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12. Data Report: Stable Isotope and Mg/Ca of Paleocene and Eocene Foraminifers, ODP Site 1209, Shatsky Rise[1]

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ABSTRACT

Stable oxygen and carbon isotope measurements ($\delta^{18}O$ and $\delta^{13}C$) of planktonic and benthic foraminifers were conducted to assess the temperature history and circulation patterns over Shatsky Rise during the Paleocene and Eocene. A record of Mg/Ca for benthic foraminifers was also constructed in order to better determine the relative influence of temperature, salinity, and/or ice volume upon the benthic $\delta^{18}O$ record. Isotopic analyses were carried out on several planktonic taxa (*Acarinina, Morozovella, Globigerinatheka, Praemurica,* and *Subbotina*) as well as several benthic taxa (*Nuttalides, Oridorsalis, Cibicidoides, Gavelinella,* and *Lenticulina*). Elemental analyses were restricted to three benthic taxa: *Nuttalides*, *Oridorsalis,* and *Gavelinella*. All specimens were derived from the composite sediment section recovered from Ocean Drilling Program Site 1209 on the Southern High of Shatsky Rise.

INTRODUCTION

The primary aim of this investigation is to provide a geochemical record of the evolution of the thermal structure of the water column and of circulation patterns over Shatsky Rise during the Paleocene and Eocene. This was accomplished through stable isotope analyses of planktonic and benthic foraminifers paired with elemental analyses (Mg, Ca, Sr, Mn, and Fe) of benthic foraminifers. The combination of a

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Mg/Ca based temperature reconstruction with the $\delta^{18}O$ record allows for independent assessment of temperature, salinity, and/or ice volume through time for deep waters bathing the pelagic sediment cap on Shatsky Rise. Mg/Ca and stable isotope results for surface-dwelling planktonic foraminifers across the Paleocene/Eocene boundary interval are further documented in Zachos et al. (2003).

Site 1209 (32°39.1081′N, 158°30.3564′E) is located on the Southern High of Shatsky Rise at a water depth of 2387 m. The sediment cored at Site 1209 contains an expanded Paleogene section consisting of unlithified calcareous ooze with well preserved foraminifers. This site is the shallowest in a series of four sites along a depth transect of Paleogene sediments cored during ODP Leg 198 and was situated well above the carbonate compensation depth (CCD) during most of the Paleocene and Eocene (Hancock and Dickens, this volume) at a paleodepth of ~2500 m. In this report, we document the procedure and results for 220 stable isotope ($\delta^{18}O$ and $\delta^{13}C$) measurements of planktonic and benthic foraminifers, as well as 51 elemental (Mg, Sr, Ca, Mn, and Fe) measurements of benthic foraminifers from the Paleocene and Eocene composite section of Site 1209.

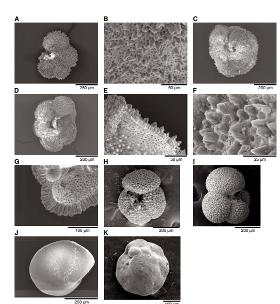
METHODS

Approximately one 10-cm³ sample per section was selected from the Site 1209 composite splice (Bralower, Premoli Silva, Malone, et al., 2003) for isotopic and elemental analyses. Samples were dried overnight in an oven at <50ºC, weighed, and subsequently disaggregated in buffered deionized water (pH ~10). Each sample was wet-sieved over 125- and 63-µm sieves, dried overnight, and weighed again to obtain the weight percent of coarse fraction (>63 µm) (Table T1). The >125-µm size fraction was then dry-sieved into four size fractions: >355, 300–355, 250–355, and 125–250 µm. Planktonic foraminifers were picked from a narrow size fraction (300–355 µm) to minimize complicating factors of ontogenetic and other vital effects upon geochemical compositions (Shackleton et al., 1985; Corfield and Cartlidge, 1991; Pearson et al., 1993).

T1. Sand fraction from samples, p. 13.

Preservation of primary shell microstructure was also assessed by scanning electron microscope (SEM) images of several different taxa from a wide stratigraphic range using a Hitachi S3200N scanning electron microscope at the University of Michigan (Fig. F1). Paleocene and Eocene foraminifers at Site 1209 are generally moderately to well preserved; some specimens display a minor component of secondary calcite. Specimens that were fragmented, corroded, discolored, or obviously recrystallized were not chosen for analysis. Foraminiferal dissolution features were observed more frequently in upper Eocene sediment, which is characterized by increased fragmentation, lower carbonate content, and an increased amount of phillipsite (Hancock and Dickens, this volume).

F1. SEM images of foraminifer taxa, p. 7.



No single surface-dwelling foraminifer could provide a continuous record across this long time interval; therefore, several species were selected for analysis, and offsets in isotope compositions were evaluated where the range of these species overlap. Species of the genera *Morozovella* and *Acarinina* were selected because of their morphologic distinctiveness, their abundance through the section, and to facilitate comparisons with other deep sea data sets, many of which have isotopic records for these two genera. *Globigerinatheka* spp. and *Praemurica incon-*

stans were analyzed in one sample each where species of *Morozovella* and *Acarinina* were absent. Other surface dwelling species analyzed in this study include the Morozovellids *M. angulata, M. formosa, M. velascoensis, M. subbotinae* (includes *M. gracilis*), *M. aragonensis, M. conicotruncana* (one sample), and the Acaraninids *A. soldadoensis* and *A. bullbrooki*. To assess conditions deeper in the water column, *Subbotina* spp. was also analyzed. Species of *Subbotina* were combined due to taxonomic uncertainties. Several benthic taxa were selected for stable isotope analysis including *Nuttalides* spp., *Oridorsalis* spp., *Cibicidoides* spp., *Lenticulina* spp., and *Gavelinella* spp. Elemental data were generated using *Nuttalides truempyi*, *Oridorsalis umbonatus*, and *Gavelinella beccariiformis* because these species were typically most abundant. All benthic foraminifers were picked from size fractions >125 µm.

Each stable isotope sample consisted of multiple specimens to determine an average composition for the sample: four to seven individuals for planktonic species and one to five individuals for benthic species. Specimens used for stable isotope analysis were ultrasonically cleaned in deionized water to remove adhering particles, dried, and roasted under vacuum at ~200°C. Samples were reacted with phosphoric acid in an automated Kiel device coupled to a Finnigan MAT 251 mass spectrometer at the University of Michigan (USA). Accuracy and precision were assessed by daily analysis of standard reference material NBS-19. Stable isotope data are reported in standard permil (‰) notation relative to the Vienna Peedee belemnite (VPDB) standard. During the 6-month time period that these samples were run, precision was maintained at ±0.055‰ for $\delta^{18}O$ and ±0.028‰ for $\delta^{13}C$ (1σ; N = 547); these values are representative of the precision maintained over the past decade on this instrument. To assess the isotopic variability between different specimens from the same sample, 11 individual foraminifers of the species *M. velascoensis* were analyzed in Sample 198-1209C-12H-5, 40–42 cm.

Each sample for elemental analysis consisted of 11 to 28 specimens. Where possible, more than one taxon was analyzed to evaluate the offset in Mg/Ca ratios between taxa. Three duplicate samples (i.e., multiple samples comprising different individual foraminifers derived from the same sediment sample) were measured for *Nuttalides*. Benthic foraminifers used for elemental analysis were individually crushed on glass slides and transferred to acid-washed centrifuge tubes for rigorous cleaning to remove carbonate debris and other possible contaminant phases (e.g., clays and organic matter). These samples were cleaned using the protocol described in Barker et al. (2003) as modified from Boyle (1981) and Boyle and Keigwin (1985). This treatment does not include a reductive cleaning step, which has been demonstrated to result in lower Mg/Ca values in comparison to samples not subjected to reductive cleaning (Martin and Lea, 2002; Barker, et al., 2003). These studies are at odds in determining whether lower Mg/Ca values associated with the reductive cleaning step are the result of further shell dissolution or the removal of contaminant phases (e.g., oxide coatings). We chose to omit the reductive cleaning step in order to make the results comparable with published benthic Mg/Ca records (Lear et al., 2000; Billups and Schrag, 2003) and monitored Mn/Ca for all samples to detect possible contamination from Mn-oxide coatings as well as Fe/Ca to detect the presence of residual clays. One to two hours prior to analysis, samples were diluted to 500 µL with 0.075-N HNO_3 in acid-leached vials.

