Supplement of Biogeosciences, 22, 6765–6785, 2025
https://doi.org/10.5194/bg-22-6765-2025-supplement

Biogeosciences Open Access EGU

Supplement of

A δ^{11}B-pH calibration for the high-latitude foraminifera species *Neogloboquadrina pachyderma* and *Neogloboquadrina incompta*

Elwyn de la Vega et al.

Correspondence to: Elwyn de la Vega (elwyn.dlvega@gmail.com) and Audrey Morley (audrey.morley@universityofgalway.ie)

Supplementary Tables

Supplementary Table S1: Stable isotope ($\delta^{18}O$) data for *N. pachyderma* and *N. incompta* from core tops and seawater $\delta^{18}O$ depth profiles.
Supplementary Table S2: Regression results with different scenarios of TPB correction applied.
Supplementary Table S3: Hydrographic datasets used for stations of this study.
Supplementary Table S4: Core top locations and age used in this study
Supplementary Table S5: Hydrographic data, $\delta^{11}B_{foram}$ measured on *N. pachyderma* from core tops. See also Fig. 5a
Supplementary Table S6: Input and output parameters for the calculation of pCO2 for core tops with available Mg/Ca and $\delta^{18}O$

Supplementary Figures

Figure S1: $\delta^{11}B$ regression showing high-TPB samples that have undergone a TPB correction (orange points), a regression with high-TPB samples removed and with high-TPB samples not TPB-corrected.
Figure S2: Relationship between the $\delta^{11}B$ of towed *N. pachyderma* and *N. incompta* with the $\delta^{11}B$ of seawater borate.
Figure S3: Same as Figure 5 in the main manuscript, except that $\delta^{11}B_{borate}$ values for the Yu et al. (2013) dataset were estimated at 150 m water depth instead of at 50 m.

Supplemental Table S1:

Core top $\delta^{18}O$ data

Species	Station	$\delta^{18}O_c$	1sd	inferred foram depth habitat (m)
N. pachyderma	2	2.47	0.06	85
N. pachyderma	9	3.54	0.06	91
N. pachyderma	10	3.66	0.06	50
N. pachyderma	12	3.46	0.06	33
N. pachyderma	16	2.62	0.06	64

Seawater $\delta^{18}O$ depth profiles

Temp	Water temperature in degrees Celsius and Kelvin.
$\delta^{18}O_{sw}$ (SMOW)	$\delta^{18}O$ of seawater (VSMOW scale). All measured except station 10 and 12, where d18Osw is derived from salinity using regional $\delta^{18}O$sw-salinity relationship for central and Eastern Nordic Seas from Kozdon et al. (2009), Simstich et al. (2003). $\delta^{18}O$sw up and lw denote upper and lower uncertainties
$\delta^{18}O_c$ (PDB)	Equilibrium $\delta^{18}O$ of inorganic calcite (PDB scale) calculated from Shackleton (1974). $\delta^{18}O_c$ (PDB) up and lw denote upper and lower uncertainties

