Mosher, D.C., Erbacher, J., and Malone, M.J. (Eds.)
Proceedings of the Ocean Drilling Program, Scientific Results Volume 207

11. Data Report: Organic Carbon, Total Nitrogen, Carbonate Carbon, and Carbonate Oxygen Isotopic Compositions of Albian to Santonian Black Shales from Sites 1257–1261 on the Demerara Rise[1]

Philip A. Meyers[2] and Stefano M. Bernasconi[3]

ABSTRACT

Organic carbon, total nitrogen, carbonate carbon, and carbonate oxygen isotopic compositions were measured for 95 samples selected from the black shale sequences drilled during Ocean Drilling Program Leg 207 on the Demerara Rise. Most samples have organic $\delta^{13}C$ values smaller than –27‰, with the exception of several samples that have values between –24.9‰ and –23.9‰ that may correspond to oceanic anoxic events. Bulk $\delta^{15}N$ values range between –4.2‰ and +4.4‰ and become smaller as organic carbon concentrations increase. Comparison of the $\delta^{15}N$ values of nondecarbonated samples to their decarbonated analogs reveals no systematic effect of the acid treatment used in the decarbonation.

INTRODUCTION

The organic carbon isotopic compositions of mid-Cretaceous black shales commonly deviate from those of most Cenozoic marine sequences. Dean et al. (1986) note that marine organic matter in most Cretaceous black shales has $\delta^{13}C$ values between –28‰ and –26‰, whereas in Neogene organic carbon–rich sediments the values range be-

[1]Meyers, P.A., and Bernasconi, S.M., 2006. Data report: organic carbon, total nitrogen, carbonate carbon, and carbonate oxygen isotopic compositions of Albian to Santonian black shales from Sites 1257–1261 on the Demerara Rise. *In* Mosher, D.C., Erbacher, J., and Malone, M.J. (Eds.), *Proc. ODP, Sci. Results,* 207: College Station, TX (Ocean Drilling Program), 1–13. doi:10.2973/odp.proc.sr.207.106.2006
[2]Marine Geology and Geochemistry Program, Department of Geological Sciences, The University of Michigan, Ann Arbor MI 48109-1005, USA. pameyers@umich.edu
[3]Geologisches Institut, Eidgenössische Technische Hochschule (ETH), CH-8092 Zürich, Switzerland.

Initial receipt: 13 July 2005
Acceptance: 13 January 2006
Web publication: 6 November 2006
Ms 207SR-106

tween –23‰ and –16‰. They attribute this difference to greater availability of dissolved CO_2 to marine algae because of the higher pCO_2 of the Cretaceous atmosphere. Moreover, $\delta^{13}C_{org}$ values generally become more negative as the concentration of organic carbon increases (Hofmann et al., 2000), with the important exceptions of the Aptian oceanic anoxic event (OAE) 1a and the Cenomanian–Turonian OAE2, in which shifts to less negative values record the greatly amplified marine productivity at those times (Sliter, 1989; Erbacher et al., 1996; Menegatti et al., 1998; Tsikos et al., 2004; Bowman and Bralower, 2005; Erbacher et al., 2005).

Like the organic $\delta^{13}C$ values, bulk $\delta^{15}N$ and carbonate $\delta^{18}O$ values of mid-Cretaceous black shales are also typically smaller than those of most Cenozoic marine sediments. Black shale $\delta^{15}N$ values are typically between –3‰ and +1‰ (Rigby and Batts, 1986; Rau et al., 1987; Kuypers et al., 2004; Dumitrescu and Brassell, 2006), which contrasts against the average of about +5‰ for modern marine sediments (Altabet and Francois, 1994). This difference is generally interpreted as indicating the widespread existence of cyanobacterial nitrogen fixation during times of black shale deposition. Carbonate $\delta^{18}O$ values that are ~2‰ smaller than precyrospheric Cenozoic sediments manifest the globally warmer temperatures of the mid-Cretaceous (e.g., Clarke and Jenkyns, 1999).

The Albian to Santonian black shale sequences recovered at Sites 1257–1261 on the Demerara Rise in the western equatorial Atlantic Ocean present special opportunities to examine in greater detail the lighter mid-Cretaceous isotopic compositions reported by earlier investigators. The dark calcareous claystones typically contain between 2 and 15 wt% organic carbon and range in thickness from 56 m at Sites 1258 and 1259 to 93 m at Site 1260. We report here the results of organic matter and carbonate isotopic analyses of samples selected from these sequences.

METHODS

Two suites of samples were combined for our study of the isotopic compositions of the Demerara Rise black shale sequences. The first suite consists of 64 3-cm-thick samples selected from Sites 1257, 1258, and 1260 specifically for isotope analyses. The second suite consists of 31 10- to 20-cm-thick samples that were selected from the black shale sequences at Sites 1257, 1258, 1259, and 1261 for a multiproxy paleoclimate reconstruction (Bice et al., 2006). Samples were freeze-dried on board the *JOIDES Resolution* in preparation for shore-based analyses.

Concentrations of calcium carbonate in ground sediment samples were measured by the routine coulometric procedure used on the *JOIDES Resolution* (Engleman et al., 1985). Carbon and oxygen isotopic compositions of carbonates were determined by reaction with 100% phosphoric acid at 90°C on a mass spectrometer fitted with an automated isocarb common acid bath preparation system. The mass spectrometer was calibrated with National Bureau of Standards (NBS) 19, NBS 18, and NBS 20 standards. The isotopic compositions are reported in the conventional delta-notation with respect to the Vienna Peedee belemnite (VPDB) standard. Analytical reproducibility is better than ±0.1‰ for both $\delta^{13}C$ and $\delta^{18}O$.