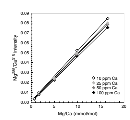
Analysis of Mg, Ca, Sr, Mn, and Fe was performed using a Varian Vista axial inductively coupled plasma–atomic emission spectrometer

(ICP-AES) at The Australian National University. To facilitate analysis of small volumes of solution, the instrument was fitted with a low-volume spray chamber (Cinnabar, Glass Expansion), which greatly decreased the necessary wash-out time, as well as a low-uptake nebulizer (Micromist, Glass Expansion) with a nominal uptake rate of 0.1 mL/min. The analytical method generally follows that described in de Villiers et al. (2002), which employs an intensity-ratio calibration method.

Self-absorption of calcium in the plasma results in curvature of sensitivity at high concentrations. This results in a Ca matrix effect that is manifest by variable measured element/Ca for solutions with different Ca concentrations but identical element/Ca ratios. This effect has been reported for both ICP-AES and ICP-mass spectrometry (MS) instruments (Rosenthal et al., 1999; de Villiers et al., 2002). To quantify the Ca matrix effect for this instrument, five standards with different Mg/Ca and Sr/Ca ratios and constant Ca concentration (~100 ppm) were prepared using commercially available single-element standard solutions (Table T2). These standards were then diluted to produce three additional suites of standards at 50, 25, and 10 ppm Ca to bracket the range of Ca concentrations in the samples. Using the intensity-ratio calibration method described in de Villiers et al. (2002) still produces a quantifiable and statistically significant Ca matrix effect for Mg/Ca (Fig. F2). No matrix effect was observed for Sr/Ca, Mn/Ca, or Fe/Ca. Because each sample had a slightly different Ca concentration, the appropriate Mg/Ca intensity–Ca concentration calibration line was interpolated based on the slopes and intercepts calculated for the four suites of standards. This calculation was performed after blank subtraction and drift correction of the raw data. The drift correction calculation was based on repeated analysis of a check standard throughout the analysis (Schrag, 1999).

T2. Calibration standards for ICP-AES measurements, p. 14.

F2. Standards calibration. p. 8.



Precision as defined by 28 repeated measurements of a check standard during the run was determined for each ratio, reported here as the mean ± 1 standard deviation (percent relative standard deviation [rsd]): Mg/Ca = 5.049 ± 0.019 (0.37%), Sr/Ca = 1.851 ± 0.006 (0.32%), Mn/Ca = 1.147 ± 0.005 (0.32%), and Mn/Ca = 1.497 ± 0.007 (0.48%). External accuracy of the standard solutions was determined using commercially available multi-element standard and internal laboratory standards from Cambridge University (England).

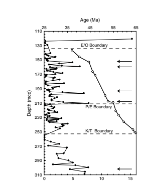
T3. Stable isotope data, p. 15.

T4. Elemental data, p. 19.

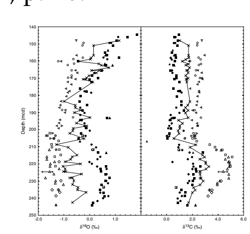
RESULTS

Percent of sand fraction is tabulated in Table T1. Stable isotope and elemental data are tabulated in Tables T3 and T4, respectively. Data are listed according to sample placement in terms of core-section-interval, meters below seafloor (mbsf), and meters composite depth (mcd). Taxon and size fraction are also specified for all samples. Elemental composition of internal standard solutions for ICP-AES calibration is listed in Table T2. SEM images for some of the taxa are shown in Figure F1. Calcium matrix effects on the Mg/Ca ratio are shown in Figure F2. Percent sand fraction is plotted relative to depth and compared to an age-depth graph based on nannofossil biostratigraphy at Site 1209 (**Bralower,** this volume) (Fig. F3). During the Paleocene and Eocene, >5% sand fraction samples appear to be roughly correlative to hiatuses identified by the nannonfossil biostratigraphy and to lysocline shoaling at the Paleocene/Eocene Thermal Maximum (Bralower, Premoli Silva, Malone, et al., 2003). Stable isotope and elemental data are plotted by taxa vs. depth in Figure F4. Single specimen stable isotope analyses of

F3. Percent sand fraction by depth, p. 9.



F4. Foraminiferal isotopes by depth, p. 10.



11 individuals from Sample 198-1209C-12H-5, 40–42 cm, are displayed in Figure F5. Mg/Ca values of benthic foraminifers are shown relative to depth in Figure F6. These data are further discussed and interpreted by Dutton et al. (in press).

ACKNOWLEDGMENTS

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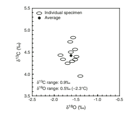
F5. Isotope composition for foraminifer samples, p. 11.



F6. Mg/Ca values by depth for foraminifer samples, p. 12.

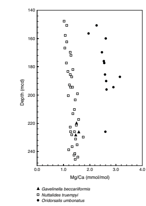


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Figure F1. SEM images of several taxa. These images demonstrate typical preservation of shell surface and chamber walls. Nannofossil debris on the surface of foraminiferal tests is evident in several images; this debris was removed by ultrasonification and cleaning of shells before chemical analysis. The samples imaged were selected at random across a range of depths. **A**, **B.** *Morozovella gracilis* (Sample 198-1209C-11H-2, 40-42 cm). **C.** *Morozovella velascoensis* (Sample 198-1209C-13H-3, 40–42 cm). **D–F.** *Morozovella angulata* (Sample 198-1209C-13H-6, 42–44 cm). **G.** *Acarinina bullbrooki* (Sample 198-1209B-20H-5, 42–44 cm). **H.** *Acarinina bullbrooki* (Sample 198-1209C-6H-6, 40–42 cm). **I.** *Subbotina* sp. (Sample 198-1209B-20H-4, 42–44 cm). J. *Oridorsalis umbonatus* (Sample 198-1209C-13H-3, 40–42 cm). **K.** *Nuttalides truempyi* (Sample 198-1209A-19H-3, 50–52 cm).

