Supplement of Biogeosciences, 14, 497–510, 2017
http://www.biogeosciences.net/14/497/2017/
doi:10.5194/bg-14-497-2017-supplement
© Author(s) 2017. CC Attribution 3.0 License.

Biogeosciences Open Access EGU

Supplement of

Trends in element incorporation in hyaline and porcelaneous foraminifera as a function of pCO_2

Inge van Dijk et al.

Correspondence to: Inge van Dijk (inge.van.dijk@nioz.nl)

The copyright of individual parts of the supplement might differ from the CC-BY 3.0 licence.

Supplementary Table S1: Measured calcitic element (E) to calcium ratio, calculated partition coefficients and experimental/field conditions. Reported E/Ca are reported either as a range of values (min-max), or as average values. 'Study type' refers to core-top/sediment trap calibrations (1) or culture experiment (2). 'n.m.' means not measured or not reported. For a number of (field) studies, seawater element concentrations are not measured, but are here calculated ('*') to obtain a partition coefficient. Assumed concentrations at salinity of 35 are 10.3 mmol/kg for Ca, 0.469 mol/kg for Na, 528 mmol/kg for Mg, 0.0909 mmol/kg or Sr and 0.101 µmol/kg for Ba.

Mg/Ca

#	species	calcite (mmol/mol)	seawater (mmol/mol)	Avg D_E (*10^-3)	T (^{0}C)	S	study type	ref
5	*Uvigerina spp.*	2.5	5126*	0.32	20	n.m.	1	[1]
6	*Globigerinoides ruber*	3.5 - 5.5	5126*	0.89	20-26	n.m.	1	[2]
7	*Globigerinoides sacculifer*	5.2	5126*	1	26	36	2	[3]
8a	*Ammonia tepida*	2-7	5158	0.895	25	32.2	2	[4]
8b	*Ammonia tepida*	1.3 – 2.2	5080	0.345	20.0	32.5	2	[5]
8c	*Ammonia tepida*	1-3	5100 – 5300	0.505	18.0	35.0	2	[6]
8d	*Ammonia tepida*	2.1	5565	0.40	25	35.2	2	[7]
9	*Elphidium crispum*	4.3	5126	0.84	25	n.m.	2	[8]
10a	*Amphistegina lessonii*	68 – 86	5126*	15	21 – 29	n.m.	1	[9]
10b	*Amphistegina lessonii*	40 – 60	5200	9.85	24	35	2	[10]
11	*Amphistegina lobifera*	50 – 70	5200	11.3	24	35	2	[10]
12	*Neorotalia calcar*	214 – 267	5126*	47	21 – 29	n.m.	1	[9]
13	*Heterostegina depressa*	110 – 140	5200-6200	21.7	18.0	35.0	2	[6]
14	*Operculina ammonoides*	141	5330	27	24	37	2	[11]
19	*Marginopora vertebralis*	213 – 255	5126*	46	21 – 29	n.m.	1	[9]
20	*Amphisorus hemprichii*	224 – 256	5126*	47	21 – 29	n.m.	1	[9]
21	*Quinqueloculina* sp.	150.9	5126	29.4	25	n.m.	2	[8]

Sr/Ca

#	species	calcite (mmol/mol)	seawater (mmol/mol)	Avg D_E	T (^{0}C)	S	study type	ref
7	*Globigerinoides sacculifer*	1.35	8.83*	0.15	26	36	2	[3]
8a	*Ammonia tepida*	1.2 – 1.9	9.47	0.165	25	32.2	2	[4]
8b	*Ammonia tepida*	1.4 – 2.0	9.27	0.185	20.0	32.5	2	[5]
8c	*Ammonia tepida*	1.35	4.6 – 15.6	0.165	18.0	35.0	2	[6]
8d	*Ammonia tepida*	1.36	5.91	0.23	25	35.2	2	[13]