Station	Water depth (m)	Temp (°C)	Temp (K)	Salinity (psu)	$\delta^{18}O_{sw}$	$\delta^{18}O_{sw}$ (up)	$\delta^{18}O_{sw}$ (lw)	$\delta^{18}O_c$ -0.27	$\delta^{18}O_c$ (up)	$\delta^{18}O_c$ (lw)
2	9	10.5	283.6	34.7	0.34	0.40	0.28	1.59	1.65	1.53
2	16	10.4	283.5	34.7	0.36	0.42	0.30	1.64	1.70	1.58
2	30	10.1	283.2	34.8	0.42	0.48	0.36	1.77	1.83	1.71
2	41	9.5	282.6	34.9	0.36	0.42	0.30	1.86	1.92	1.80
2	60	7.8	281.0	35.0	0.36	0.42	0.30	2.27	2.33	2.21
2	99	6.6	279.7	35.1	0.36	0.42	0.30	2.59	2.65	2.53
2	151	5.9	279.1	35.1	0.36	0.42	0.30	2.76	2.82	2.70
2	400	4.1	277.2	35.0	0.36	0.42	0.30	3.24	3.30	3.18
9	7	3.3	276.5	34.4	0.1	0.16	0.04	3.19	3.25	3.13
9	13	3.3	276.5	34.4	0.08	0.14	0.02	3.17	3.23	3.11
9	42	3.6	276.8	34.5	0.15	0.21	0.09	3.16	3.22	3.10
9	60	3.5	276.6	34.7	0.25	0.31	0.19	3.30	3.36	3.24
9	101	2.3	275.4	34.9	0.25	0.31	0.19	3.63	3.69	3.57
9	199	1.5	274.7	34.9	0.29	0.35	0.23	3.86	3.92	3.80
9	499	0.4	273.6	34.9	0.26	0.32	0.20	4.15	4.21	4.09
10	5	3.9	277.0	34.5	0.23	0.42	0.04	3.18	3.37	2.99
10	10	3.9	277.0	34.5	0.23	0.42	0.04	3.18	3.37	2.99
10	20	3.9	277.0	34.5	0.23	0.42	0.04	3.18	3.37	2.99
10	30	3.9	277.0	34.5	0.23	0.42	0.04	3.18	3.37	2.99
10	40	3.8	277.0	34.5	0.24	0.43	0.05	3.20	3.39	3.01
10	50	2.6	275.8	34.9	0.39	0.58	0.20	3.66	3.85	3.47
10	60	2.5	275.6	34.9	0.39	0.58	0.20	3.71	3.90	3.52
10	70	2.4	275.5	34.9	0.40	0.59	0.21	3.74	3.93	3.55
10	80	2.2	275.4	34.9	0.40	0.59	0.21	3.78	3.97	3.59
10	90	2.0	275.2	34.9	0.40	0.59	0.21	3.84	4.03	3.65
10	100	2.1	275.2	34.9	0.40	0.59	0.21	3.83	4.02	3.64
10	120	1.8	274.9	34.9	0.40	0.59	0.21	3.91	4.10	3.72
10	140	1.7	274.8	34.9	0.40	0.59	0.21	3.94	4.13	3.75
10	160	1.4	274.5	34.9	0.40	0.59	0.21	4.01	4.20	3.82
10	180	1.4	274.6	34.9	0.40	0.59	0.21	4.01	4.20	3.82
10	200	1.4	274.5	34.9	0.40	0.59	0.21	4.03	4.22	3.84
10	220	1.3	274.4	34.9	0.40	0.59	0.21	4.05	4.24	3.86