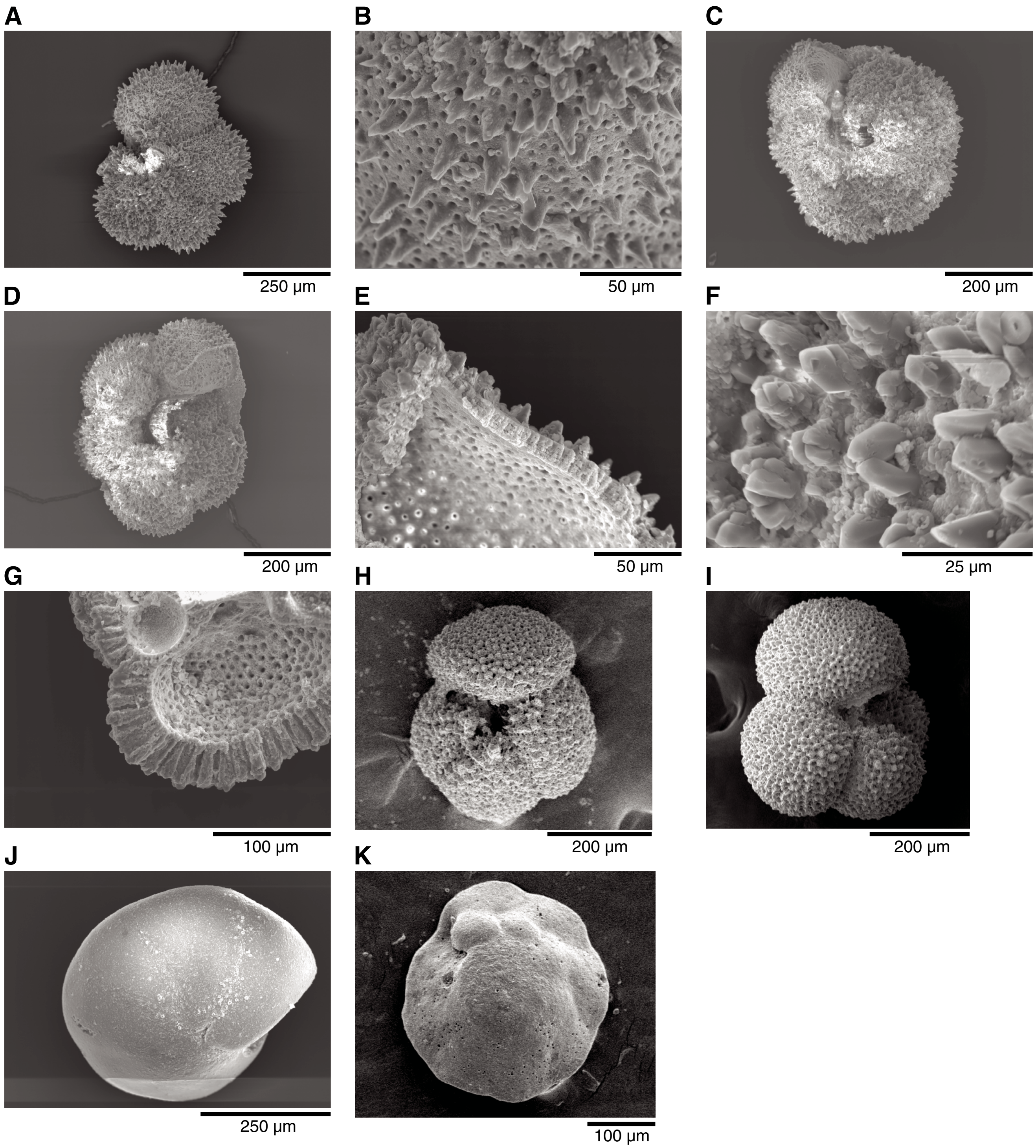

Figure F2. Calibrations for four different dilutions of the standards listed in Table T2, p. 14, are shown as intensity ratios plotted vs. Mg/Ca.

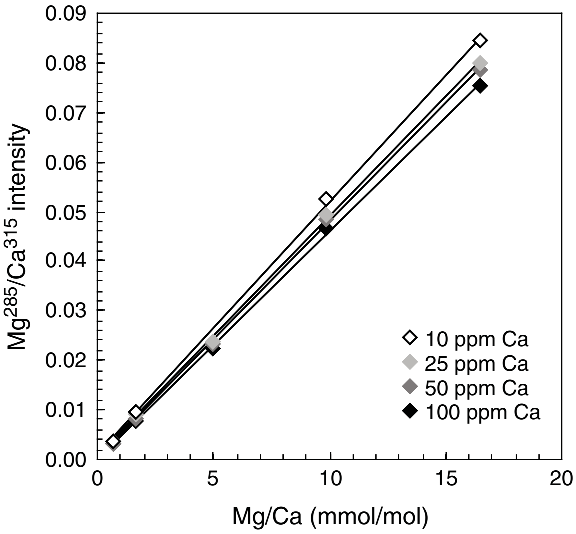

Figure F3. Percent sand fraction plotted relative to depth (solid circles). Nannofossil age datums (**Bralower,** this volume) are also shown relative to depth (open circles). Placement of boundaries is based on shipboard nannofossil and foraminiferal biostratigraphy (Bralower, Premoli Silva, Malone, et al., 2003). Higher percent sand fraction (~>5%) is approximately correlative to hiatuses identified using nannofossil biostratigraphy and to lysocline shoaling at the Paleocene/Eocene Thermal Maximum. E/O = Eocene/Oligocene, P/E = Paleocene/Eocene, K/T = Cretaceous/Tertiary.

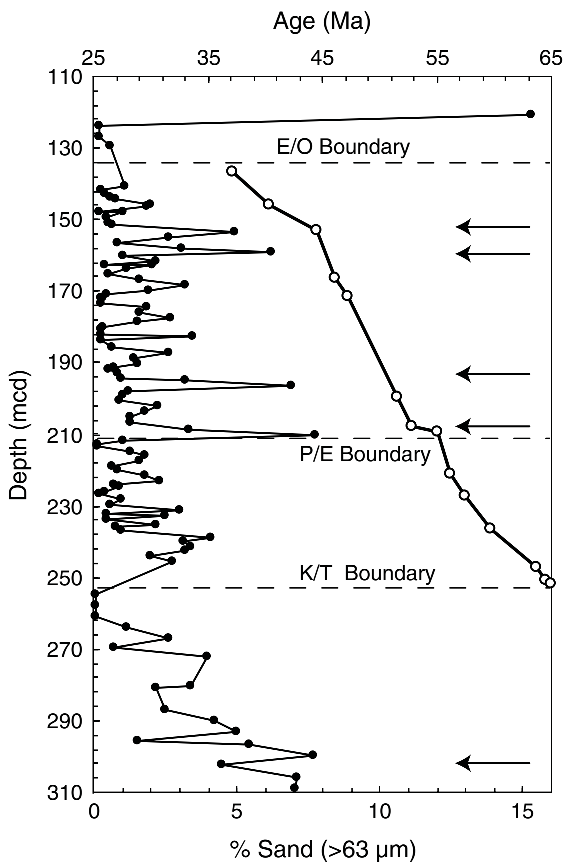

Figure F4. Foraminiferal oxygen isotope (left panel) and carbon isotope (right panel) data plotted relative to depth for Site 1209. The double-headed arrows at ~225 mcd indicate the range in composition of 11 single specimen analyses from the same sample. Open symbols = surface planktonics, solid symbols = benthics, X = deep dwelling planktonics.