In preparation for analysis of their total organic carbon (TOC) and total nitrogen (TN) concentrations and isotopic compositions, ground sediment samples were decarbonated by treatment with 3-N HCl and then washed with distilled water to remove the acid. The concentrations and isotopic compositions of the dried carbonate-free residue were analyzed with an elemental analyzer interfaced directly with a mass spectrometer in the Geological Institute at Eidgenössische Technische Hochschule, Zürich. The absolute precisions of the TOC and TN analyses are both ±0.05%. Concentrations of TOC and TN are reported on a whole-sediment basis. The $\delta^{13}C$ is given relative to the VPDB standard, and the $\delta^{15}N$ of each sample is expressed relative to atmospheric dinitrogen. Regular analysis of standards shows that measurements of both isotopic values have precisions of better than ±0.1‰.

Because the decarbonation procedure has the potential for removing a portion of the total nitrogen content and thereby altering the nitrogen isotopic compositions of the samples, we also determined $\delta^{15}N$ values of the nondecarbonated bulk sediment of 41 of the 91 samples that we analyzed for nitrogen isotopes to assess the impact of the decarbonation procedure.

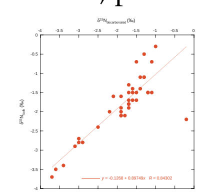
RESULTS

Comparison of $\delta^{15}N$ Values of Decarbonated and Bulk Samples

The range of differences in the $\delta^{15}N$ values of 26 of the 41 pairs of decarbonated and bulk samples is within analytical precision (±0.1‰), but the remaining pairs have values that differ by –0.8‰ to +2.0‰ (Table T1). The $\delta^{15}N$ values of some samples are clearly sensitive to the decarbonation procedure, although the effect is randomly larger or smaller and is variable in magnitude. Differences between sample pairs have no obvious relation to either TN or TOC concentrations. In general, the decarbonated samples yield slightly smaller $\delta^{15}N$ values than the bulk samples (Fig. F1), although the overall mean of the differences is 0.0‰. Because >60% of the sample pairs in our comparison agree within analytical precision and the difference in the remaining sample pairs is randomly negative or positive, we considered both analyses as valid data and averaged their results in our overall compilation of N isotopic compositions (Table T2).

T1. $\delta^{15}N$ values, p. 11.

F1. $\delta^{15}N$ values, p. 8.



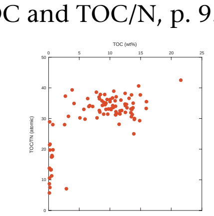
Organic Carbon Concentrations and Total Organic Carbon/Total Nitrogen Ratios

TOC concentrations of the Albian to Santonian samples range between 0.14 and 21.56 wt% (Table T2). Most of these samples are black shales and therefore have TOC concentrations >5 wt%, which contrasts dramatically with values of <0.5 wt% for the Campanian to Paleogene samples in our isotopic survey that resemble most Cenozoic marine sediments.

T2. C, N, and isotope values, p. 12.

With the exception of four Late Cretaceous samples from Hole 1258B, all of the samples have atomic C/N values >10 and most have values between 30 and 40 (Fig. F2). These high values are unusual for marine organic matter, which usually has values between 5 and 8 (Emerson and Hedges, 1988; Meyers, 1997), but they are common in mid-Cretaceous black shales (e.g., Rau et al., 1987; Meyers, 1989; Dumitrescu and Brassell, 2006). Somewhat elevated TOC/TN values are also found

F2. TOC and TOC/N, p. 9.



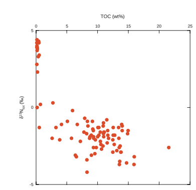
in modern sediments deposited under areas of high productivity. Verardo and MacIntyre (1994) proposed that these seemingly anomalous values indicate less efficient recycling of carbon relative to nitrogen during export of organic matter from the photic zone. As such, the elevated TOC/TN values indicate that mid-Cretaceous biogeochemical recycling functioned very differently than today and favored the improved preservation of organic carbon evident in the high TOC concentrations of the black shale sequences.

Organic Carbon and Bulk Nitrogen Isotopic Compositions

Organic $\delta^{13}C$ values range between –23.4‰ and –29.7‰ but are mostly lower than –27‰ (Table T2). Dean et al. (1986) comment that these $\delta^{13}C$ values mimic those of modern land plants even though the organic matter content of most mid-Cretaceous black shales is marine in origin, and they postulate that the isotopically light marine organic matter reflects the high CO_2 content of the mid-Cretaceous atmosphere. On the Demerara Rise, deposition of isotopically light marine organic matter occurred from the Albian to the Paleogene independent of the TOC concentrations of most of the samples we surveyed (Table T2). However, dramatic +6‰ excursions from this isotopically light background are documented by Erbacher at el. (2005) in high-resolution sampling done across the Cenomanian/Turonian boundary intervals at Sites 1258, 1259, 1260, and 1261. The concordant excursions evidently record magnified marine productivity and associated drawdown of dissolved $^{12}CO_2$ over the Demerara Rise during the Cenomanian–Turonian OAE2. Based on their relatively larger $\delta^{13}C$ values in Table T2, Samples 207-1258B-46R-1, 44–64 cm, and 207-1259C-18R-4, 120–140 cm, may include part of the OAE2 intervals in our low-resolution surveys at Sites 1258 and 1259. Another sample (207-1260B-38R-1, 84–86 cm) also has a relatively larger $\delta^{13}C$ value (–24.9‰), which may identify the earlier mid-Cenomanian event in the Site 1260 black shale sequence.

The range of bulk $\delta^{15}N$ values is from –4.2‰ to +4.4‰ (Table T2). In contrast to the organic $\delta^{13}C$ values, a relation exists between the nitrogen isotopic values and TOC concentrations (Fig. F3). Samples with TOC >1 wt% generally have negative $\delta^{15}N$ values, whereas samples with TOC <1 wt% have $\delta^{15}N$ values above +3‰, with the exception of several low-TOC Albian samples that also have low $\delta^{15}N$ values. These nitrogen isotopic compositions are very different from modern marine sediments and suggest that marine nitrogen fixation was probably widespread during much of the mid-Cretaceous (e.g., Kuypers et al., 2004, Dumitrescu and Brassell, 2006.

