

Supplementary material to

A $\delta^{11}\text{B}$ -pH calibration for the high-latitude foraminifera species *Neogloboquadrina pachyderma* and *Neogloboquadrina incompta*.

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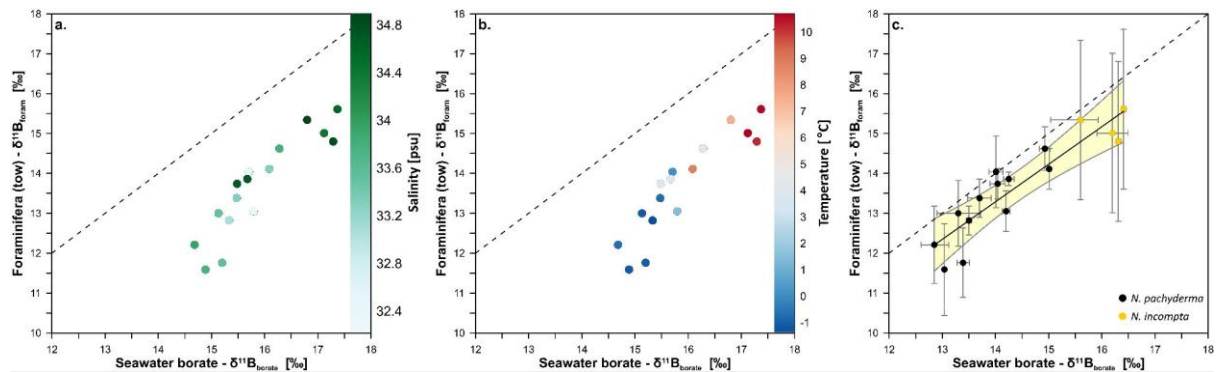


Figure S1 Relationship between the $\delta^{11}\text{B}$ of towed *N. pachyderma* and *N. incompta* with the $\delta^{11}\text{B}$ of seawater borate. Panel a. and b. show $\delta^{11}\text{B}$ of towed specimens against $\delta^{11}\text{B}$ of seawater borate while the colour gradient is showing salinity and temperature respectively. The 1:1 line is shown by the black dashed line. Panel c. is showing $\delta^{11}\text{B}$ of towed specimens against $\delta^{11}\text{B}$ of seawater borate calculated using a temperature dependent α_{B} (as in Hoenish et al. 20XX). 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).

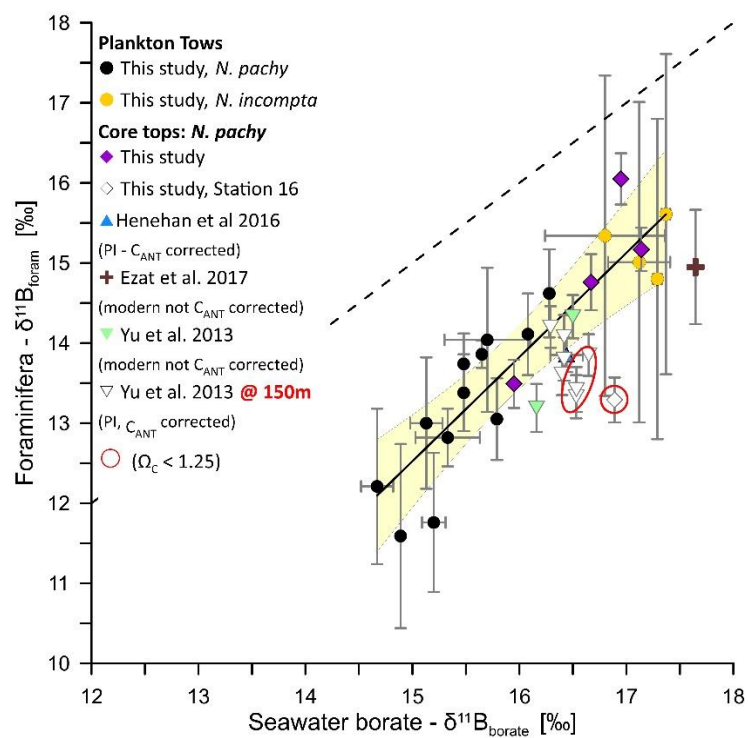


Figure S2. Same as Figure 5 in the main manuscript, except that $\delta^{11}B_{borate}$ values for the Yu et al. (2013) dataset were estimated at 150 m water depth instead of at 50 m.

Supplementary Table S1. Hydrographic datasets used for station 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

Table S2. Core top locations and age used in this study

Region	Cruise ID	Station ID	Lat [DMM]	Long [DMM]	Elevation [m]	AMS ¹⁴ C Age [ka]	1σ	Reference
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° 48.00'N	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 et al. 2014

Table S3. Hydrographic data and $\delta^{11}\text{B}_{\text{foram}}$ measured on *N. pachyderma* for core tops analyzed in this study. Calcification depth are inferred from $\delta^{18}\text{O}$ (this study) or assumed at 50m. See also Fig. 5a

Cruise	Station	Depth	Size fraction	Cant	pH	Temp	Sal	$\delta^{11}\text{B}_{\text{bor}}$	$\delta^{11}\text{B}_{\text{foram}}$	BW	Reference					
								err	err	Ωc						
ID	ID	[m]	1 σ	[μm]		1 σ	[$^{\circ}\text{C}$]	[psu]	[‰]	(lw)	(up)	[‰]	err ($\pm$)			
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	FI-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

Table S4. Input and output parameters for the calculation of pCO₂ for core tops with available Mg/Ca and δ¹⁸O

Cruise/Station		Depth	TALK		Mg/Ca _(corr)		Temp		Salinity		δ ¹¹ B _{foram}		δ ¹¹ B _{sw}	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 <i>N.pachyderma</i> 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.
δ ¹¹ B _{foram}	Boron isotopic composition of <i>N. pachyderma</i> measured by MC-ICPMS. Core JM-FI-19PC is corrected for analytical offset with NTIMS (Farmer et al., 2016)
δ ¹¹ B _{sw}	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 δ ¹¹ B _{foram} and corrected for local sea-air disequilibrium and foraminifera depth. Value reported is the average of the 10, 000 realisations of the Monte Carlo simulation.