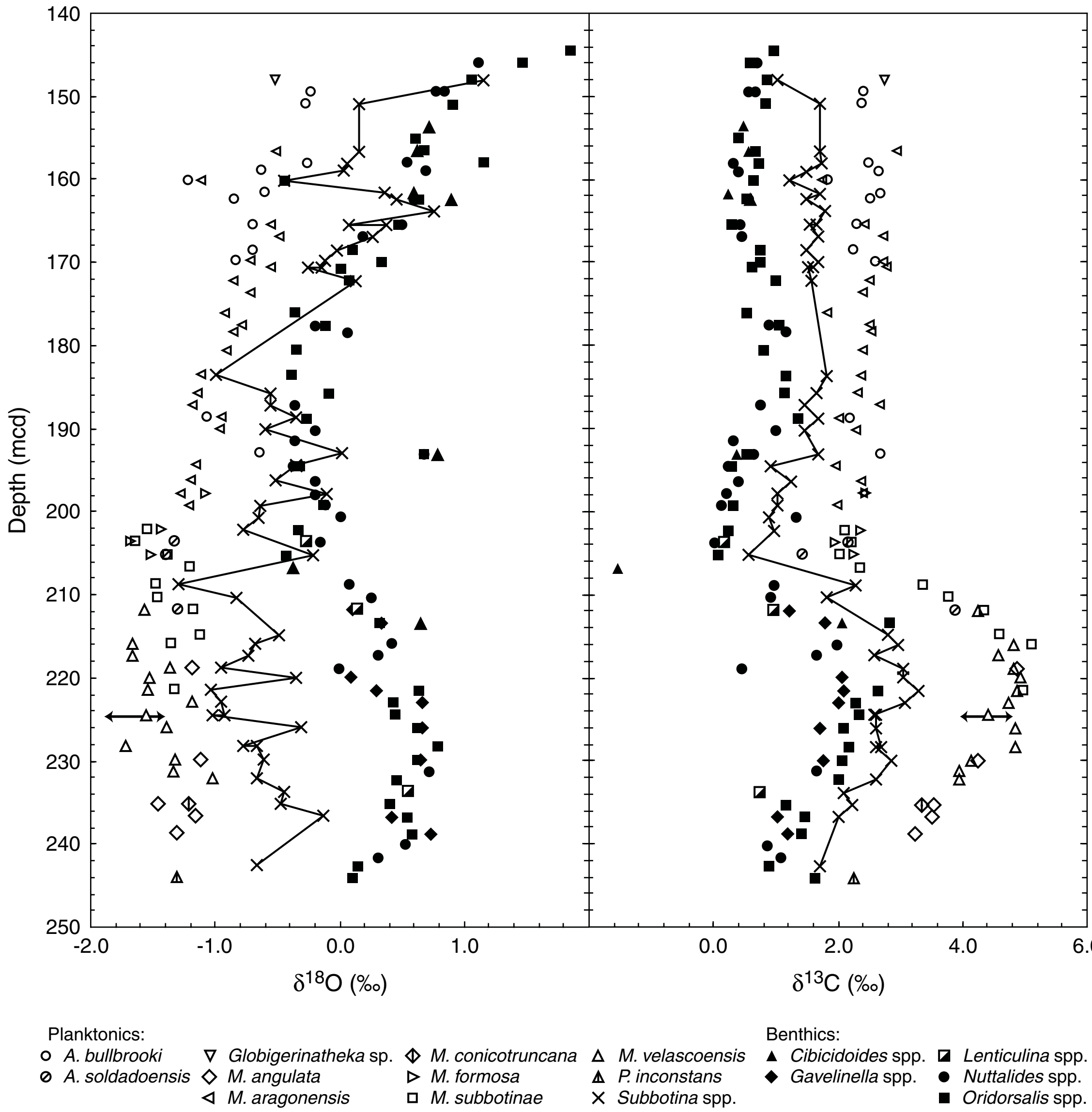

Figure F5. Carbon isotope vs. oxygen isotope composition for 11 single specimens of *Morozovella velascoensis* from Sample 198-1209C-12H-5, 40–42 cm. The size of the open ellipses represents the analytical error associated with each measurement.

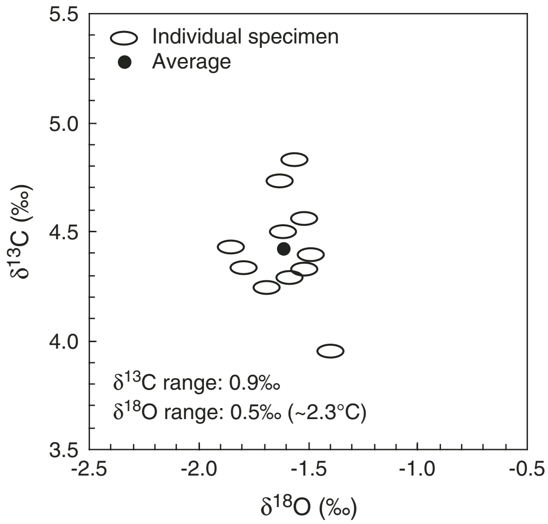

Figure F6. Benthic Mg/Ca values are plotted relative to depth for *Gavelinella beccariiformis*, *Nuttalides truempyi*, and *Oridorsalis umbonatus*.

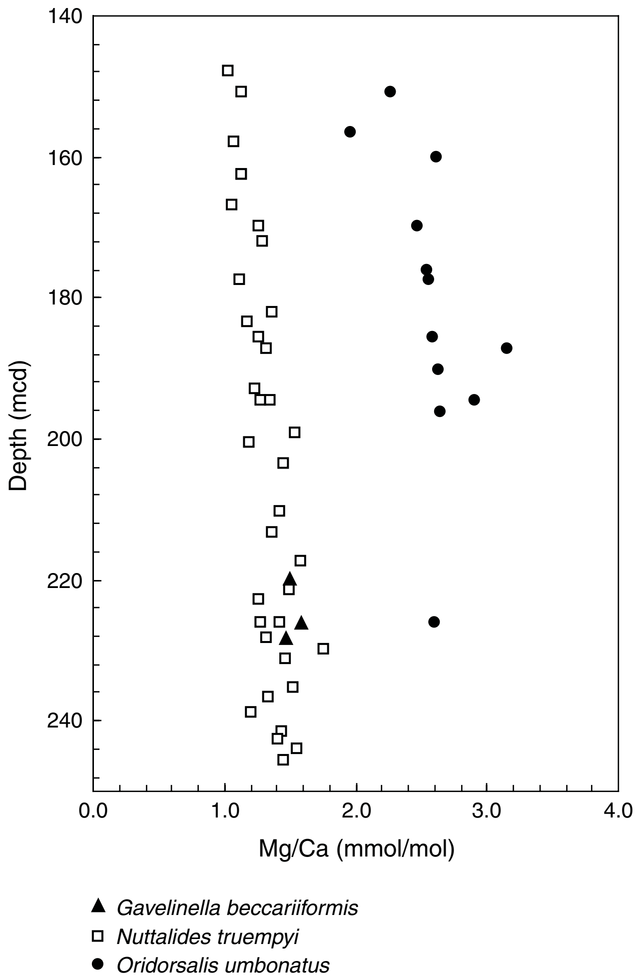

Table T1. Sand fraction computed as weight-percent from oven-dried samples.

Core, section, interval (cm)	Depth (mcd)	Sand fraction (wt% >63 µm)
198-1209A-		
12H-6, 51–53	120.57	15.32
13H-1, 50–52	123.62	0.20
13H-3, 51–53	126.63	0.21
13H-5, 51–53	129.63	0.59
15H-1, 50–52	140.51	1.07
15H-3, 50–52	143.51	0.57
15H-5, 50–52	146.51	1.88
16H-1, 50–52	151.27	0.63
16H-3, 50–52	153.56	4.95
16H-5, 50–52	156.56	0.86
17H-1, 51–53	162.45	2.07
17H-3, 52–54	165.46	0.53
17H-5, 51–53	168.45	3.17
18H-1, 51–53	171.69	0.34
18H-3, 50–52	174.68	1.88
18H-7, 56–58	180.03	0.31
19H-1, 50–52	182.73	3.43
19H-3, 50–52	185.73	0.66
19H-5, 50–52	188.73	1.42
20H-1, 50–52	191.85	0.52
20H-3, 50–52	194.85	3.17
20H-5, 50–52	197.85	1.24
22H-1, 50–52	212.90	0.15
22H-3, 51–53	215.91	1.79
22H-5, 50–52	218.90	0.65
23H-1, 50–52	223.85	0.68
23H-3, 50–52	226.85	0.17
23H-5, 50–52	229.85	0.59
24H-1, 50–52	232.73	2.50
24H-3, 51–53	235.74	0.75
24H-5, 51–53	238.74	4.11
26H-2, 51–53	254.66	0.06
26H-4, 52–54	257.67	0.09
26H-6, 52–54	260.67	0.09
27X2, 50–52	264.15	1.14
27X4, 50–52	267.15	2.60
28X2, 51–53	269.36	0.73
28X4, 51–53	272.36	3.98
198-1209B		
16H-1, 40–42	147.89	0.22
16H-2, 40–42	149.39	0.46
16H-3, 40–42	150.89	0.54
18H-2, 40–42	170.62	0.46
18H-3, 40–42	172.12	0.27
18H-4, 40–42	173.62	0.27
19H-2, 40–42	180.56	0.27
19H-3, 40–42	182.06	0.29
19H-4, 40–42	183.56	0.25
20H-3, 42–44	191.47	0.73
20H-4, 42–44	192.97	0.84
20H-5, 42–44	194.47	0.93
198-1209C		
6H-4, 40–42	160.13	1.02
6H-6, 40–42	162.43	0.36
10H-2, 40–42	200.69	0.87
10H-3, 40–42	202.19	2.26
10H-4, 40–42	203.69	1.77
10H-5, 40–42	205.19	1.26
10H-6, 40–42	206.69	1.28
11H-2, 40–42	208.81	3.35
11H-4, 40–42	211.81	1.02
11H-5, 40–42	213.31	0.15
11H-6, 40–42	214.81	1.27
12H-3, 40–42	221.47	1.82
12H-4, 40–42	222.97	2.33
12H-5, 40–42	224.47	0.87
12H-6, 40–42	225.97	0.42
13H-3, 40–42	232.24	0.44
13H-4, 40–42	233.76	0.42
13H-5, 40–42	235.24	2.18
13H-6, 42–44	236.74	0.99
14H-4, 42–44	242.58	3.19
14H-5, 42–44	244.08	2.00
14H-6, 42–44	245.58	2.74
19H-1, 145–147	280.08	3.37
19H-2, 51–53	280.64	2.18
20H-2, 51–53	287.04	2.47
20H-4, 51–53	290.04	4.24
20H-6, 51–53	293.04	5.02
21H-1, 126–127	295.79	1.50
21H-2, 55–57	296.58	5.45
21H-4, 51–53	299.54	7.70
21H-6, 50–52	302.53	4.48
22H-2, 51–53	306.04	7.13
22H-4, 50–52	309.03	7.07
22H-6, 50–52	312.03	2.70

Table T2. Elemental composition of internal laboratory standards for calibration of ICP-AES measurements.

