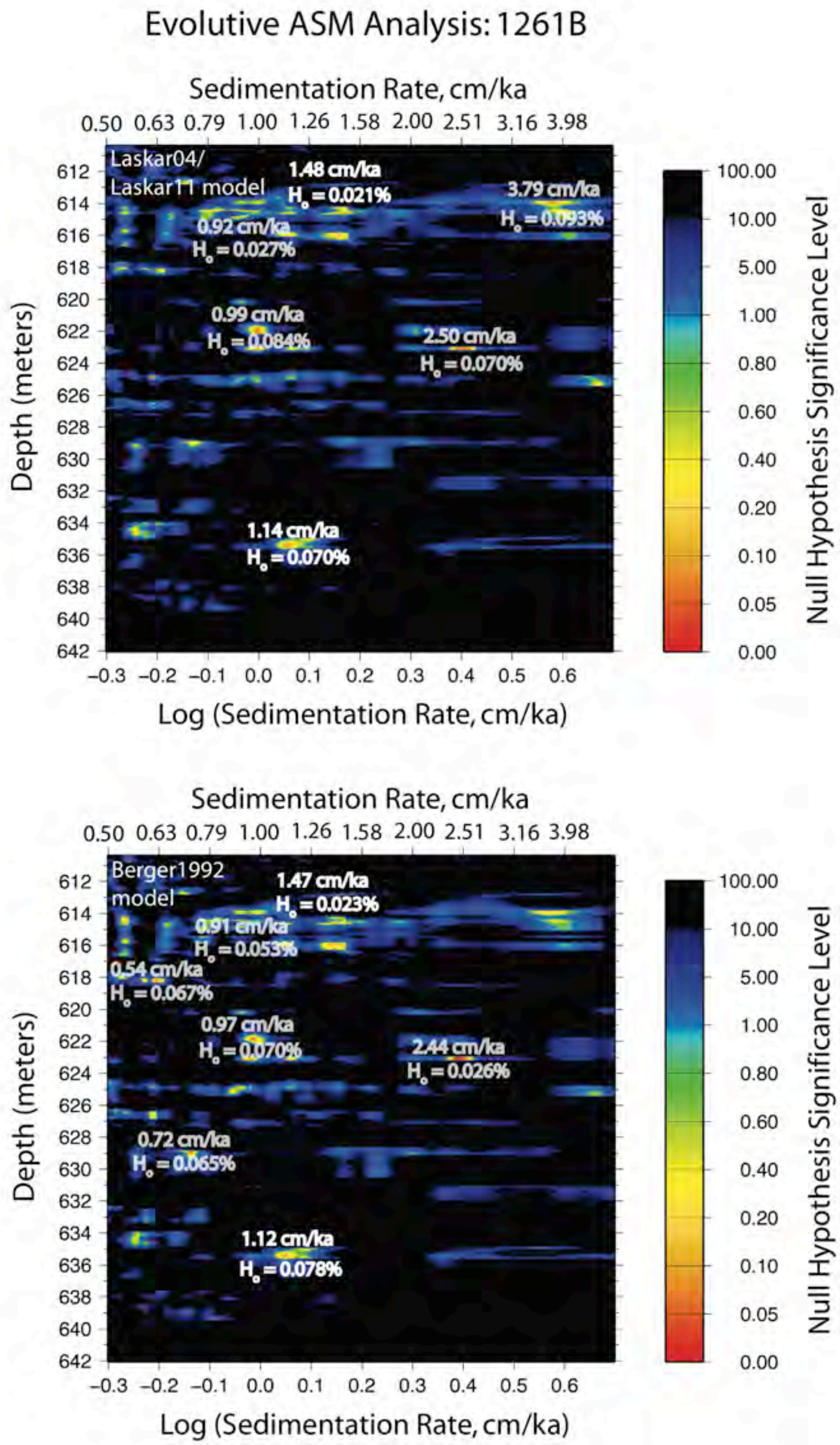

Figure S4. Evolutive ASM analysis for the Demerara Rise EHA results in Figure 7. ASM is calculated using 200 individual sedimentation rates spanning 0.5 to 5 cm/ka (log scaling). The upper plot evaluates the astronomical model of Laskar et al. (2004; 2011), and the lower plot evaluates the astronomical model of Berger et al. (1992). Representative sedimentation rates with null hypothesis significance levels ≤ 0.1% are indicated.