10	240	1.2	274.3	34.9	0.41	0.60	0.22	4.08	4.27	3.89
10	260	1.1	274.3	34.9	0.41	0.60	0.22	4.09	4.28	3.90
10	280	1.0	274.1	34.9	0.40	0.59	0.21	4.13	4.32	3.94
10	300	0.9	274.0	34.9	0.40	0.59	0.21	4.17	4.36	3.98
10	400	0.4	273.6	34.9	0.40	0.59	0.21	4.28	4.47	4.09
12	5	2.5	275.6	32.6	-0.45	-0.26	-0.64	2.87	3.06	2.68
12	10	2.5	275.6	32.6	-0.44	-0.25	-0.63	2.87	3.06	2.68
12	15	2.6	275.7	32.8	-0.37	-0.18	-0.56	2.92	3.11	2.73
12	20	2.6	275.7	32.8	-0.36	-0.17	-0.55	2.93	3.12	2.74
12	25	2.5	275.6	32.8	-0.35	-0.16	-0.54	2.96	3.15	2.77
12	30	2.4	275.5	32.9	-0.34	-0.15	-0.53	3.01	3.20	2.82
12	35	-0.2	273.0	33.9	0.03	0.22	-0.16	4.08	4.27	3.89
12	40	-1.4	271.7	33.9	0.04	0.23	-0.15	4.45	4.64	4.26
12	50	-1.3	271.8	34.0	0.07	0.26	-0.12	4.46	4.65	4.27
12	60	-1.0	272.1	34.2	0.14	0.33	-0.05	4.44	4.63	4.25
12	70	-0.8	272.4	34.3	0.18	0.37	-0.01	4.40	4.59	4.21
12	80	-0.2	272.9	34.4	0.22	0.41	0.03	4.29	4.48	4.10
12	90	0.1	273.3	34.5	0.25	0.44	0.06	4.22	4.41	4.03
12	100	0.5	273.6	34.6	0.28	0.47	0.09	4.16	4.35	3.97
12	110	0.6	273.7	34.6	0.30	0.49	0.11	4.14	4.33	3.95
12	120	1.0	274.2	34.7	0.33	0.52	0.14	4.05	4.24	3.86
12	140	1.6	274.8	34.8	0.37	0.56	0.18	3.91	4.10	3.72
12	160	1.6	274.7	34.8	0.38	0.57	0.19	3.94	4.13	3.75
12	180	1.4	274.6	34.9	0.38	0.57	0.19	3.98	4.17	3.79
12	200	1.3	274.4	34.9	0.38	0.57	0.19	4.03	4.22	3.84
12	220	1.3	274.5	34.9	0.39	0.58	0.20	4.02	4.21	3.83
12	240	1.1	274.3	34.9	0.39	0.58	0.20	4.07	4.26	3.88
12	260	1.2	274.3	34.9	0.39	0.58	0.20	4.07	4.26	3.88
12	280	0.9	274.1	34.9	0.39	0.58	0.20	4.13	4.32	3.94
12	300	0.8	273.9	34.9	0.39	0.58	0.20	4.18	4.37	3.99
12	400	0.6	273.7	34.9	0.39	0.58	0.20	4.24	4.43	4.05
16	5	8.8	281.9	35.0	0.24	0.30	0.18	1.91	1.97	1.85
16	11.8	8.8	281.9	35.0	0.20	0.26	0.14	1.87	1.93	1.81
16	34.7	8.8	281.9	35.0	0.17	0.23	0.11	1.84	1.90	1.78
16	75.9	4.6	277.7	34.9	0.19	0.25	0.13	2.94	3.00	2.88
16	148.3	3.4	276.5	34.9	0.19	0.25	0.13	3.27	3.33	3.21
16	233.4	2.4	275.5	34.9	0.31	0.37	0.25	3.65	3.71	3.59
16	299.1	1.4	274.5	34.9	0.21	0.27	0.15	3.83	3.89	3.77
16	501.6	0.1	273.2	34.9	0.15	0.21	0.09	4.14	4.20	4.08

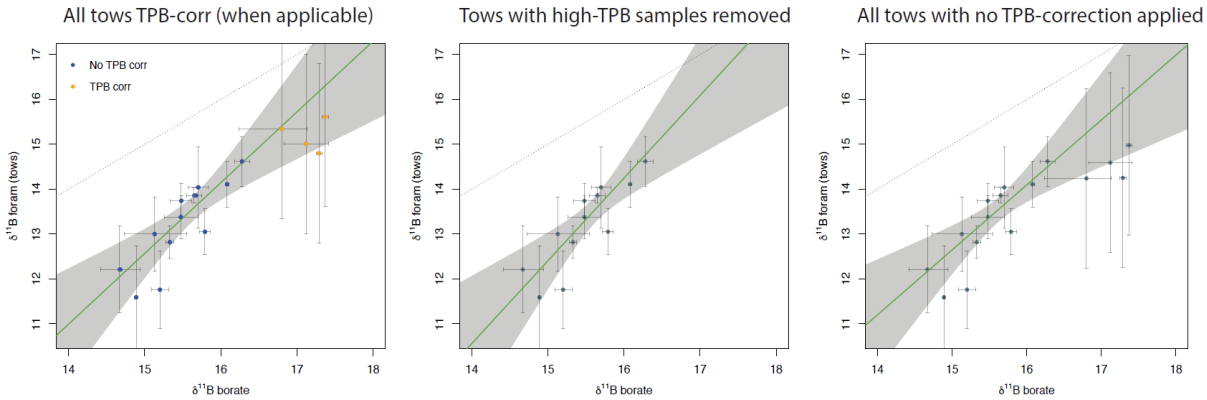

Figure S1. (a) d11B regression showing high-TPB samples that have undergone a TPB correction (orange points), (b) regression with high-TPB samples removed and (c) with high-TPB samples not TPB-corrected.