Standard	Elemental ratio (mmol/mol)			
	Mg/Ca	Sr/Ca	Mn/Ca	Fe/Ca
S1	0.66	0.46	7.30	7.20
S2	1.65	0.91	4.38	4.32
S3	4.95	1.83	1.46	1.44
S4	9.89	9.15	0.73	0.72
S5	16.49	5.49	0.73	0.72

Table T3. Stable isotope data. (See **table note.** Continued on next three pages.)

Core, section, interval (cm)	Depth (mbsf)	Depth (mcd)	Species	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	Size fraction (µm)
Surface planktonics						
198-1209A-						
15H-6, 40–42	139.60	147.91	*Globigerinatheka* sp.	2.76	–0.51	250–300
16H-5, 5052	146.99	156.56	*M. aragonensis*	2.94	–0.51	300–355
16H-6, 40–42	148.39	157.96	*A. bullbrooki*	2.49	–0.25	300–355
16H-7, 40–42	149.39	158.96	*A. bullbrooki*	2.68	–0.62	300–355
17H-3, 5254	154.22	165.46	*A. bullbrooki*	2.31	–0.69	300–355
17H-3, 5254	154.22	165.46	*M. aragonensis*	2.43	–0.55	300–355
17H-4, 40–42	155.60	166.84	*M. aragonensis*	2.72	–0.48	300–355
17H-5, 5153	157.21	168.45	*A. bullbrooki*	2.26	–0.69	300–355
17H-6, 40–42	158.60	169.84	*A. bullbrooki*	2.62	–0.82	300–355
17H-6, 40–42	158.60	169.84	*M. aragonensis*	2.72	–0.71	300–355
18H-4, 40–42	165.10	176.08	*M. aragonensis*	1.83	–0.93	300–355
18H-5, 40–42	166.60	177.58	*M. aragonensis*	2.51	–0.78	300–355
18H-6, 40–42	167.39	178.37	*M. aragonensis*	2.52	–0.85	300–355
19H-3, 5052	173.20	185.73	*M. aragonensis*	2.30	–1.15	300–355
19H-4, 40–42	174.60	187.13	*M. aragonensis*	2.66	–1.18	300–355
19H-5, 5052	176.20	188.73	*A. bullbrooki*	2.19	–1.06	300–355
19H-5, 5052	176.20	188.73	*M. aragonensis*	2.01	–0.95	300–355
19H-6, 40–42	177.60	190.13	*M. aragonensis*	2.30	–0.96	300–355
20H-4, 40–42	184.10	196.25	*M. aragonensis*	2.38	–1.20	300–355
20H-5, 5052	185.70	197.85	*M. aragonensis*	2.38	–1.28	300–355
20H-5, 5052	185.70	197.85	*M. formosa*	2.46	–1.07	300–355
20H-6, 40–42	187.10	199.25	*M. aragonensis*	1.98	–1.21	300–355
22H-3, 5153	201.71	215.91	*M. subbotinae*	5.12	–1.35	300–355
22H-3, 5153	201.71	215.91	*M. velascoensis*	4.83	–1.66	300–355
22H-4, 40–42	203.10	217.30	*M. velascoensis*	4.57	–1.66	300–355
22H-5, 5052	204.70	218.90	*M. angulata*	4.88	–1.18	300–355
22H-5, 5052	204.70	218.90	*M. velascoensis*	4.81	–1.36	300–355
23H-4, 40–42	212.60	228.25	*M. velascoensis*	4.84	–1.71	300–355
23H-5, 5052	214.20	229.85	*M. angulata*	4.25	–1.12	300–355
23H-5, 5052	214.20	229.85	*M. velascoensis*	4.13	–1.32	300–355
23H-6, 40–42	215.60	231.25	*M. velascoensis*	3.95	–1.33	300–355
24H-5, 5153	223.71	238.74	*M. angulata*	3.25	–1.30	300–355
198-1209B-						
16H-2, 40–42	140.00	149.39	*A. bullbrooki*	2.43	–0.23	300–355
16H-3, 40–42	141.50	150.89	*A. bullbrooki*	2.40	–0.26	300–355
18H-2, 40–42	159.00	170.62	*M. aragonensis*	2.79	–0.55	300–355
18H-3, 40–42	160.50	172.12	*M. aragonensis*	2.50	–0.85	300–355
18H-4, 40–42	162.00	173.62	*M. aragonensis*	2.40	–0.72	300–355
19H-2, 40–42	168.50	180.56	*M. aragonensis*	2.39	–0.90	300–355
19H-4, 40–42	171.50	183.56	*M. aragonensis*	2.36	–1.11	300–355
20H-4, 40–42	181.02	192.97	*A. bullbrooki*	2.70	–0.63	300–355
20H-5, 40–42	182.52	194.47	*M. aragonensis*	1.96	–1.15	300–355
198-1209C-						
6H-4, 40–42	150.40	160.13	*A. bullbrooki*	1.84	–1.21	300–355
6H-4, 40–42	150.40	160.13	*M. aragonensis*	1.75	–1.12	300–355
6H-5, 40–42	151.90	161.63	*A. bullbrooki*	2.71	–0.60	300–355
6H-6, 40–42	152.70	162.43	*A. bullbrooki*	2.52	–0.84	300–355
10H-3, 40–42	186.90	202.19	*M. subbotinae*	2.14	–1.54	300–355
10H-3, 40–42	186.90	202.19	*M. formosa*	2.37	–1.42	300–355
10H-4, 40–42	188.40	203.69	*M. subbotinae*	2.22	–1.64	300–355
10H-4, 40–42	188.40	203.69	*M. formosa*	1.96	–1.67	300–355
10H-4, 40–42	188.40	203.69	*A. soldadoensis*	2.17	–1.32	300–355
10H-5, 40–42	189.90	205.19	*M. subbotinae*	2.05	–1.37	300–355
10H-5, 40–42	189.90	205.19	*M. formosa*	2.26	–1.51	300–355
10H-5, 40–42	189.90	205.19	*A. soldadoensis*	1.45	–1.39	300–355
10H-6, 40–42	191.40	206.69	*M. subbotinae*	2.37	–1.20	300–355
11H-2, 40–42	194.90	208.81	*M. subbotinae*	3.37	–1.47	300–355
11H-3, 40–42	196.40	210.31	*M. subbotinae*	3.78	–1.46	300–355
11H-4, 40–42	197.90	211.81	*A. soldadoensis*	3.89	–1.29	300–355
11H-4, 40–42	197.90	211.81	*M. velascoensis*	4.24	–1.57	300–355
11H-4, 40–42	197.90	211.81	*M. subbotinae*	4.36	–1.17	300–355
11H-6, 40–42	200.90	214.81	*M. subbotinae*	4.60	–1.11	300–355
12H-2, 40–42	204.40	219.97	*M. velascoensis*	4.94	–1.52	300–355
12H-3, 40–42	205.90	221.47	*M. velascoensis*	4.89	–1.53	300–355
12H-3, 40–42	205.90	221.47	*M. subbotinae*	4.98	–1.31	300–355

Table T3 (continued).