F3. TOC and $\delta^{15}N$, p. 10.



Carbonate Carbon and Oxygen Isotopic Compositions

Carbonate $\delta^{13}C$ values are highly variable (from –6.6‰ to +3.3‰) in the Demerara Rise samples that we surveyed (Table T2). Because they represent the carbon isotopic compositions of bulk samples, they likely combine a complicated mix of biotic, environmental, and diagenetic signals. Carbonate $\delta^{18}O$ values are less variable (from –4.1‰ to –1.7‰), and smaller than bulk carbonate values of ~0‰ that Clarke and Jenkyns (1999) report for Oligocene–Miocene sediments from Ocean Drilling Program Leg 122 Site 762 on the Exmouth Plateau, which suggests warmer temperatures during deposition of the Demerara Rise black shale sequences.

ACKNOWLEDGMENTS

We thank M.J. Malone and an anonymous reviewer for comments that helped to improve this contribution. This research used samples and/or data provided by the Ocean Drilling Program (ODP). ODP is sponsored by the U.S. National Science Foundation (NSF) and participating countries under management of Joint Oceanographic Institutions (JOI), Inc. Funding for this research was provided by a grant to P.A.M from the United States Science Support Program.

REFERENCES

Altabet, M.A., and Francois, R., 1994. Sedimentary nitrogen isotopic ratio as a recorder for surface ocean nitrate utilization. *Global Biogeochem. Cycles,* 8:103–116. **doi:10.1029/93GB03396**

Bice, K.L., Birgel, D., Meyers, P.A., Dahl, K.A., Hinrichs, K.-U., and Norris, R.D., 2006. A multiple proxy and modeling study of Cretaceous upper ocean temperatures and atmospheric CO_2 concentrations from tropical Atlantic foraminifera and organic matter. *Paleoceanography,* 21:PA2002. **doi:10.1029/2005PA001203**

Bowman, A.R., and Bralower, T.J., 2005. Paleoceanographic significance of high-resolution carbon isotope records across the Cenomanian–Turonian boundary in the western interior and New Jersey coastal plain, USA. *Mar. Geol.,* 217:305–321. **doi:10.1016/j.margeo.2005.02.010**

Clarke, L.J., and Jenkyns, H.C., 1999. New oxygen isotope evidence for long-term Cretaceous climatic change in the Southern Hemisphere. *Geology,* 27:699–702. **doi:10.1130/0091-7613(1999)027<0699:NOIEFL>2.3.CO;2**

Dean, W.E., Arthur, M.A., and Claypool, G.E., 1986. Depletion of ^{13}C in Cretaceous marine organic matter: Source, diagenetic, or environmental signal? *Mar. Geol.,* 70:119–157. **doi:10.1016/0025-3227(86)90092-7**

Dumitrescu, M., and Brassell, S.C., 2006. Compositional and isotopic characteristics of organic matter for the early Aptian oceanic anoxic event at Shatsky Rise, ODP Leg 198. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 235(1–3):168–191. **doi:10.1016/j.palaeo.2005.09.028**

Emerson, S., and Hedges, J.I., 1988. Processes controlling the organic carbon content of open ocean sediments. *Paleoceanography,* 3:621–634.

Engleman, E.E., Jackson, L.L., and Norton, D.R., 1985. Determination of carbonate carbon in geological materials by coulometric titration. *Chem. Geol.,* 53:125–128.

Erbacher, J., Friedrich, O., Wilson, P.A., Birch, H., and Mutterlose, J., 2005. Stable organic carbon isotope stratigraphy across oceanic anoxic Event 2 of Demerara Rise, western tropical Atlantic. *Geochem., Geophys., Geosyst.,* 6(6):Q06010. **doi:10.1029/2004GC000850**

Erbacher, J., Thurow, J., and Littke, R., 1996. Evolution patterns of radiolaria and organic matter variations: a new approach to identify sea level changes in mid-Cretaceous pelagic environments. *Geology,* 24:499–502. **doi:10.1130/0091-7613(1996)024<0499:EPORAO>2.3.CO;2**

Hofmann, P., Ricken, W., Schwark, L., and Leythaeuser, D., 2000. Carbon-sulfur-iron relationships and $\delta^{13}C$ of organic matter for late Albian sedimentary rocks from the North Atlantic Ocean: paleoceanographic implications. *Palaeogeogr., Palaeoclimatol., Palaeoecol.,* 163:97–113. **doi:10.1016/S0031-0182(00)00147-4**

Kuypers, M.M.M., van Breugel, Y., Schouten, S., Erba, E., and Sinninghe Damsté, J.S., 2004. N_2-fixing cyanobacteria supplied nutrient N for Cretaceous oceanic anoxic events. *Geology,* 32:853–856. **doi:10.1130/G20458.1**

Menegatti, A.P., Weissert, H., Brown, R.S., Tyson, R.V., Farrimond, P., Strasser, A., and Caron, M., 1998. High resolution $\delta^{13}C$ stratigraphy through the early Aptian "Livello Selli" of the Alpine Tethys. *Paleoceanography,* 13:530–545. **doi:10.1029/98PA01793**

Meyers, P.A., 1989. Sources and deposition of organic matter in Cretaceous passive margin deep-sea sediments: a synthesis of organic geochemical studies from Deep Sea Drilling Project Site 603, outer Hatteras Rise. *Mar. Petrol. Geol.,* 6:182–189. **doi:10.1016/0264-8172(89)90021-4**