Supplementary Table S2. Regression results with different scenarios of TPB correction applied.

	intercept	slope	mswd
All tows with TPB correction when applicable *(this study, Figure S1a)*	-11.09 (+/-5.91)	1.58(+/-0.38)	0.579
Tows with high-TPB samples removed *(Figure S1b)*	-15.23(+/-7.31)	1.84 (+/-0.47)	0.7
All tows without applying a TPB-correction *(Figure S1c)*	-9.07 (+/-5.88)	1.45(+/-0.38)	0.663

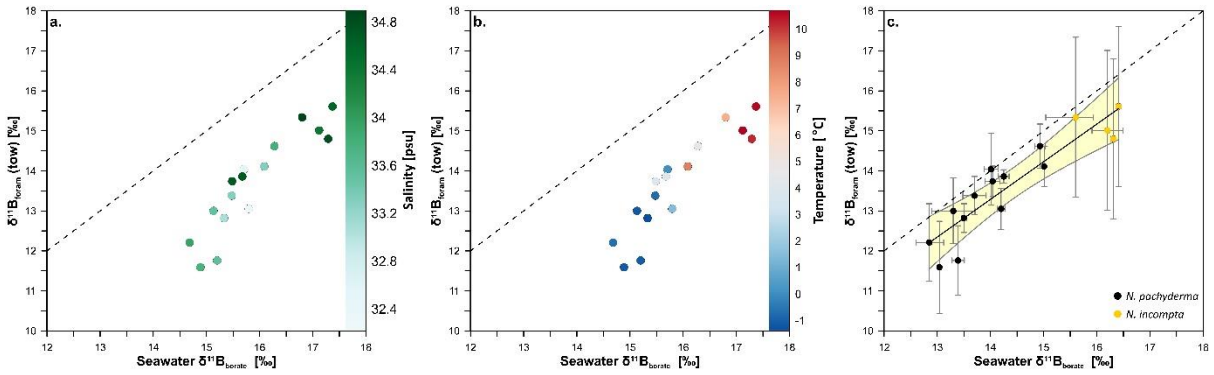

Figure S2 Relationship between the $\delta^{11}B$ of towed *N. pachyderma* and *N. incompta* with the $\delta^{11}B$ of seawater borate. Panel **a**. and **b.** show $\delta^{11}B$ of towed specimens against $\delta^{11}B$ of seawater borate while the colour gradient is showing salinity and temperature respectively. The 1:1 line is shown by the black dashed line. Panel **c**. is showing $\delta^{11}B$ of towed specimens against $\delta^{11}B$ of seawater borate calculated using a temperature dependent αB (as in Hönisch et al. 2019). The 1:1 line is shown by the black dashed line. The data are fitted with a York regression (black line) and a 95% confidence envelope (yellow shade).

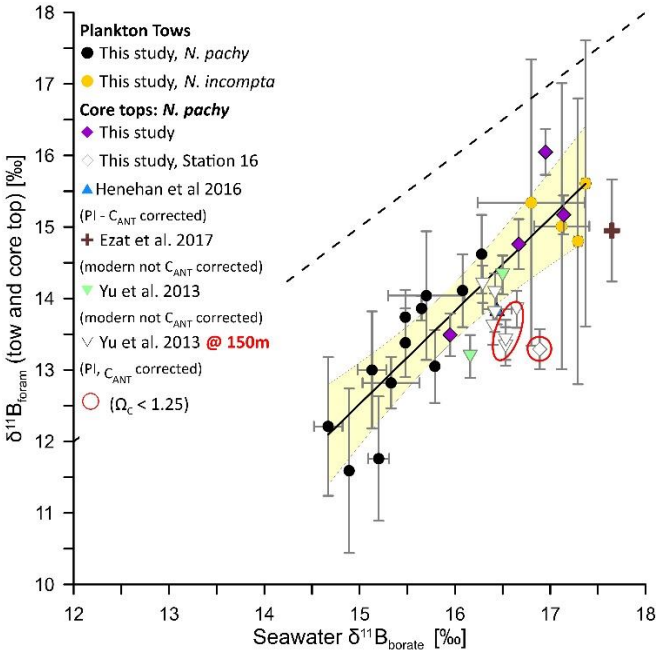

Figure S3. Same as Figure 5 in the main manuscript, except that $\delta^{11}B_{borate}$ values for the Yu et al. (2013) dataset were estimated at 150 m water depth instead of at 50 m.