Core, section, interval (cm)	Depth (mbsf)	Depth (mcd)	Species	δ13C (VPDB)	δ18O (VPDB)	Size fraction (µm)
12H-4, 40–42	207.40	222.97	*M. velascoensis*	4.73	–1.18	300–355
12H-5, 40–42	208.90	224.47	*M. velascoensis*	4.24	–1.69	300–355
12H-5, 40–42	208.90	224.47	*M. velascoensis*	4.50	–1.62	300–355
12H-5, 40–42	208.90	224.47	*M. velascoensis*	4.56	–1.52	300–355
12H-5, 40–42	208.90	224.47	*M. velascoensis*	4.33	–1.80	300–355
12H-5, 40–42	208.90	224.47	*M. velascoensis*	4.73	–1.63	300–355
12H-5, 40–42	208.90	224.47	*M. velascoensis*	4.43	–1.86	300–355
12H-5, 40–42	208.90	224.47	*M. velascoensis*	4.29	–1.59	300–355
12H-5, 40–42	208.90	224.47	*M. velascoensis*	4.33	–1.52	300–355
12H-5, 40–42	208.90	224.47	*M. velascoensis*	4.83	–1.56	300–355
12H-5, 40–42	208.90	224.47	*M. velascoensis*	3.95	–1.40	300–355
12H-5, 40–42	208.90	224.47	*M. velascoensis*	4.40	–1.49	300–355
12H-5, 40–42	208.90	224.47	*M. velascoensis*	4.36	–1.39	300–355
12H-6, 40–42	210.40	225.97	*M. velascoensis*	4.84	–1.39	300–355
13H-3, 40–42	215.40	232.24	*M. velascoensis*	3.95	–1.02	300–355
13H-5, 40–42	218.40	235.24	*M. angulata*	3.54	–1.45	300–355
13H-5, 40–42	218.40	235.24	*M. conicotruncana*	3.36	–1.21	300–355
13H-6, 42–44	219.90	236.74	*M. angulata*	3.51	–1.15	300–355
14H-5, 42–44	227.92	244.08	*P. inconstans*	2.27	–1.30	250–300
Deep-dwelling planktonics						
198-1209A-						
13H-3, 5153	116.21	126.63	*Subbotina* sp.	1.02	1.30	250–300
15H-6, 40–42	139.60	147.91	*Subbotina* sp.	1.02	1.16	300–355
16H-5, 5052	146.99	156.56	*Subbotina* sp.	1.70	0.16	300–355
16H-6, 40–42	148.39	157.96	*Subbotina* sp.	1.75	0.06	300–355
16H-7, 40–42	149.39	158.96	*Subbotina* sp.	1.50	0.04	300–355
17H-2, 40–42	152.60	163.84	*Subbotina* sp.	1.81	0.76	300–355
17H-3, 5254	154.22	165.46	*Subbotina* sp.	1.67	0.07	300–355
17H-3, 5254	154.22	165.46	*Subbotina* sp.	1.55	0.38	300–355
17H-4, 40–42	155.60	166.84	*Subbotina* sp.	1.69	0.26	300–355
17H-5, 5153	157.21	168.45	*Subbotina* sp.	1.50	–0.02	300–355
17H-6, 40–42	158.60	169.84	*Subbotina* sp.	1.68	–0.11	300–355
19H-3, 5052	173.20	185.73	*Subbotina* sp.	1.67	–0.56	300–355
19H-3, 5052	173.20	185.73	*Subbotina* sp.	1.70	–1.33	250–300
19H-4, 40–42	174.60	187.13	*Subbotina* sp.	1.48	–0.55	300–355
19H-5, 5052	176.20	188.73	*Subbotina* sp.	1.70	–0.35	300–355
19H-6, 40–42	177.60	190.13	*Subbotina* sp.	1.46	–0.59	300–355
20H-4, 40–42	184.10	196.25	*Subbotina* sp.	1.26	–0.51	300–355
20H-5, 5052	185.70	197.85	*Subbotina* sp.	1.02	–0.10	300–355
20H-6, 40–42	187.10	199.25	*Subbotina* sp.	1.02	–0.63	300–355
22H-3, 5153	201.71	215.91	*Subbotina* sp.	2.98	–0.68	300–355
22H-4, 40–42	203.10	217.30	*Subbotina* sp.	2.59	–0.73	300–355
22H-5, 5052	204.70	218.90	*Subbotina* sp.	3.06	–0.95	300–355
23H-4, 40–42	212.60	228.25	*Subbotina* sp.	2.71	–0.77	300–355
23H-4, 40–42	212.60	228.25	*Subbotina* sp.	2.61	–0.66	300–355
23H-5, 5052	214.20	229.85	*Subbotina* sp.	2.86	–0.61	300–355
198-1209B-						
16H-3, 40–42	141.50	150.89	*Subbotina* sp.	1.71	0.16	300–355
18H-2, 40–42	159.00	170.62	*Subbotina* sp.	1.61	–0.14	300–355
18H-2, 40–42	159.00	170.62	*Subbotina* sp.	1.53	–0.25	300–355
18H-3, 40–42	160.50	172.12	*Subbotina* sp.	1.59	0.13	300–355
19H-4, 40–42	171.50	183.56	*Subbotina* sp.	1.83	–0.98	300–355
20H-4, 42–44	181.02	192.97	*Subbotina* sp.	1.70	0.02	300–355
20H-5, 42–44	182.52	194.47	*Subbotina* sp.	0.92	–0.34	300–355
198-1209C-						
6H-4, 40–42	150.40	160.13	*Subbotina* sp.	1.23	–0.44	300–355
6H-5, 40–42	151.90	161.63	*Subbotina* sp.	1.72	0.36	300–355
6H-6, 40–42	152.70	162.43	*Subbotina* sp.	1.50	0.45	300–355
10H-2, 40–42	185.40	200.69	*Subbotina* sp.	0.89	–0.65	300–355
10H-3, 40–42	186.90	202.19	*Subbotina* sp.	0.97	–0.77	300–355
10H-5, 40–42	189.90	205.19	*Subbotina* sp.	0.56	–0.21	300–355
11H-2, 40–42	194.90	208.81	*Subbotina* sp.	2.29	–1.29	300–355
11H-3, 40–42	196.4	210.3	*Subbotina* sp.	1.82	–0.83	300–355
11H-6, 40–42	200.90	214.81	*Subbotina* sp.	2.80	–0.49	300–355
12H-2, 40–42	204.40	219.97	*Subbotina* sp.	3.06	–0.35	300–355
12H-3, 40–42	205.90	221.47	*Subbotina* sp.	3.31	–1.03	300–355
12H-4, 40–42	207.40	222.97	*Subbotina* sp.	3.07	–0.95	300–355
12H-5, 40–42	208.90	224.47	*Subbotina* sp.	2.62	–1.02	250–300

Table T3 (continued).