9	*Elphidium crispum*	2.4	17.1	0.14	25	n.m.	2	[8]
10a	*Amphistegina lessonii*	1.6 – 1.9	8.83*	0.2	21 - 29	n.m.	1	[9]
12	*Neorotalia calcar*	1.9 – 2.2	8.83*	0.235	21 - 29	n.m.	1	[9]
13	*Heterostegina depressa*	2.56	4.8 – 17.8	0.3	18.0	35.0	2	[6]
14	*Operculina ammonoides*	2.56	8.42	0.3	24	37	2	[11]
19	*Marginopora vertebralis*	0.6 – 1.8	8.83*	0.14	21 - 29	n.m.	1	[9]
20	*Amphisorus hemprichii*	1.8 – 1.9	8.83*	0.21	21 – 29	n.m.	1	[9]
21	*Quinqueloculina* sp.	3.4	17.1	0.19	25	n.m.	2	[8]

Na/Ca

#	species	calcite (mmol/mol)	seawater (mol/mol)	Avg D_E (*10^-3)	T (^{0}C)	S	study type	ref
6	*Globigerinoides ruber*	5.9 – 7.6	45.5*	0.15	n.m.	n.m.	1	[16]
7	*Globigerinoides sacculifer*	5.5 – 6.0	45.5*	0.125	n.m.	n.m.	1	[17]
8b	*Ammonia tepida*	6.12	47.8	0.13	20.0	32.5	2	[5]
9	*Elphidium crispum*	7.3	52.7	0.13	25	n.m.	2	[8]
14	*Operculina ammonoides*	24	41.6	0.58	24	37	2	[11]
21	*Quinqueloculina* sp.	5.9	52.7	0.11	25	n.m.	2	[8]

Zn/Ca

#	species	calcite (nmol/mol)	seawater (µmol/mol)	Avg D_E	T (^{0}C)	S	study type	ref
8d	*Ammonia tepida*	89.0	66	1.3	25	35.2	2	[13]

