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Geochimica et Cosmochimica Acta 209 (2017) 123–134

Geochimica et Cosmochimica Acta

www.elsevier.com/locate/gca

# Relationship between water and aragonite barium concentrations in aquaria reared juvenile corals

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Received 2 June 2016; accepted in revised form 3 April 2017; Available online 9 April 2017

**Abstract**

Coral barium to calcium (Ba/Ca) ratios have been used to reconstruct records of upwelling, river and groundwater discharge, and sediment and dust input to the coastal ocean. However, this proxy has not yet been explicitly tested to determine if Ba inclusion in the coral skeleton is directly proportional to seawater Ba concentration and to further determine how additional factors such as temperature and calcification rate control coral Ba/Ca ratios. We measured the inclusion of Ba within aquaria reared juvenile corals (*Favia fragum*) at three temperatures (~27.7, 24.6 and 22.5 °C) and three seawater Ba concentrations (73, 230 and 450 nmol $kg^{-1}$). Coral polyps were settled on tiles conditioned with encrusting coralline algae, which complicated chemical analysis of the coral skeletal material grown during the aquaria experiments. We utilized Sr/Ca ratios of encrusting coralline algae (as low as 3.4 mmol $mol^{-1}$) to correct coral Ba/Ca for this contamination, which was determined to be 26 ± 11% using a two end member mixing model. Notably, there was a large range in Ba/Ca across all treatments, however, we found that Ba inclusion was linear across the full concentration range. The temperature sensitivity of the distribution coefficient is within the range of previously reported values. Finally, calcification rate, which displayed large variability, was not correlated to the distribution coefficient. The observed temperature dependence predicts a change in coral Ba/Ca ratios of 1.1 μmol $mol^{-1}$ from 20 to 28 °C for typical coastal ocean Ba concentrations of 50 nmol $kg^{-1}$. Given the linear uptake of Ba by corals observed in this study, coral proxy records that demonstrate peaks of 10–25 μmol $mol^{-1}$ would require coastal seawater Ba of between 60 and 145 nmol $kg^{-1}$. Further validation of the coral Ba/Ca proxy requires evaluation of changes in seawater chemistry associated with the environmental perturbation recorded by the coral as well as verification of these results for *Porites* species, which are widely used in paleo reconstructions.
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*Keywords:* Coral Ba/Ca; Barium; Aragonite; Distribution coefficient; *Favia fragum*

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http://dx.doi.org/10.1016/j.gca.2017.04.006
0016-7037/Published by Elsevier Ltd.

## 1. INTRODUCTION

Coral inclusion of barium (Ba) has been linked to changes in ocean chemistry with variability in coral Ba/Ca implicated as a climate proxy of river discharge, river sediment transport, upwelling, and groundwater discharge (itself a rainfall proxy) (Table 1 and references therein). Reconstruction of such environmental records provides valuable insight into past climate conditions. The utility of the coral Ba/Ca proxy stems from several factors. First, Ba readily substitutes for Ca within the aragonite skeleton due to similar ionic radii. Second, terrestrial water and sediment sources have elevated Ba compared to seawater (Gaillardet et al., 2003; Shaw et al., 1998). Finally, the temperature dependent partitioning of Ba between inorganic aragonite and fluid has been determined experimentally

Table 1
Coral Ba/Ca environmental proxy studies.

| Reference | Ba/Ca baseline (μmol mol$^{-1}$) | Ba/Ca peak (μmol mol$^{-1}$) | Proxy | Species | Location |
|---|---|---|---|---|---|
| Jupiter et al. (2008) | 3.5 | 7 | River | *Porites* | Round Top island, Great Barrier Reef |
| | 4 | 6 | River | *Porites* | Keswick Island, Great Barrier Reef |
| | 3 | 8 | River | *Porites* | Scawfell Island, Great Barrier Reef |
| Prouty et al. (2010) | 3.4 | 8.0 | Sediment | *P. lobata* | Kamalo, Molok'a Reef, Hawaii |
| | 5.5 | 10.2 | Sediment | *P. lobata* | One Ali'i, Molok'a Reef, Hawaii |
| | 2.8 | 21.6 | Sediment | *P. lobata* | Umpipa'a, Molok'a Reef, Hawaii |
| | 3 | 17.8 | Sediment | *P. lobata* | Pala'au, Molok'a Reef, Hawaii |
| Wyndham et al. (2004) | 4 | 15 | Unknown | *Porites* | Havannah Island, Great Barrier Reef |
| | 4 | 15 | Unknown | *Porites* | Pandora Reef, Great Barrier Reef |
| McCulloch et al. (2003) | 4 | 12 | River | *Porites* | Havannah Island and Pandora Reef, Great Barrier Reef |
| Reuer et al. (2003) | 4.7 | 5.7 | Upwelling | *Montastrea annularis* | Isla Tortuga, Venezuela |
| Sinclair and McCulloch (2004) | 4 | 12 | River | *Porites* | King Reef, Great Barrier Reef |
| | 4 | 17 | River | *Porites* | Pandora Reef, Great Barrier Reef |
| Chen et al. (2011) | 6 | 15 | Physiological | *Porites* | Daya Bay, South China Sea |
| | 6 | 15 | Physiological | *Porites* | Daya Bay, South China Sea |
| Fleitmann et al. (2007) | 4 | 50 | River/ sediment | *Porites* | Kenya |
| | 4 | 9.5 | River/ sediment | *Porites* | Kenya |
| Sinclair (2005) | 4 | 13 | Unknown | *Porites* | Cow Island, Great Barrier Reef |
| | 4 | 12 | Unknown | *Porites* | Orpheus Island, Great Barrier Reef |
| Alibert et al. (2003) | 4.5 | 14 | River | *Porites* | Pandora Reef, Great Barrier Reef |
| | 3 | 6 | River | *Porites* | Davies Reef, Great Barrier Reef |
| Montaggioni et al. (2006) | 4.3 | 21 | Upwelling | *P. lobata* | Amedee Islet, New Caledonia |
| | 1.3 | 5.2 | River | *P. lobata* | Vata Ricaudy Reef, New Caledonia |
| Lea et al. (1989) | 4.1 | 5.1 | Upwelling | *Pavona clavus* | Galapagos Islands |
| Alibert and Kinsley (2008) | 4 | 25 | Upwelling | *Porites* | New Ireland, Papua New Guinea |
| Carriquiry and Horta-Puga (2010) | 7.5 | 9.3 | River | *Montastraea faveolata* | Anegada de Adentro Reef, Veracruz Reef System, Gulf of Mexico |
| | 7.5 | 9.3 | River | *M. Faveolata* | Isla Verde, Veracruz Reef System, Gulf of Mexico |
| Horta-Puga and Carriquiry (2012) | 4.7 | 7.5 | Groundwater | *M. annularis* | Cancun, Mexico |
| | 4.3 | 5.6 | Groundwater | *M. annularis* | Cancun, Mexico |
| Fallon et al. (1999) | 3.9 | 5.1 | Upwelling | *P. lobata* | Shirigai Bay, Japan |
| Moyer et al. (2012) | 3.3 | 4.8 | River | *M. Faveolata* | Fajardo Puerto Rico |
| Tudhope et al. (1996) | 5 | 15 | Upwelling | *Porites* | Marbat, Oman, Red Sea |
| | 3 | 6 | Upwelling | *Porites* | Wadi Ayn, Oman, Red sea |