Meyers, P.A., 1997. Organic geochemical proxies of paleoceanographic, paleolimnologic, and paleoclimatic processes. *Org. Geochem.,* 27:213–250. **doi:10.1016/S0146-6380(97)00049-1**

Rau, G.H., Arthur, M.A., and Dean, W.E., 1987. $^{15}N/^{14}N$ variations in Cretaceous Atlantic sedimentary sequences: implication for past changes in marine nitrogen biogeochemistry. *Earth Planet. Sci. Lett.,* 82:269–279. **doi:10.1016/0012-821X(87)90201-9**

Rigby, D., and Batts, B.D., 1986. The isotopic composition of nitrogen in Australian coals and oil shales. *Chem. Geol.,* 58(3):273–282. **doi:10.1016/0168-9622(86)90016-3**

Sliter, W.V., 1989. Aptian anoxia in the Pacific Basin. *Geology,* 17:909–912. **doi:10.1130/0091-7613(1989)017<0909:AAITPB>2.3.CO;2**

Tsikos, H., Jenkyns, H.C., Walsworth-Bell, B., Petrizzo, M.R., Forster, A., Kolonic, S., Erba, E., Premoli Silva, I., Baas, M., Wagner, T., and Sinninghe-Damsté, J.S., 2004. Carbon-isotope stratigraphy recorded by the Cenomanian–Turonian Oceanic Anoxic Event: correlation and implication based on three localities. *J. Geol. Soc.,* 161:711–719.

Verardo, D.J., and McIntyre, A., 1994. Production and destruction: control of biogenous sedimentation in the tropical Atlantic 0–300,000 years B.P. *Paleoceanography,* 9:63–86. **doi:10.1029/93PA02901**

Figure F1. Comparison of $\delta^{15}N$ values from bulk and decarbonated sediment samples. Linear regression shows a good correlation (*R* = 0.84, *N* = 61) between values from bulk and decarbonated sample pairs and a small negative difference (–0.1‰) between bulk and decarbonated values. Data for individual samples are presented in Table **T1**, p. 11.

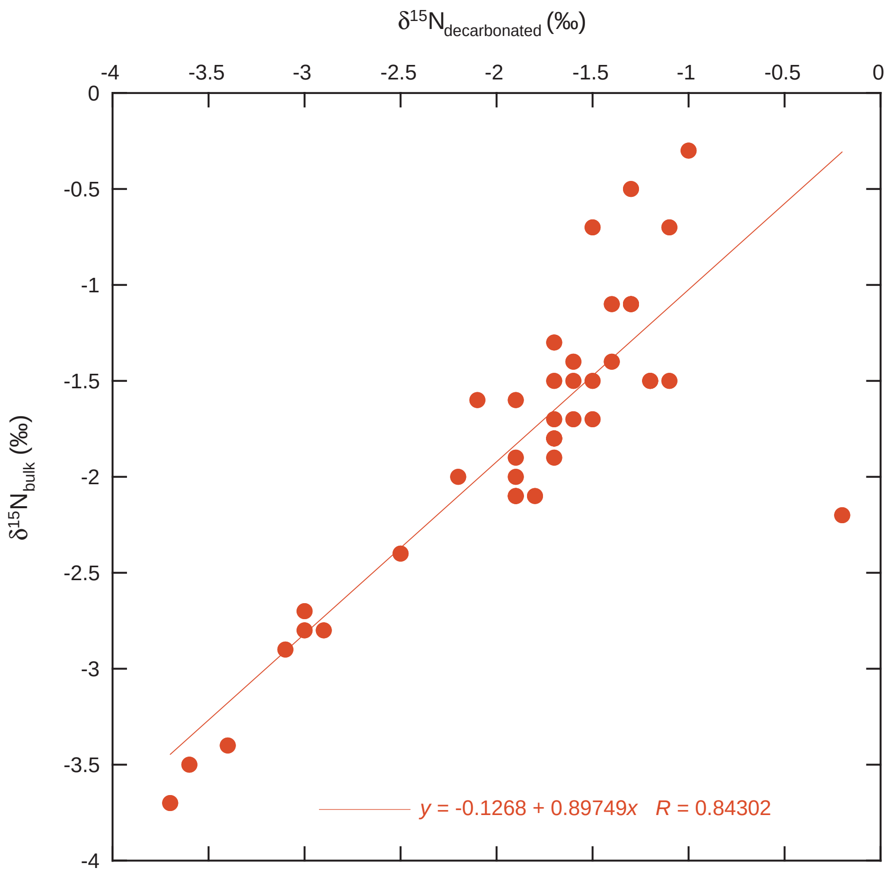


Figure F2. Comparison of total organic carbon (TOC) concentrations and atomic TOC/total nitrogen (TN) values of Demerara Rise samples listed in Table T2, p. 12. Correspondence of high TOC concentrations and high TOC/TN values implies better preservation of organic carbon relative to nitrogen-rich organic matter components in these black shale samples.