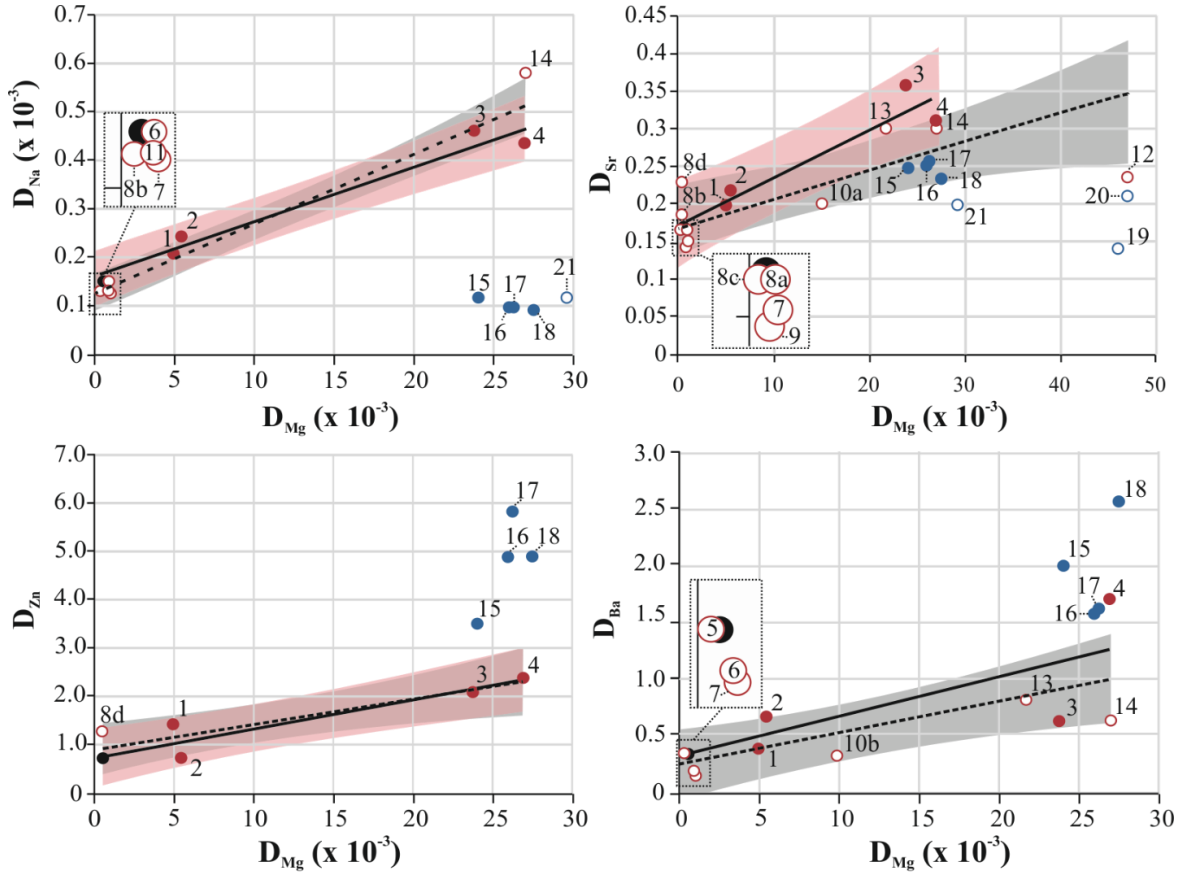
Ba/Ca

#	species	calcite (mmol/mol)	seawater (µmol/mol)	Avg D_E	T (^{0}C)	S	study type	ref
5	*Uvigerina spp.*	1.9 – 4.7	4.6 - 13.1	0.33	n.m.	n.m.	1	[18]
6	*Globigerinoides ruber*	0.7 – 1.0	3.3 – 4.0	0.18	n.m.	n.m.	1	[19]
7	*Globigerinoides sacculifer*	0.65 – 2.17	4.4 - 15	0.145	22-39	36.7	2	[20]
10b	*Amphistegina lessonii*	10-40	50 - 90	0.32	25	32.5	2	[22]
13	*Heterostegina depressa*	30 - 90	50 - 90	0.81	25	32.5	2	[22]
14	*Operculina ammonoides*	0.3 – 13.5	15 - 19	0.62	24	37	2	[11]

Supplementary Table S2: R^2 and p-values of linear trendline of DE versus DMg of all hyaline species of this studies

D_E versus D_{Mg}		R^2	p-value
D_{Na}	This study	0.97	<0.0005
	All studies	0.95	<0.0005
D_{Sr}	This study	0.90	<0.0025
	All studies	0.48	<0.0025
D_{Zn}	This study	0.88	<0.005
	All studies	0.80	<0.01
D_{Ba}	This study	0.58	<0.05
	All studies	0.54	<0.005

Supplementary Figure S1. Partition coefficient of Na, Sr, Zn and Ba versus D_{Mg} of hyaline (red symbols) and miliolid (blue symbols) species in this study (closed symbols) and other studies (open symbols). Black lines represent trendlines (solid = this study; dashed = all studies). The 95% confidence intervals are indicated in pink (this study) and grey (all studies), which sometimes overlap. Black dots represent the NFHS, in-house carbonate standard, consisting of planktonic foraminifera. Numbers correspond to foraminiferal species analyzed (See supplementary Table S1)



Hyaline species

● This study

1 Amphistegina gibbosa
2 Asterigerina carinata
3 Planorbulina acervalis
4 Heterostegina antillarum

○ Other studies

5 Uvigerina spp.
6 Globigernoides ruber
7 Globigerinoides sacculifer
8a Ammonia tepida

Other studies (continued)

8b Ammonia tepida
8c Ammonia tepida
8d Ammonia tepida
9 Elphidium crispum
10a Amphistegina lessonii
10b Amphistegina lessonii
11 Amphistegina lobifera
12 Neorotalia calcar
13 Heterostigina depressa
14 Operculina ammonoides