Supplementary Table S3. Hydrographic datasets used for stations of this study.

Station ID	Lat	Long	Date	Hydrographic data [survey, station ID, location, date, data]	offset tow -hydro
CE20009 -2	70° 55.27'N	14° 21.5' E	30/08/2020	this study [T, S, DIC, Alk, Silicate, Phosphate, d18Osw]	paired
CE20009 -5	77° 37.19'N	09° 56.8' E	02/09/2020	this study [T, S, DIC, Alk, Silicate, Phosphate, d18Osw]	paired
GeoB 19913-2	65° 42.29' N	57° 7.63' W	03/07/2015	ArcticNet/ Geotracers; Station 39-BB1, 66°51.502N, 59°04.450W, 03/08/2015 [T, S, DIC, Alk, Silicate, Phosphate] GLODAP for d18Osw	31 days
GeoB 19929-3	74° 34.49' N	67° 13.10' W	10/07/2015	GLODAP Station 209 & 211 75.311N, 67.002W, 31/07/2003 - Profiles match CTD and pH sensor very well. [T, S, DIC, Alk, Silicate, Phosphate, d18Osw]	-12 years, 21 days
GeoB 455	68° 58.12' N	59° 34.38' W	04/09/2008	Davies Strait Time Series; Stn. 34 (68.4965N, 59.69W), 36 (68.539N, 59.338W), 37 (68.5695N, 59.098W) 08.09.2008 [T, S, DIC, Alk, Silicate, Phosphate, d18Osw]	4 days
GeoB 415	52° 40.01' N	51° 57.99' W	08/22/2008	CLIVAR_LINE_2008; Station 3; 22/08/2008; 53.6757N, 55.5365W [T, S, DIC, Alk, Silicate, Phosphate]	0 day
GeoB 433	54° 55.98' N	54° 20.09' W	26/08/2008	CLIVAR_LINE_2008; Station 6 and or 13; 22/08/2008; 53.6757N, 55.5365W [T, S, DIC, Alk, Silicate, Phosphate]	0 day
GeoB 434	55° 10.76' N	54° 02.30' W	26/08/2008	CLIVAR_LINE_2008; Closest Station 13; 26/08/2008; 55.9067N, 53.408W [T, S, DIC, Alk, Silicate, Phosphate]	0 day
GeoB 435	55° 26.98' N	53° 43.96' W	26/08/2008	CLIVAR_LINE_2008; Closest Station 13; 26/08/2008; 55.9067N, 53.408W [T, S, DIC, Alk, Silicate, Phosphate]	0 day
GeoB 460	72° 20.57' N	67° 21.41' W	07/09/2008	CTD used for Temperature, GLODAP for Carb Chem 11.08.1997 [T, S, DIC, Alk, Silicate, Phosphate]	-11 years

Supplementary Table S4. Core top locations and age used in this study

Region	Cruise	Station	Lat	Long	Elevation	AMS ^{14}C Age		Reference
	ID	ID	[DMM]	[DMM]	[m]	[ka]	1σ	
Norwegian Sea	CE20009	2	70°55.27'N	14°21.50'E	2170	*NA*	*NA*	This study
	CE20009	9	75°49.93'N	08°11.12'W	1985	*4.60*	*0.02*	This study
	CE20009	10	75°00.00'N	11°85.28'W	2637	*NA*	*NA*	This study
	CE20009	12	70°29.57'N	17°55.49'W	1674	*0.26*	*0.02*	This study
	CE20009	16	65°48.07'N	03°29.35'W	2890	*NA*	*NA*	This study
	JM11	FI-19PC	62°49.00'N	03°52.00'W	1179	*3.10*	*0.03*	Ezat et al. 2017
South Iceland Basin	RAPiD	24-13B	60° 10.20'N	39° 07.20'W	2748	*2.33*	*0.04*	Yu et al. 2013
	RAPiD	24-13B	60° 10.20'N	39° 07.20'W	2748	*2.33*	*0.04*	Yu et al. 2013
Labrador Sea	RAPiD	29-18B	58° 48.00N	44° 51.60'W	2145	*2.33*	*0.04*	Yu et al. 2013
	RAPiD	31-21B	58° 36.60'N	46° 54.60'W	2570	*3.04*	*0.04*	Yu et al. 2013
	RAPiD	32-22B	58° 15.00'N	47° 00.60'W	3096	*1.08*	*0.04*	Yu et al. 2013
	RAPiD	33-23B	57° 56.40'N	46° 30.60'W	3016	*1.43*	*0.04*	Yu et al. 2013
	RAPiD	34-24B	57° 35.24"N	48° 30.60'W	3496	*0.93*	*0.04*	Yu et al. 2013
	RAPiD	35-25B	57° 30.60'N	48°43.20'W	3486	*0.04**	*0.02*	Yu et al. 2013
	RAPiD	38-27B	54° 31.80'N	52° 25.80'W	2152	*0.33*	*0.04*	Yu et al. 2013
Southern Ocean	KN7812	6BC				*NA*	*NA*	Henehan et al. 2016