Core, section, interval (cm)	Depth (mbsf)	Depth (mcd)	Species	δ13C (VPDB)	δ18O (VPDB)	Size fraction (µm)
12H-5, 40–42	208.90	224.47	*Subbotina* sp.	2.59	–0.92	250–300
12H-6, 40–42	210.40	225.97	*Subbotina* sp.	2.62	–0.31	250–300
13H-3, 40–42	215.4	232.2	*Subbotina* sp.	2.61	–0.67	250–300
13H-4, 40–42	216.92	233.76	*Subbotina* sp.	2.11	–0.44	300–355
13H-5, 40–42	218.40	235.24	*Subbotina* sp.	2.24	–0.47	300–355
13H-6, 42–44	219.90	236.74	*Subbotina* sp.	2.00	–0.13	300–355
14H-4, 42–44	226.42	242.58	*Subbotina* sp.	1.73	–0.66	250–300
Benthics						
198-1209A-						
13H-3, 5153	116.21	126.63	*Cibicidoides* sp.	1.57	0.71	125–250
15H-6, 40–42	139.60	147.91	*Oridorsalis* sp.	0.15	1.06	125–250
16H-4, 40–42	145.39	154.96	*Oridorsalis* sp.	–0.30	0.60	125–250
16H-5, 5052	146.99	156.56	*Cibicidoides* sp.	0.57	0.35	250–355
16H-5, 5052	146.99	156.56	*Oridorsalis* sp.	–0.04	0.67	>355
16H-6, 40–42	148.39	157.96	*Nuttalides* sp.	–0.02	0.23	125–300
16H-6, 40–42	148.39	157.96	*Oridorsalis* sp.	0.02	1.15	250–300
16H-7, 40–42	149.39	158.96	*Nuttalides* sp.	0.07	0.42	125–250
17H-3, 5254	154.22	165.46	*Nuttalides* sp.	0.08	0.17	125–250
17H-3, 5254	154.22	165.46	*Oridorsalis* sp.	–0.41	0.47	125–250
17H-4, 40–42	155.60	166.84	*Nuttalides* sp.	0.11	–0.22	125–250
17H-5, 5153	157.21	168.45	*Oridorsalis* sp.	0.04	0.11	250–300
17H-6, 40–42	158.60	169.84	*Oridorsalis* sp.	0.03	0.34	125–300
18H-4, 40–42	165.10	176.08	*Oridorsalis* sp.	–0.18	–0.36	125–250
18H-5, 40–42	166.60	177.58	*Nuttalides* sp.	0.56	–0.71	125–250
18H-5, 40–42	166.60	177.58	*Oridorsalis* sp.	0.34	–0.12	125–300
18H-6, 40–42	167.39	178.37	*Nuttalides* sp.	0.83	–0.39	125–250
19H-3, 5052	173.20	185.73	*Oridorsalis* sp.	0.42	–0.08	125–250
19H-4, 40–42	174.60	187.13	*Nuttalides* sp.	0.41	–0.92	125–300
19H-5, 5052	176.20	188.73	*Oridorsalis* sp.	0.64	–0.26	>125
19H-6, 40–42	177.60	190.13	*Nuttalides* sp.	0.65	–0.71	125–250
20H-4, 40–42	184.10	196.25	*Nuttalides* sp.	0.06	–0.71	125–250
20H-5, 5052	185.70	197.85	*Nuttalides* sp.	–0.12	–0.70	125–250
20H-6, 40–42	187.10	199.25	*Nuttalides* sp.	–0.21	–0.60	125–250
20H-6, 40–42	187.10	199.25	*Oridorsalis* sp.	–0.40	–0.14	125–250
22H-3, 5153	201.71	215.91	*Nuttalides* sp.	1.64	0.07	125–250
22H-4, 40–42	203.10	217.30	*Nuttalides* sp.	1.32	–0.07	125–250
22H-5, 5052	204.70	218.90	*Nuttalides* sp.	0.12	–0.47	125–250
23H-4, 40–42	212.60	228.25	*Oridorsalis* sp.	1.47	0.78	125–250
23H-5, 5052	214.20	229.85	*Oridorsalis* sp.	1.34	0.62	300–355
23H-5, 5052	214.20	229.85	*Gavelinella* sp.	1.77	0.32	300–355
23H-6, 40–42	215.60	231.25	*Nuttalides* sp.	1.33	0.46	125–250
24H-5, 5153	223.71	238.74	*Oridorsalis* sp.	0.68	0.59	250–300
24H-5, 5153	223.71	238.74	*Gavelinella* sp.	1.20	0.40	250–300
24H-6, 40–42	225.10	240.13	*Nuttalides* sp.	0.53	0.21	125–250
24H-7, 40–42	226.60	241.63	*Nuttalides* sp.	0.74	–0.07	125–250
198-1209B-						
15H-4, 40–42	133.50	144.46	*Oridorsalis* sp.	0.24	1.84	125–250
15H-5, 40–42	135.00	145.96	*Oridorsalis* sp.	–0.14	1.47	125–250
15H-5, 40–42	135.00	145.96	*Nuttalides* sp.	0.37	0.96	125–250
16H-2, 40–42	140	149.39	*Nuttalides* sp.	0.35	0.61	125–250
16H-2, 40–42	140.00	149.39	*Nuttalides* sp.	0.23	0.52	125–250
16H-3, 40–42	141.50	150.89	*Oridorsalis* sp.	0.13	0.91	>300
16H-3, 40–42	143.99	153.56	*Cibicidoides* sp.	0.50	0.44	>355
18H-2, 40–42	159.00	170.62	*Oridorsalis* sp.	–0.09	0.01	250–300
18H-3, 40–42	160.50	172.12	*Oridorsalis* sp.	0.30	0.08	125–250
19H-2, 40–42	168.50	180.56	*Oridorsalis* sp.	0.08	–0.35	300–355
19H-4, 40–42	171.50	183.56	*Oridorsalis* sp.	0.45	–0.39	250–300
20H-3, 42–44	179.52	191.47	*Nuttalides* sp.	–0.02	–0.92	125–250
20H-4, 42–44	181.02	192.97	*Oridorsalis* sp.	–0.18	0.68	300–355
20H-4, 42–44	181.02	192.97	*Nuttalides* sp.	0.30	0.40	250–300
20H-4, 42–44	181.02	192.97	*Cibicidoides* sp.	0.38	0.50	300–355
20H-5, 42–44	182.52	194.47	*Oridorsalis* sp.	–0.43	–0.32	250–300
20H-5, 42–44	182.52	194.47	*Nuttalides* sp.	–0.11	–0.94	250–300

Table T3 (continued).

Core, section, interval (cm)	Depth (mbsf)	Depth (mcd)	Species	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	Size fraction (µm)
198-1209C-						
6H-4, 40–42	150.40	160.13	*Oridorsalis* sp.	–0.07	–0.45	300–355
6H-5, 40–42	151.90	161.63	*Cibicidoides* sp.	0.23	0.31	125–250
6H-6, 40–42	152.70	162.43	*Cibicidoides* sp.	0.58	0.61	>355
6H-6, 40–42	152.70	162.43	*Nuttalides* sp.	0.22	0.30	125–250
6H-6, 40–42	152.70	162.43	*Oridorsalis* sp.	–0.18	0.64	125–250
10H-2, 40–42	185.40	200.69	*Nuttalides* sp.	0.98	–0.44	125–250
10H-3, 40–42	186.90	202.19	*Oridorsalis* sp.	–0.48	–0.33	250–300
10H-4, 40–42	188.40	203.69	*Lenticulina* sp.	–0.85	–0.60	250–300
10H-4, 40–42	188.40	203.69	*Nuttalides* sp.	–0.31	–0.65	125–250
10H-5, 40–42	189.90	205.19	*Oridorsalis* sp.	–0.65	–0.43	250–300
10H-6, 40–42	191.40	206.69	*Cibicidoides* sp.	–1.54	–0.66	300–355
11H-2, 40–42	194.90	208.81	*Nuttalides* sp.	0.65	–0.36	250–300
11H-3, 40–42	196.40	210.31	*Nuttalides* sp.	0.57	–0.14	125–250
11H-4, 40–42	197.90	211.81	*Lenticulina* sp.	–0.07	–0.18	250–300
11H-4, 40–42	197.90	211.81	*Gavelinella* sp.	1.22	–0.23	300–355
11H-5, 40–42	199.40	213.31	*Oridorsalis* sp.	2.11	0.32	250–300
11H-5, 40–42	199.40	213.31	*Gavelinella* sp.	1.80	0.00	>355
11H-5, 40–42	199.40	213.31	*Cibicidoides* sp.	2.08	0.36	>355
12H-2, 40–42	204.40	219.97	*Gavelinella* sp.	2.07	–0.24	>355
12H-3, 40–42	205.90	221.47	*Gavelinella* sp.	2.09	–0.04	>355
12H-3, 40–42	205.90	221.47	*Oridorsalis* sp.	1.93	0.64	>355
12H-4, 40–42	207.40	222.97	*Gavelinella* sp.	2.00	0.33	250–300
12H-4, 40–42	207.40	222.97	*Oridorsalis* sp.	1.57	0.43	250–300
12H-5, 40–42	208.90	224.47	*Oridorsalis* sp.	1.63	0.44	>355
12H-6, 40–42	210.40	225.97	*Oridorsalis* sp.	1.39	0.62	300–355
12H-6, 40–42	210.40	225.97	*Gavelinella* sp.	1.73	0.33	300–355
13H-3, 40–42	215.40	232.24	*Oridorsalis* sp.	1.28	0.46	300–355
13H-4, 40–42	216.92	233.76	*Lenticulina* sp.	–0.28	0.22	250–300
13H-5, 40–42	218.40	235.24	*Oridorsalis* sp.	0.44	0.40	300–355
13H-6, 42–44	219.90	236.74	*Oridorsalis* sp.	0.76	0.53	300–355
13H-6, 42–44	219.90	236.74	*Gavelinella* sp.	1.02	0.09	250–300
14H-4, 42–44	226.42	242.58	*Oridorsalis* sp.	0.16	0.14	250–300
14H-5, 42–43	227.92	244.08	*Oridorsalis* sp.	0.92	0.10	250–299
14H-5, 42–44	227.92	244.08	*Oridorsalis* sp.	0.92	0.10	250–300