Milliolid species

● This study

15 Peneroplis pertusus
16 Laevipeneroplis bradyi
17 Archaias angulatus
18 Sorites marginalis

○ Other studies

19 Marginapora vertebralis
20 Amphisorus hemprichii
21 Quinqueloculina sp.

Supplementary references

1. Elderfield, H., et al., *Calibrations for benthic foraminiferal Mg/Ca paleothermometry and the carbonate ion hypothesis.* Earth and Planetary Science Letters, 2006. **250**(3): p. 633-649.
2. Babila, T.L., Y. Rosenthal, and M.H. Conte, *Evaluation of the biogeochemical controls on B/Ca of Globigerinoides ruber white from the Oceanic Flux Program, Bermuda.* Earth and Planetary Science Letters, 2014. **404**: p. 67-76.
3. Dueñas-Bohórquez, A., et al., *Effect of salinity and seawater calcite saturation state on Mg and Sr incorporation in cultured planktonic foraminifera.* Marine Micropaleontology, 2009. **73**(3–4): p. 178-189.
4. De Nooijer, L.J., et al., *Variability in calcitic Mg/Ca and Sr/Ca ratios in clones of the benthic foraminifer Ammonia tepida.* Marine Micropaleontology, 2014. **107**: p. 32-43.
5. Wit, J.C., et al., *A novel salinity proxy based on Na incorporation into foraminiferal calcite.* Biogeosciences, 2013. **10**(10): p. 6375-6387.
6. Dueñas-Bohórquez, A., et al., *Independent impacts of calcium and carbonate ion concentration on Mg and Sr incorporation in cultured benthic foraminifera.* Marine Micropaleontology, 2011. **81**(3-4): p. 122-130.
7. van Dijk, I., et al., *Impacts of pH and [CO_3^{2-}] on the incorporation of Zn in foraminiferal calcite.* Geochimica et Cosmochimica Acta, 2017. **197**: p. 263-277.
8. De Nooijer, L.J., et al., *The impacts of seawater Mg/Ca and temperature on element incorporation in foraminiferal calcite.* in prep.
9. Raja, R., et al., *Magnesium and strontium compositions of recent symbiont-bearing benthic foraminifera.* Marine Micropaleontology, 2005. **58**(1): p. 31-44.
10. Segev, E. and J. Erez, *Effect of Mg/Ca ratio in seawater on shell composition in shallow benthic foraminifera.* Geochemistry, Geophysics, Geosystems, 2006. **7**(2): p. n/a-n/a.
11. Evans, D., et al., *Mg/Ca-temperature and seawater-test chemistry relationships in the shallow-dwelling large benthic foraminifera Operculina ammonoides.* Geochimica et Cosmochimica Acta, 2015. **148**: p. 325-342.
12. Hendry, K.R., et al., *Controls on stable isotope and trace metal uptake in Neogloboquadrina pachyderma (sinistral) from an Antarctic sea-ice environment.* Earth and Planetary Science Letters, 2009. **278**(1): p. 67-77.
13. Van Dijk, I., et al., *Impacts of pH and [CO_3^{2-}] on the incorporation of Zn in foraminiferal calcite* Geochimica et Cosmochimica Acta), in review.
14. Yu, J., et al., *Determination of multiple element/calcium ratios in foraminiferal calcite by quadrupole ICP-MS.* Geochemistry, Geophysics, Geosystems, 2005. **6**(8).
15. Dawber, C. and A. Tripati, *Relationships between bottom water carbonate saturation and element/Ca ratios in coretop samples of the benthic foraminifera Oridorsalis umbonatus.* Biogeosciences, 2012. **9**(8): p. 3029-3045.
16. Ni, Y., et al., *A core top assessment of proxies for the ocean carbonate system in surface-dwelling foraminifers.* Paleoceanography, 2007. **22**(3).
17. Bian, N. and P.A. Martin, *Investigating the fidelity of Mg/Ca and other elemental data from reductively cleaned planktonic foraminifera.* Paleoceanography, 2010. **25**(2).
18. Lea, D. and E. Boyle, *Barium content of benthic foraminifera controlled by bottom-water composition.* Nature, 1989. **338**: p. 751-753.
19. Lea, D.W. and E.A. Boyle, *Barium in planktonic foraminifera.* Geochimica et Cosmochimica Acta, 1991. **55**(11): p. 3321-3331.
20. Lea, D.W. and H.J. Spero, *Assessing the reliability of paleochemical tracers: Barium uptake in the shells of planktonic foraminifera.* Paleoceanography, 1994. **9**(3): p. 445-452.
21. Hall, J.M. and L.H. Chan, *Ba/Ca in Neogloboquadrina pachyderma as an indicator of deglacial meltwater discharge into the western Arctic Ocean.* Paleoceanography, 2004. **19**(1).
22. De Nooijer, L.J., *Personal communication.* 2016.