**reference for core top age is Moffa-Sanchez at al. 2014*

Supplementary Table S5. Hydrographic data and $\delta^{11}B_{foram}$ measured on *N. pachyderma* for core tops analysed in this study. Calcification depths are inferred from $\delta^{18}O$ (this study) or assumed at 50m. See also Fig. 5a

Cruise	**Station**	**Depth**	**Size fraction**	**C_{ant}**	**pH**		**Temp**	**Sal**	**$\delta^{11}B_{bor}$**			**$\delta^{11}B_{foram}$**		**BW Ωc**	**Reference**
ID	ID	[m]	1σ [µm]			1σ	[°C]	[psu]	[‰]	err (lw)	err (up)	[‰]	err (±)		
CE20009	2	85	30 *200-250*	yes	8.15	0.005	6.96	35.09	16.95	0.09	0.08	15.95	0.32	1.47	This study
CE20009	9	91	30 *200-250*	yes	8.19	0.029	2.32	34.93	16.67	0.14	0.32	14.76	0.35	1.69	This study
CE20009	10	50	30 *200-250*	yes	8.23	0.037	2.64	34.89	17.14	0.29	0.4	15.17	0.27	1.24	This study
CE20009	12	33	30 *200-250*	no	8.24	0.016	1.10	33.78	15.95	0.22	0.43	13.49	0.3	1.69	This study
CE20009	16	64	30 *200-250*	yes	8.17	0.022	5.30	34.94	16.89	0.26	0.47	13.29	0.28	1.24	This study
JM11	19PC	50	30 *150-250*	yes	8.19	0.017	9.83	34.99	17.65	0.14	0.25	14.95	0.71	NA	Ezat et al. 2017
RAPiD	24-13B	50	30 *150-250*	yes	8.19	0.004	7.04	34.96	17.28	0.22	-0.02	13.8	0.27	1.40	Yu et al. 2013
RAPiD	24-13B	50	30 *150-250*	yes	8.19	0.004	7.04	34.96	17.28	0.22	-0.02	14.08	0.27	1.40	Yu et al. 2013
RAPiD	29-18B	50	30 *150-250*	yes	8.20	0.025	5.24	34.68	17.13	0.16	0.51	14.2	0.26	1.54	Yu et al. 2013
RAPiD	31-21B	50	30 *150-250*	yes	8.20	0.026	6.07	34.90	17.22	0.26	0.43	13.61	0.26	1.43	Yu et al. 2013
RAPiD	32-22B	50	30 *150-250*	yes	8.22	0.026	6.11	34.92	17.46	0.46	0.21	13.85	0.26	1.23	Yu et al. 2013
RAPiD	33-23B	50	30 *150-250*	yes	8.21	0.024	6.34	35.12	17.35	0.36	0.32	13.33	0.27	1.26	Yu et al. 2013
RAPiD	34-24B	50	30 *150-250*	yes	8.12	0.024	5.83	34.77	17.34	0.24	0.40	13.42	0.28	1.16	Yu et al. 2013
RAPiD	35-25B	50	30 *150-250*	no	8.12	0.030	5.94	34.74	17.30	0.21	0.39	14.33	0.27	1.16	Yu et al. 2013
RAPiD	38-27B	50	30 *150-250*	no	8.20	0.040	3.53	34.31	16.91	0.26	0.35	13.19	0.3	1.61	Yu et al. 2013
KN7812	6BC	?	30 *250-300*	yes	8.18	0.008	1.36	34.03	16.44	0.15	0.15	13.85	0.21	NA	Henehan et al. 2016