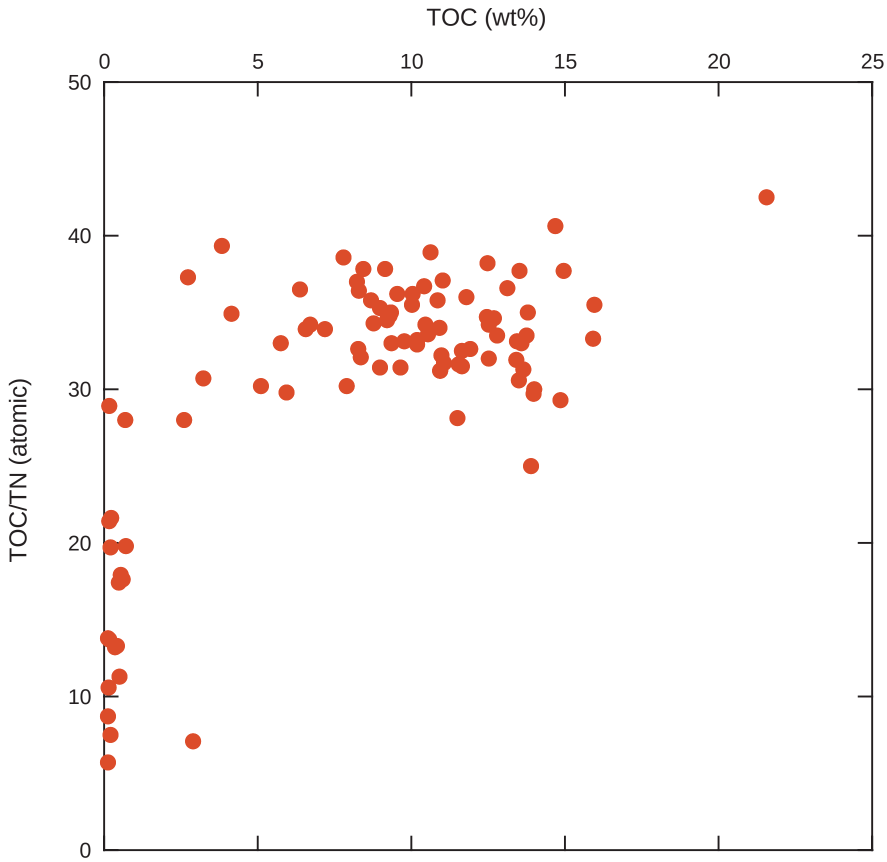


Figure F3. Comparison of total organic carbon (TOC) concentrations and bulk $\delta^{15}N$ values of Demerara Rise samples listed in Table T2, p. 12. Correspondence of high TOC concentrations and low $\delta^{15}N$ values implies important contributions of nitrogen-fixing bacteria during production of organic matter in these black shale samples.

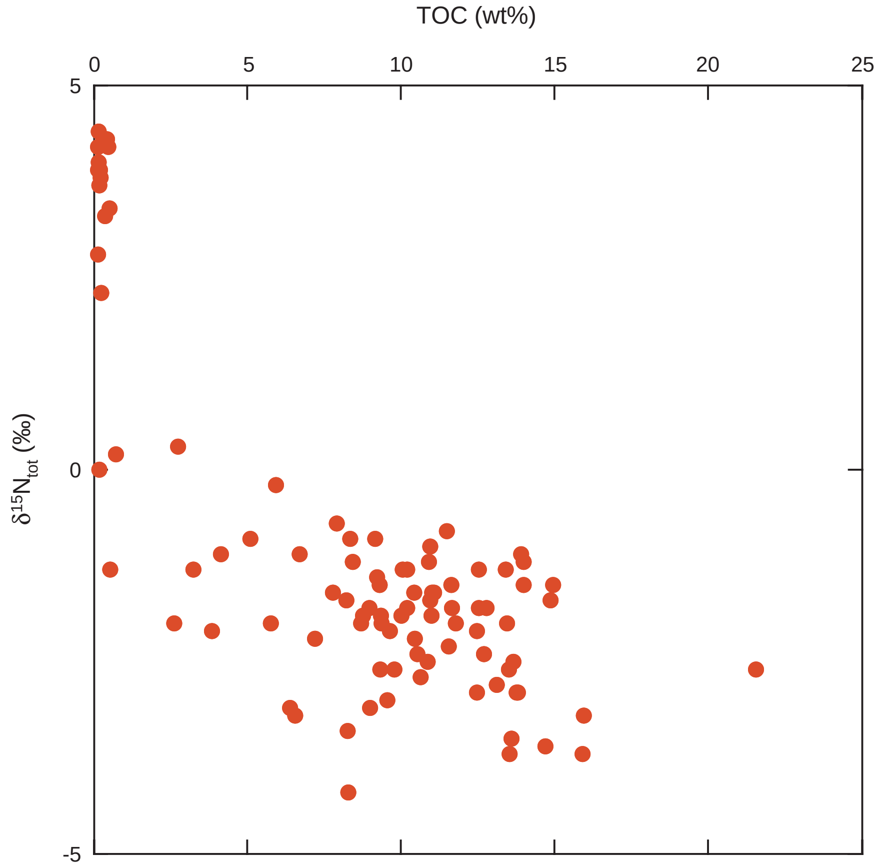


Table T1. Comparison of ^{15}N values from bulk and decarbonated sediment samples, Sites 1257, 1258, and 1260.