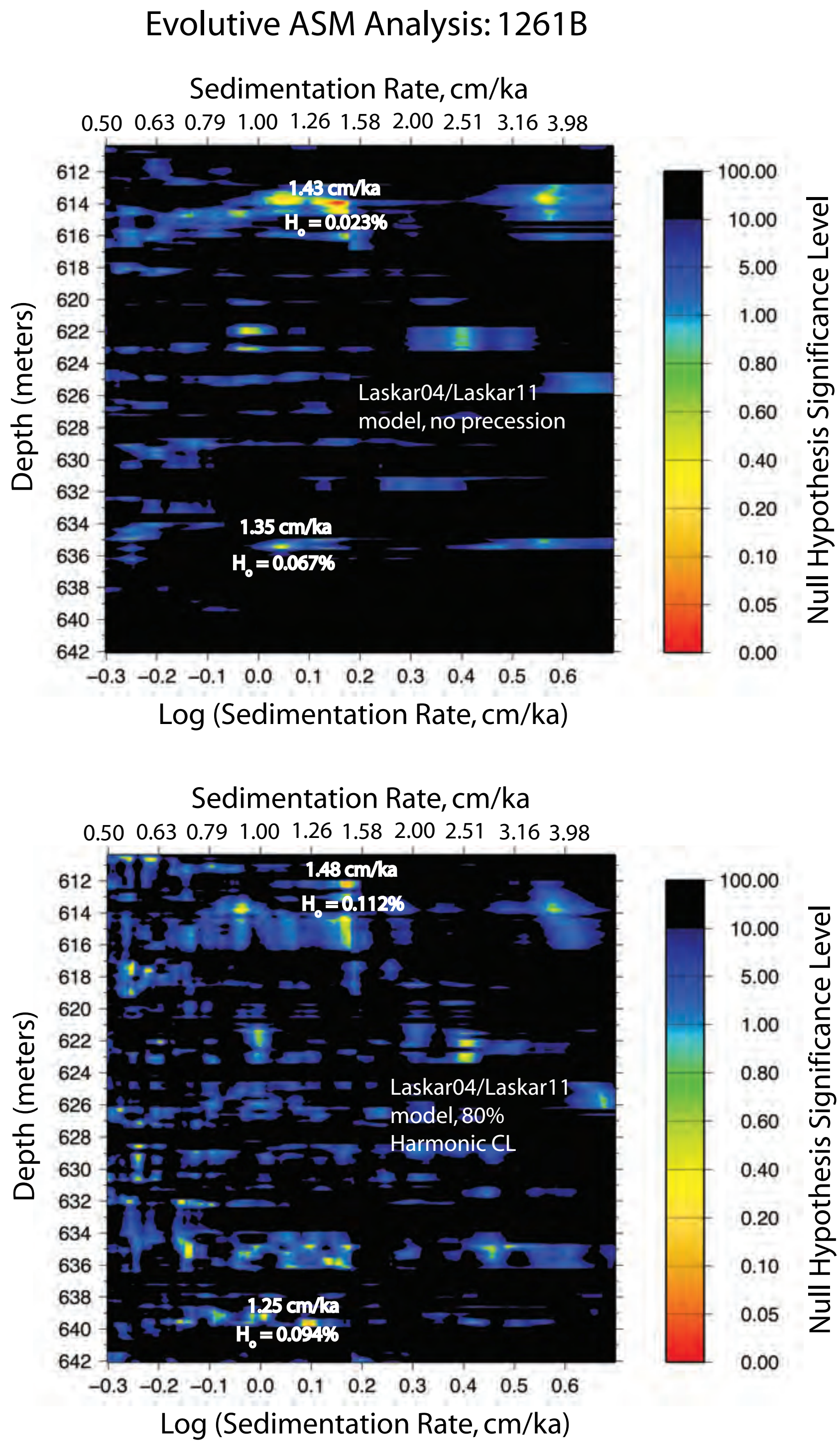

Figure S5. Evolutive ASM analysis for the Demerara Rise EHA results in Figure 7. ASM is calculated using 200 individual sedimentation rates spanning 0.5 to 5 cm/ka (log scaling). The upper plot evaluates the astronomical model of Laskar et al. (2004; 2011), excluding the precession terms. The lower plot evaluates the astronomical model of Laskar et al. (2004; 2011), using all frequencies with harmonic confidence levels ≥ 80%. Representative sedimentation rates with null hypothesis significance levels ≤ 0.12% are indicated.

Astronomical Tuning Procedures

Following the identification and calibration of astronomical cycles at DSDP 603B, Tarfaya S13 and Demerara Rise Site 1261B, orbital time scales were independently constructed at each site. For DSDP 603B, a uniform ASM-derived sedimentation rate of 0.80 cm/ka was applied to convert depth to time, motivated by the remarkable stability of sedimentation at DSDP 603B (as illustrated by the EHA results in Figure 3). Given the unsteady sedimentation observed at Tarfaya S13 and Demerara Rise, orbital timescales were constructed using a frequency domain ‘minimal tuning’ approach (e.g., Meyers et al., 2001). For the Tarfaya S13 astrochronology, the spatial frequency of the well-resolved O1 term (48.54 ka; Figure 5) was used to construct a detailed record of the sedimentation history, and this sedimentation rate curve was numerically integrated to develop the depth to time transformation function (see Meyers et al., 2001). At Demerara Rise Site 1261B, the expression of the persistent short eccentricity terms (E2 and E3; 126.98 and 96.91 ka; Figure 7) was used to develop the sedimentation rate curve. The results of the tuning are displayed in Figure S6, including the astronomically calibrated carbon isotope excursions at each location.