Note: VPDB = Vienna Peedee belemnite.

Table T4. Elemental data.

Core, section, interval (cm)	Depth (mbsf)	Depth (mcd)	Taxon	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	Mn/Ca (mmol/mol)	Fe/Ca (mmol/mol)	Size fraction (mm)	N
198-1209A-									
15H-6, 40–42	139.60	147.91	*Nuttalides truempyi*	1.04	0.74	—	0.02	>125	12
16H-5, 50–52	146.99	156.56	*Oridorsalis umbonatus*	1.96	0.89	—	0.03	>125	16
16H-6, 40–42	148.39	157.96	*Nuttalides truempyi*	1.08	0.75	—	0.02	>125	23
17H-4, 40–42	155.60	166.84	*Nuttalides truempyi*	1.06	0.74	—	0.02	>125	20
17H-6, 40–42	158.60	169.84	*Nuttalides truempyi*	1.27	0.74	—	0.03	>125	15
17H-6, 40–42	158.60	169.84	*Oridorsalis umbonatus*	2.48	0.80	—	0.02	>125	17
18H-4, 40–42	165.10	176.08	*Oridorsalis umbonatus*	2.54	0.84	—	0.02	>125	23
18H-5, 40–42	166.60	177.58	*Nuttalides truempyi*	1.13	0.79	—	0.01	>125	15
18H-5, 40–42	166.60	177.58	*Oridorsalis umbonatus*	2.56	0.79	—	0.02	>125	19
19H-3, 50–52	173.20	185.73	*Nuttalides truempyi*	1.26	0.76	—	0.03	>125	26
19H-3, 50–52	173.20	185.73	*Oridorsalis umbonatus*	2.59	0.78	—	0.02	>125	17
19H-4, 40–42	174.60	187.13	*Nuttalides truempyi*	1.32	0.76	—	0.02	>125	21
19H-4, 40–42	174.60	187.13	*Oridorsalis umbonatus*	3.15	0.75	—	0.05	>125	12
19H-6, 40–42	177.60	190.13	*Oridorsalis umbonatus*	2.63	0.74	—	0.02	>125	16
20H-4, 40–42	184.10	196.25	*Oridorsalis umbonatus*	2.65	0.79	—	0.03	>125	19
20H-6, 40–42	187.10	199.25	*Nuttalides truempyi*	1.55	0.71	—	0.02	>125	15
22H-4, 40–42	203.10	217.30	*Nuttalides truempyi*	1.58	0.62	—	0.04	>125	19
23H-4, 40–42	212.60	228.25	*Gavelinella beccariiformis*	1.48	1.00	—	0.05	>125	14
23H-4, 40–42	212.60	228.25	*Nuttalides truempyi*	1.33	0.66	—	0.07	>125	12
23H-5, 50–52	214.20	229.85	*Nuttalides truempyi*	1.76	0.63	—	0.05	>125	25
23H-6, 40–42	215.60	231.25	*Nuttalides truempyi*	1.47	0.64	—	0.07	>125	20
24H-5, 51–53	223.71	238.74	*Nuttalides truempyi*	1.21	0.75	—	0.02	>125	18
24H-7, 40–42	226.60	241.63	*Nuttalides truempyi*	1.45	0.74	—	0.04	>125	18
198-1209B-									
16H-3, 40–42	141.50	150.89	*Nuttalides truempyi*	1.13	0.75	—	0.03	>125	16
16H-3, 40–42	141.50	150.89	*Oridorsalis umbonatus*	2.27	0.75	—	0.02	>125	11
18H-3, 40–42	160.50	172.12	*Nuttalides truempyi*	1.29	0.76	—	0.07	>125	22
19H-3, 40–42	170.00	182.06	*Nuttalides truempyi*	1.36	0.74	—	0.03	>125	25
19H-4, 40–42	171.50	183.56	*Nuttalides truempyi*	1.18	0.76	—	0.03	>125	28
20H-4, 42–44	181.02	192.97	*Nuttalides truempyi*	1.23	0.74	—	0.06	>125	25
20H-5, 42–44	182.52	194.47	*Nuttalides truempyi*	1.36	0.71	—	0.03	>125	25
20H-5, 42–44	182.52	194.47	*Nuttalides truempyi*	1.28	0.72	—	0.03	>125	25
20H-5, 42–44	182.52	194.47	*Oridorsalis umbonatus*	2.90	0.74	—	0.02	>125	12
198-1209C-									
10H-2, 40–42	185.40	200.69	*Nuttalides truempyi*	1.20	0.72	—	0.02	>125	17
10H-4, 40–42	188.40	203.69	*Nuttalides truempyi*	1.45	0.86	—	0.02	>125	11
11H-3, 40–42	196.40	210.31	*Nuttalides truempyi*	1.43	0.67	—	0.07	>125	22
11H-5, 40–42	199.40	213.31	*Nuttalides truempyi*	1.37	0.62	—	0.04	>125	23
12H-2, 40–42	204.40	219.97	*Gavelinella beccariiformis*	1.50	1.00	—	0.02	>125	17
12H-3, 40–42	205.90	221.47	*Nuttalides truempyi*	1.50	0.63	—	0.30	>125	22
12H-4, 40–42	207.40	222.97	*Nuttalides truempyi*	1.27	0.68	—	0.03	>125	24
12H-6, 40–42	210.40	225.97	*Gavelinella beccariiformis*	1.59	1.00	—	0.02	>125	11
12H-6, 40–42	210.40	225.97	*Nuttalides truempyi*	1.27	0.66	—	0.04	>125	25
12H-6, 40–42	210.40	225.97	*Nuttalides truempyi*	1.42	0.66	—	0.05	>125	17
12H-6, 40–42	210.40	225.97	*Oridorsalis umbonatus*	2.61	0.85	—	0.02	>125	14
13H-5, 40–42	218.40	235.24	*Nuttalides truempyi*	1.52	0.71	—	0.07	>125	20
13H-6, 42–44	219.90	236.74	*Nuttalides truempyi*	1.33	0.72	—	0.03	>125	13
14H-4, 42–44	226.42	242.58	*Nuttalides truempyi*	1.41	0.75	—	0.02	>125	27
14H-5, 42–44	227.92	244.08	*Nuttalides truempyi*	1.56	0.69	—	0.04	>125	20
14H-6, 42–44	229.42	245.58	*Nuttalides truempyi*	1.46	0.74	—	0.03	>125	15
6H-4, 40–42	150.40	160.13	*Oridorsalis umbonatus*	2.61	0.77	—	0.02	>125	25
6H-6, 40–42	152.70	162.43	*Nuttalides truempyi*	1.14	0.75	—	0.05	>125	26
6H-6, 40–42	152.70	162.43	*Nuttalides truempyi*	1.14	0.75	—	0.02	>125	25

Notes: — = Below detection limits. N = Number of analyses.