Core, section, interval (cm)	TOC (wt%)	TN (wt%)	$^{15}N_{decarb}$ (‰)	$^{15}N_{bulk}$ (‰)	$^{15}N_{decarb-bulk}$ (‰)
207-1257C-					
11R-1, 102–105	11.07	0.39	–1.6	–1.7	0.1
12R-1, 68–71	15.91	0.54	–3.7	–3.7	0.0
12R-2, 43–46	8.27	0.28	–3.4	–3.4	–0.1
13R-1, 30–33	9.21	0.31	–1.4	–1.4	0.0
13R-3, 30–33	12.53	0.43	–1.4	–1.1	–0.3
14R-1, 107–110	13.59	0.46	–3.6	–3.5	–0.1
14R-2, 107–110	10.94	0.39	–1.7	–1.8	0.1
15R-1, 114–117	10.99	0.33	–1.9	–1.9	0.0
207-1258B-					
45R-1, 27–30	13.80	0.46	–3.0	–2.7	–0.3
46R-4, 51–54	13.99	0.54	–1.7	–1.3	–0.4
48R-1, 0–5 cm	10.86	0.33	–2.5	–2.4	–0.1
51R-1, 54–57	11.64	0.41	–1.5	–1.5	0.0
52R-3, 87–90	12.53	0.41	–1.9	–1.6	–0.3
53R-1, 66–68	8.98	0.29	–1.7	–1.8	0.2
54R-2, 120–123	9.30	0.31	–1.6	–1.4	–0.2
55R-1, 46–49	10.42	0.33	–1.7	–1.5	–0.2
56R-3, 28–31	8.35	0.32	–1.1	–0.7	–0.4
57R-1, 20–30	7.90	0.30	–1.0	–0.3	–0.8
57R-1, 145–148	5.10	0.19	–1.3	–0.5	–0.8
57R-3, 3–6	5.94	0.20	–0.6	0.2	–0.8
207-1258C-					
18R-1, 4–7	9.64	0.33	–2.2	–2.0	–0.2
18R-2, 18–22	12.79	0.41	–1.7	–1.8	0.0
18-3, 68–69	12.48	0.34	–3.0	–2.8	–0.2
19R-1, 71–73	9.55	0.31	–3.1	–2.9	–0.2
21R-1, 115–118	11.65	0.38	–1.7	–1.9	0.2
21R-2, 7–10	9.36	0.30	–1.9	–2.1	0.2
207-1260B-					
34R-2, 7–10	13.13	0.40	–2.9	–2.8	0.0
35R-1, 98–100	14.00	0.56	–1.3	–1.1	–0.2
35R-3, 23–25	13.45	0.39	–1.9	–2.0	0.1
36R-3, 104–106	10.92	0.35	–1.3	–1.1	–0.2
36R-6, 14–18	13.42	0.39	–1.2	–1.5	0.3
37R-1, 78–81	10.19	0.35	–1.1	–1.5	0.4
37R-5, 17–20	10.05	0.24	–1.2	–1.5	0.3
38R-1, 7–10	14.96	0.41	–1.6	–1.5	0.0
38R-3, 19–23	9.35	0.26	–1.8	–2.1	0.3
39R-1, 145–148	7.79	0.24	–1.5	–1.7	0.2
39R-6, 1–3	8.44	0.22	–0.2	–2.2	2.0
40R-2, 48–51	4.15	0.17	–1.5	–0.7	–0.8
40R-4, 17–20	8.00	0.24	–1.7	–1.7	0.0
41R-2, 14–16	8.23	0.26	–2.1	–1.6	–0.5
42R-1, 45–49	8.70	0.24	–1.9	–2.1	0.2

Note: Total organic carbon (TOC) and total nitrogen (TN) concentrations are given on a whole-sediment basis.

Table T2. Carbon concentrations; TOC/TN; and C, N, and O isotope values of selected Albian–Paleogene samples from the Demerara Rise, Sites 1257–1261. (See table notes. Continued on next page.)