Determination of the duration of the excursion at each site is dependent upon how the termination is defined (e.g., see Sageman et al., 2006), and further limitations are presented by the variable resolution of the carbon isotopic data, as well as the judgment of correlative features given the complexity of some records. Not surprisingly, greater density of sampling tends to reveal greater complexity in the pattern of the isotope excursion, making inferences about such features as the “end of the plateau” more challenging (Tsikos et al., 2004; Sageman et al., 2006). The full astronomically-tuned data sets are illustrated in Figure S6, to allow assessment of the timing of any features of interest.

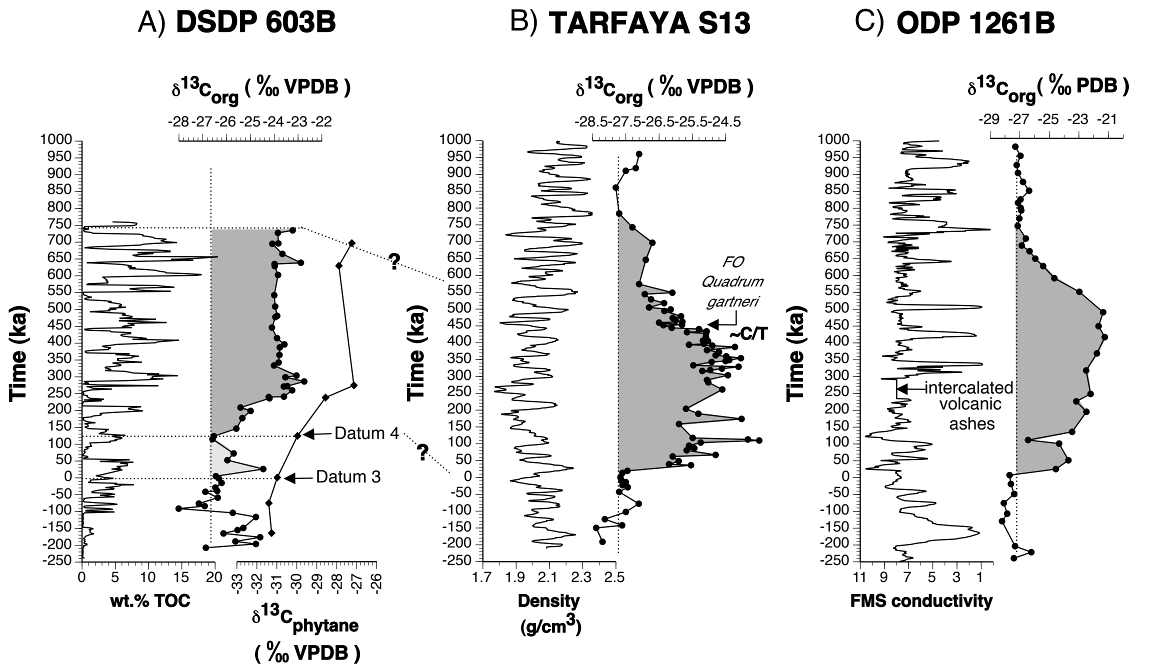

Figure S6. Astronomically tuned data from DSDP 603B, Tarfaya S13, and Demerara Rise Site 1261B. The temporal axis indicates the approximate time since initiation of the OAE 2 carbon isotope excursion at each location. A) Weight percent total organic carbon (wt. % TOC; Herbin et al., 1987), the carbon isotopic value of bulk organic matter (new isotopic data combined with data previously published by Kuypers et al., 2004) ($\delta^{13}C_{org}$; per mil VPDB), and the carbon isotopic value of sulfur-bound phytane ($\delta^{13}C_{phytane}$; per mil VPDB) for samples from the upper portion of the Hatteras Formation at DSDP Site 603B (Kuypers et al., 2004). "Datum 3" and "Datum 4" constrain the initiation of OAE 2 as defined by $\delta^{13}C_{phytane}$. B) New density data (g/cm^3) (kindly provided by Prof. Wolfgang Kuhnt) and the carbon isotopic value of bulk organic matter ($\delta^{13}C_{org}$; per mil VPDB) for Cenomanian/Turonian strata in the Tarfaya S13 core (Kolonic et al., 2005). The location of the C/T boundary is based on the first occurrence of the nannofossil *Quadrum gartneri* (Kolonic et al., 2005). C) FMI data (uncalibrated conductivity; Shipboard Scientific Party, 2004) and the carbon isotopic value of bulk organic matter ($\delta^{13}C_{org}$; per mil PDB; Erbacher et al., 2005) for Cenomanian/Turonian strata at Demerara Rise ODP Site 1261B.