Supplementary Table S6. Input and output parameters for the calculation of pCO_2 for core tops with available Mg/Ca and $\delta^{18}O$

Cruise/Station		Depth	TALK		$Mg/Ca_{(corr)}$	Temp		Salinity		$\delta^{11}B_{foram}$		$\delta^{11}Bsw$	$CO_{2\ offset}$	$CO_{2\ offset}$	C_{Ant}	pH	pCO2					
ID		[m]	[mol.kg^{-1}]	1σ	[mmol.mol^{-1}]	[C]	1σ	[psu]	1σ	[‰]	1σ	[‰]	air-sea	NP-0m			1σ (-)	1σ (+)	[ppm]	1σ (-)	1σ (+)
CE20009	2	85	2315.8	17.10	0.864	9	1.22	35.10	1.5	16.1	0.32	39.61	-49.2	40	yes	8.16	8.12	8.20	316.3	285.0	347.2
CE20009	9	91	2307.5	32.25	0.423	1.4	0.81	34.90	1.5	14.8	0.35	39.61	-72.7	54	yes	8.17	8.12	8.21	329.8	293.3	366.6
CE20009	10	50	2303.7	14.75	0.498	3.1	0.86	34.90	1.5	15.2	0.27	39.61	-73.9	27	yes	8.18	8.14	8.21	347.3	319.2	375.6
CE20009	12	33	2255.7	53.42	0.507	3.3	0.88	33.80	1.5	13.5	0.3	39.61	-66	36	no	8.04	8.00	8.09	447.5	397.6	497.0
CE20009	16	64	2303.1	7.08	0.738	7.3	1.09	34.90	1.5	13.3	0.28	39.61	-47.7	28	yes	7.97	7.92	8.01	530.5	470.5	591.0
RAPiD	35-25B	50	2301.2	7.68	0.696	6.7	1.02	34.74	1.5	14.3	0.27	39.61	-59.5	61	no	8.06	8.03	8.10	392.9	353.0	432.1
JM11	FI-19PC	50	2315.5	16.22	0.570	4.6	0.91	34.99	1.5	15	0.71	39.61	-41	18	yes	8.13	8.05	8.22	364.1	287.7	439.0

Depth		Foraminifera average depth determined by projection of foraminifera d18O onto seawater equilibrium d18O of calcite
TALK		Modern seawater total alkalinity (umol/kg) from CTD bottle (CE20009) or GLODAP v2 (RAPID 35-25 and JM-FI-19PC)
$Mg/Ca_{(corr)}$		Mg/Ca ratio of *N.pachyderma* corrected for CO_3 effect (Morley et al., 2024)
Temp		Mg/Ca-derived sea temperature corrected for CO_3 effect (Morley et al., 2024)
Salinity		Seawater salinity from CTD profiles or Glodap v2.
$\delta^{11}B_{foram}$		Boron isotopic composition of *N. pachyderma* measured by MC-ICPMS. Core JM-FI-19PC is corrected for analytical offset with NTIMS (Farmer et al., 2016)
$\delta^{11}Bsw$		Boron isotopic composition of seawater (Foster et al., 2010)
$CO_{2\ offset}$	(air-sea)	CO_2 difference between sea surface and the atmosphere (Takahashi et al., 2009)
$CO_{2\ offset}$	(NP-0m)	CO_2 difference (ppm) between foraminifera depth habitat and sea surface (CO_2 offset = CO_2[foram depth]-CO_2[surface]), derived from TA and DIC (dissolved inorganic carbon) from bottoel CTD or Glodap v2. DIC was corrected for anthropogenic carbon (Lauvset et al., 2016) for coretops of pre-industrial age.
pH		pH (total scale) calculated from d11B. Value reported is the average of the 10, 000 realisations of the Monte Carlo simulation.
pCO_2		pCO_2 (ppm) calculated from $\delta^{11}B_{foram}$ and corrected for local sea-air disquilibrium and foraminifera depth. Value reported is the average of the 10, 000 realisations of the Monte Carlo simulation.