Hole, section, interval (cm)	Depth (mbsf)	Depth (mcd)	Age	TOC (wt%)	TOC/TN (atomic)	$^{13}C_{org}$ (‰)	$^{15}N_{total}$ (‰)	$CaCO_3$ (wt%)	$^{13}C_{carb}$ (‰)	$^{18}O_{carb}$ (‰)
207–										
1257C-3R-3 130–150	105.50	107.50	Paleogene	0.42	13.3	–28.4	4.3	48.6	2.9	–2.3
1257C-5R-2 130–150	123.30	125.97	Paleogene	0.48	17.4	–29.0	4.2	45.8	3.3	–2.2
1257C-9R-4, 124–144	164.40	166.85	Campanian/Maastrichtian	0.22	19.7	–29.0	3.8	39.2	0.3	–1.7
1257C-10R-1, 106–109	169.46	171.87	late Campanian	0.24	21.6	–27.6	2.3	38.9	0.2	–1.9
1257C-10R-2, 7–10	169.97	172.38	late Campanian	0.18	21.4	–28.5	3.7	15.4	1.8	–2.0
1257C-11R-1, 84–89	178.84	181.39	Santonian	11.79	36.0	–26.7	–2.0	56.2	0.2	–3.5
1257C-11R-1, 102–105	179.02	181.57	Santonian	11.07	31.7	–27.4	–1.6	41.6	–1.4	–2.5
1257C-12R-1, 68–71	188.38	190.93	Coniacian	15.91	33.3	–27.6	–3.7	45.1	0.1	–3.4
1257C-12R-2, 70–90	189.90	192.45	Coniacian	13.53	37.7	–27.7	–3.7	48.4	–1.5	–3.0
1257C-12R-2, 43–46	189.63	192.63	Coniacian	8.27	32.6	–27.8	–3.4	30.9	–0.2	–3.4
1257C-13R-1, 30–33	197.60	200.15	Coniacian	9.21	34.5	–27.4	–1.4	21.2	0.9	–2.7
1257C-13R-2, 120–140	200.00	202.55	Coniacian	10.20	33.2	–26.7	–1.8	50.9	–0.6	–3.2
1257C-13R-3, 30–33	200.60	203.15	Turonian	12.53	32.0	–27.4	–1.3	26.8	0.6	–3.1
1257C-14R-1, 76– 82	207.76	210.31	Turonian	13.66	31.3	–28.1	–2.5	35.5	–1.3	–2.9
1257C-14R-1, 107–110	208.07	210.62	Turonian	13.59	33.0	–27.1	–3.5	41.1	–0.8	–3.3
1257C-14R-2, 107–110	209.58	212.13	Turonian	10.94	31.2	–27.6	–1.7	32.3	0.9	–3.0
1257C-15R-1, 114–117	217.74	220.29	Cenomanian	10.99	32.2	–28.3	–1.9	45.7	–0.1	–2.8
1257C-15R-CC, 15–18	219.83	222.38	Cenomanian	0.18	13.7	–26.8	BD	78.8	–6.6	–1.7
1257C-16R-1, 44–46	226.64	227.80	Albian	0.51	11.3	–26.9	3.4	32.1	1.1	–2.5
1257C-16R-6, 0–20	233.67	234.83	Albian	0.60	17.6	ND	ND	32.7	1.7	–2.7
1258B-36R-3, 100–120	334.10	346.91	Campanian/Maastrichtian	0.21	7.5	–28.2	3.9	41.2	0.9	–2.4
1258B-42R-1, 110–130	384.90	407.01	Campanian/Maastrichtian	0.15	10.6	–27.6	4.4	40.9	ND	ND
1258B-43R-2, 120–140	390.50	412.61	Campanian/Maastrichtian	0.14	5.7	–27.7	4.2	37.2	ND	ND
1258B-44R-1, 11–14	393.61	414.11	Turonian	0.14	8.7	–28.3	2.8	41.5	–4.7	–2.6
1258B-44R-1, 59–62	394.09	414.59	Turonian	2.89	7.1	ND	ND	37.1	–3.1	–2.7
1258B-45R-1, 27–30	397.77	418.60	Turonian	13.80	35.0	–27.4	–2.9	38.0	–0.3	–3.6
1258B-45R-2, 54–75	399.04	419.87	Turonian	8.99	35.3	–27.8	–3.1	61.9	ND	ND
1258B-45R-3, 30–33	399.66	420.49	Turonian	13.76	33.5	–27.1	–2.9	32.5	0.2	–3.8
1258B-46R-1, 44–64	403.54	425.60	Cenomanian/Turonian	14.70	40.6	–24.3	–3.6	7.9	ND	ND
1258B-46R-2, 18–21	403.92	425.98	Cenomanian	15.95	35.5	–25.6	–3.2	23.8	–3.6	–3.6
1258C-18R-1, 4–7	404.14	428.25	Cenomanian	9.64	31.4	–28.2	–2.1	56.2	–1.0	–3.0
1258C-18R-1, 48–51	404.58	428.69	Cenomanian	13.51	30.6	–29.3	–2.6	36.8	–0.2	–3.4
1258C-18R-2, 18–22	405.59	429.70	Cenomanian	12.79	33.5	–27.7	–1.8	45.0	–0.1	–3.1
1258B-46R-4, 51–54	406.73	429.73	Cenomanian	13.99	29.7	–28.1	–1.5	20.0	–0.1	–3.3
1258C-18R-3, 68–69	407.57	431.57	Cenomanian	12.48	38.2	–27.3	–2.9	42.3	–0.8	–3.2
1258C-19R-1, 71–73	409.81	433.81	Cenomanian	9.55	36.2	–28.0	–3.0	54.3	–2.3	–2.9
1258C-19R-1, 83–89	409.93	434.04	Cenomanian	9.78	33.1	–28.9	–2.6	40.4	0.0	–3.2
1258C-19R-2, 43–47	410.70	434.81	Cenomanian	6.56	33.9	–28.1	–3.2	63.6	–1.8	–3.1
1258B-48R-1, 0–5	412.70	436.09	Cenomanian	10.86	35.8	–28.1	–2.5	51.2	–1.4	–3.0
1258C-20R-1, 48–51	414.18	438.29	Cenomanian	8.29	36.4	–29.0	–4.2	67.2	–2.5	–3.0
1258B-49R-2, 0–5	418.20	441.95	Cenomanian	2.61	28.0	–28.5	–2.0	10.6	–0.9	–3.2
1258C-21R-1, 115–118	419.85	443.96	Cenomanian	11.65	32.5	–28.8	–1.8	39.2	–1.2	–3.0
1258C-21R-2, 7–10	420.02	444.13	Cenomanian	9.36	33.0	–29.0	–2.0	46.0	–1.3	–3.1
1258C-21R-2, 18–22	420.13	444.24	Cenomanian	10.95	31.2	–29.7	–1.0	36.5	–0.7	–3.1
1258B-51R-1, 54–57	426.84	451.16	Cenomanian	11.64	31.5	–28.5	–1.5	36.9	0.0	–3.4
1258B-51R-2, 0–20	427.72	452.04	Cenomanian	10.54	33.6	–29.5	–2.4	39.4	ND	ND
1258B-52R-2, 80–100	433.81	458.13	Cenomanian	12.70	34.6	–28.6	–2.4	48.2	ND	ND
1258B-52R-3, 87–90	434.88	459.20	Cenomanian	12.53	34.2	–28.7	–1.8	46.7	–1.2	–3.1
1258B-53R-1, 66–68	436.56	461.20	Cenomanian	8.98	31.4	–28.9	–1.8	56.2	–1.4	–3.0
1258B-54R-2, 120–123	444.16	468.64	Cenomanian	9.30	34.8	–29.0	–1.5	54.2	–1.7	–2.8
1258B-54R-3, 10–30	444.48	468.96	Cenomanian	9.33	35.0	–29.7	–2.6	47.8	ND	ND
1258B-55R-1, 46–49	445.96	472.82	Cenomanian	10.42	36.7	–28.6	–1.6	42.3	–0.4	–3.1
1258B-55R-3, 68–88	448.37	475.23	Cenomanian	6.71	34.2	–28.5	–1.1	25.3	ND	ND
1258B-56R-3, 28–31	453.39	477.96	Albian	8.35	32.1	–28.5	–0.9	29.0	0.2	–2.6
1258B-57R-1, 20–23	455.40	479.97	Albian	7.90	30.2	–28.5	–0.7	27.9	–0.4	–2.5
1258B-57R-1, 145–148	456.65	481.22	Albian	5.10	30.2	–28.5	–0.9	17.6	–3.2	–2.5
1258B-57R-3, 3–6	458.23	482.80	Albian	5.94	29.8	–28.4	–0.2	6.1	–2.2	–2.4
1259C-8R-6, 130–150	444.29	445.54	Campanian/Maastrichtian	0.17	28.9	–28.9	4.0	70.4	1.4	–2.0
1259C-10R-3, 130–150	488.95	490.38	Campanian/Maastrichtian	0.37	13.2	–27.4	3.3	34.6	1.1	–2.4
1259C-11R-4, 130–150	494.73	496.97	Santonian	11.55	31.6	–29.2	–2.3	46.3	1.2	–3.3
1259C-15R-1, 17–27	513.97	518.79	Turonian	6.39	36.5	–27.7	–3.1	22.0	–0.2	–3.6
1259C-16R-5, 117–137	525.45	528.98	Turonian	3.84	39.3	–26.2	–2.1	67.3	–0.3	–3.6
1259C-17R-1, 116–136	529.06	532.18	Turonian	13.91	25.0	–26.8	–1.1	32.9	1.1	–3.5
1259C-18R-4, 120–140	543.20	547.53	Cenomanian	10.63	38.9	–23.9	–2.7	41.8	0.1	–3.2
1259C-19R-2, 88–110	549.32	551.67	Albian	0.72	19.8	–23.4	0.2	0.9	1.5	–2.9
1260B-34R-2, 7–10	407.27	409.97	Turonian	13.13	36.6	–27.6	–2.8	47.4	–0.1	–3.8

Table T2 (continued).

Hole, section, interval (cm)	Depth (mbsf)	Depth (mcd)	Age	TOC (wt%)	TOC/TN (atomic)	$^{13}C_{org}$ (‰)	$^{15}N_{total}$ (‰)	$CaCO_3$ (wt%)	$^{13}C_{carb}$ (‰)	$^{18}O_{carb}$ (‰)
1260B-34R-2, 10–17	407.30	410.00	Turonian	11.02	37.1	–27.5	–1.6	56.6	0.1	–4.1
1260B-35R-1, 98–100	416.28	420.82	Turonian	14.00	30.0	ND	–1.2	11.6	0.0	–3.3
1260B-35R-2, 4–13	416.84	421.38	Turonian	14.86	29.3	–27.4	–1.7	2.8	2.6	–3.5
1260B-35R-3, 23–25	418.53	423.07	Turonian	13.45	33.1	–27.5	–2.0	14.7	–0.4	–3.9
1260B-36R-3, 104–106	428.94	432.29	Cenomanian	10.92	34.0	–27.8	–1.2	38.8	–0.5	–3.4
1260B-36R-3, 107–113	428.97	432.32	Cenomanian	11.50	28.1	–28.1	–0.8	40.1	–0.1	–3.3
1260B-36R-6, 14–18	432.55	435.90	Cenomanian	13.42	31.9	–28.6	–1.3	37.8	0.5	–3.1
1260B-37R-1, 78–81	435.28	437.70	Cenomanian	10.19	32.9	–28.4	–1.3	49.3	0.6	–3.2
1260B-37R-5, 17–20	440.67	443.09	Cenomanian	10.05	36.2	–27.4	–1.3	64.1	1.2	–3.3
1260B-38R-1, 7–10	444.17	448.24	Cenomanian	14.96	37.7	–28.4	–1.5	37.7	0.7	–3.4
1260B-38R-1, 84–86	444.94	449.01	Cenomanian	21.56	42.5	–24.9	–2.6	47.2	ND	ND
1260B-38R-3, 19–23	447.29	451.36	Cenomanian	9.35	35.0	–28.9	–1.9	59.2	0.0	–3.4
1260B-39R-1, 115–122	454.85	457.63	Cenomanian	9.16	37.8	–28.9	–0.9	64.7	ND	ND
1260B-39R-1, 145–148	455.15	457.93	Cenomanian	7.79	38.6	–29.2	–1.6	73.3	0.3	–3.4
1260B-39R-3, 125–128	457.95	460.73	Cenomanian	2.74	37.3	ND	0.3	88.2	0.5	–4.1
1260B-39R-6, 1–3	461.21	463.99	Cenomanian	8.44	37.8	–27.1	–1.2	69.7	–0.1	–3.4
1260B-40R-2, 48–51	465.08	469.66	Cenomanian	4.15	34.9	–29.1	–1.1	29.9	0.0	–3.7
1260B-40R-2, 97–103	465.57	470.15	Cenomanian	10.02	35.5	–29.7	–1.9	58.9	ND	ND
1260B-40R-4, 17–20	467.77	472.35	Cenomanian	8.23	37.0	–28.9	–1.7	65.2	0.3	–3.6
1260B-41R-1, 72–75	473.42	477.58	Cenomanian	7.19	33.9	–29.3	–2.2	64.8	0.1	–3.6
1260B-41R-1, 114–120	473.84	478.00	Cenomanian	10.45	34.2	–29.5	–2.2	60.1	ND	ND
1260B-41R-2, 14–16	474.34	478.50	Cenomanian	8.77	34.3	–29.0	–1.9	37.8	–0.1	–3.3
1260B-42R-1, 45–49	482.75	485.43	Albian	8.70	35.8	–29.0	–2.0	60.3	0.0	–3.3
1260B-42R-1, 87–96	483.17	485.85	Albian	3.24	30.7	–28.7	–1.3	33.2	ND	ND
1260B-43R-1, 110–114	489.00	491.68	Albian	0.68	28.0	–25.2	BD	9.5	–0.9	–3.5
1260B-43R-2, 110–114	490.50	493.18	Albian	0.54	17.9	–28.3	–1.3	0.0	0.1	–3.1
1261B-4R-3, 130–150	553.50	554.54	Campanian/Maastrichtian	0.13	13.8	–26.7	3.9	66.7	ND	ND
1261B-6R-2, 130–150	571.20	572.46	Santonian	5.76	33.0	–28.3	–2.0	65.8	ND	ND
1261B-13R-5, 130–150	642.86	641.62	Cenomanian	12.47	34.7	–29.0	–2.1	37.3	ND	ND

Notes: TOC = total organic carbon, TN = total nitrogen. BD = below detection, ND = not determined.